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An ecological study of the coral reefs of Kuwait islands

AlHazeem, Shaker Hamzah

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AN ECOLOGICAL STUDY OF THE CORAL REEFS OF KUWAIT ISLANDS

Shaker Hamzah AlHazeem

School of Ocean Sciences

University of Wales, Bangor

2007

BSc. Oregon State University, USA, 1989

MSc. Southern Cross University, Australia, 1998

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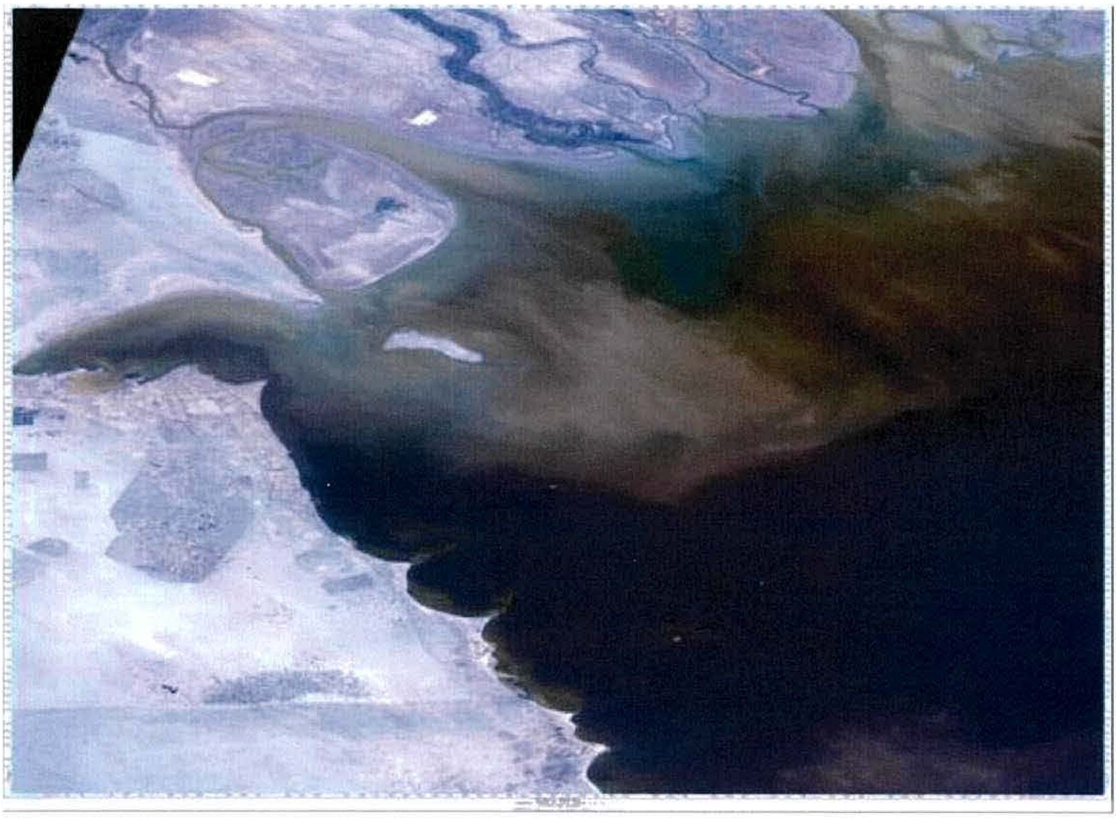
*"In the Name of Allah, The Beneficent The merciful.
All Praise is to Him, Lord of the Worlds.
Let Allah's Blessings be upon Muhammad
And upon his righteous and pure family."*



"He has let free the two seas. They meet together. Between them there is a barrier which they do not transgress. From them emerge the pearl and the coral."

Qur'an; Sura 55 Rahman; The most gracious, verses 19, 20 and 22:

ABSTRACT

Changes in the coral reef ecosystem around three of Kuwait's island reefs, Kubbar, Qaru and Umm AlMaradim, situated at 29° N and 48° E in the northern Arabian Gulf were studied between 2003 and 2005 with particular emphasis on the role and impact of sea urchins in structuring the coral reef communities. Diver ground truthing surveys and Global Information Systems (GIS) were used to map the biological and physical features around the coral reefs. A diver survey of benthic cover along transects at different depths around the reefs demonstrated no significant differences in mean percentage cover between years or between surveys along most transects. Reef biodiversity was highly variable and depended on water depth and aspect (i.e. the windward or leeward side of the reefs), although no differences in composition of the coral reef communities were noted during the study period. No significant differences in sea urchin (*Echinometra mathaei* and *Diadema setosum*) densities were found between 2003 and 2004 (density 19.35-33.44 m^{-2}) nor between transect, coral reef island, by depth or by exposure. Similar patterns of coral recruitment were observed in 2003 and 2005 (0.18 m^{-2} to 0.59 m^{-2}), although higher numbers of recruiting corals were observed on the more sheltered, leeward sides of the reefs. The presence of coral recruitment along the reefs is indicative that natural recruitment processes are regularly taking place and this can be considered a positive signal that the reefs are being restored naturally. Observations and counts of the number of damaged coral colonies on the reefs between 2003 and 2005 (0.26 m^{-2}) confirmed a connection between coral damage and the number of pleasure and dive boats visiting the reefs. Coral colonies around all the reefs were regularly damaged by boat anchors and was quantified from video surveys. Damage to the coral reef at Umm AlMaradim was particularly noticeable during 2004 & 2005 during and following the construction of a new marina around the island in April 2004. A coral bleaching event in April 2005 was a further factor affecting coral reef health. The contribution of sea urchins to the bioerosion of the coral reefs was investigated using cage exclusion and gut evacuation experiments. Kuwait's offshore islands coral reefs constitute unique ecosystems in the Arabian Gulf. Despite various adverse and anthropogenic natural factors, the reefs are flourishing as evidenced by the regular arrival of new coral recruits. Future prospects for the region's coral reefs are discussed, including the need for the immediate implementation of active restoration measures. A long-term monitoring plan to regularly assess the condition of the reefs is also advocated.

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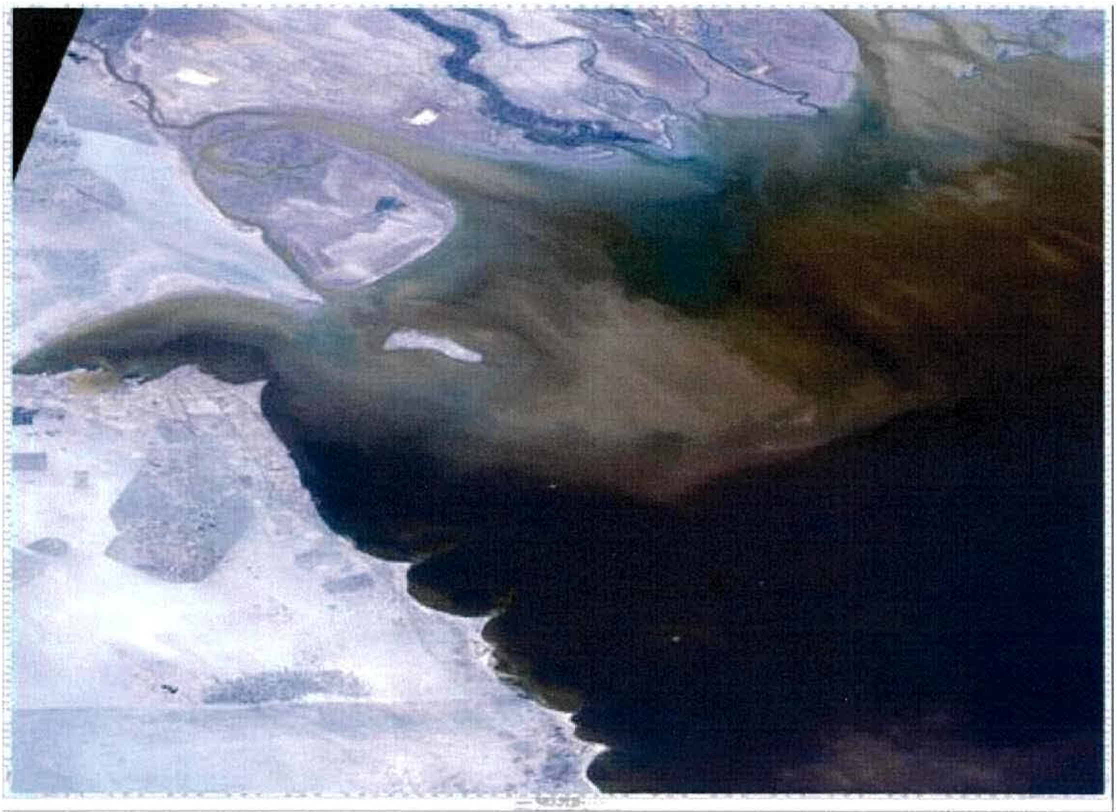

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CHAPTER 1; General Introduction

1.1 Introduction

This chapter provides a general introduction to the present study of Kuwait's coral reef ecosystems. To this end Kuwait's southern islands coral reef ecosystems were surveyed and the impacts upon them and the changes assessed over a period of three years (2003 – 2005). The three coral reef islands that were the focus of this research were Kubbar, Qaru and Umm AlMaradim; Kubbar island reef, which is the most frequently visited reef due to its proximity to land and ease of access from the harbours of mainland Kuwait, is the most vulnerable location; Umm AlMaradim island reef is less frequently visited and is more distant from the shore (approximately 65km), whilst Qaru island reef is the furthest reef from any access site, and therefore the least frequently visited.

The Arabian Gulf, also known as the Persian Gulf or the Gulf, is surrounded by arid environments, and is characterized by high air temperatures, high evaporation rates and low rainfall. This and the enclosed nature of the Gulf results in a higher than average salinity of the seawater. Salinities of 40, rising to 50 over large areas and exceeding 70 in most embayments are common (Sheppard 1993). The asymmetric floor of the Arabian Gulf slopes from the shallow deltaic northern waters to the deeper southern waters, and from the shallow west to deeper waters along the coast of Iran. In spite of the harsh environmental conditions, the Arabian Gulf is considered one of the most productive water bodies in the world in terms of its benthic production (Price et al. 1993). In addition to the unusually harsh and extreme marine conditions in the coastal waters, several oil fields with an extensive network of offshore oil operations and a high density of undersea piping carrying crude oil and fuel oils, are located in northwestern Kuwaiti waters and other parts of the Arabian Gulf.

Kuwait's marine environment is a shallow shelf with depths increasing in a southeasterly direction but with depths rarely exceeding 30 m. Most of Kuwait Bay is between 0 and 10 m with a maximum depth of 28 m. Freshwater influx and nutrients into the marine environment are supplied primarily by the Shatt Al-Arab River in the north and the currents of the Arabian Sea to the south. In spite of the Shatt Al-Arab's discharge, evaporation rates are excessive; with little input of freshwater creating hypersaline waters (Sheppard 1993). The Arabian Gulf marine environment is sub-tropical. Its seawater temperatures range from 11.5° C in winter to 35° C in summer and these temperatures are associated with long hours of highly intense sunlight (Coles and Fadlallah 1991). Air temperatures rise as high as 55° C in the summer and approach 0° C in the winter (Downing 1985). Despite the semi-enclosed nature of the Arabian Gulf, its water mass is subject to total renewal once every 1.5 to 3 years (Hunter 1984). Due to the difference in water mass density between the Arabian Gulf and the Arabian Sea, the latter enters the Gulf on the Iranian side running along the east coast and coming down and out along the west coast through the Strait of Hormuz (Fig.1.1). The coral reefs around Kuwait are the most northern and stretch south towards the United Arab Emirates and Oman in the southern part of the Gulf.

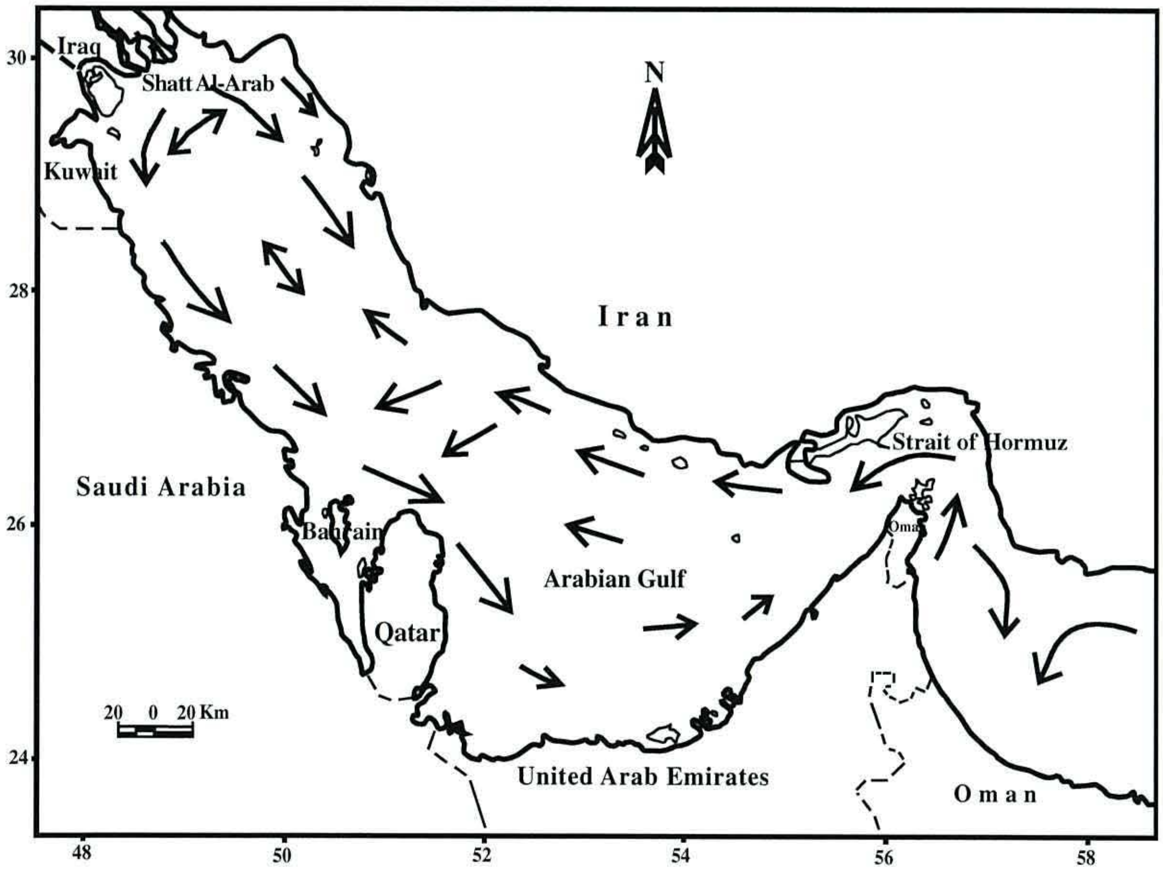

Figure.1.1. Schematic diagram of surface currents (arrows) in the Arabian Gulf. (Adapted from Reynolds, 1993).

1.2 Physical Characteristics of Kuwait's Coral Reef Systems

Kuwait lies along the north-western shore of the Arabian Gulf (Fig.1.1) and its coral reef habitats are largely restricted to its southern waters (Fig.1.2). Compared with Kuwait's northern waters, corals are more abundant in the country's southern waters, where they take the form of platform or patch reefs, or fringing coral assemblages. Seawater temperatures can reach 14° C in winter and 37° C in summer. All reefs occur in waters <15m deep, and the greatest coral growth and diversity occurs at depths of <10m. These coral reefs include a range of offshore platforms and smaller patch reefs, near shore patch reefs, and fringing coral assemblages along the southern coastline. The inshore small patch reefs are Qitat Uraifjan, Qitat Qulai'ah, Qitat Bnaider, Qitat Salam, Qitat Az-Zor and Qitat Benaya; the offshore platforms are coral cays located around the islands of Kubbar, Qaru and Umm AlMaradim (Fig.1.2). The northern area is highly affected by turbidity emanating from the river AlForat north of the Gulf. These subtropical coral reef systems, situated along the coast of Kuwait at 29° north, are important centres of marine biodiversity, and have additional ecological value in Kuwait. They provide essential habitats for many species of algae, corals, worms, molluscs, crustaceans, sponges, echinoderms and world endangered green and leatherback sea turtles. The coral reef sites are used by feeding and breeding, commercially important fish species such as Hamoor *Epinephelus coioides* and other groupers *E. caeruleopunctatus* and *E. multinotaltus* (Carpenter et al., 1997).

The best developed offshore coral reefs associated with a number of islands are sandy cays (cay is a small, low island consisting mostly of sand or coral) and are composed of very coarse coral-mollusc sands. Kubbar is the northern most of the three coral islands. The island is located at latitude 29° 04. 039' N and longitude 48° 29. 284'E. Roughly circular in shape and about 500 m in diameter, Kubbar Island is encircled by an extensive beach. The windward beachrock is well developed and has distinctive large slabs and boulders that have been deposited at higher elevations by major storms. The leeward position inhibits erosion by virtue of its protective setting. A surrounding elliptical-shaped reef is about 1300m long and 900m wide. Kubbar's shallowest reefs occur in depths of between 2–4 m and are dominated by both living and dead *Porites*, with reduced cover of *Acropora* and other coral species. Several small patch reefs with less cover and diversity of coral species are found to the north and northwest of Kubbar Island.

The largest and southernmost of Kuwait's coral islands is Umm AlMaradim. This island is located at latitude 28° 41. 000' N and longitude 48° 39. 000'E. Oval in shape, the island is ~550m in length and is surrounded by sandy beach and beachrock. The surrounding reef is ~1100m wide and 1400m long and is dominated by large stands of corals e.g. *Porites*, both living and dead, and small colonies of branching *Acropora* and *Stylophora*. Smaller patch reefs are located northwest and southeast of Umm AlMaradim Island. Patch reefs to the northwest exhibit relatively high coral cover and diversity along the reef margins.

Qaru is the smallest of the three coral islands and is only 300m in diameter. This island is located in the centre of the reef and occurs at latitude 28° 49. 000' N and longitude 48° 46. 000'E. It is surrounded by an elliptical-shaped reef, with length and width dimensions of 1300m and 600m, respectively. Although the island is unvegetated, the reef of Qaru Island is possibly Kuwait's most diverse and visually attractive. The extensive reef flat is dominated by colonies of branching and table *Acropora* some as large as 4m in diameter, with large stands, both living and dead *Porites*. Other corals and reef organisms and diverse assemblages of fish occur down to depths of 15 m. Large *Porites lutea* colonies, estimated to be hundreds of years old, dominate the reef edge, mostly on the eastern side of the reef. A small patch reef is located about 2 km northwest of Qaru Island (Carpenter et al., 1997).

There are other reefs not directly associated with the coral islands. These include six inshore reefs and two offshore patch reefs, Mudayrah Reef and Umm AlAish. Mudayrah are the furthest offshore reefs and occurs in possibly the most consistently clear water. The Mudayrah Reef community is diverse and includes a wide range of branching and encrusting corals (Carpenter et al., 1997). Umm AlAish Reef, also known as Taylor Rock, is located about 10km southeast of Kubbar. It is small, with poor coral diversity in open water caused by the strong currents. The inshore reefs are subject to increased sediment loads and higher turbidity, so development is more restricted than that of the offshore reefs. Qit'at Uraifjan is perhaps the most important inshore reef. Located about 10km southeast of the Shu'aibah Port (oil supply port), this reef has been exposed to major pollution events, such as the discharge of oil during the Gulf War. The eastern reef slope consists of patches of living *Porites*, brain corals and other large corals (Carpenter et al., 1997). South of Qit'at Uraifjan, several small patch reefs occur close to shore. These include the following: Qit'at Julai'ah, Qit'at Bnaider, Qit'at Salama, Qit'at Benaya, Aardh Bard Halq, the reef near Ras AlZour, and others that are unnamed. Outcrops of corals occur in coastal areas as far north as Kuwait Bay (Fig.1.2), and some of these assemblages are comprised of surprisingly high numbers of species (Carpenter et al., 1997).

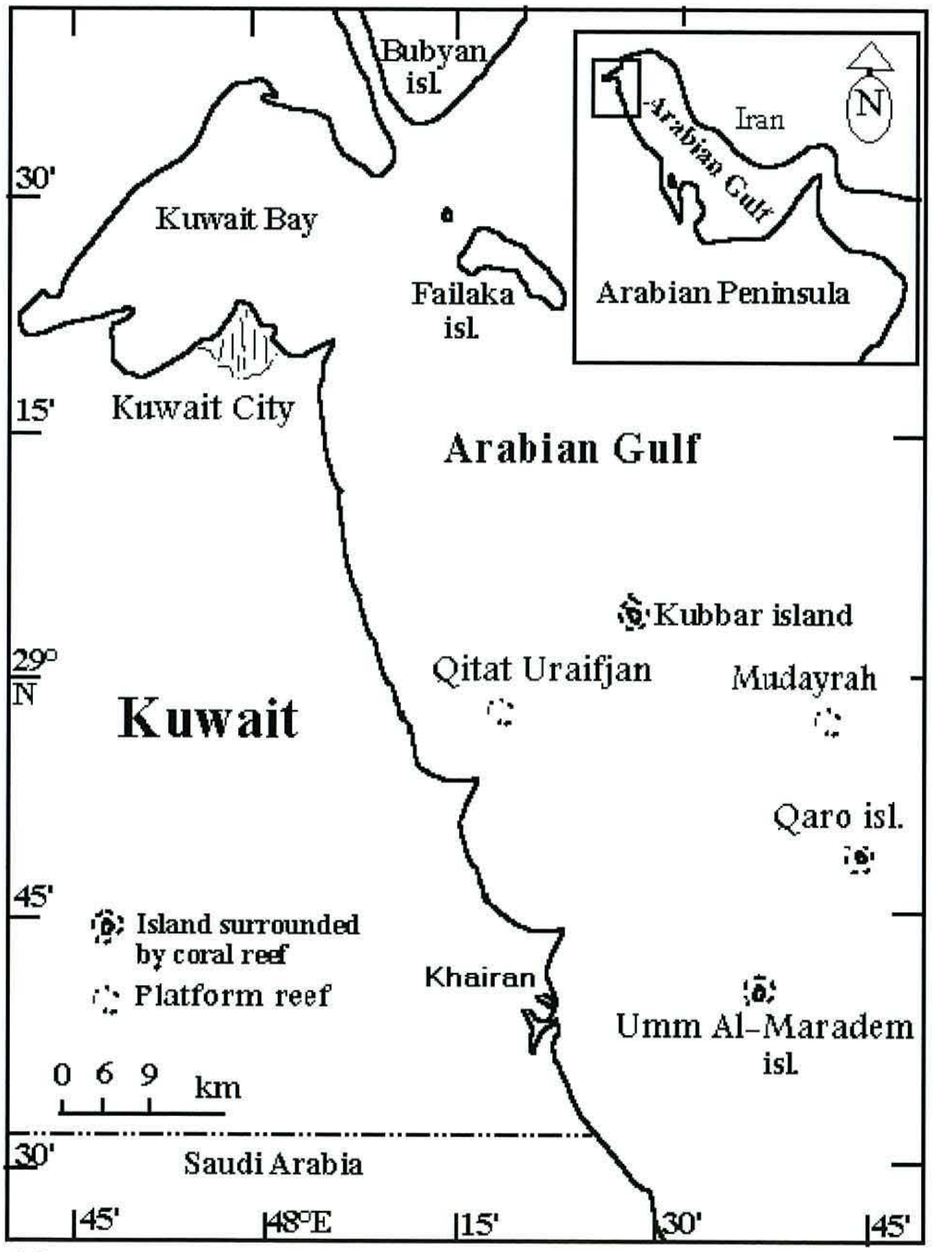

Figure.1.2. Location of the major coral reefs of Kuwait.

The coral reefs of Kuwait are under severe pressure from many interactive factors relating to human activities, pollution and environmental factors (e.g. extreme water temperatures). Eutrophication has caused shifts from hard corals to fleshy algal dominance, (personal observations, 1996) potentially increasing opportunities for grazers such as sea urchins to establish themselves and multiply on the reefs due to the highly favourable conditions. It is well known that the presence of major predators (fish) and grazers in normal numbers increases diversity on coral reefs (McClanahan, 1995; Guidetti et al., 2007). However higher numbers may cause monopolisation by one species of coral, decreasing diversity, while overgrazing may lead to a decrease in diversity (McClanahan and Shafir 1990). However mass mortality of sea urchins has affected reef algal abundance, reef species composition, metabolism and other coral reef herbivores (Carpenter 1985). The sea urchin *Echinometra mathaei* for example grazes on the filamentous turf algae which coat dead coral surfaces, and scrapes away and ingests some of the calcium carbonate skeletons (Downing and El-Zahr 1987). Although sea urchins graze on the algal cover on the reefs as their main food source, scraping algae from the surface of dead coral heads creates a grazing effect, and other factors may simultaneously affect the reefs. Surveys of Kuwait's reefs indicated that significant periods of stress, bleaching and coral mortality occurred in 1982-83 and 1984-85, and in the winter of 1991-92 (Downing, 1985, 1989, 1992; Downing and Roberts, 1993).

Other factors causing impacts on the coral reefs are coastal developments in Kuwait and regional events such as the Gulf War of 1990, which caused oil spills and were damaged by missiles. Harrison *et al*'s (1997) and Khuraibet's (2002) observations of Kuwait's reef systems and McClanahan et al.'s study of Kenyan reefs (1997 b) indicated that sea urchins have become more abundant, which may be due to environmental stresses (McClanahan and Muthiga 1998a). High numbers of *Echinometra mathaei* (de Blainville) have been observed on reefs adjacent to large human populations (e.g. Hibino and Woesik 2000). With growing populations and increased exploitation of coral reefs there has been increasing pressure on these resources. Reef exploitation is expected to continue in the future particularly due to the expansion of local diving operations.

However, coral reefs are important and fragile habitats that require immediate action for their protection and conservation. In addition, coral reefs are a public resource that provides recreational and commercial benefits to reef visitors and generates income for the local economy. Therefore, protection and maintenance of the reefs should be a prime objective of the Kuwait government. It is essential that these ecosystems and their ecology are regularly monitored through surveying permanent transect sites, to evaluate alterations in these reefs, to ensure their management and to promote their sustainable use and development.

The current knowledge of Kuwait's coral reefs is patchy and the available data on the coral reef ecology of Kuwait does not provide baseline data with which to assess temporal changes in the health of the coral reefs. To this end a series of permanent survey stations will be established with which to carry out follow up future surveys.

1.3 Overall aim and objectives

The main aim of this part of the project was to survey the coral reef ecosystems within the marine environment of Kuwait, with a view to developing relevant management plans for marine protection and conservation. The surveys focused on Kuwait's best developed southern island coral reef ecosystems and investigated the impacts upon them.

An aim of the coral reef surveys was to investigate the possible causes of the high abundances of the sea urchin *Echinometra mathaei* (20 to 80 urchins m^{-2}) on the reef at Kubbar, Qaru and Umm AlMaradim (see Downing and Roberts, 1993). It is not known whether the increases in sea urchin abundances are a natural event or an indicator of population explosion due to environmental stress. Other possible causes could be global warming resulting in sea water temperature increases and salinity stress, over-fishing, boat anchor damage, turbidity, and oil seepage.

The study set out to firstly establish regular quantitative measures to assess the benthic cover around the coral islands' reefs and then to assess whether it was possible to detect changes and alterations in benthic cover over time. One view that has been suggested is that coral reef degradation has increased due to the presence of sea urchins which have dramatically increased in abundance. This study quantitatively assessed the distribution and abundance of sea urchins along the three islands' reefs, and to present suggestions for the management and protection of these reefs. Hence, I am proposing that the dominant high abundance of the sea urchins

Echinometra mathaei around Kuwaits southern island coral reef ecosystems indicates either coral reef ecosystem degradation (coral erosion) caused by man or by natural impacts, or an increase in numbers of sea urchins. Experiments were undertaken to remove sea urchins from areas of the reefs to assess the effect of controlling their numbers on the reef ecosystem and to investigate if their removal might enhance the coral reef ecosystem, such as increasing the biodiversity of the reefs.

The specific objectives of this study are:

(1) To map the reefs around the three islands and to quantify and provide geographical data for these reefs;

(2) To study three of Kuwait's island coral reefs over two years in order to quantify the status of the physical structure and benthic cover during the winter and summer;

(3) To investigate the distribution and abundance of the sea urchin *Echinometra mathaei* on the reefs in depths between 10 – 3m during the winter and summer;

(4) To investigate experimentally the grazing impacts of the sea urchin *E. mathaei* on the reefs, using 3 x 3m enclosure cages and calculating the gut evacuation rate to determine the grazing rate on these coral reefs;

(5) To document coral recruitment abundance and distribution on the three island reefs;

(6) To develop a base line data set for the current ecological status of the coral reefs of Kuwait, as input to an eventual marine management plan for their protection and sustainable development.

1.4 Thesis layout

In chapter 2 the coral reef habitats are mapped around the three islands.

In chapter 3 the physical structure and benthic cover along each transect were quantified during the winter and summer during each of the three years (2003 to 2005).

Chapter 4 reports an investigation of coral recruitment by assessing the abundance and distribution of newly recruiting coral polyps at Kubbar, Qaru and Umm AlMaradim between 2003 and 2005. The recruitment of coral juveniles could be a major indicator of the condition and health of the coral populations and community structure in the coral reef marine ecosystems. High numbers of coral recruits on a reef site could be used to indicate the health of a reef (Connell, 1997; Ahamada et al., 2002).

Chapter 5 details the abundance and distribution of the sea urchins *Echinometra mathaei, Diadema setosum* and pencil sea urchins at Kubbar, Qaru, and Umm AlMaradim at depths of between 2-10 m. The fauna and benthic cover were recorded along transect line at water depths between 2 and 8 m.

Sea urchin grazing impact was investigated through gut evacuation rates. The particles produced by these bioeroding organisms were characterized and their contribution to the production of coral reef sediment estimated. The total sediment produced at each site was estimated. The sediment traps would reflect in part the eroding activity of the sea urchins at each site. However, these bioerosion products represent only a fraction of the total sediment in sedimentary deposits. The interaction of the activities of reef building organisms and bioeroders allows an assessment of the state of the health of a reef. Rates of bioerosion were estimated using experimental sea urchin gut evacuation rates as an indicator of grazing rates on the reef. The following were undertaken

In chapter 6 damaged coral colonies and their distribution were quantified, to investigate other possible factors and the causes of degradation to the three islands reefs.

Chapter 7 is a general discussion and a summary of all data collected and analyzed and these data are drawn together to formulate a management plan for the coral reefs of Kuwaiti waters.

CHAPTER 2; Kuwait's Reef Habitat Classification and Mapping

2.1. Introduction

In this chapter the aim is to map the reefs habitats of three of Kuwait's islands along the southern coastline of Kuwait, Kubbar, Qaru and Umm AlMaradim (Fig. 2.1 and Fig. 2.2) and to provide a description of the abundance and distribution of the benthic coral communities along profiles of these island reefs. The chapter examines the relative merits of Landsat-7 ETM+ data, IKONOS coverage and aerial photographs for mapping the reef habitats in Kuwait. The coral reefs chosen for study include a range of offshore platforms and smaller patch reefs, near shore patch reefs, and fringing coral assemblages around the three islands. These coral reefs are the best-developed reefs in Kuwait at 29° north, 48° east.

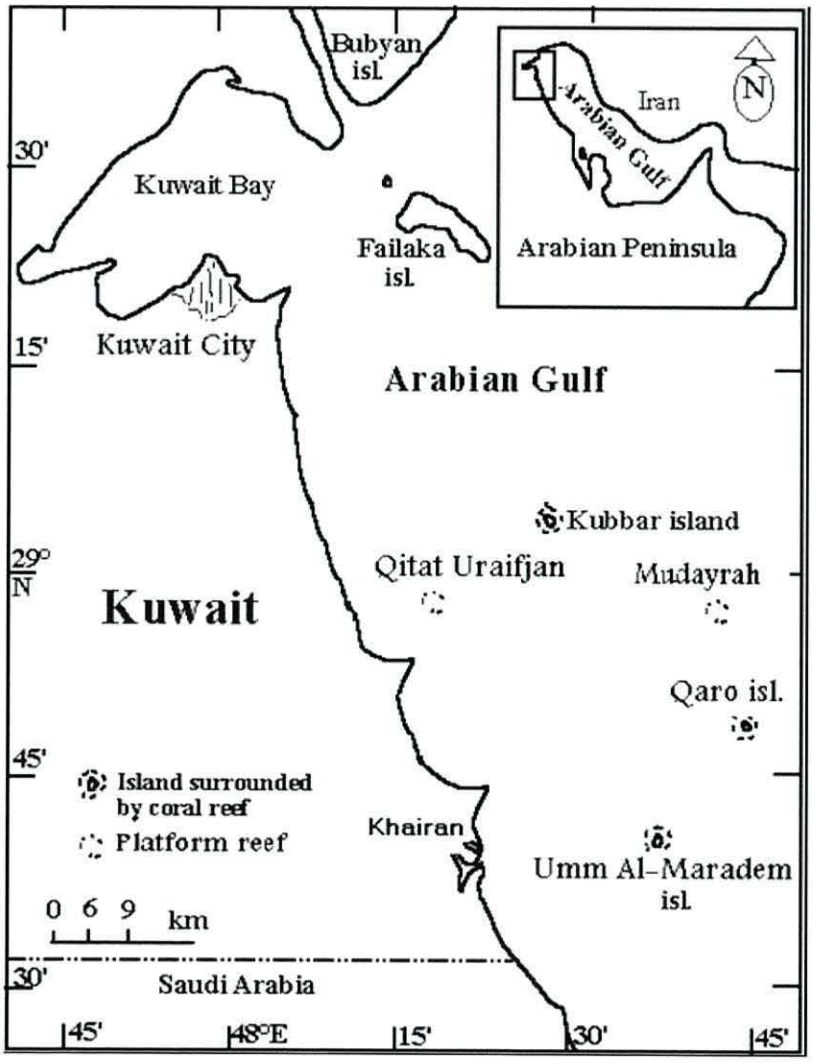

Figure 2.1. Map of Kuwait, northern Arabian Gulf showing the three island reefs and Khairan where the main sea cruises were undertaken.

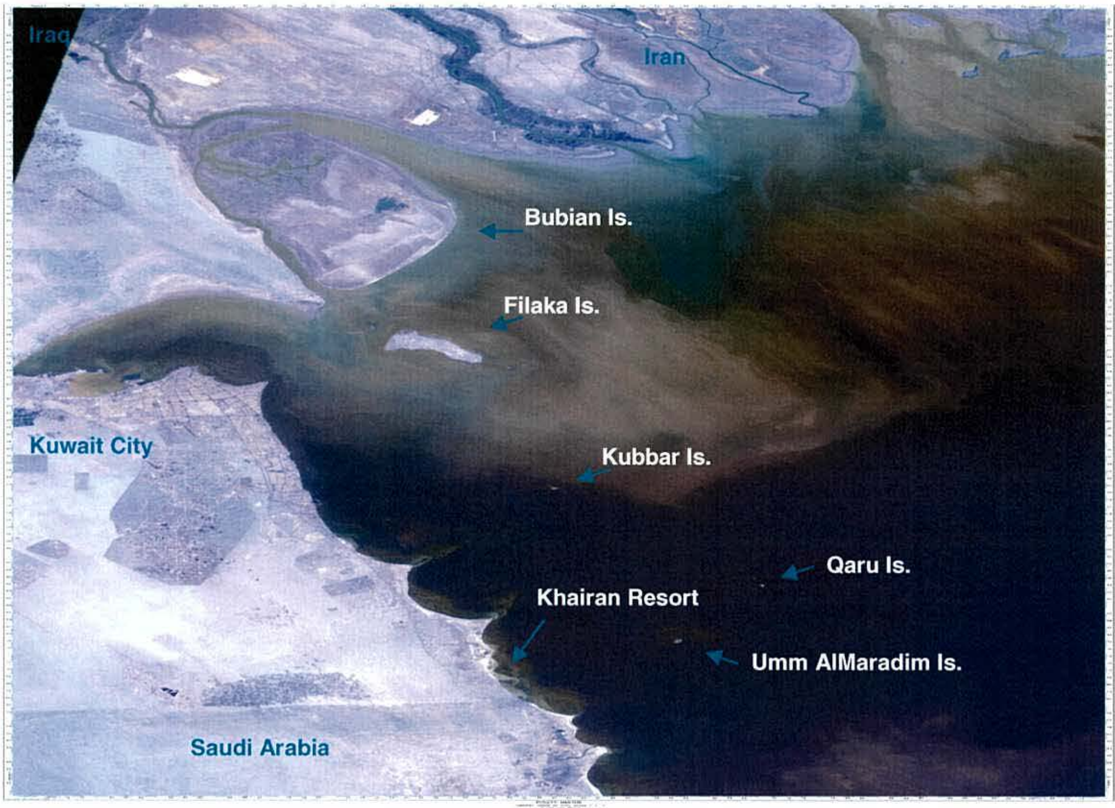

Figure 2.2. Landsat-7 ETM+ image of 30 m resolution taken in 1999 and covering the northern east part of Kuwaits Arabian Gulf. The three islands and Khairan resort where the main sea cruises were undertaken are shown (source the Kuwait Institute for Scientific Research).

The principal natural factor considered to influence general reef morphology is current for outer reef edges are structured by waves and currents (McClanahan and Muthiga 1988). The dominant sea water current in the north part of the Gulf is anticlockwise in direction (see Fig.1.1 in chapter 1). This natural condition can contribute to the general reef morphology.

Remote sensing techniques and geographic information system (GIS) were used to study and map the reef habitats. The remote sensing techniques used were LANDSAT 7 ETM+, IKONOS and atmospherically corrected aerial photographs covering the study area and these were obtained from the remote sensing laboratory of the Kuwait Institute for Scientific Research. The computer hardware, software and geographic data for capturing, managing, analyzing and displaying all forms of geographically referenced information GIS were similar to those used by Oliver (1993). Remote sensing data together with GIS technologies have great potential to provide critical information on coral reef habitats and involve less time and cost to research scientists using traditional survey techniques of the reefs. Remote sensing data with coordinate points are input into GIS systems and the distribution of features placed on maps to show distribution patterns of marine organisms. Reef mapping shows where both biological and physical features are located on the Kuwait reefs. Kuwait's coral reef habitats around the three reef islands were mapped for the first time in this study.

Remote sensing has been used in coral reef mapping only recently but aerial photography, a most time/cost effective technique, was first used more than 95 years ago (Hopley 1982). Aerial photography, however, can only be used to provide a visual interpretation of the reef features (Hopley 1982). For example, aerial photography has been used as a tool for mapping hard corals, soft corals, seagrasses, and macro algae occurring on exposed areas of reef flats and reef edges e.g. (Claasen, 1986; Kuchler et al., 1988). Aerial photographs continue to play an important part in habitat surveys particularly where low spatial resolution is required. They have minimum value when studying small habitats in great detail. However, remote sensing techniques e.g. LANDSAT together with aerial photography have been used in reef mapping since the early 1970's along the 2000 km Australian Great Barrier Reef (Kuchler 1983). Remote sensing data such as high resolution aerial photography and multispectral data of moderate to high resolution, e.g. LANDSAT and SPOT (Claasen 1986), were not originally designed for water mapping or reef work but rather for determining crop state and for geological mapping. SPOT satellite images have the same kind of spectral resolution as LANDSAT images (Claasen 1986). High resolution remote sensing techniques that cover small study areas and reefs are QuickBird (Kuchler 1986) or IKONOS (Klaus and Turner 2004; Yamano et al. 2006). Hyperspectral airborne imaging system using a Compact Airborne Spectrographic Imager has been used to map coral reefs e.g. (Klaus, 2004; Kutser et al., 2006). High resolution remote sensing information has been used to identify coral reef areas for marine protection and management (McClanahan and Obura 1997; Ahamada et al. 2002). The current study has mapped the reef habitats of the three islands using available 37 cm high resolution aerial photos rectified against Landsat-7 ETM+ (30 m) and IKONOS (1 m) data.

There are two types of map image classification 1) supervised in which the operator puts on features into the maps and 2) unsupervised in which the computer uses different kinds of grey scale to be input on to the maps. The most popular map image classification used involves superimposed techniques, and this approach was used in this study, and distinguished class features were manually traced. The identification of features depended mainly on ground trouthed or field information that identified the location the type of site-use and the benthic cover e.g. the location and type of different benthic cover. These field data were used to identify features on the images and to classify areas on the map images.

2.2. Aims and objectives

Mapping the reef habitats and describing the abundance and distribution of the benthic coral communities around the three coral islands (Kubbar, Qaru and Umm AlMaradim) using aerial photography was the aim of this chapter.

The objectives of the study were to develop a simple methodology for mapping the biotic distributions around the reefs and to apply the findings from this research to reef management. The specific objectives were:

1. To acquire atmospherically corrected remotely sensed data of the Kuwait islands reefs from the Kuwait Institute for Scientific Research (KISR) Remote Sensing laboratory.
2. To identify 10 geo-reference points (RPs) on each island, to correct geographic location and orientation.
3. To ground truth 90 points around the 3 islands, to record their habitats and to classify aerial maps of the reefs. Sites were ground truthed by diving and the benthic cover assessed from 385 m^2 quadrats deployed on each reef.
4. To map and quantify the coral reef habitats.
5. To establish two 150 m long transects on each reef on the leeward and windward sides to investigate the structure, abundance and distribution of the reef communities.

2.3. Material and methods

Atmospherically corrected remotely sensed data (LANDSAT 7 ETM+, IKONOS and aerial photos) of the Kuwait island reefs were obtained from the Kuwait Institute for Scientific Research Remote Sensing laboratory. The remotely sensed data were collected and analysed using the program (ERDAS-Imagine TM ver.8.5) in the GIS laboratory of (KISR). In general the GIS Geographic Information Systems were analysed using the program (ArcGIS ver.9). Databases were used as an integral pool for the remotely sensed data, base maps, thematic maps and attribute data sets that were collected during the field surveys. The remotely sensed data (LANDSAT-7 ETM+, IKONOS and aerial photography), were integrated with the thematic maps using the 10 field geo-reference points (RPs) on each island. The data were rectified using the (RPs) on each island, to correct geographic location and orientation. A summary of the classification process is shown in figure 2.3. When the GPS point position fixes were superimposed on the geometrically corrected image there was some difference between the GPS point position fixing and the coordinates on the corrected image thus giving some idea of the accuracy of the GPS point position fix to the geometrically corrected image. The data collected from the field were superimposed onto the aerial maps at the end of the GIS operations. This measured how accurate the classifications of substrates type and organism distribution predicted using the GIS were to the actual observed distributions. Classification accuracy has often been assessed with reference to aerial photographs and field data (Green et al. 2000). Using the reference point data from the field was therefore considered to be enough to modify or measure the classification accuracy on rectified aerial photographs.

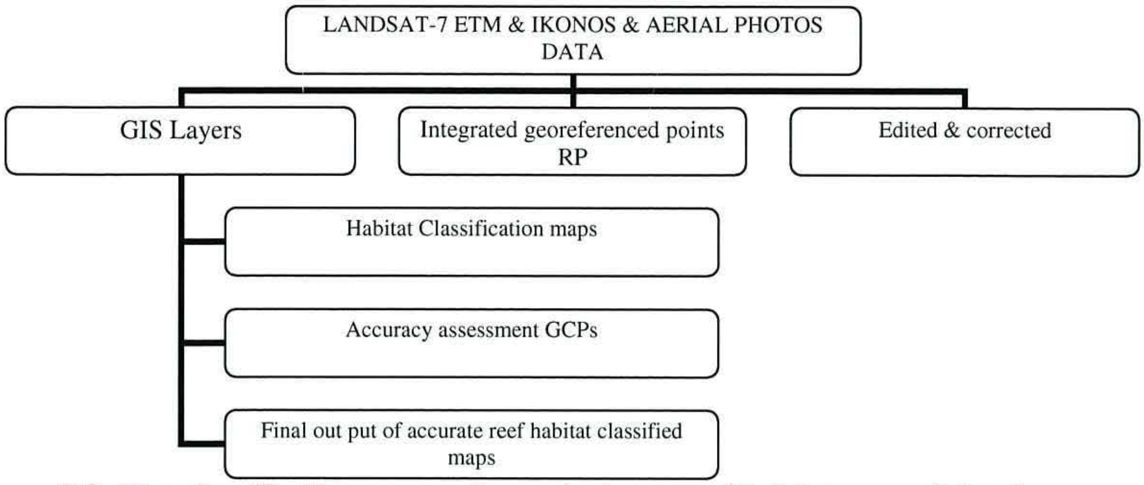

Figure 2.3. The classification process in producing a reef habitat map of the three island reefs.

2.3.1. Acquired data

Topographic maps (scale 1:50 000), bathymetry maps (scale 1:200 000), aerial photographs of 37 cm resolution (6th October 2003), IKONOS images of 1 m resolution (25th May 2001) and LANDSAT data of 30 m resolution (LANDSAT-7 ETM+ 29th April 2003) were obtained from the Kuwait Institute for Scientific Research Remote Sensing laboratory. The island locations were identified on the Kuwait Admiralty chart (source Kuwait Ministry of Communication Surveys 1985, WGS 84 + depth in metres) (Fig. 2.3.4). The camera used in the aerial photography was an RC 30 with lens 30/4 NAT-S number 17111. The camera was set at an aperture of f4.0, and the filter set on the goniometer at 450 nm. The principal distance for focussing was 850 m with a radial distortion of 302 μm. The film used was Kodak Panachromatic x2412, and the developer Kodak HC 110. The islands' reef images were rectified using ERDAS Imagine TM using 10 reference points (RP) recorded on each island, and compared with airborne imagery that was obtained from Kuwait government Municipality.

2.3.2. Collection of field data

Ten reference points were identified on each island, the minimum number of ground control points (GCP) required for each image in order to give accurate results with a geometric error of < 1 pixel (10 cm) (see Thamrong-nawasawat, 1996). Using the 10 reference points the digital maps for each island were rectified (see appendix 1). On each island distinguishable marks were located using GPS co-ordinates point reference using a hand held Garmen-76 GPS projection to Longitude/Latitude WGS 84. Each GPS point was converted to X and Y points and imported into the ERDAS Imagine TM and ArcGIS programmes. The reference points were imported into Excel and converted to a dbase (dbf) data format as required in ArcGIS. The data were in X and Y data format (Latitude Y and Longitude X). A scale reference of the measured length of a pier feature at Qau Island was used in calibration. ArcMap has the feature of geographical scale after the maps have been rectified in ERDAS and orientated to North.

On each of the reefs on the 3 islands, 90 ground control points (GCPs) scattered randomly around the reef were selected and the general reef benthic diversity at each GCP recorded. This was achieved using two divers. One diver observed the reef features whilst the other recorded the GPS co-ordinates. At each GCP on the reef a snorkeler swam over the shallow reef alongside a small boat, reporting what underwater benthic cover occurred and each GPS point was referenced. Many areas of the island reefs consisted of patchy coral interspersed by sand. So, GPS readings were occasionally taken over areas that were not strictly reef. Also, the reef edge was not always visible due to the high turbidity of the water. Classification of the reef requires ground control points (GCPs) on each reef to estimate the benthic cover and to assess class accuracy of the classified reef map and to reduce errors to a minimum. Benthic cover classes were ground truthed by visiting specific locations control points (GCPs) on the lee and fore reefs and assessing the physical habitat structure and benthic cover in $5m^2$ areas at 38 stations. Benthic cover is the combination of the habitat and community, so the dominant organisms and major physical modifiers such as being in the lee or fore reef site were identified. The physical appearance of each habitat as influenced or shaped by the living organisms was also recorded. The 5 m^2 areas were randomly scattered around each reef in order to scale the benthic percentage cover and their positions noted on the classified reef maps (appendix 2). In each $5m^2$ area a diver swam over the area and noted the estimated percentage cover of the major benthic organisms in the area and recorded the GPS points and depth. The benthic cover class data were superimposed in a GIS layer into the five maps to check the accuracy and to scale the coral intensity appearance to percentage cover.

2.3.3. Map coverage and data automation and conversion into ArcGIS ready layers and habitat mapping.

The existing bathymetry map from the Kuwait Admiralty chart was scanned and used as a base map reference (Fig. 2.3.4). The Landsat-7 ETM+ and IKONOS atmospherically corrected data available from the KISR remote sensing laboratory were superimposed onto the aerial coverage. The different enhancement techniques using ERDAS Imagine TM program highlighted the benthic features using different images and aerial photos. Atmospheric conditions and the attenuation of light within the water were taken into consideration and the maps altered to enhance the quality of the displayed images. Image enhancement was undertaken in order to visually identify the distributions of reef biota and improve the accuracy of the estimates. The coverage was considered as raster file maps used in the ERDAS Imagine program. Each raster file was geometrically corrected using the 10 georeference points on each of 3 islands. The corrected raster aerial maps were imported into the ArcGIS program to produce different GIS layers. Boundaries of features on the raster maps were traced around as polygons using ArcMap – ArcInfo (Fig. 2.3.1, Fig. 2.3.2 and Fig.2.3.3). Finally, the data from the 90 GCPs and 35 x 5m² areas from each reef were entered and linked with each thematic layer formed in different layers in GIS. The classifications were provided with a site-use/benthic cover map for the reefs that had been verified against the field collected data.

2.3.4. Depth gradient profiles along two 150 m long reefs.

After tracing and mapping the reefs around each of the 3 islands the structure of the reef communities with depth were assessed from the reef edge 8 m to front 1 m depth on both the leeward and windward sides of each reef (Fig 2.3.4 and Fig.2.3.5). Two 150 m long reef profiles taken perpendicular to the beach on the leeward and windward sides of each reef were video surveyed in September 2005. The video survey was conducted along a 150 m line using a Sony digital video camera in a Handy Cam housing, water depth was automatically recorded using a depth gauge computer (Suunto Spyder) which appeared in the video every 1 metre. Natural light was used during video recording at all sites, as it was sunny most of the time. The video recording was carried out by a diver swimming along the 150 m line at a constant speed, approximately 50 cm above the substratum and with the camera pointed vertically downwards. The swimming speed was approximately 0.2 m s^{-1} in order to obtain images in focus. The video coverage of the organisms taken along the 150 m line was analysed from about 186 images grabbed at 3 second intervals. Images were selected and the organisms identified by placing 6 random placed points on the 17 inch computer screen recording benthic cover under each point together with the recorded depth. The benthic data list with depth and position along the transect were recorded in Excel and converted to a percentage cover at each 2 m depth interval. The depths were summarized with the benthic percentage cover over 2 m depth intervals and pie charts were plotted for each depth interval to show the benthic distribution on the 150 m profile line with the depth variability.

2.4 Results

Kuwait island reef classification.

This study mapped the reef habitats of the three islands using the available high resolution 37 cm aerial photographs rectified against Landsat-7 ETM+ (30 m) and IKONOS (1 m) data with 10 RPs and the maps have been georefernced successfully. Supervised classification using the high resolution rectified aerial photographs has produced classified reef maps showing the different types of benthic cover and their intensity with good accuracy. Each of the reef habitats has been classified, to show the distribution, quantity and diversity of the marine benthic cover around each island. In addition the reef coverage and reef distance together with the measurement of each area around each island has been estimated (see Table 2). The pier on Qaru island which was used as a scale reference was measured at 153 m long. Supervised of the rectified aerial photographs divided the reef classification into 5 benthic cover classes (island, sand, high, medium and low live coral cover) and resulted in the classification of three reef habitats.

2.4.1 Habitats classification descriptions.

Using the five cover classes superimposed onto the 5 m^2 benthic cover survey data with other data site description information and the 90 reference points ground truthed in the field, the following classification descriptions were developed:

a. Class 1: island

The island feature class was clearly identified and traced onto the maps with the intertidal zone lines clearly distinguishable. Identification of some terrestrial field marks together with vegetation features allowed the separation of the edge of the land from the water. The areas beyond the water edge were classified as different classes.

b. Class 2: sand

The sand class was clearly identified and traced from the water edge on the fringing beaches to the reef edge. The border of the sand was identified from the coral cover using the ground-truthed field data and physical features on the aerial maps. Fortunately the shallow nature of the surrounding waters and the time the aerial photographs were taken during the lowest tide allowed good classification of the sand areas. Turbidity of the coastal waters was observed along the reef edge, but because it was the lowest tide fine to coarse (broken shells) sand could be clearly identified. The substrata around the reefs ranged from sand to sand with areas of fine algae coverage. Coral rubble (small pieces of dead coral) was also classified but as part of the coral cover class habitat 3 (next section), and could easily be separated from the sand class.

c. Class 3: coral

The coral cover class was clearly identified and traced starting from the sand class edge. However it was difficult to distinguish coral variability within this class. Each coral cover class was divided into three different classes. The collected benthic cover field data and physical features of the coral reefs were superimposed onto this class in an attempt to divide the coral class into three classes. Coral intensity features were converted to percentage coral cover in order to distinguish between live coral and dead coral percentage cover. The darker feature class indicated where there was a higher percentage of live coral cover present and these areas contrasted with areas where there was dead coral and coral rubble. These different areas were identified and confirmed in the ground-truthing surveys conducted in the field. On the basis of these observations the three percentage coral cover classes were divided into 90%, 50% and 10%, as three coral cover intensity classes.

2.4.2 Traced reef classification

The reef surrounding each island was traced using ArcMap - ArcInfo (Fig.2.4.1, Fig.2.4.4 and Fig.2.4.5). Initially it was found that tracing all the fine details of the entire Qaru reef was too time consuming and it appeared during the work that this level of detail was not really required. Instead the major benthic cover classes were traced all around the 3 reefs, and only the left half of the reef from north to south of the site was traced and analyzed in detail (see Fig. 2.4.2 and Fig.2.4.3 as an example). The major benthic cover classes indicated sand patches and different coral intensity cover around each reef. These data were useful as they demonstrated where most areas of the coral reef were depleted in coral cover, the extent of the coral around each island and where sand was accumulating.

2.4.3 Benthic cover ground control points GCPs

The ~90 GCPs were plotted on each map which had had the benthic intensity manually traced classes superimposed onto them. The ground control points were also used to correct the positions of the traced classes too. In addition the benthic cover data obtained from the 38 x 5 m^2 quadrats were also plotted on each map to emphasize the manually traced benthic classes. However the GPS points did not match on the images as they were plotted ~600 m off the true position. The reasons why the positions were "off" may possibly have occurred because the satellite had shifted during the second Gulf War. An attempt to correct the GPS points by contacting the makers of the Garmen-76 GPS brand which was used at the time was not successful as no reply has been received to date i.e. the 15th February 2007.

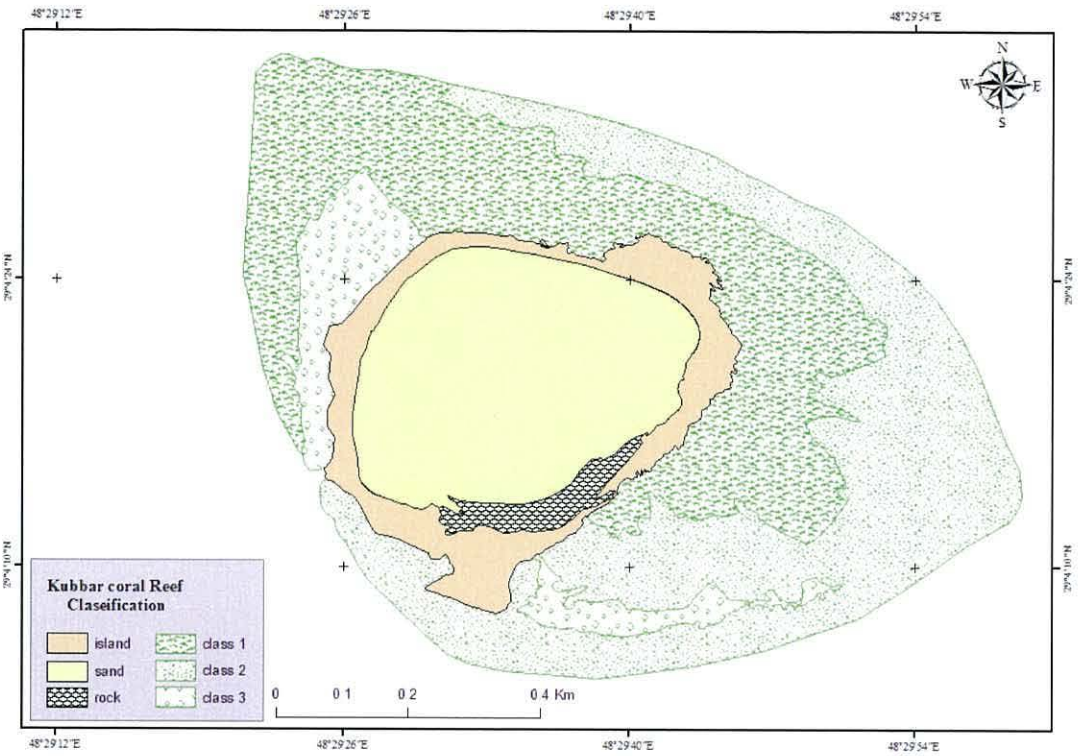

Figure 2.4.1. Kubbar Island Reef habitat mapped and classified; class 1 is 70% coral, class 2 is 50% coral and class 3 is 10% coral.

Figure 2.4.2. Kubbar Island Reef habitat mapped and traced.

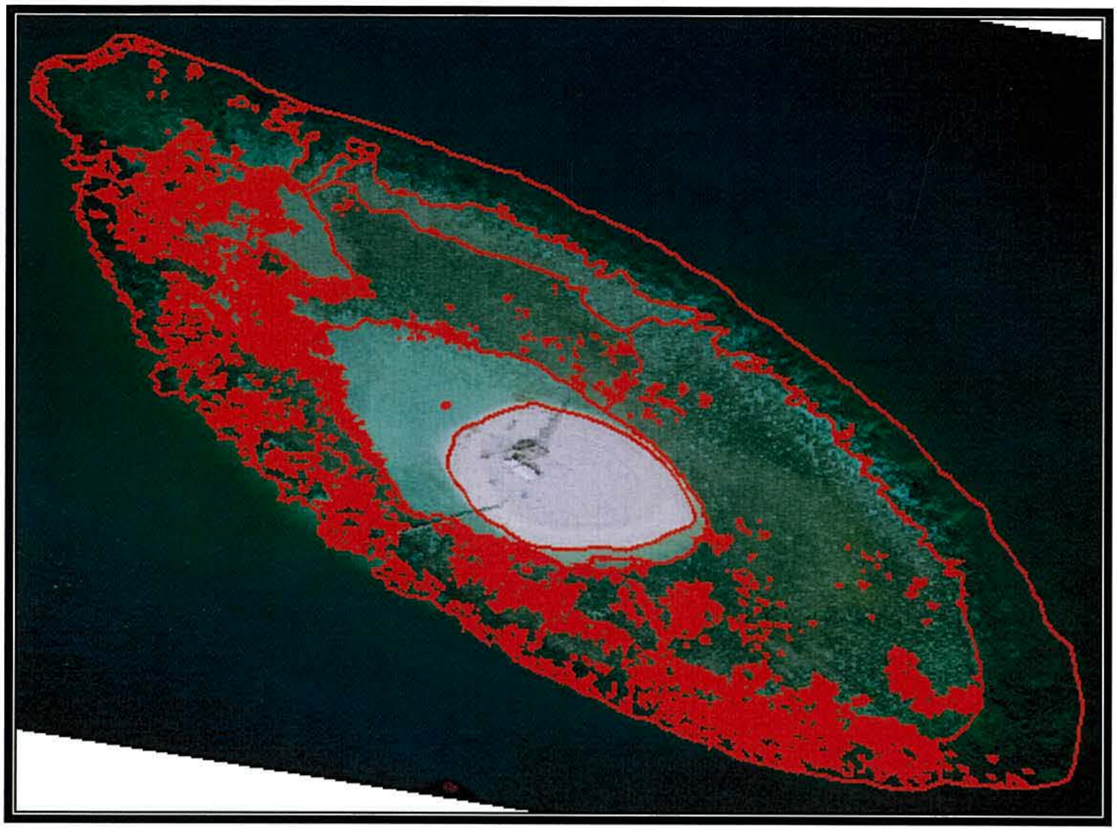

Figure 2.4.3. Qaru Island Reef habitat mapped and traced.

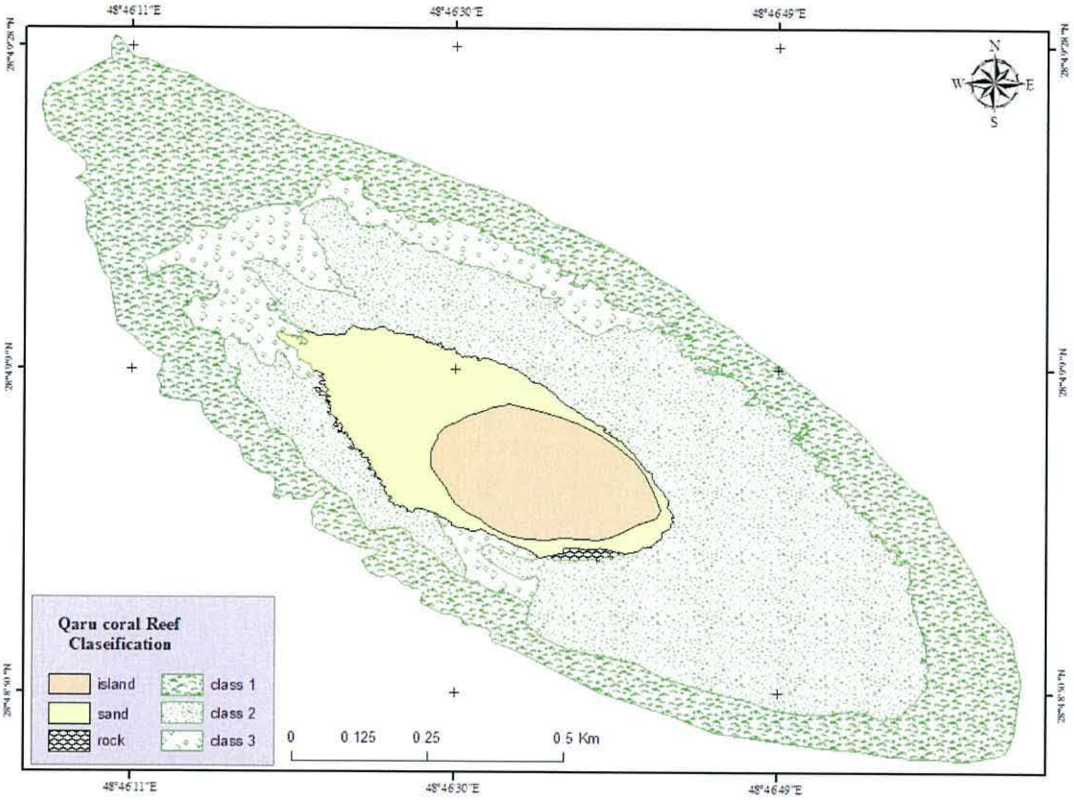

Figure 2.4.4. Qaru Island Reef habitat mapped and classified; class 1 is 70% coral, class 2 is 50% moving to lighter grain to class 3 is 10%.

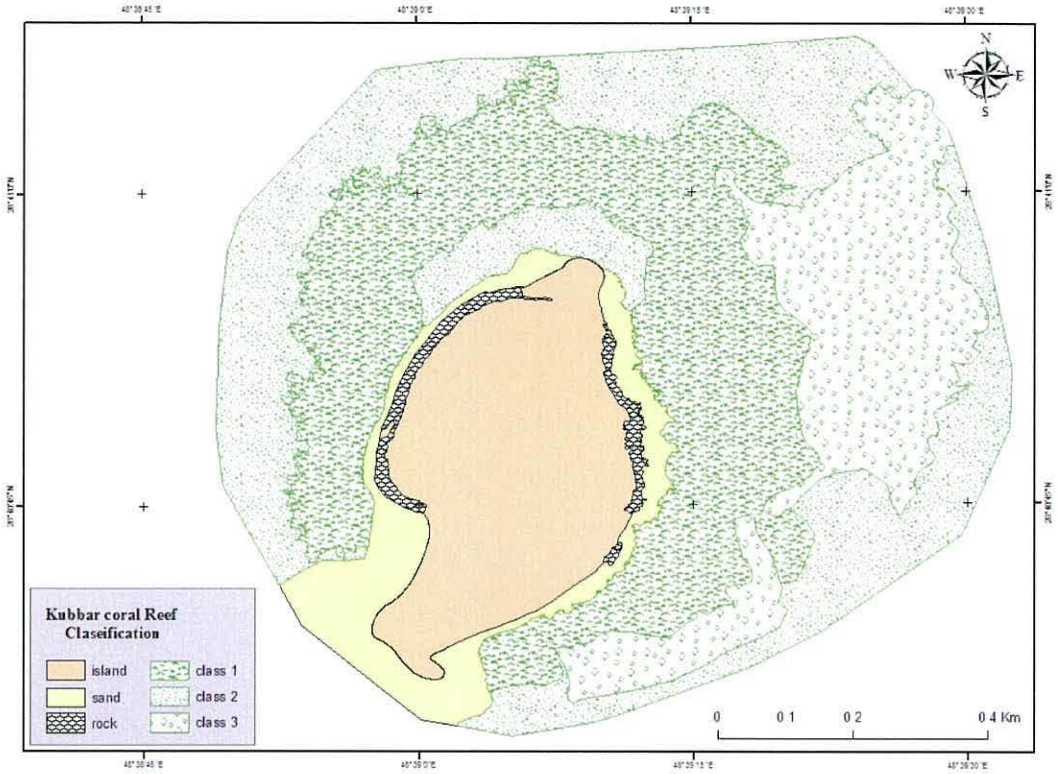

Figure 2.4.5. Umm AlMaradim Island Reef habitat mapped and classified with island; class 3 is 10% coral, class 2 is 50% coral and class 1 is 70% coral.

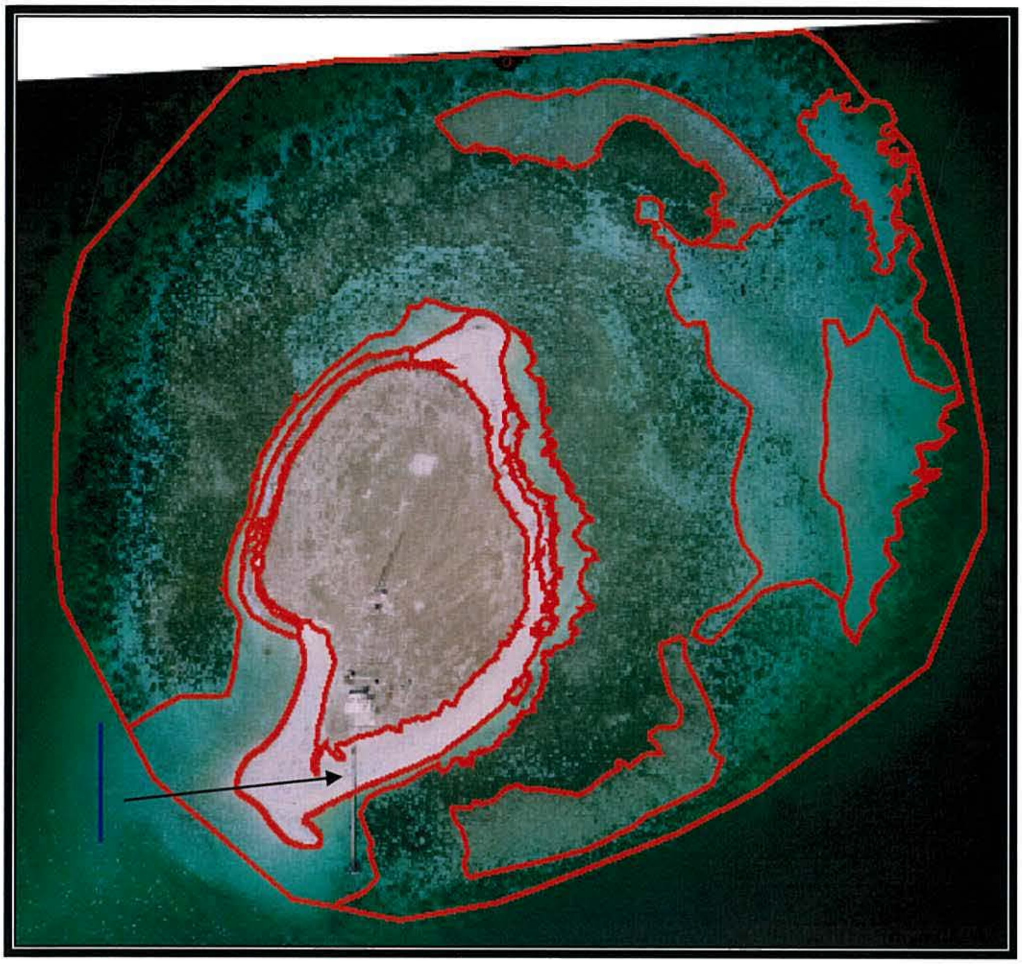

Figure 2.4.6. Umm AlMaradim Island Reef habitat mapped and traced (red line). A blue line scale (150 m) measured from the island pier is shown by an arrow.

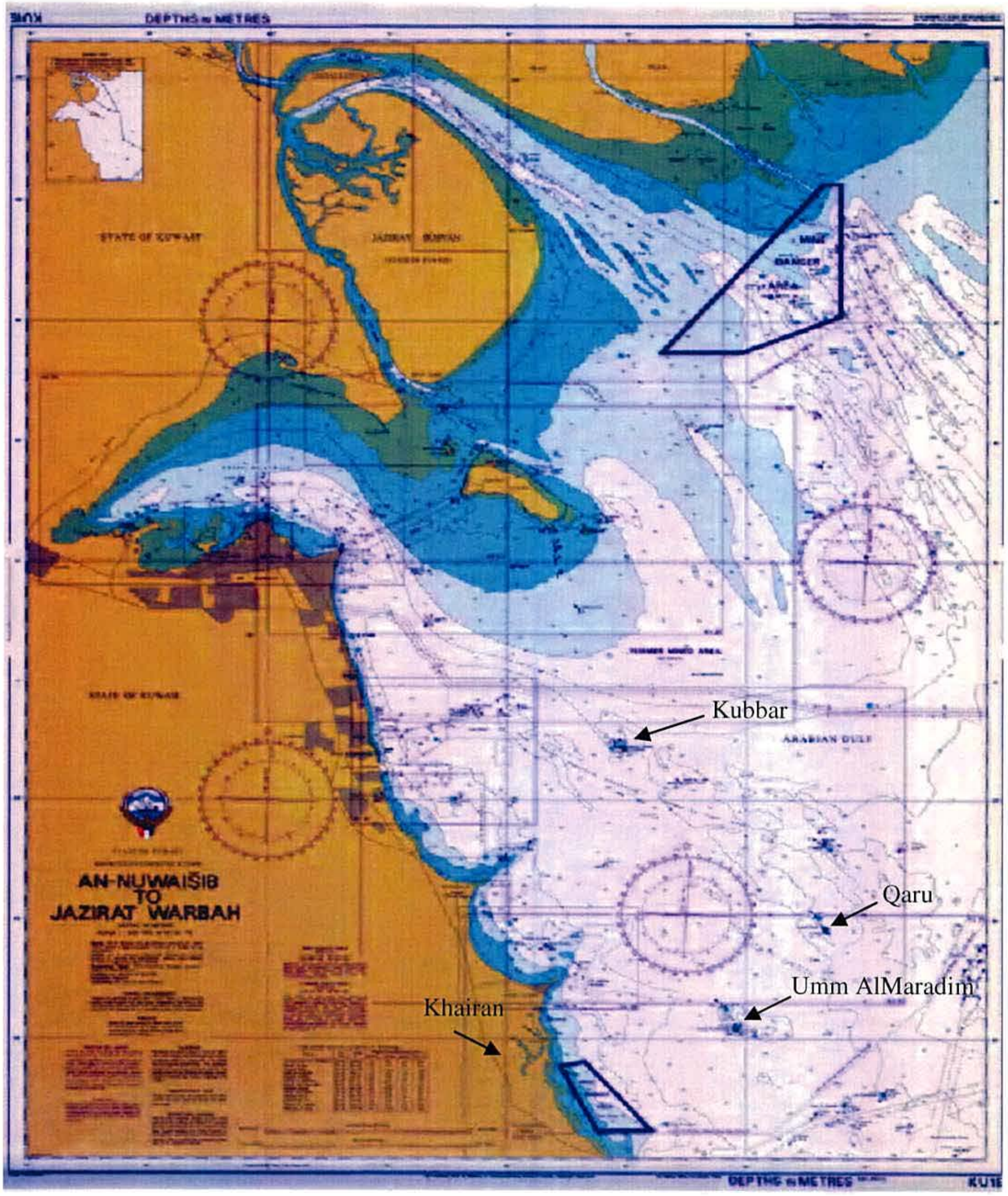

Figure 2.4.7. A Bathymetry map of Kuwaiti waters digitized from the Admiralty chart (source Kuwait Ministry of Communication Surveys 1985, WGS 84 + depth in meters) (three arrows show the 3 reefs, Kubbar, Qaru and Umm AlMaradim surveyed from the Khairan main sea cruises marina).

2.4.4 Reef setting and description using the 150 m reef profile surveys and following classification of the reefs maps

The geological data of each island location were added to the maps of each reef. And the length of the reef coastline calculated and the profiles of the 150 m reef surveys illustrated on maps. The benthic percentage cover was calculated from the analysed video images taken along the 150 m profiles of all the surveys conducted along the leeward and windward stations at the three sites to illustrate changes in organism distributions and diversity with depth (see Pie charts Fig.2.4.10, Fig.2.4.11, Fig.2.4.13 and Fig.2.4.15). The three reefs Kubbar, Qaru and Umm AlMaradim are surrounded by sandy bays and dominated by very coarse coral-mollusc sand which forms most of their beaches (Fig. 2.4.8).

Figure 2.4.8. A sample of coarse coral-mollusc sand taken from the Island beach of Umm AlMaradim.

The 3 coral reef islands are indicated (arrows) in Fig. 2.4.7. Kubbar Island (latitude 29° 04' 039' north and longitude 48° 29' 284' east, Fig. 2.4.1) is the northern most of the three coral islands. Beachrock is prominent on the southeast and northwest beaches of each of the three islands. The leeward beachrock at Kubbar is particularly widespread covering 120 m of the beach (see Fig. 2.4.9). The windward beachrock is well developed and has unique large beach rock slabs and rock boulders thrown up around the upper limits of the intertidal zone most likely by major storms (see Fig. 2.4.1). By contrast the leeward beach position is protected from erosion but is exposed to seasonally high waves driven by longer fetch waves coming from the open water during storm conditions. The surrounding, subtidal elliptical-shaped reef is about 791 m long in a north west and south east direction and 338 m on each side in an east to west direction but mostly along the east side of the island (see Fig. 2.4.1 and Table 2.4.1). This type of reef distribution is typical of all the 3 island reefs, with a larger reef length along the east side than the west side and similar lengths of reefs on the south east and north west sides of all the reefs.

Figure 2.4.9. Large beach rock slabs about 6 m in width and extending about 120 m along the beach on the southeast side are normal features of the three islands.

2.4.5 Species abundance and distribution along the 150 m profile of the reef communities a) Kubbar reef

Kubbar's reef flat, in a depth of water between 2 – 4 m, is dominated by both living and dead *Porites*, with reduced cover of *Acropora* and other coral species (see Fig. 2.4.10 and 2.4.11). Several small patch reefs with less cover and diversity of coral species were found at the north and northwest of Kubbar Island as is shown in the classified map (Fig. 2.4.1), 537,705.9m^2 and in the pie chart (Fig. 2.4.11). Sites with a greater degree of protection from wave action have a higher abundance of delicate plate or branching *Acropora* species (Fig. 2.4.10) and constituted ~ 20% of the benthic diversity recorded at that depth.

Table 2.4.1. Reef distances from beach to the reef edge around each coral island site, calculated from the classified created reef maps in the ArcInfo GIS program.

Reef Island	Direction from beach	Island reef distances in m
Kubbar	North West	339.06
	East	233.80
	South East	452.20
	West	103.88
Qaru	North West	658.83
	East	288.60
	South East	686.19
	West	145.66
Umm AlMaradim	North East	531.84
	South West	194.86
	North West	337.01
	South East	462.31

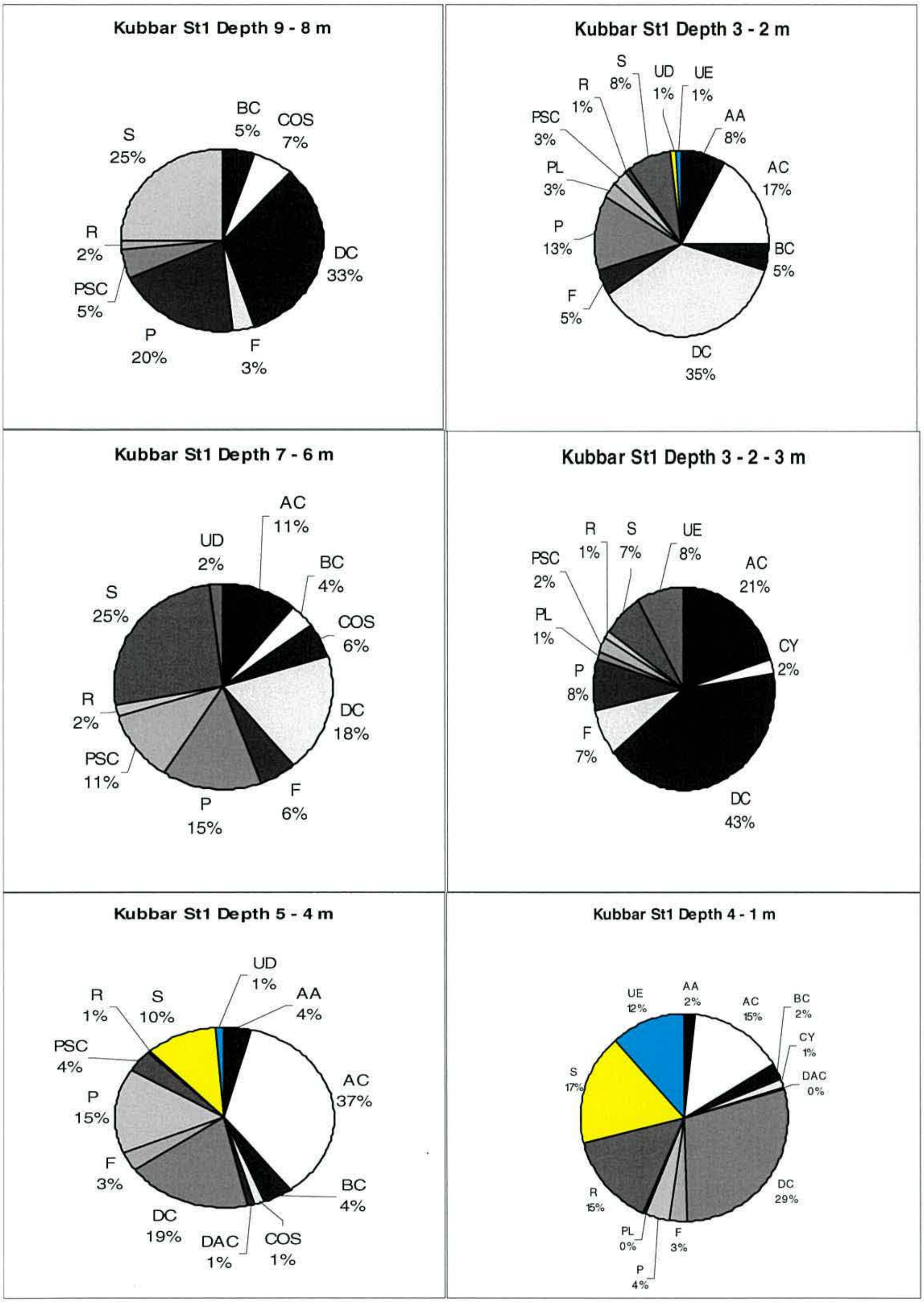

Figure 2.4.10. Kubbar station 1 pie charts for the species composition recorded along the 150 m profile in September 2005, showing benthic percentage cover at 1-2 m depth intervals reading from the reef edge towards the shallow side (changing depths from 9 – 8 – 7 – 6 – 5 – 4 - 3 – 2 – 3 – 2 – 3 – 4 – 1 m respectively). Benthic cover codes as AA *Acropora arabensis*; AC *Acropora clathrata*; DAC dead AC; BC brain coral; PL *Platygyra daedalea*; F *Favia pallida*; COS *Coscinaraea columna*; P *Porities*; PSC *Psamocora contigua*; CY *Cyphastrea serailia*; DC dead coral; R rubble; S sediment (sand); UE *Echinometra mathaei*; and UD *Diadema setosum*.

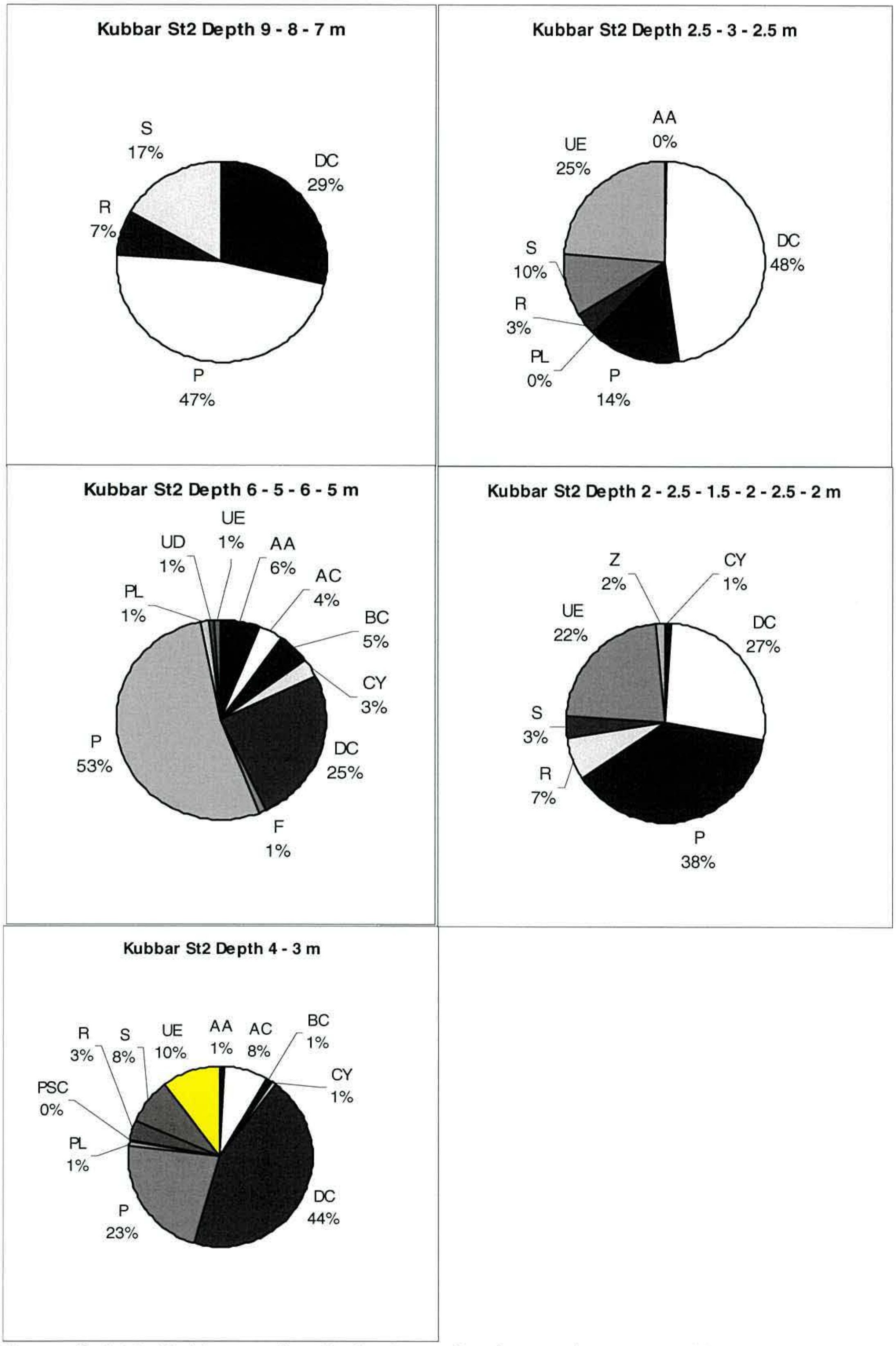

Figure 2.4.11. Kubbar station 2 pie charts for the species composition recorded along the 150 m profile in September 2005, showing benthic percentage cover at 1-2 m depth intervals from the reef edge towards the shallow side (changing depth from 9 – 8 – 7 – 6 – 5 – 6 – 5 – 4 – 3 – 2.5 – 3 – 2.5 – 3 – 2.5 – 2 – 2.5 – 1.5 – 2 – 2.5 – 2 m respectively). Benthic cover codes as Fig. 2.4.10

The 150 m long profile of Kubbar reef started at the reef edge in a depth of 9 m to the reef flat at 2 m depth (Fig. 2.4.10 and 2.4.11). Starting at station 1 leeward, from the base of the reef at 9 m depth, the benthic cover was mostly sand S and dead coral DC with a few live corals e.g. *Porites* P, *Coscinaraea columna* COS, *Psamocora contigua* PSC, brain coral BC and *Favia* F. *Acropora arabensis* AA and *Acropora clathrata* AC however appeared only at a depth of 7 m at the end of the profile (see Fig. 2.4.12 and Pie chart Fig. 2.4.10). This mixed benthic community was present all the way along the profile to a depth of 1 m but with different intensities. The levels of dead coral were similar along the profile. Sea urchins *Echinometra mathaei* (UE) were recorded mostly at this site with even distribution between depths 3 to 1 m, *Diadema setosum* (UD), however, occurred in the deeper sites at depths of 7 m, below this no sea urchins were recorded at depths between 7 & 8 m. Station 2 windward, showed a similar species composition and abundance at the base of the profile along station 1, but with more live coral *Porites* (P) (see Fig. 2.4.12 and Pie chart Fig. 2.4.11). The profile showed similar mixed communities all the way to the top of the profile into depths of 2 m, but with more *Porites* (P) and less *A. arabensis* (AA) and *Acropora clathrata* (AC). Sea urchins were mostly *E. mathaei* (UE) at this site and were evenly distributed between depths of 4 to 1 m, with no records of UE sea urchins found deeper than 4 m to 9 m at the base of the profile.

b) Umm AlMaradim reef

The largest and southernmost of Kuwait's coral reef islands is Umm AlMaradim (see Fig. 2.4.5 and Fig 2.4.7) 736,245.65m^2 calculated from the classified map. Location of this island is at latitude 28° 41' 000' north and longitude 48° 39' 000' east. Rather oval in shape, the island is about 550 m in length and is surrounded by a sandy beach and beachrock (see Fig 2.4.5 and Fig 2.4.9). The surrounding reef is about 727 m wide extending northeast with southwest reef lengths of 799 m long adding northwest with southeast reef lengths (see Table.2.4.1) and is dominated by massive stands of *Porites* (P) corals, both living and dead coral (DC), and small colonies of branching *A. clathrata* (AC) and *A. arabensis* (AA). Smaller patch reefs are located northwest and southeast of Umm AlMaradim Island. The reef edge contains more live coral than the shallower reef where mostly dead coral occurs (see Fig. 2.4.13).

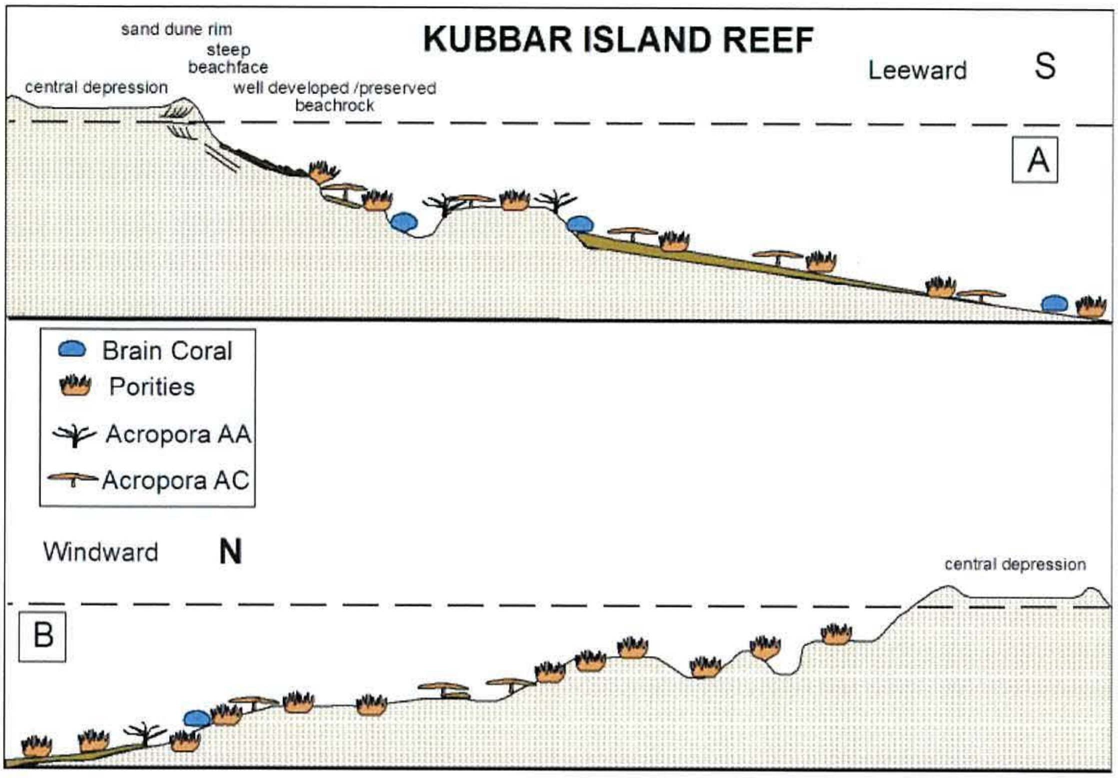

Figure 2.4.12. Kubbar Island reef 150 m profile survey in September 2005, showing diagram along the leeward side of A) station 1 and B) windward side of station 2.

The 150 m long Umm AlMaradim reef profile started in a depth of 8 m to the reef flat at 1 m depth (see Fig. 2.4.14 and Fig. 2.4.13). Beginning at station 1 on the leeward side, from the base of the profile (8 m depth) with mostly sand (S) and dead coral (DC) with few live corals *Porites* (P), *Platygyra* (PL), *Acropora clathrata* (AC), brain coral (BC) and *Favia* (F) (see Pie chart Fig. 2.4.13). The profile showed similar mixed communities all the way until the shallower depths (1 m) at the top of the profile, but with mostly dead coral (DC) and sand (S). Sea urchins were mostly *E. mathaei* (UE) at this site with even distribution in depths between 6 & 3 m, but not seen in the deeper sites and high numbers in the shallow depths (2.5 to 1 m). Station 2 at the windward site, from the base of the profile (9 m depth) was mostly sand (S) and dead coral (DC) with low numbers of individuals contributing to a mixed community (see Fig. 2.4.13 and Fig. 2.4.14). The mixed communities showed a similar trend towards the end of the profile but with more *A. clathrata* (AC) starting at 6 m depth (see Fig. 2.4.13). Sea urchins were mostly *E. mathaei* (UE) along the profile but with a few *D. setosum* (UD) appearing at the base of the profile at a depth of only 5 m.

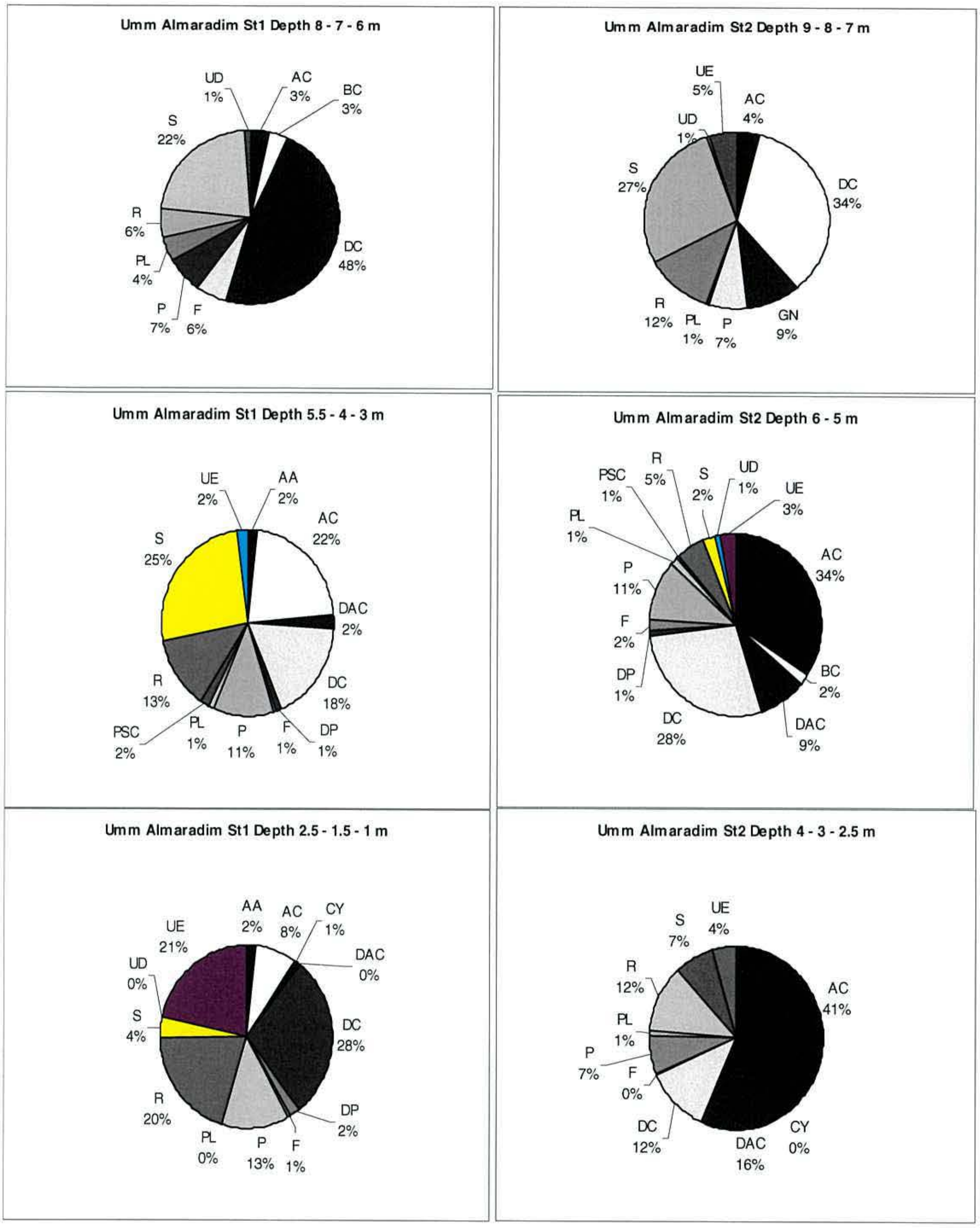

Figure 2.4.13. Umm AlMaradim station 1 and 2 pie charts for the species composition recorded along the 150 m profile survey in September 2005, showing the benthic percentage cover at 1-2 m depth intervals from the reef edge towards the shallow water side (changing depth at St 1 from 8 – 7 – 6 – 5.5 – 4 – 3 – 2.5 – 1.5 – 1 m, and at St2 from 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2.5 m respectively).

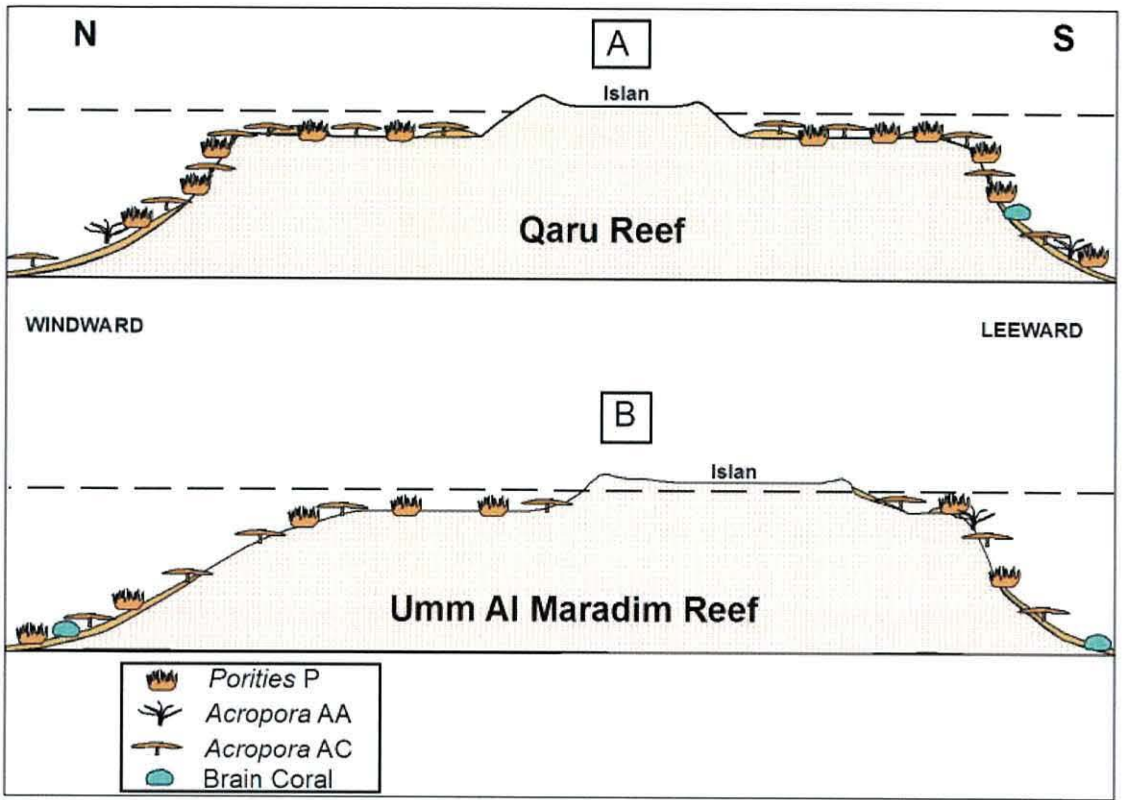

Figure 2.4.14. Qaru Island reef (A) and Umm AlMaradim Island reef (B) 150 m profile survey in September 2005, showing diagram along the leeward side station 1 and windward side station 2.

C) Qaru reef.

Qaru is the smallest of the three coral islands; it is only 289 m in diameter, but with a larger reef area to that of the other reefs (see Fig. 2.4.4) 724,743m^2 calculated from the classified map. Location of the island in the centre of the reef is at latitude 28° 49' 000' north and longitude 48° 46' 000' east. It is surrounded by an elliptical-shaped reef, with a length of 1345 m and width of 434 m. Although the island is unvegetated, the reef of Qaru Island is probably Kuwait's most diverse and visually attractive one. The extensive reef flat is dominated by colonies of branching and table *Acropora* (AC), some as large as 4 m in diameter, and massive stands of both living and dead *Porites* (P). Other corals and reef organisms were seen at depths of 10 m. Large *P. lutea* (PU) colonies, estimated to be hundreds of years in age (Carpenter et al., 1997), dominated the reef edge mostly at east side of the reef.

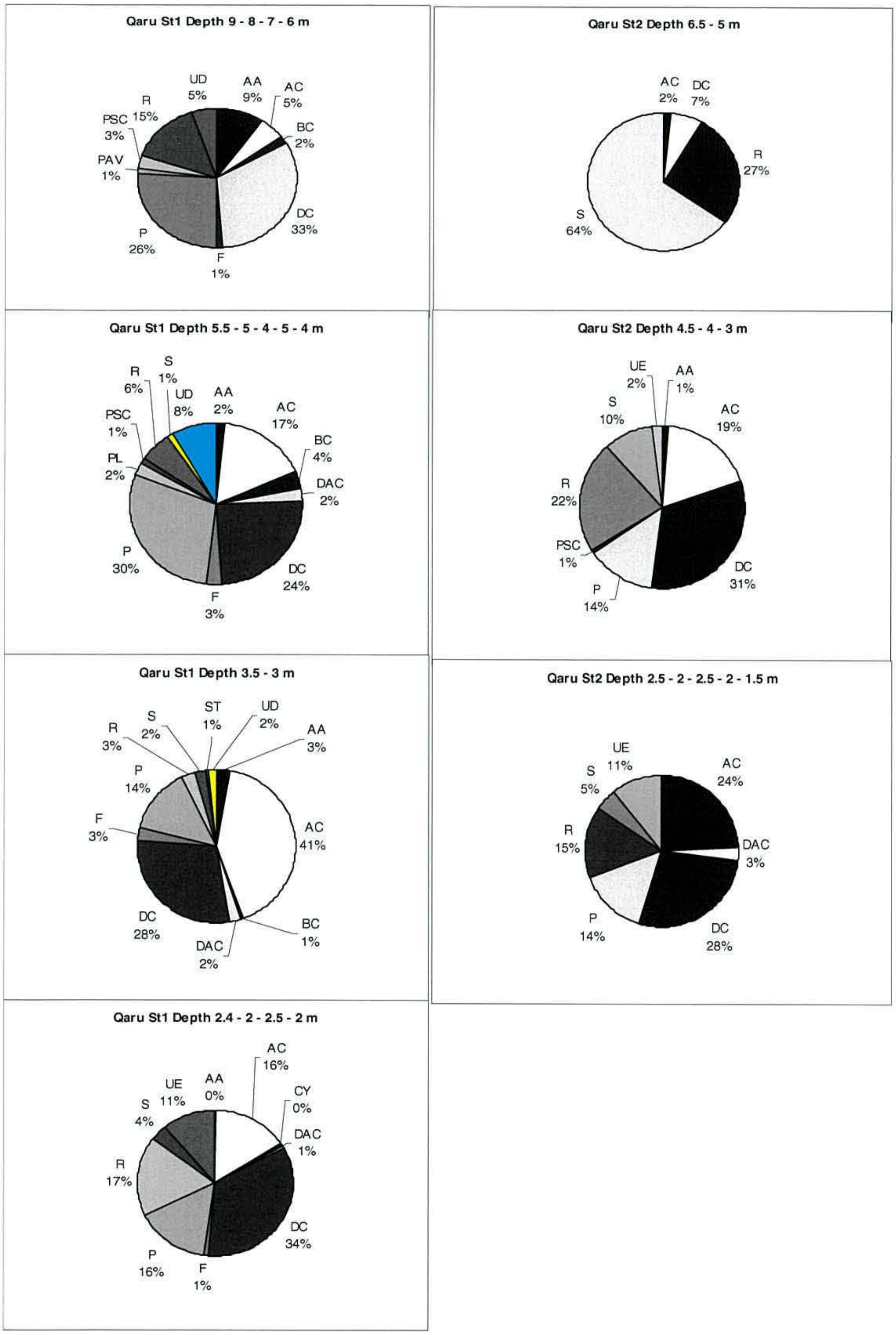

Figure 2.4.15. Qaru station 1 and 2 pie charts for the species composition recorded along the 150 m profile survey in September 2005, showing the benthic percentage cover at 1-2 m depth intervals from the reef edge towards the shallow water side (changing depth at St1 from 9 - 8 – 7 – 6 – 5.5 – 5 - 4 – 5 – 4 – 3.5 – 3 – 2.4 – 2 – 2.5 – 2 m, and at St2 from 6.5 – 5 – 4.5 – 4 - 3 – 2.5 – 2 – 2.5 – 2 – 1.5 m respectively).

The Qaru reef profiles, 150 m long from reef edge in the south and in the northwest to reef flat perpendicular to the beach. Station 1 on the leeward side started at 9 m depth on the south side of the island and comprised mainly of *Porites* (P) 26% and dead coral 33% with a few other live corals e.g. *A. clathrata* (AC) 5%, *A. arabensis* (AA) 9%, *Pavona decussata* (PAV) 1%, *Psamocora contigua* (PSC) 3% *Favia* (F) and *Cyphastrea serailia* (CY) 1% (see Pie chart Fig. 2.4.15). This profile showed the same mixed communities all the way from the edge of the reef at the shallowest depths until the top of the profile at a depth of 2 m, but with a few sand patches and more *A. clathrata* (AC) appearing at 6 m depth. Sea urchins were mostly *D. setosom* (UD) from the base of the profile at 6 m depth to a depth of 3 m, then *E. mathaei* (UE) to 2 m depth at the end of profile (Pie chart Fig. 2.4.15). Station 2 on the windward side started at 6.5 m depth northwest with mostly sand (S) 64% and rubble (R) 27% with a few dead coral 7% and 2% *A. clathrata* (AC) colonies (Pie chart Fig. 2.4.15). The windward profile showed more live coral at depths of 4.5 e.g. *A. clathrata* (AC) 19%, *A. arabensis* (AA) 1% and *Porites* (P) 14% with almost the same numbers to 1.5 m depth at the top of the profile. Sea urchins were mostly *E. mathaei* (UE) 2% to 11% and were present from depths of 4.5 m to 1.5 m along the profile (Pie chart Fig. 2.4.15).

2.5 Discussion

Since aerial photographs have a resolution of 37 cm, then manually traced classes were considered to be best directed to run as a supervised classification. A number of accuracy assessment reference points together with the habitats found at those points were used to construct the habitat maps. The high resolution coverage used in this study made it easy to correlate reference points with each classified image. Digitized aerial photographs in reef habitat mapping have been conducted for the three coral reef islands and some of the best developed offshore reefs (Carpenter et. al., 1997). It is therefore reasonable to assume that habitat maps resemble the real reefs and they have subsequently been used in the management of the marine environment (e.g. Klaus and Turner 2004; Turner and Klaus 2005). Digitized aerial photographs and classified habitat maps should be used to replace the visual interpretation of aerial photographs so that more important information can be gained which will be of greater use for scientists engaged in reef management (Thamrong-nawasawat 1996).

Previously used coral reef remote sensing techniques have many constraints (Thamrong-nawasawat 1996). Using high resolution coverage e.g. aerial photographs of small reefs has made it relatively easy to apply the techniques for generally monitoring the marine environment in particular for coral reefs. Habitat mapping is therefore a useful method for monitoring the marine environment and they can form the basis for the formulation of protection plans.

2.5.1 Benthic reef habitat classification

The major benthic reef habitat classification demonstrated sand patches and different coral intensity cover around each of the 3 reefs. The surveys showed where most sites were depleted of coral cover and where the coral reef edge was situated around each island and where sand was accumulating. The sand was coarse and was mixed with broken shells and pieces of coral skeleton (see Fig. 2.4.8). Substratum type was the most needed classification to provide base-line data with which to assess any differences in future reef habitat classification maps of the areas. These data are required in Kuwaiti waters because of the need to manage the vulnerable environments around Kuwait. It is vitally important for any management strategies that the current condition of the coral reefs has been assessed and the geographical size of the reef around each island is known so that any changes in the future can be observed. To this end the topography and shorelines in and around the reef areas and islands were studied and in the future they must be monitored to investigate any changes in the coral reefs. From the output maps it could clearly be seen how the reef habitat intensity was distributed. Adding on other environmental data e.g. showing current movements, wind speed and temperatures assist in understanding the general settings of the coral reef islands (e.g. Fig.1.1 in chapter 1).

2.5.2 The reef classes

The five identified classes are the most important classes that contribute mostly to the over all reef morphology. Sand movement clearly can be seen around each island and it can then be compared with future reef habitat classification maps to detect how changes have occurred and the extent of the changes can be measured (Flood 1974; Cannon 1979). Over all looking at the three mapped reefs the shape is almost the same i.e. an oval shape. Reef shape was mostly correlated with the dominant current direction from a northwest direction (see Fig.1.1 in chapter 1) (Reynolds 1993; Price 1998). These currents can carry sediments out in the flow from the northern Shatt Al-Arab river and from any sediment disturbed during coastal developments in Kuwait Bay. This could easily be seen in the Kuwait satellite image covering the northern side of the Gulf (see Fig.2.2) (Kwarteng and Al-Ajmi 1997). In addition the artisanal fishery activities during the trawling fishing season (February to September) caused much of sedimentation disturbance especially around the north of Kubbar island. This was clearly evident during the time when I was diving around Kubbar island reef which had the worst visibility of all the 3 sites. Similarly sedimentation impacts of artisanal fishing gear on Kenya's coral reef ecosystems was found to be extensive (Mangi and Roberts 2006). Scientists have argued that the trawling industry generates significant impacts in the marine environment (Sheppard 2006). Water currents contribute to some sediment suspension on the windward reef sites on the northeast side of each reef.

2.5.3 Reef profile and depth gradients

The three islands reefs showed the same depth variability pattern, high depth variability on the leeward sites of the islands but they were not that variable on the windward sites (see Pie graph Fig.2.4.10, Fig.2.4.11, Fig.2.4.13 and Fig.2.4.15). The more depth variability there was the more benthic variability there was. At Kubbar island reef, sand mostly covered the reef edge and was correlated with low benthic diversity, in the middle of the profile there was more variability in depth and this was associated with more benthic diversity and this continued to the end of the shallow depth profile (Pie graph Fig.2.4.10). The abundance of dead coral was similar along the length of the profile from the edge of the reef into shallow depths (Pie graph Fig.2.4.10). However, the windward side was dominated by *Porites* sp. on all the profiles as the most dominant coral species (Pie graph Fig.2.4.11, Fig.2.4.13 and Fig.2.4.15). Starting at the reef edge where there was a low coral diversity only *Porities* sp. were recorded together with sand and dead coral; more coral diversity was seen on the leeward sides of the islands. The smallest reef of all was the most affected by the currents with its sediment load coming from the north site carried out from the Shatt-Alarab River and from sedimentation caused by coastal developments in Kuwait bay (see Fig.2.2).

Qaru island reef was also dominated by *Porites* on the leeward side of the reef edge to mid way along the profile, but *A. clathrata* dominated from mid way to the end of the profile in the shallow reef (Fig.2.4.15). There was more dead coral from mid way to the end of the profile. These dead corals could be correlated to storms which cause high waves and large fetch waves which are common on the leeward side of the reef. However, windward station 2 was dominated by *A. clathrata* at the end of the shallow reef profile. At the start of the profile there was mostly sand (Fig.2.4.15). Qaru reef is considered the second largest reef ($7.25x10^6m^2$) of all and is the most offshore reef, therefore less impacted by the sedimentation carried by the currents. However the currents have over time affected the shape of the reef to some extent making it an oval shape (Fig.2.4.4).

At Umm AlMaradim reef there was a similar variability in depth on both sides, and with a similar diversity of benthic cover. It is the closest island reef to Kuwait mainland, only 18 miles away (Fig.2.4.7). At the start of the profile at station 1 dead coral was mostly recorded with sand as well, but with more diversity of benthic cover (Pie graph Fig.2.4.13). In the middle of the profile along to the end there was high sand and dead coral cover but also with high *A. clathrata* cover and high diversity of other benthic organisms. This reef showed a unified pattern of depth and benthic cover variation, which could possibly correlate with the common current direction along the reefs. However Umm AlMaradim is the southern most reef and the closest to land, therefore, it is less impacted by sediment carried by currents and possibly by large fetch waves during the storm season. In general the shape of this reef is circular not like the other 2 reefs which are oval shaped (see Fig.2.4.5).

2.6 Conclusions

The reef habitats were mapped using rectified aerial photographs through Landsat-7 ETM+ and IKONOS data photographed in 2003 and ground truthed data a year later in 2004. The high resolution remote sensing information quantified and classified the benthic cover habitat and can now be used reliably to design marine protected areas for the management of the sustainable resources of Kuwait.

CHAPTER 3 Kuwait islands reef habitat benthic cover

3.1. Introduction

Benthic percentage cover of the Kuwait coral reef islands at the permanent stations was assessed during the three years of the study to highlight any changes with time. The survey was conducted over two seasons, during the winter and summer, between September 2003 and September 2005. Generally the coral reefs of Kuwait are marginal for reef development, being located in high latitudes at 28° North 48° East (see Fig. 2.2.2) and are in a naturally environmentally stressed ecosystem, where the seawater temperatures are cool (16°C) during the winter and very hot (35°C) in summer (Harrison et al., 1997). Monthly air temperature (minimum and maximum, °C) and precipitation data for January 2004 – September 2005 for Kuwait city (Fig.3.1) were obtained from a local weather web page (Anonymous, 1995-2006, the weather channel interactive). Rainfall indirectly indicates how much freshwater runoff might have occurred each year and this in turn might have affected the intertidal zone around each reef. During the last three years, Kuwait islands coral reefs have undergone major changes. The greater impacts have been through human activities, for example through an increase in the number of divers and an increase in power boat and sailing boat recreation and from those associated with natural impacts e.g. coral bleaching. All these activities are believed to have contributed to the coral reefs degraded state. During the years, 1983-1997, scarcely any reef evaluation had been carried out and the reefs of Kuwait were uncharacterized. There were no baseline data with which to compare subsequent changes in the reefs biodiversity and therefore no data with which to analyze any trends in reef community structure. The natural forces which affect the reefs in Kuwait are not well understood (Downing 1985), and coral assemblages vary markedly, even between reefs in neighbouring sites. The importance of the complex networks of interactions between algae, their grazers and corals for structuring coral assemblages have hitherto not been studied.

Many coral reef ecological studies have been conducted in the Arabian Gulf (McCain et al. 1984; Coles 1988; Sheppard and Wells 1988; Sheppard 1988; Coles and Fadlallah 1991; Sheppard and Sheppard 1991; Sheppard et al. 1992; Downing and Roberts 1993; Gerges 1993; Price et al. 1993; Fadlallah et al. 1995; Coles 1997;

Price 1998; Benzoni et al. 2004). Coral reef monitoring programmes have been carried out around the world either on one occasion or as part of a regular program (Lassig et al. 1988; Craik et al. 1990; Aronson et al. 1994; Heyward et al. 1996; Harriott 1996). As well as reef systems the marine environment around the world should be monitored and protected as good ethics too, as the turnout would be best for the environment and human beings in general (Shirazi 2000). There is a great need for the environment to be monitored and protected, particularly as more environmental resources are used and there is an urgent need to manage sustainable resources so that future generations can benefit from them.

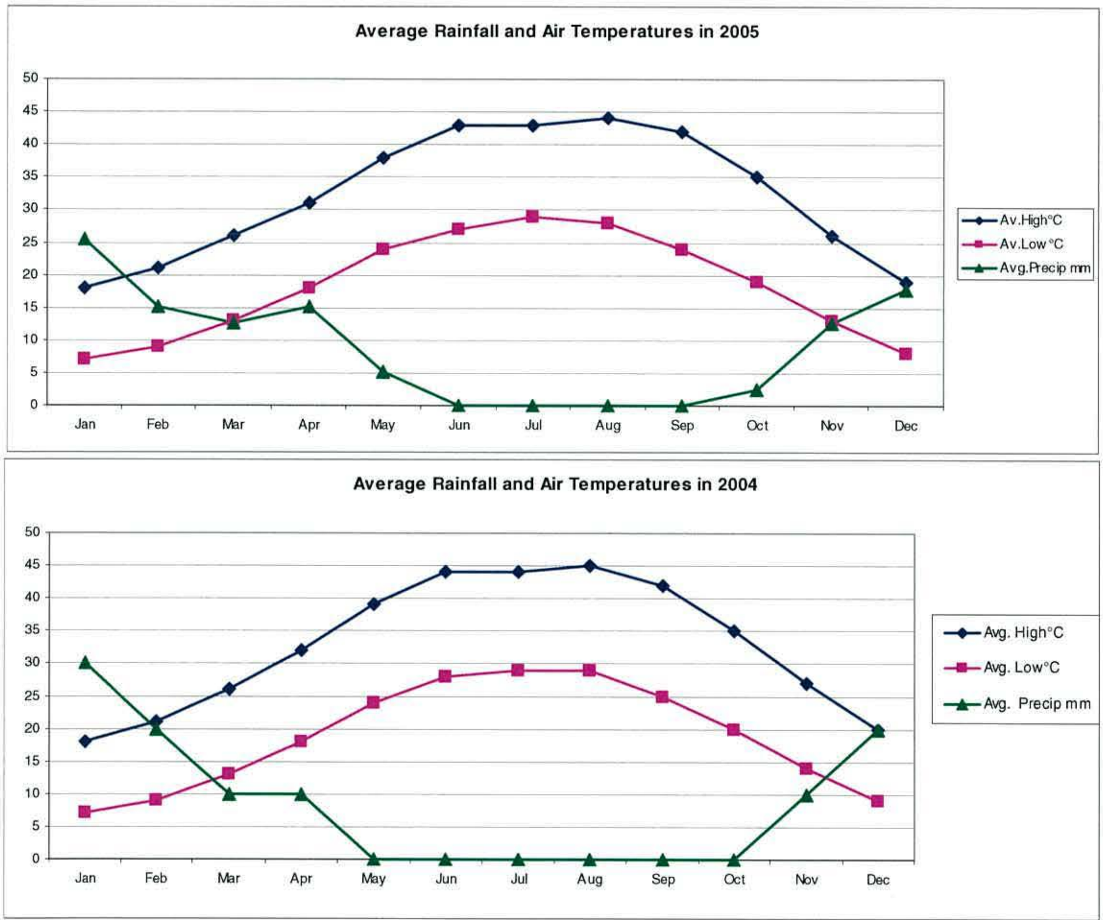

Figure 3.1. Average monthly maximum and minimum air temperatures and the amount of rainfall in Kuwait (data obtained from the weather web in 2004 and 2005).

Early surveys of Kuwait's reefs indicated that significant periods of stress, bleaching and coral mortality occurred in 1982-83 (Downing 1985), and 1984-85 (Downing 1989), and in the winter of 1991-92 (Downing 1992; Downing and Roberts 1993). Gishler, *et al.* (2005) cored *Porites lutea* corals on coral reefs off Qaru reef in 2002 and obtained cores to extract climate proxy data. They reported that these reefs had gone through several significant temperature stress periods and reconstructed seawater temperature ranges between 16 & 34°C (Gischler et al., 2005). In addition to human impacts arising form coastal developments with the inevitable impacts on these reefs, I personally found evidence around the coastal coral reef patches of new coral recruits which had died as a result of being covered completely with sand.

Previous surveys of the coral cover diversity in Kuwait has reported low coral diversity with 24 Scleractinian species in 17 genera (Downing 1985); Downing (1985) has provided a descriptive account of the changes in reef cover over time using site line transect surveys. Downing's survey sites should be marked as permanent stations using global positioning systems (GPS) and repeated surveys conducted over time to investigate possible changes. Data generated can be used to investigate any changes in reef structure. Coral reefs naturally change over time but there is a need to obtain information on how they are changing and to define some criteria with which to measure these changes. It is unknown how Kuwait's coral reefs, which experience natural disturbances such as extreme temperatures and human disturbances, arising from coastal developments and increasing recreational boating respond to these kinds of disturbance.

In response to the increase in recreational boat traffic around the coral reef islands, 10 mooring buoys were installed and distributed around the reef edges at Kubbar, Qaru and Umm AlMaradim islands in 1994 by a Kuwait Dive Team KDT; volunteer groups supported by funds from the Environment Public Authority EPA. The Kuwait dive teams are volunteer groups working to save the environment in general and in particular the reefs, they have been funded by several local companies involved with the environment. The Kuwait government, which has responsibility for the implementation of environmental protection, started in earnest in 1991 to consider protecting the environment especially after Kuwait's liberation from the Iraqi invasion in 1990. It was hoped that the use of these mooring buoys by different sized boats visiting the reefs would reduce damage to the corals arising from anchoring. However, the number of mooring buoys are insufficient for the numbers of visiting boats, and in some cases are not strong enough for the largest recreational boats that probably cause the most damage.

The year long development and construction of a new harbour on Umm AlMaradim island which began in April 2004 is likely to have had an impact on the islands reef. During the survey work in September 2004 the reef at Umm AlMaradim was affected due to the direct physical destruction of the corals from anchorage of barges and building work and from indirect effects due to increased turbidity arising from dredging activity impacts. The changes in the fauna of the reefs and the extent of the damage that took place required quantification in order to measure this human development and its impact on the reefs surrounding Umm AlMaradim and further a field at both Kubbar and Qaru reefs. This is important for the management of personel associated with the development and to understand the extent of the impact of this development might have on Umm AlMaradim reef. Monitoring of these reefs is essential to quantify any changes in these communities that might occur over time and to provide a description of their reef communities and to form management recommendations for reef protection and restoration. In order to monitor change, to assess the state of the health of the reefs over time and to provide the background for a monitoring program the earlier suggestion that permanent survey stations were established at each site is further recognised.

Initial studies on Kuwait's coral reefs have produced data on coral benthic cover especially at the three main offshore islands reefs (Kubbar, Qaru and Umm AlMaradim). These studies were carried out using line transect survey methods (Downing, 1985, 1989, 1991, 1992; Downing and Roberts, 1993), although they were only carried out on one occasion for surveying and assessing the reef condition. A video transect survey has been used by Harrison et al. (1997) in an earlier Kuwait coral reef ecological study. However, the previous studies were not conducted to regularly monitor Kuwait's coral reef status through the establishment of permanent transect lines with permanent marks. In my study video surveying was employed and adapted to survey the fauna along several permanent transects sites with permanent markers.

The most commonly used survey methods have generally employed divers to conduct line and video transect surveys or quadrat surveys to record the percentage benthic cover over short reef distances e.g. (Vogt et al. 1996). For a broad scale survey of the coral reef benthos, divers using snorkels and the manta tow method, in which divers attached to a small boat are towed slowly along and record the organisms that are seen is a recognized procedure (Vogt et al. 1996). The method is especially useful for planning and selecting survey stations around a large reef area. Although manta tows can cover several kilometers they only provide estimates of the cover of broad benthic categories (Carleton and Done 1995).

Underwater video surveys have commonly been used for reef surveys and reef monitoring e.g. (Aronson et al., 1994; Carleton and Done, 1995; Harriott, 1995; Heyward et al., 1996; Vogt et al., 1996; Harrison et al., 1998; Alhazeem, 1998). The advantages of using video transects is that they are a cost-effective method of surveying marine benthic communities (Carleton and Done, 1995; Harriott, 1995; Harrison et al., 1997), and provide quantitative data on the status of the communities, as well as visual records of the communities. Coral reef studies and surveys in general have proved the use of video surveys as being beneficial and accurate and therefore they were used in the present study. However it is important that video survey transects are replicated at least 3 times to demonstrate that the transect statistically shows the survey sites condition and that the selected survey station is a sub-sample of the entire site and that it represents the site. Thus the more transects that are surveyed and "sampled" the more they are likely to reflect more realistically the present state of the site (Aronson et al. 1994). In addition from a statistical point of view there should be at least three different sites with different exposures to correlate and highlight natural and anthropogenic (human) impacts at the sites, and the sites should also be surveyed at different times of the year and the surveys should be conducted at permanent site stations. Sites should be located offshore at different latitudes to highlight the effects of natural change and natural impacts and they should be located at different distances from the coast so that the effects of boat access can be examined to investigate the effects of human impact and to see if there are any differences between the sites. In this chapter I will be investigating whether the island reefs are changing over time and to assess whether they are not degrading.

3.2. Aim and objectives

The aim of this chapter is to report on an investigation into the benthic cover along 2 permanent stations at each reef site over three years (September 2003 to September 2005) and to highlight any changes through time at the 3 Kuwait coral reef islands. Surveys were carried out over two seasons in winter (March) and summer (September), to investigate whether there were any changes over time during the 3 years. Data on the benthic percentage cover from the three island reefs were collected in order to provide a baseline for monitoring any changes to the marine environment of Kuwait. The specific objectives following the experimental design (Fig.3.2.1) are:

1. To locate the best representative stations on the fore and back side of each reef at Kubbar, Umm AlMaradim and Qaru.
2. To establish two permanent survey stations on the fore and back side of each reef site on the three islands.
3. To establish two 50 m long replicate transects on the reef edge and two 50 m long replicate transects on the reef shallow with one in between at each survey station.
4. To video survey all transects at each station recording any different visual features in two different seasons and years; September 2003, March 2004, September 2004 and September 2005. To record the number of boats around the reef during the time of the surveys and to estimate the effects of boat impacts during each site visit.
5. To run an efficiency assessment to estimate the number of replicate transects that would represent each station on the video transect survey at Umm AlMaradim by comparing the data obtained from 4 replicate transects with data from 9 replicate transects.
6. To quantify sediment deposition at each of the 6 survey stations over a one month period during October 2005 following construction of the harbour in April 2004 and to estimate the impact of the construction activities on the coral reefs.

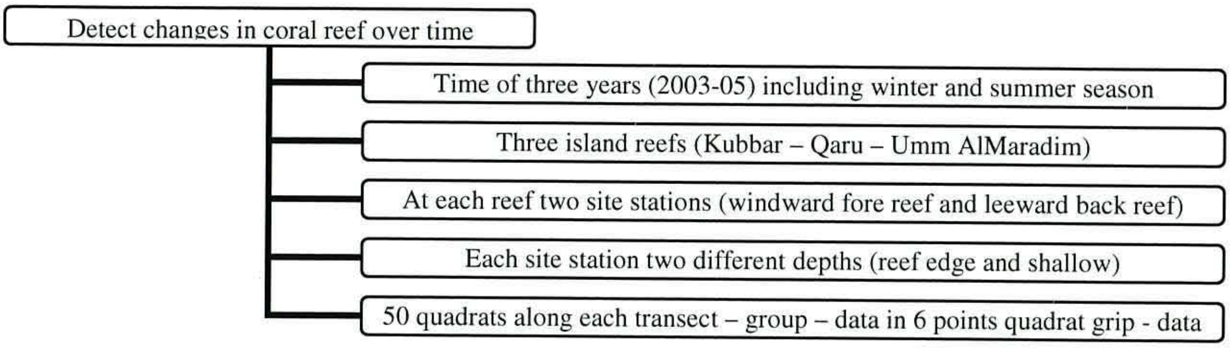

Figure 3.2.1. A summary of the proposed experimental design to study the benthic percentage cover at 2 permanent stations at each of the three island reefs.

3.2.1 Methodology for estimating the benthic cover

The permanent transect sites only represent the benthic cover at the site during each season. The three islands reefs have a similar form with the same morphology as they are all mostly affected by the northeastern current which is the common current direction for circulation of seawater off Kuwait (Fig.1.1). Since the reefs around the three islands have a similar general morphology the whole area can be represented by sub-sampling the reef to represent the reef condition. Four 50m permanent transects were established at two stations at each site and they were considered to closely represent the whole area at the same site. Two stations around each reef were selected, one on the fore reef station (windward) and the other as a back reef (leeward) station (Fig.3.2.6). The four 50m transects were positioned in a relatively homogenous area at each site as illustrated in the reef model in Fig.3.2.1.

3.2.2 Study sites

The developed coral reefs around the three southern islands (Kubbar, Qaru and Umm AlMaradim) were chosen for study (Fig 3.2.5). The reefs were investigated first using manta tows to provide a broad survey of the reef areas after first examining bathometric charts and earlier reef studies in the area (Downing 1989; Harrison et al. 1997) and the best coral community at each station was selected for detailed survey and study. Five permanent transects along the leeward back reef and windward fore reef were established at the three island reefs (Fig.3.2.2.). The permanent stations and transect edges were marked with steel pegs and tagged at the start of the transect (Fig. 3.2.2).

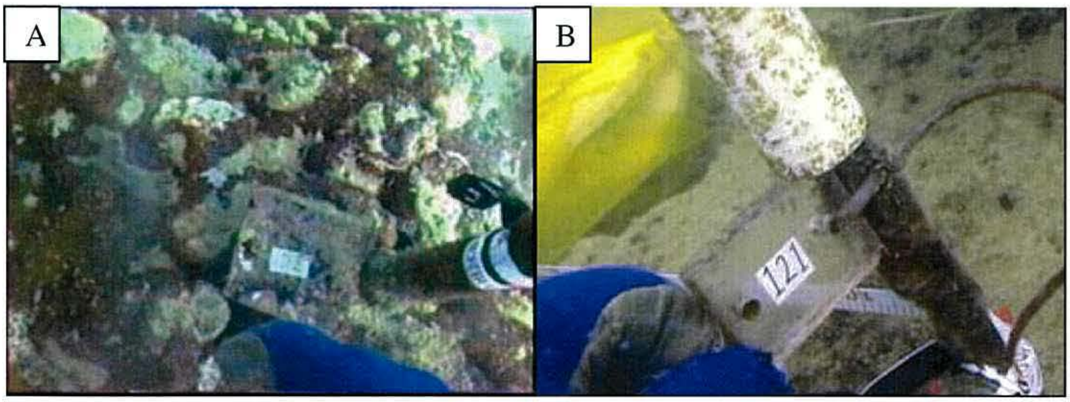

Figure 3.2.2. A) Steel peg with tag number 152 to mark the start of the first station 1 at Umm AlMaradim, B) a peg with tag 121 to mark the beginning of the first station 1 at Qaru.

Each site stations was marked at the reef edge and on the water surface by a mooring buoy. The position of both were recorded using GPS and compass bearings taken (Table 3.2.1). Video transect site stations were surveyed during September 2003, 2004 and 2005 and March 2004.

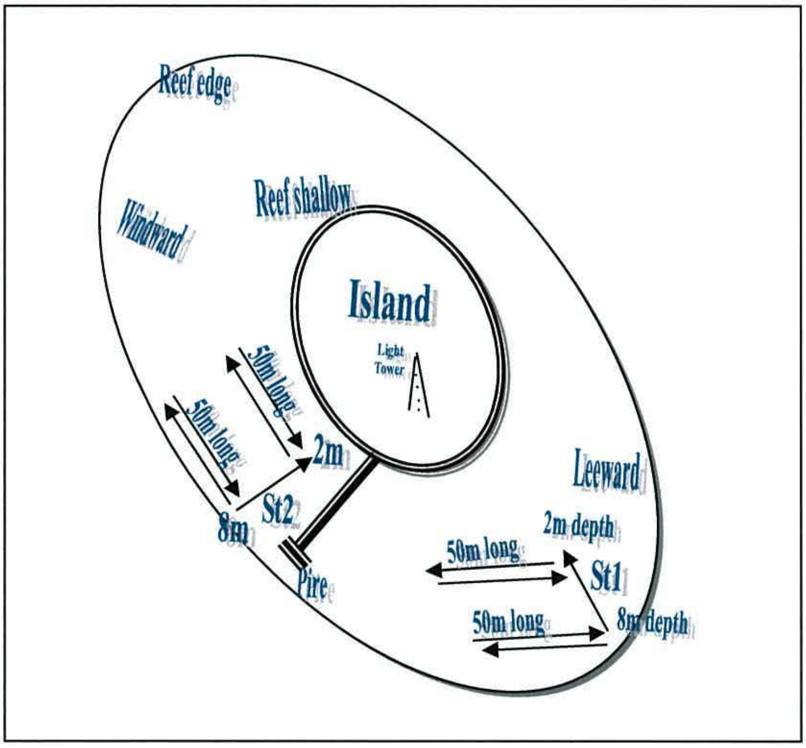

Figure 3.2.3. Model to summarize the relationship between the stations and transects around the reef edges and reef shallows around Kuwait's island reefs.

Table 3.2.1. Description of all the permanent survey site locations and transect directions at the three island coral reefs.

Site	Site Station	Start Of station GPS Point	Direction To Island (Peg marked starting transect)	Transect	Length	Start Of Transect (From Base of Radial at reef edge)	Direction From Radial
Kubbar	K1	29°04'067 N 48°29'596 E	349°	K1.1	50m	7.2m	280°
				K1.2	50m	9.2m	280°
				K1.3	20m	20m	350°
				K1.4	50m	21m	280°
				K1.5	50m	19m	280°
	K2	29°04'304 N 48°29'432 E	225°	K2.1	50m	5m	135°
				K2.2	50m	7m	135°
				K2.3	20m	24m	225°
				K2.4	50m	25m	135°
				K2.5	50m	22m	135°
Qaru	Q1	28°49'004 N 48°46'436 E	330°	Q1.1	50m	16m	270°
Marked 121				Q1.2	50m	18m	270°
				Q1.3	20m	39m	327°
				Q1.4	50m	40m	270°
				Q1.5	50m	38m	270°
	Q2	28°49'068 N 48°46'126 E	55°	Q2.1	50m	10m	330°
				Q2.2	50m	12m	330°
				Q2.3	20m	24m	55°
				Q2.4	50m	25m	330°
				Q2.5	50m	23m	330°
Umm Al Maradim	Um1	28°40'539 N 48°39'255 E	330°	UM1.1	50m	7.2m	255°
Marked 152				Um1.2	50m	9.2m	260°
				Um1.3	20m	44m	330°
				Um1.4	50m	45m	250°
				Um1.5	50m	43m	250°
	Um2	28°40'863 N	90°	Um2.1	50m	5m	0°
		48°38'855 E		Um2.2	50m	7m	0°
				Um2.3	20m	39m	90°
				Um2.4	50m	40m	0°
				Um2.5	50m	38m	0°

During the surveys each site was accessed using an 8 m speedboat hired from the Al-Boom Diving Company based at the Khairan resort marina and which had been specially adapted for diving (see Fig. 3.2.3), or from the Kuwait Institute for Scientific Research Mariculture and Fisheries department marina. The boat was equipped with GPS for the accurate positioning of the boat at the beginning of the survey at the reef edge. All sites were accessible during most weather conditions and were within 60 minutes boat journey from the Khairan resort marina. Captain Reyadh A. Al-Bannow (diving course director of Al-Boom Company NAUI diving club) was in charge of each trip to the coral reef sites.

Figure 3.2.4. 8 m long diving boat (Al-Boom Diving Company, as NAUI diving representative) which was used to perform the coral reef survey.

All diving was carried out according to the University of Wales Bangor rules and regulations.

Planning for the permanent site station selection manta tows was first carried out on the reefs of the three islands to identify the best representative site for the regular monitoring of the permanent study stations on each reef. The position (latitude/longitude according to the World Geodetic System (WGS 84)) of each monitoring station at the reef edge and the compass bearings between the mooring buoys and the light towers on each island were logged using GPS (Fig. 3.2.3 and Table 3.2.1). Two monitoring stations were located on each reef, one in the north-west area of the fore reef in a (windward) position and the second was in the south-east area of the back reef in a leeward reef position (Fig. 3.2.3). The selection of these two positions was in accordance with the prevailing northwest – southeast current (Fig.1.1) and as close as possible to Downing's (1989) original survey given that the description of his positions were based on longitude and latitudes rather than GPS positions as they were not available for comparison. The salinity of the seawater was measured with a hand-held refractometer at the start of each dive. Each site was photographed to illustrate the general view of the sampling areas and to provide a site description to enable future studies to relocate the areas particularly in light of any long-term monitoring programs that might be introduced, and to record important topographic features to enable location of the site in subsequent visits.

On subsequent visits to the reefs station positions were re-located using the GPS. The station positions were also correlated to the position of the moorings buoys around the reef edge. On the surface of the water at each site from the mooring buoy position and the GPS position, a compass bearing to the light tower on the island was followed along a radial line. However, underwater the base of the mooring buoy was used and a compass bearing to the reef edge where each station started was followed before beginning surveys along the 50 m long transect tape measure at the start of the transect. Two other 50 m long transect tapes were also laid down approximately perpendicular to the radial transect on one side following a compass bearing. Two 50 m long transects at the beginning (covering the reef edge at 8 m depth) and two at the end of the radial transect (covering the shallow reef to a depth of 2 m) (Fig. 3.2.3).

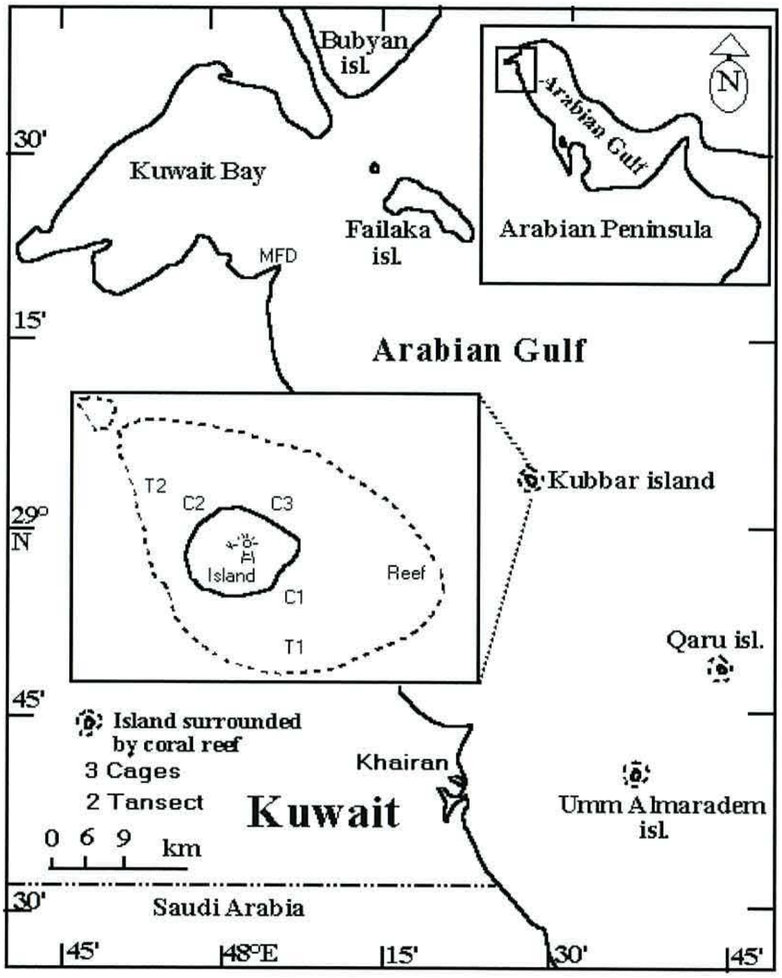

Figure 3.2.6. The islands of Kuwait with an inset showing Kubbar Island and the extent of the coral reef surrounding the island.

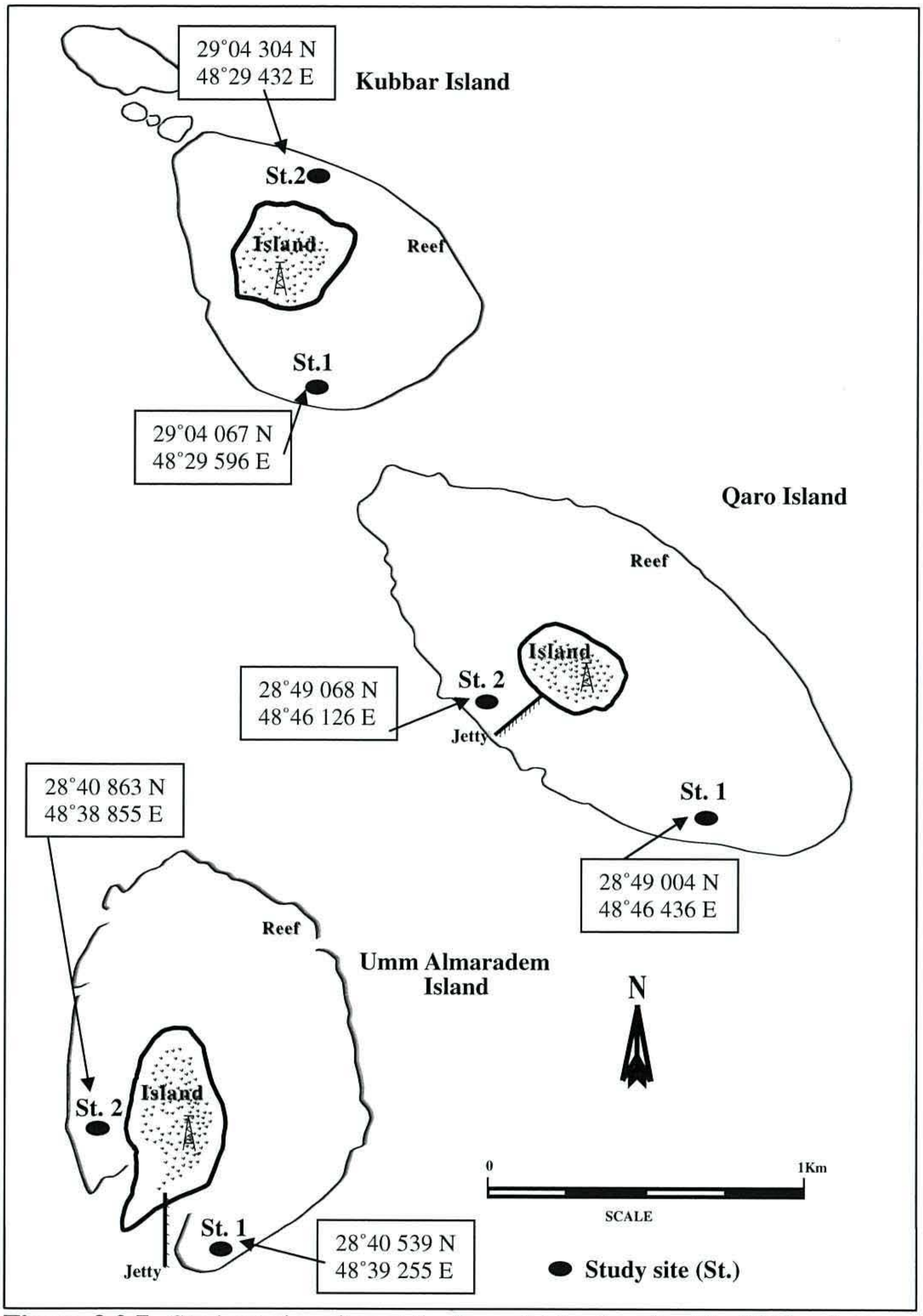

Figure 3.2.7. Study station sites at the 3 coral island reefs. The GPS points are indicated.

The number of sample points and the random position of the sampling points were identified after careful consideration. The appropriate number of sample points in a 50 m long transect line, (transect 1 at site station 1 at Qaru reef), were selected to determine the appropriate number of sample points and their position from an analysis of the videotapes of diver surveys conducted along the transects. The data were used to compare the benthic percentage cover of each benthic category within a transect area. This procedure was similar to that used by Harriott *et al.* (1995) who calculated that approximately 350 data points per 50 m of transect was a statistically appropriate sample size. During the current study, eight different sampling trials (1, 3, 6, 9, 15, 20, 25 and 30 random points) were run on a randomly selected transect in order to optimize the sampling design which was similar to the strategy adopted by Harriott *et al.* (1995) who surveyed the benthic communities along the coral reefs at Lord Howe Island, Australia. The higher sampling intensity used in the current study provided a more thorough analysis of the benthic community structure, and increased the probability of recording uncommon species.

Data precision assessment was carried out to establish that reliable results were being obtained. Coral reef studies and surveys in general have already established that video surveys are a practical and robust method for surveying coral reefs. Ideally video survey transects should contain at least 3 replicated transects and these have been statistically proven (Harriott et al. 1995) and they should show the site condition and that the selected survey stations are a sub-sample of the site and that they represent the site. This is important as the transect survey "sampled" should be a true reflection of the present state of the site (Aronson et al. 1994). To ensure the precision of the transect surveys the benthic cover at Umm AlMaradim reef, station 1 was undertaken by comparing the average percentage benthic cover along 4 transects with the benthic cover along 9 replicate transects. The precision was achieved by video surveying a further 5 replicate transect lines in addition to the 2 lines surveyed along the shallow reef and on the reef edge i.e. 9 transects were surveyed within the survey area. The biodiversity along the 9 transects was observed to ensure that the 4 transect surveys in the shallow and reef edge were truly representative of the biodiversity over the entire survey station. The increased number of replicates was beneficial in providing data which more accurately represented the community structure of the sampling sites. The benthic cover data were also compared on two different occasions by analyzing the video transect survey data twice. The objective of this analysis was to establish that the video images were correctly analyzed.

During each survey site visit the number of recreation boats around the reef was counted which amounted to a period of ~8 hours and the number of boats per site visit was calculated. The estimates were normally made during the diving season and at the weekends and would enable differences between activities at the three reefs to be quantified. In addition, the number of divers present in the water were recorded from details provided by the local dive firm NAWI at the head office of Al-Boom Diving Company. Details such as the number of new divers certified in 2004 were compared with records of how many divers were certified in 1995 to show difference in the number of divers that might have visited the islands during the 9 years time period.

Video surveys of all of the transects were made to record the different visual features which were apparent in the two different seasons and years i.e. during September 2003, March 2004, September 2004 and September 2005. Video surveys of each station were made four times during the three years of field work recording a one metre belt along 5 x 50 m transects beginning and finishing with general views of the site. The permanent survey stations were surveyed three times during the two year study in two seasons, winter and summer, starting September 2003. Extra surveys of all stations were conducted during the period of construction of the new Umm AlMaradim marina and these data are included in a separate section. Surveys were conducted at two stations on the fore and back portions of the three reefs to provide baseline data for these transects which were surveyed in September 2003, March and September 2004 at Kubbar (K1 and K2), Qaru (Q1 and Q2) and Umm AlMaradim (Um1 and Um2). They were then re-surveyed in September 2005 (see figure 3.2.3 and 3.2.6). This timing of the surveys was planned to cover the summer and winter seasons where there was the greatest variation in seawater temperatures and during the summer where there was a high possibility of documenting any bleaching events.

The Sony 805 Hi8 video camera or the Sony digital video camera were used by the divers to film the benthic cover along the transects. Natural light was used during video recording at all sites, as it was sunny most of the time during the dives. A 50m long plastic tape measure, a large size hand held compass and an A4 plastic slate board with pencil were taken on each dive to measure and record details of the organisms and any information about each transect site. The video recording was carried out by a diver who swam along the transect line at a constant speed, ~50 cm above the substratum, with the camera pointing vertically downward. The swimming speed was approximately 0.2 m sec^{-1}, so that the video coverage was clear for analysis. The diver swam along the transect 50 m line in ~4 minutes.

The Hi8 video and the digital video records of the transects were subsequently digitized by a computed Pinnacle V.8 software, for analysis. Video sequences were initially viewed on a 40cm computer monitor, using the Pinnacle V.8 software. Frames were manually selected, in which images were grabbed at random throughout the video sequences of the transects which provided ~50 frames along each of the 50 m transect. The benthic organisms or category which coincided with a randomly placed six points on the screen for each of the 50 frames were identified and recorded as a benthic code (see Fig.3.2.5). In each image, the benthic categories underlying each of the six points on the 40cm monitor were identified. In many cases, identification of a benthic category to species level was not possible from the video images, therefore, broader categories were used i.e. to genus level. These benthic data were recorded in an Excel spreadsheet and the numbers of points recorded for each benthic category were used to calculate the percentage cover of each benthic category within each transect. The mean and standard deviation of the percentage cover for each benthic category were calculated for the 5 transects at each site station. The data were then summarized into five categories: live coral cover, dead coral cover, algae, sea urchin cover and a "rest" categories classified under "other substratum" i.e. sand and rubble. The dominant benthic species were identified underwater to taxonomic level wherever possible. Besides the scleractinian corals, other major groups which were taken into account were the zoanthids (sea anemones), sea cucumbers (Holothurians) and sea urchins (echinoids).

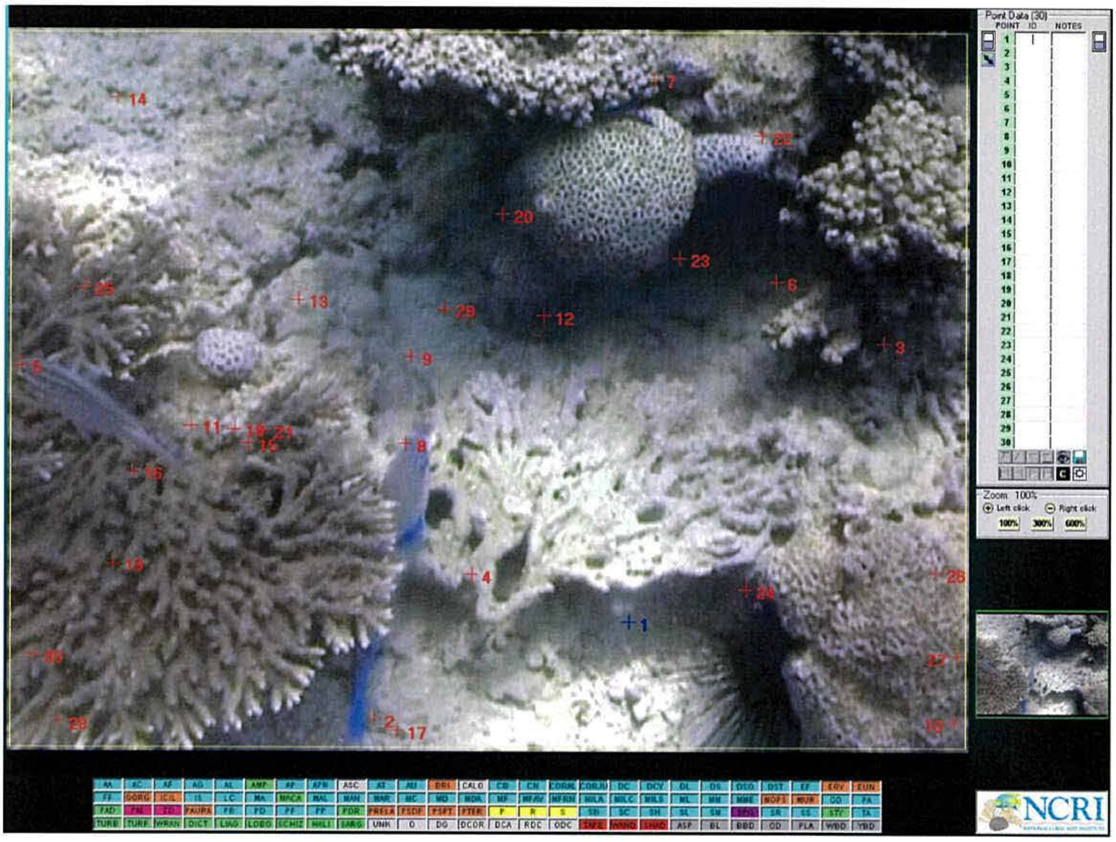

Figure 3.2.5. A digitized image obtained using the Pinnacle V.8 software to illustrate the method of the Coral Point Count (CPC program) (see Kohler and Gill 2006). The benthic cover beneath six points (points 1 to 6) was identified as 1 (Dead Coral, DC), 2 (DC), 3 (DC), 4 (Dead *Acropora clathrata* DAC), 5 (AC) and 6 (DC).

For scleractinian corals, identification was carried out routinely to genus level, but because of the low diversity in most instances, it was possible to identify specimens underwater to species level, except for the genus *Cyphastrea*. Identification and classification of the species followed the taxonomic treatment reported by Carpenter *et al.* (1997).

The distribution patterns of the major benthic groups along the transect line were quantified using the video transect surveys. The categories recorded included: live corals (LC), dead corals (DC), turf algae (A), zoanthids (Z), echinoderms (UE) *Echinometra mathaei*, (UD) *Diadema setosoum* and pencil sea urchins (UP) and sediment (sand) (S) and rubble (R) (i.e. small pieces of dead coral). For each 50 m tape length surveyed, a list of coral species, other substratum cover and other major benthic categories were compiled. At each station, the species and benthic cover along two replicate 1m apart transects on each of two perpendicular transects and one along the transect tape along a bearing to the light tower were recorded. At all stations the deeper end of the baseline transects were permanently marked by a metal spike, driven firmly into the substrate. The direction of each baseline transect was defined by a compass heading, and was, in general, perpendicular to that of the reef edge (Table 3.2.1). The positions of the baseline transects were established in 2003 and then re-surveyed in 2004 and were as close as possible to the transects first established by Downing (1989). However, in the absence of any high accuracy position fixing system in Downing's survey it was not possible to determine exactly the start positions of Downing's line transects. During the field work surveys it was not always possible, to survey the whole of the 5 transects due to strong current movements.

It was thought that the construction of the marina at Umm AlMaradim might have a high impact on the surrounding reef because of the inadequate protection provided to the reefs during the marina's construction. Large amounts of hard material were dumped on the coral reef, and sediment was observed to have spilled onto the corals as indicated in the deployed sediment traps (section 3.2.4.2). In the September 2005 surveys, the radial transect that began from the reef edge and ended in the reef shallows at each station were extended to 150 m long in the reef shallow and video surveyed. This survey additionally incorporated a depth gauge in the dive computer (TUSA IMPREX II) and the reef depths were recorded and at certain depth intervals sea urchin abundance, coral recruitment (5 cm size) and reef damage (~70 cm damaged coral colonies) from the reef base at a depth of 8 m to the reef shallow at a depth of 2 m, were recorded.

The benthic percentage cover data sets of the major benthic categories collected in 2003, 2004 and 2005 were analyzed using multivariate statistics in order to find out if any significant differences in coral community structure could be detected between the three survey years. The Primer v.5.2.9 (Primer-E Ltd. Plymouth, UK) statistical package was used to generate non-metric Multi-Dimensional Scaling (MDS) plots, and analysis of similarity (ANOSIM). A two-dimensional plot was created to group transects with similar benthic compositions together. Firstly, the data were double-square root transformed and similarities were calculated using the Bray-Curtis similarity measure (Bray and Curtis 1957, in Clarke 1993). The same approach was used to investigate and characterize possible differences in coral community structure between the Kubbar, Qaru and Umm AlMaradim reefs.

The analysis of similarity (ANOSIM), allows a test of whether there is a statistically significant difference between groups of samples. ANOSIM is built on a non-parametric permutation procedure, applied to the rank similarity matrix. The R statistic, ranging from -1 to 1, reflects the observed differences between groups of samples and contrasts differences amongst replicates within samples. A significance level in percentage terms is given by referring the observed R value to its permutation distribution. Cluster analysis aims to find groupings in the replicate transects based on similarities between transects. The resultant MDS ordinations illustrate the relationship, based on similarities, between the transects and groups of transects.

3.2.3 Environmental variables and site physical status

To assess the environment variability of the coral reef sites seawater temperatures, salinity and visibility were recorded during the field work visits. During the March 2004 and April 2005 field work visits the extent of coral bleaching was also monitored by observing the coverage of macroalgae, as algae colonises the surfaces of the dead corals. Visibility was measured using a Secchi disc. Salinity was recorded using a refractometer. The number of visiting boats around each reef was recorded only around the reef at the time of survey to measure the extent of possible anchorage on the reefs. Around each reef there are only 10 mooring buoys, so when all these buoys are occupied then the rest of the boats were observed to anchor on the reef itself. Unfortunately there was no other way to record the number of visiting boats and anchorages on each reef outside the periods of field work. So although the data set is limited it has some value in assessing the likely number of visiting boats to the reefs during the year. In April 2004 during my PhD study a new marina was constructed at Umm AlMaradim (see chapter 6). Measurement of sedimentation rates onto the three coral reefs was measured from sediment traps; two sediment trap stands comprising of a 120cm stainless steel stake each with 4 sediment traps (plastic 0.4 litre containers, with a mouth area of 314.2 cm^2) were placed underwater at a depth of 4 – 6 m at each coral reef and hammered about 80-90cms into the substratum to make them stable at each of two stations (Fig.3.2.3.1). Sediment traps had a height of 10 cm and a width of 10 cm and were set ~30 cm above the sea bed. Two X shaped baffles (9.8 cm wide) were inserted into the mouth of each trap to reduce the formation of eddies in the cup. The four cups containing the sediment were collected at Umm AlMaradim after only 1 week because of the observed high levels of sedimentation. The sedimentation cups at the other 2 reef sites were left for 4 weeks because sedimentation was low. The sediment collected was removed from the cups and filtered and washed with distilled water to remove any salt and then oven dried at 75° C for 28 hours and the dry weight determined using a Status SP300 balance (±0.01 g). The rate of sediment deposition was only determined over four weeks (October-November) and compared with the sediment collected for one week at Umm AlMaradim. It was expected that the data collected would highlight the variability in sedimentation between the one week sample collected at Umm AlMaradim with the four weeks sedimentation from the other 2 reef sites.

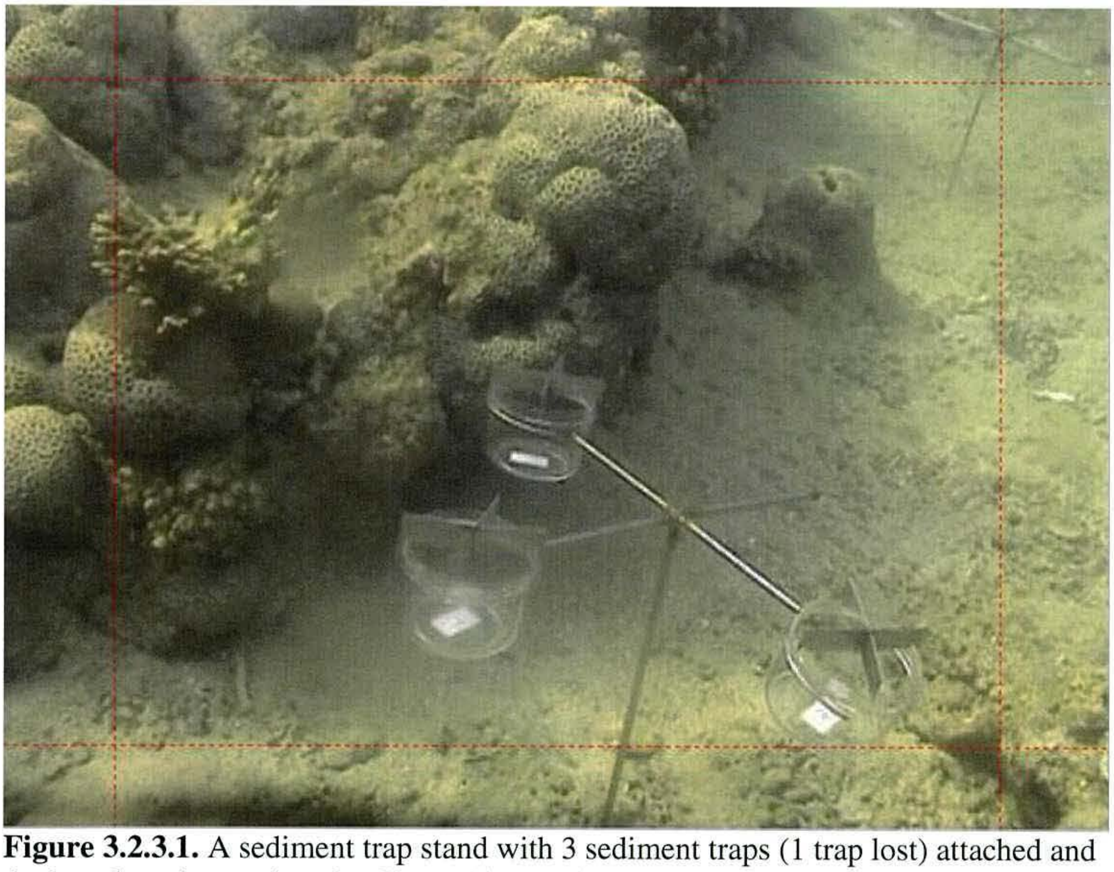

Figure 3.2.3.1. A sediment trap stand with 3 sediment traps (1 trap lost) attached and deployed on the coral reef at Umm AlMaradim.

3.3. Results

In order to determine the frequency of sampling of data from the videos of the transects that would be needed to reliably ascertain the benthic cover on the reefs, a sampling protocol was developed. One video sequence from transect 1 was selected and played and at each of the 50 quadrats the coral cover was ascertained beneath 1 point on the video image. The film was rewound and the coral cover beneath 3 points on the video image determined. This procedure was repeated using 6, 9, 15, 20, 25 and 30 points on each video frame and the percentage live coral cover ascertained beneath the points. The Coral Point Count CPC program from the National Coral Reef Institute NCRI (Kohler and Gill 2006) was used to do this (Fig.3.2.5). The live coral benthic category data were converted to mean percentage cover. Figure 3.3.1 shows the variation in percentage benthic cover along transect one using 1, 3, 6, 15, 20, 25 and 30 points. The benthic cover varied between 30 and 50% and generally the percentage benthic cover increased with increasing number of sample points. The lowest estimates of percentage benthic cover occurred when 1 & 3 points were used. However when 6 or more points were used the percentage benthic cover increased to ~40%. The results of the video transect were 386 points at 6 random points. Therefore, all transects were subsequently analyzed using 6 points at random intervals because this number of sample points provided a representative image of the percentage benthic cover. The calculated results indicated that the percentage cover did not vary greatly (less than 2% difference) among the 6 point trials. For consistency, the 6 random sampling points in each group formed about 300 points along the transect line and this approach was used in all subsequent surveys.

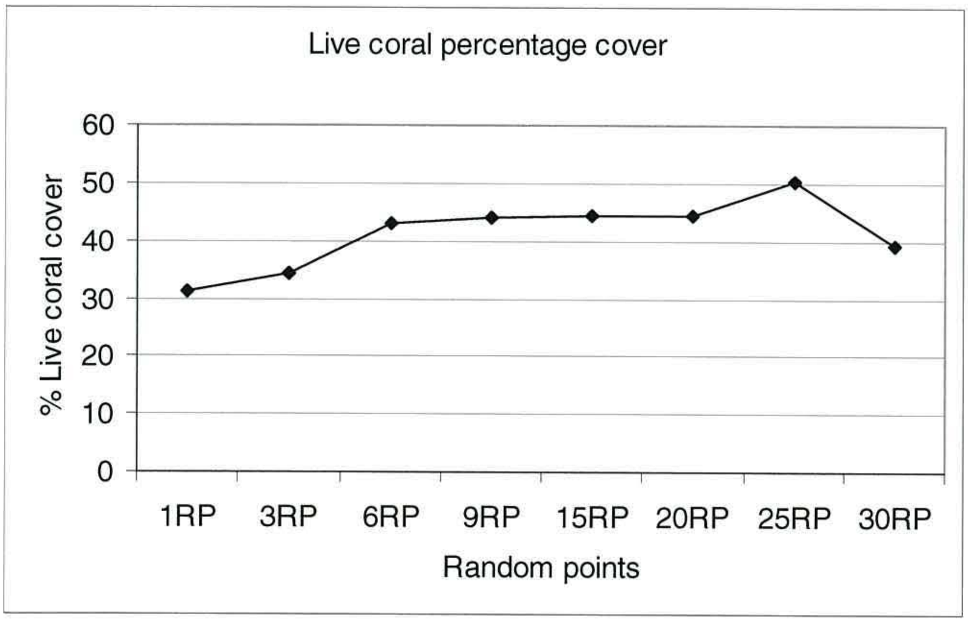

Figure 3.3.1. Variation of random sample points (RP) representing live coral cover in September 2005 at Qaru station 1. Data from the video footage from one transect.

Comparison of the benthic cover data recorded from 4 replicate transects were compared with the data obtained from 9 replicate transects and indicated that estimates of the percentage benthic cover were very similar using the 2 different numbers of transects (Fig. 3.3.2). Thus in the surveys only 4 transects were analyzed.

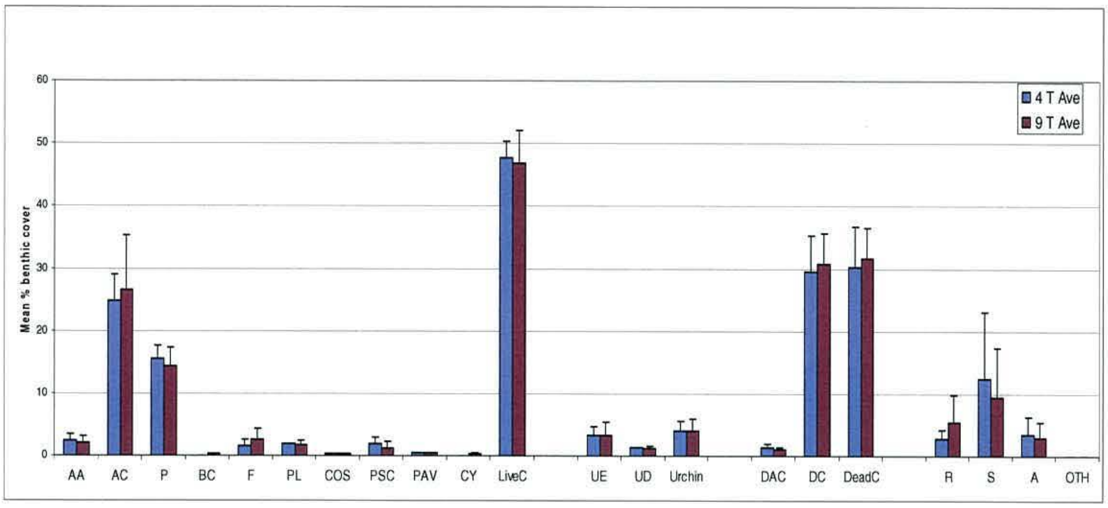

Figure 3.3.2. A comparison of the mean percentage benthic data obtained from 4 replicate transects versus 9 replicate transects. Data collected from surveys conducted at station 1 in September 2004 at Umm AlMaradim. The key to the benthic cover (AA) *Acropora arabensis*, (AC) *A. clathrata*, (P) *Porites*, (BC) Brain coral (F) *Favia*, (PL) *Platygyra daedalea*, (COS) *Coscinaraea columna*, (PSC) *Psammocora contigua*, (PAV) *Pavona decussata*, (CY) *Cyphastrea serailia*, (Live C) Live coral, (UE) *Echinometra mathaei*, (UD) *Diadema setosum*, Urchin, (DAC) Dead *Acropora clathrata* DAC, (DC) Dead Coral, Dead coral, (R) Rubble, (S) Sediment (sand), (A) turf Algae and Others benthic.

The same video transects were compared on 2 separate occasions to assess the precision of the data gathering. On one occasion the video was viewed and on the other because of the quality of the images they were enhanced using the programme Photoshop (adjusted data). The mean percentage benthic cover data for station 1 from the three sites were very similar (Fig. 3.3.3) and emphasized the precision of data analysis on the two occasions the videos were analysed.

3.3.1 Benthic community descriptions

Coral reefs around the islands in general showed about a 10% increase in coral cover during the three years of study (2003 to 2005) (Fig.3.3.4, and Fig.3.3.6). The three reefs consisted of about (40%) dead coral cover, which serves as a foundation for the recruitment of living coral, algae and other organisms. The three reefs consisted of between 2-15 % rubble, which was covered with algal turf and pink-coloured coralline algae. The three reefs consisted of sand benthic cover ranging between 5-27 %, except in Umm AlMaradim where the sand benthic cover was 50 % at the fore reef edge. In general the reef structure around the 3 islands was similar (Fig. 3.3.6). However the fore reef depth profile change faster from 8m to 2m depth

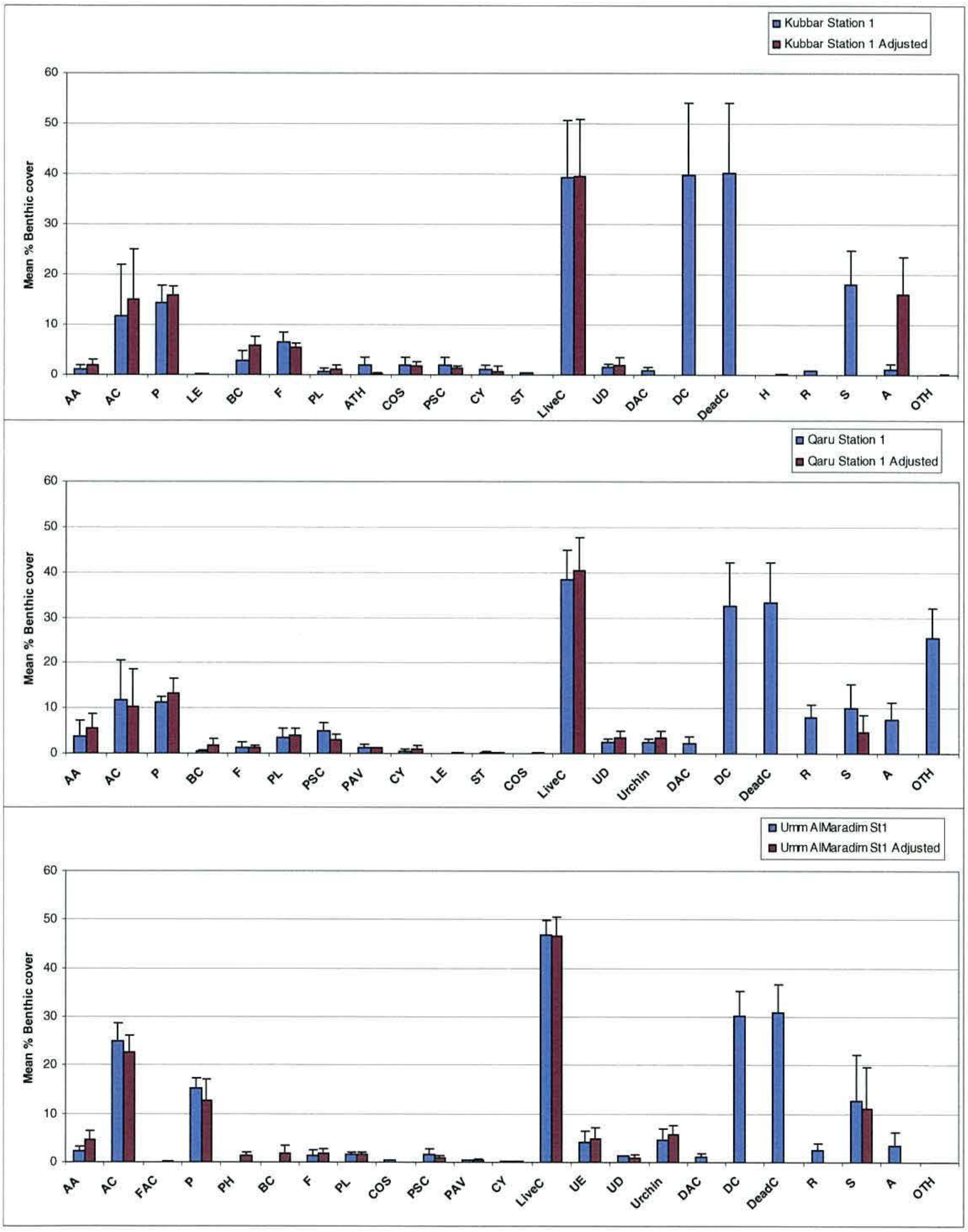

Figure 3.3.3. A comparison of the percentage benthic cover obtained during 2 separate analyses of the video surveys taken in September 2004 along the transects at station 1 at the three coral reef sites. The key to the benthic and species is as above.

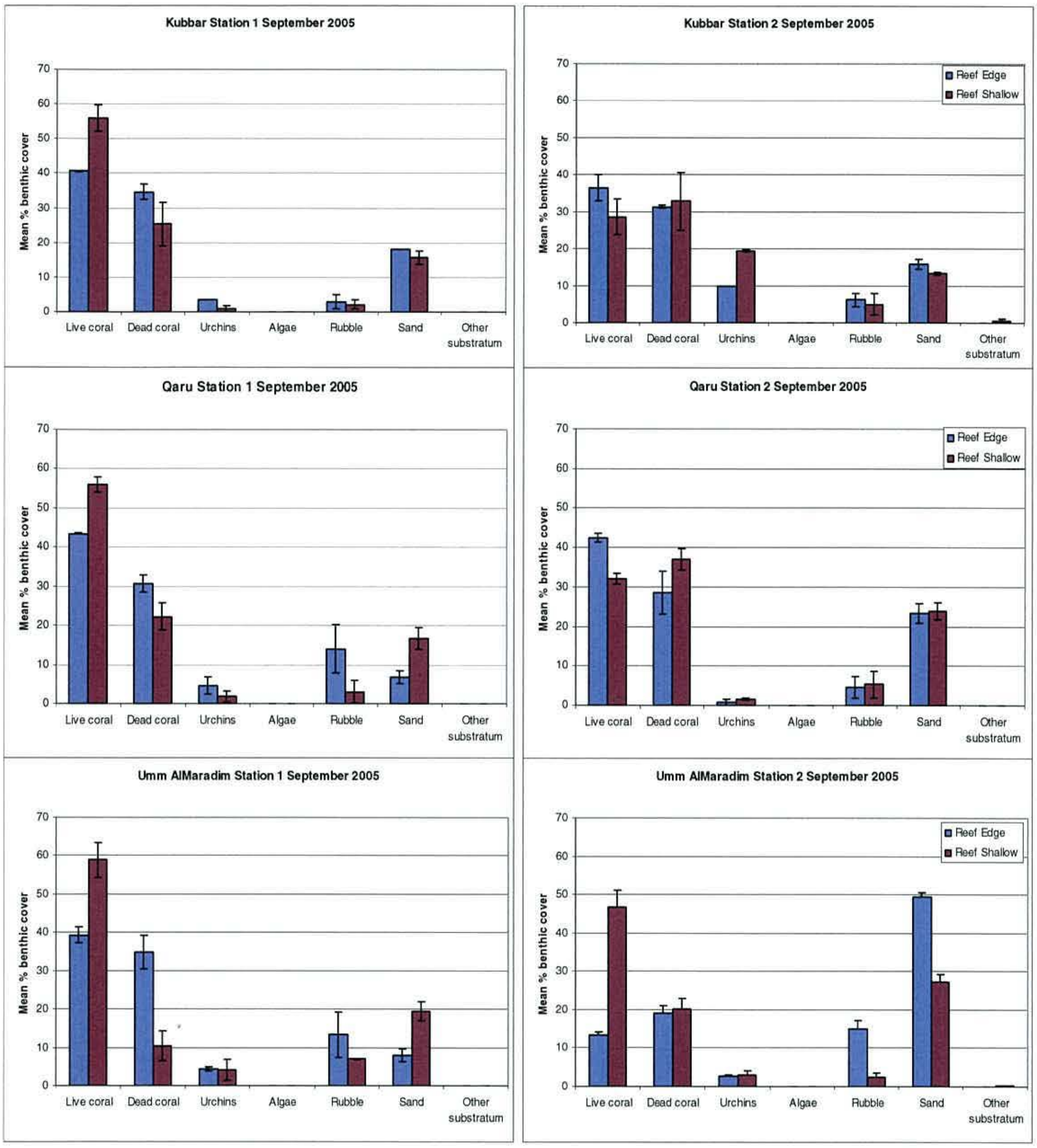

Figure 3.3.4. Percentage cover of benthic substrate types (live coral, dead coral, sea urchins, algae, rubble, sand and other substrata). Mean and standard deviation bar of two transects at the reef edge (8m depth) and in the shallow reef (2m depth) at Kubbar, Qaru and Umm AlMaradim, for the two site stations in September 2005.

within a 40m long transect than the back reef where changes between 8m to 2m depth take place within a 150m long transect. In general the benthic percentage cover on the fore reef began at 8 m depth with less of a mixed benthic community than at the shallow depths (Fig. 3.3.6).

The back reefs tended to show a highly variable depth profile along the 150 m transect starting at 9 m depth with a more mixed benthic community than at the shallow sites (2m depth). After about 40 m along the transects in depths of 2 m there was a similar benthic community see the pie graphs in chapter 2 (Fig. 2.4.1, Fig.2.4.2, Fig.2.4.3 and Fig.2.4.4). All sites had high live coral cover ranging between 40 & 55 % at Kubbar and Qaru, but only 15 % at the edge of the fore reef at Umm AlMaradim (Fig.3.3.4, Fig.3.3.5 and Fig.3.3.6). However the data collected during the winter in March 2004 showed a different trend to all of the data and this was probably related to the extensive occurrence of a seasonal brown macroalga *Colpomenia sinuosa* on the reef. The reefs are composed of a high number of dead corals, the dead coral cover ranged between (40% along the fore reef station to 75% on the back reef station) and was mostly recorded at Kubbar reef in March 2004 (Fig. 3.3.7).

The mean percentage benthic cover (± standard deviation) recorded at station 1 and 2 along two 50 m transects at the reef edge and shallow depths in September 2003 are illustrated in figure 3.3.6. The percentage benthic cover at Kubbar Island reef at station 1 consisted of 30 ± 5% live coral cover at the reef edge and 48 ± 3% live coral cover in the reef shallow and 12 ± 6% dead coral at reef edge and 6 ± 3% dead coral in the shallow reef. Mean percentage cover of algae was 35 ± 3% at the reef edge and 22 ± 1% at the shallow reef. The mean percentage sand cover of 29 ± 5% was almost the same at both depths and rubble was 2 ± 2% was similar at both depths too. The sea urchin density was 3 ± 0.4% with mostly *Diadema setosum* at the reef edge and 7 ± 6% in the shallow reef. Other organisms present were mostly zoanthids and holothurians which had a low cover, for example at station 1 there were only 0.06% zoanthids (Fig. 3.3.6).

However, at station 1 on Qaru Island reef the mean percentage live coral cover was 29 ± 2% at the reef edge and 48 ± 2% in the reef shallows. The mean percentage cover of dead coral was 35 ± 5% at the reef edge and 30 ± 2% at the reef shallow. The mean percentage of algal cover was 30 ± 4% at the reef edge and 35 ± 5% in the shallow reef. Mean percentage cover of sand was 18 ± 2% at the reef edge and had the same coverage of 18 ± 4% in the reef shallow. The mean percentage rubble cover was 19 ± 5% at the reef edge and 2 ± 1% in the reef shallows. Sea urchins were mostly *Echinometra mathaei* with a mean percentage cover of 2 ± 1% both at the reef edge and in the shallow reef (Fig. 3.3.6).

Umm AlMaradim Island reef at station 1 had a benthic percentage cover consisting of 40 ± 7% live coral at the reef edge and 44 ± 2% at the reef shallow.

Dead coral percentage cover was 35 ± 10% at the reef edge and 27 ± 10% at the reef shallow. The algae percentage cover was 1 ± 1% at the reef edge and in the shallow reef. Sand cover was 8 ± 1% at the reef edge and 12 ± 6% at the reef shallow. Rubble percentage cover was 13 ± 5% at the reef edge and 9 ± 1% at the reef shallow. Sea urchins were mostly *E. mathaei* with a percentage cover of 4 ± 7% at the reef edge and 7 ± 0.6% at reef shallow (Fig. 3.3.6).

Mean benthic percentage cover recorded at station 2 along two of the 50 m transects at the reef edge and reef shallows in September 2003 is illustrated in Fig. 3.4.6. At Kubbar Island reef (station 2) the benthic cover consisted of 28 ± 5% live coral cover at the reef edge and 20 ± 5% in the reef shallow, and 45 ± 10% dead coral at the reef edge and similar cover along the reef shallow. Mean percentage algae cover was low (3 ± 0.6%) at the reef edge with almost no algal cover in the reef shallows. Mean percentage sand cover was 18 ± 2% at the reef edge and 20 ± 5% in the reef shallows. Mean percentage rubble cover was 5 ± 2% on the reef edge with similar cover in the reef shallows. Sea urchin cover mostly comprised of *D. setosum* (5 ± 5 %) at the reef edge and (10 ± 5%) in the reef shallows (Fig. 3.3.6).

However, at Qaru Island reef station 2 live coral percentage benthic cover was 28 ± 0.6% at the reef edge and 15 ± 5% in the reef shallows. The mean percentage dead coral cover was 33 ± 8% at the reef edge and 60 ± 5% in the reef shallows. Algal cover accounted for 8 ± 2% of the benthic cover at the reef edge and 2 ± 0.6% in the reef shallows, whilst the rubble percentage benthic cover consisted of 11 ± 7% and 8 ± 8% at the reef edge and in the reef shallows respectively. Mean percentage sand cover consisted of 20 ± 1% at the reef edge and 5 ± 1% in the reef shallows. The sea urchins consisted of 2 ± 1% *E. mathaei* at the reef edge and 9 ± 1% in the reef shallows (Fig. 3.3.6).

The mean percentage cover at Umm AlMaradim Island reef station 2 consisted of 12 ± 3% live coral at the reef edge and 65 ± 4% in the reef shallows. Dead coral was 15 ± 1% at both depths with a similar distribution of algae although with a lower cover 2 ± 2%. The mean percentage of sand was 55 ± 1% and 12 ± 2% at the reef edge and the reef shallows respectively, and rubble mean percentage was 11 ± 3% at the reef edge and 5 ± 3% in the reef shallows. Sea urchins were mostly *E. mathaei* 2 ± 0.6% at both depths (Fig. 3.3.6). These results illustrate the position during a survey in September 2003, figures 3.3.4 and 3.3.5 illustrate the position in 2004 and 2005 respectively.

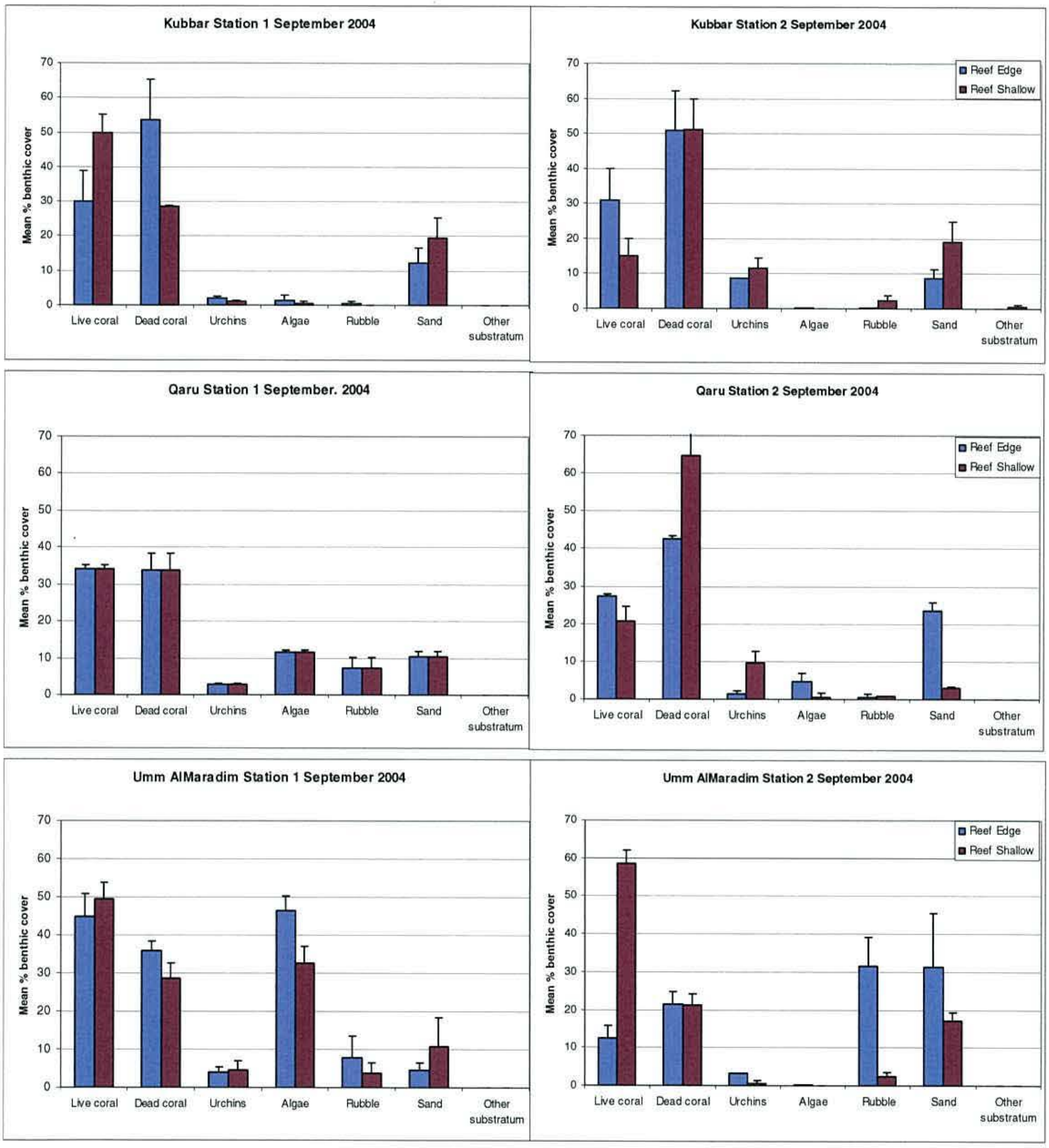

Figure 3.3.5. Percentage cover of benthic substrate type (live coral, dead coral, sea urchins, algae, rubble, sand and other substrata). The means of two transects at the reef edge (8m depth) and in the shallow reef (2m depth) at the three islands, for the two site stations in September 2004.

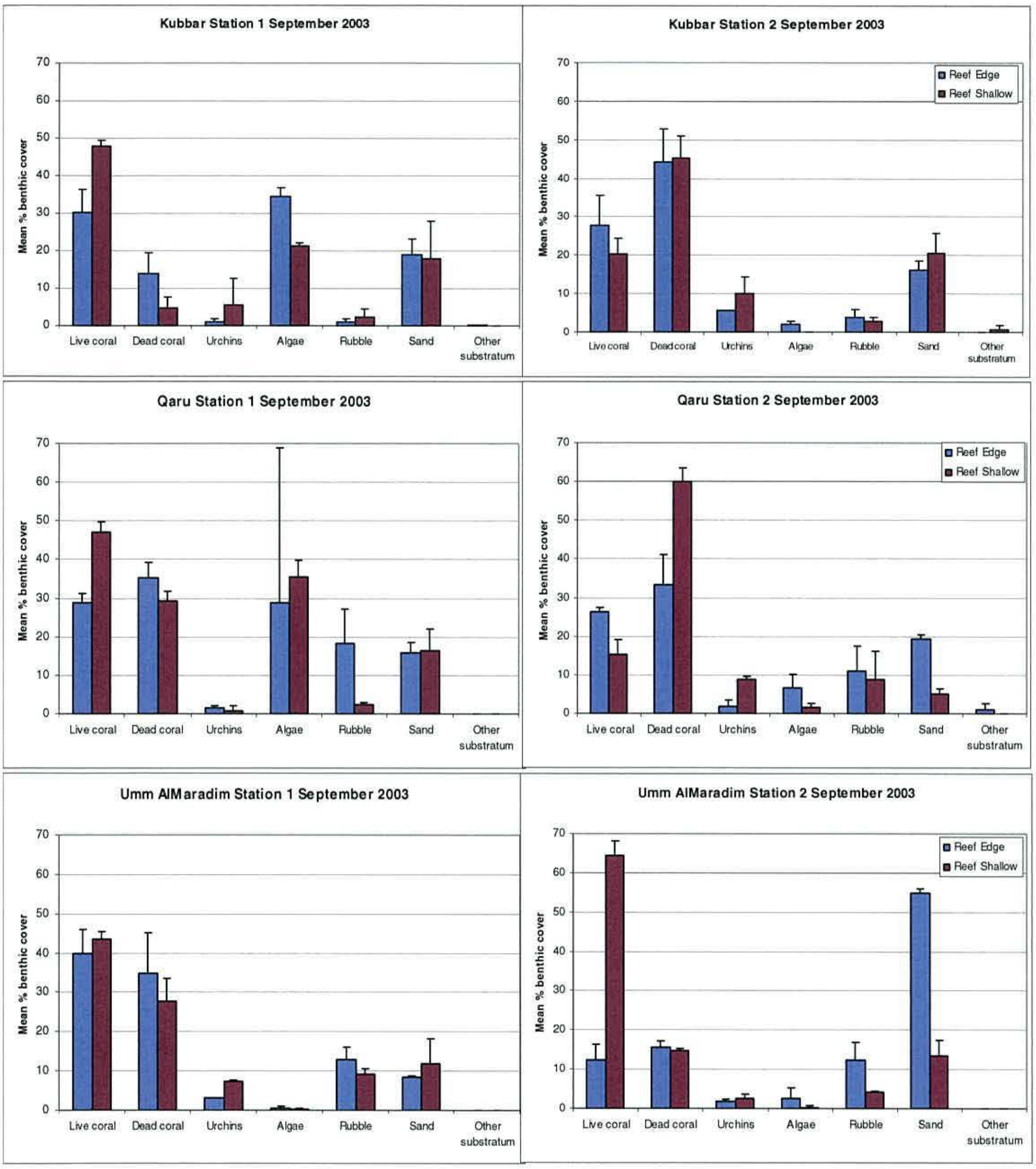

Figure 3.3.6. Percentage cover of benthic substrate type (live coral, dead coral, sea urchins, algae, rubble, sand and other substrata). Means of two transects at the reef edge (8m depth) and along the shallow reef (2m depth) at the three islands, for the two site stations in September 2003.

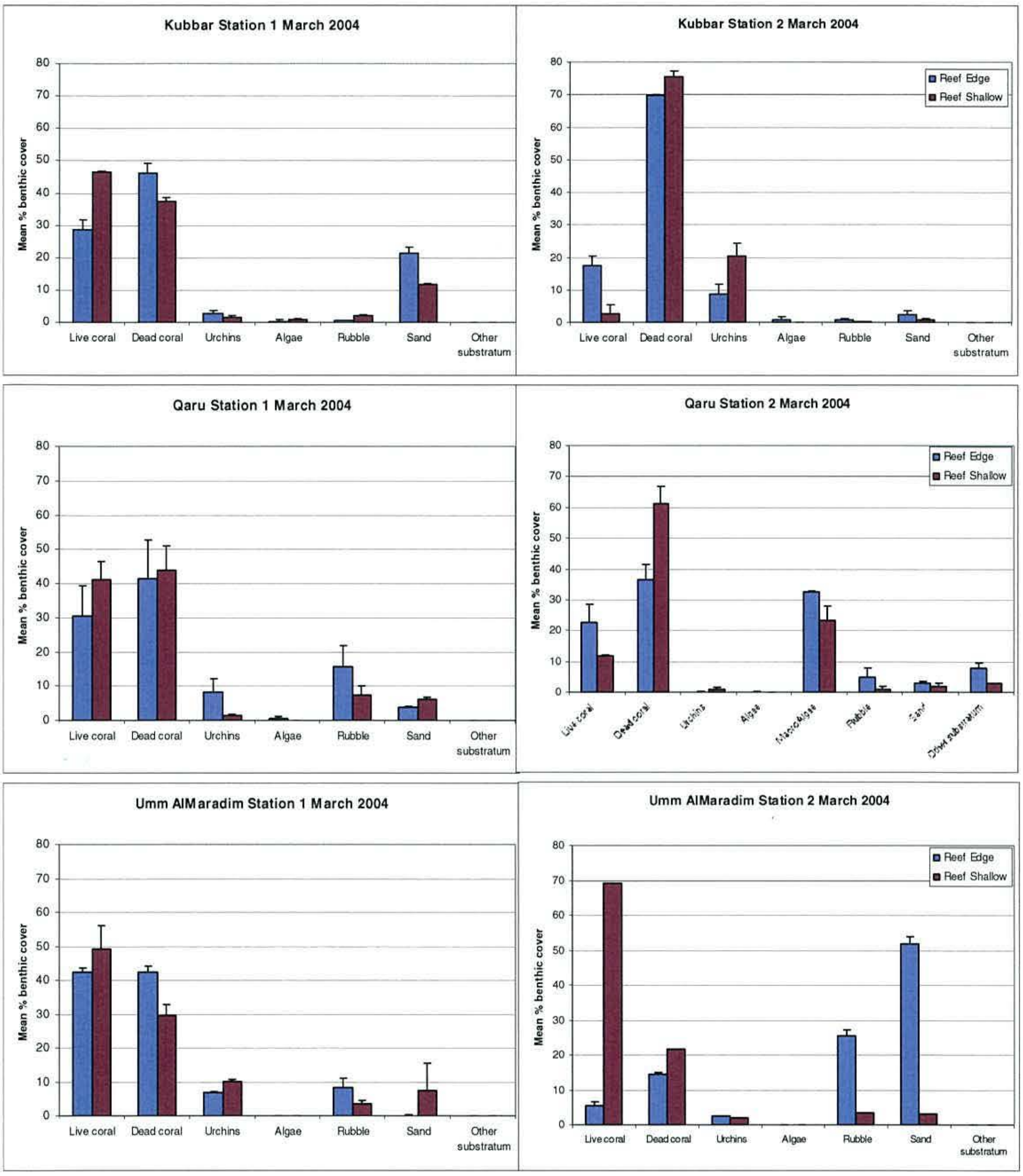

Figure 3.3.7. Percentage cover of benthic substrate type (live coral, dead coral, sea urchins, algae, rubble, sand and other substrata). Mean of two transects along the reef edge (8m depth) and on the shallow reef (2m depth) at the three islands, for the two site stations in March 2004.

The percentage benthic cover obtained during the diver surveys along the four transects for the three years with two seasons in 2003 and 2004, but only during the summer season in 2005, was explored in detail (Fig. 3.3.6 and 3.3.7). The survey carried out during the winter season in March 2005 recorded a coral "bleaching" event in which there was the loss of the microscopic symbiotic algae that provide the corals with most of their colour and with their energy supply (Fig.3.3.8a). Coral bleaching is a seasonal phenomenon occurring in every winter season (personal communication with the local diving club) and mostly resulted from the extreme seawater temperatures recorded around the reefs in winter. The winter season in general also showed an increase in the macroalga *Colpomenia sinuosa* on dead corals and in static pools next to the beach and it was even observed as an overgrowth on top of the live corals (Fig. 3.3.9). The winter season (March 2005) coral bleaching event resulted in 42% of the corals becoming bleached (Fig.3.3.8 A). Coral bleaching occurred in all coral species, *Acropora clathrata* (AC), *Acropora arabensis* (AA), *Goniopora lobata* (GP), *Porites* (P), *Stylophora* (ST) and brain corals (BC), but with different intensity (see Fig.3.3.8 B).

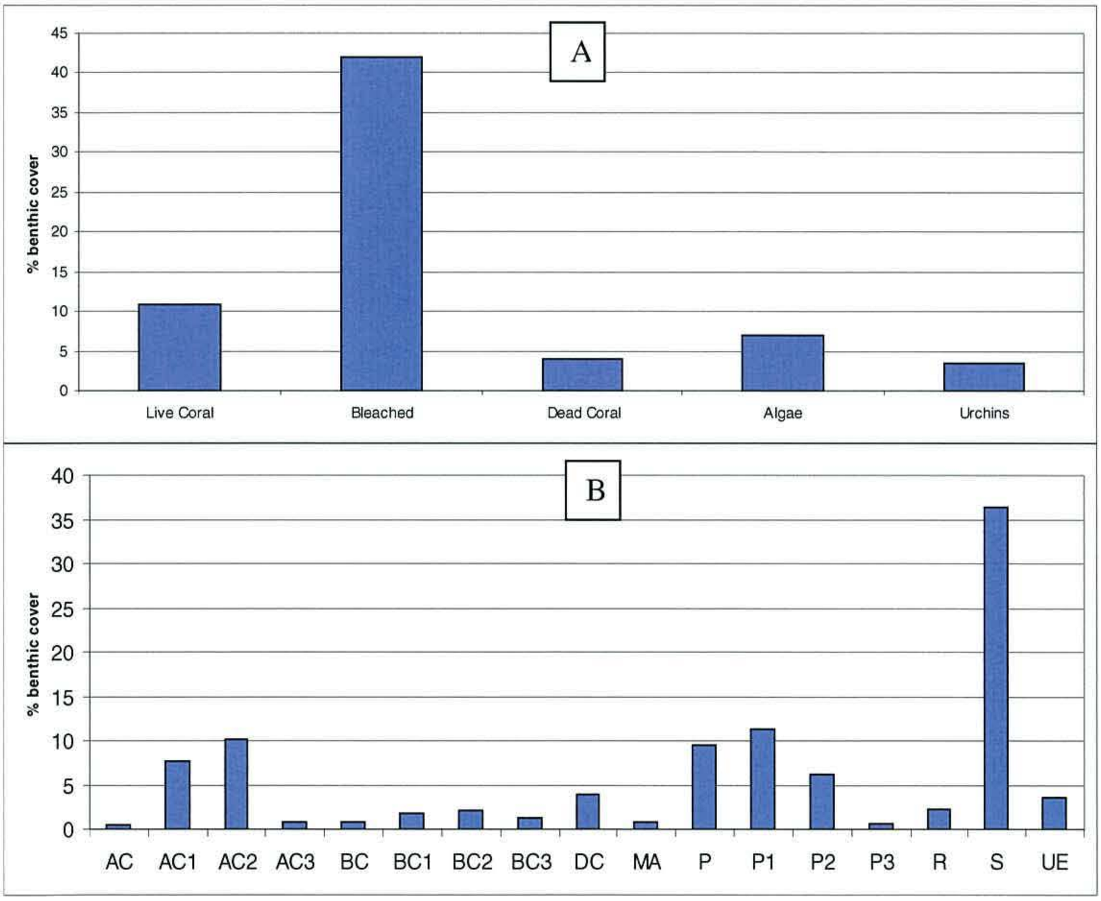

Figure 3.3.8. A. percentage coral bleaching and other benthic percentage cover along a 250 m transect around Umm AlMaradim in March 2005. B. Degree of coral species colouration to bleached stage 1 - 3. (Sp.1. pale color; Sp.2. intense pale colour; and Sp.3. bleached completely) (AC *Acropora clathrata*; BC brain coral; DC dead coral; MA macroalgae; P *Porites*; R rubble; S sediment (sand); and UE *Echinometra mathaei*).

Figure 3.3.9. The macroalga *Colpomenia sinuosa* growing on top of live coral around Umm AlMaradim in March 2005. Scale is 50cm the blue line.

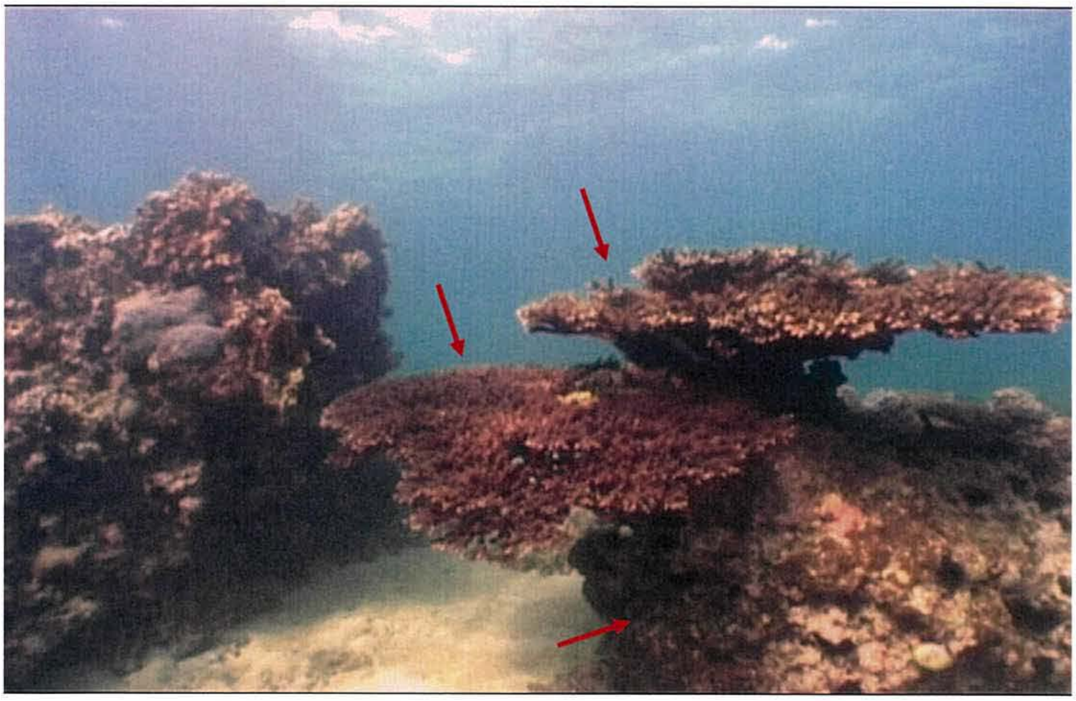

Figure 3.3.10. A general view of a coral reef at 5 m depth at Umm AlMaradim reef in September 2004 showing a sand and rubble sea bed with mostly *Porites* colonies and two colonies of *Acropora clathrata*, pointed with red arrows.

The trends in the benthic cover were almost the same at station 1 on the leeward sides of the 3 coral reefs, yet some of the coral species which dominated station 2 on the windward side were different from station 1, such as *Goniopora lobata* and *Acropora clathrata* and *Acropora arabensis* (the most fragile sp.) were absent from the station (Fig.3.3.11). Turf algal cover was almost the same at all depths where it covered hard substrata such as dead coral and rubble. Algae were recorded as cover only when covering the hard substrata. Corals at the reef edge (5-8m depth) on all sites were mostly flat plate like growth forms, with dominant species such as *Porites* and *Acropora clathrata* present (Fig. 3.3.10) (Fig. 3.3.11).

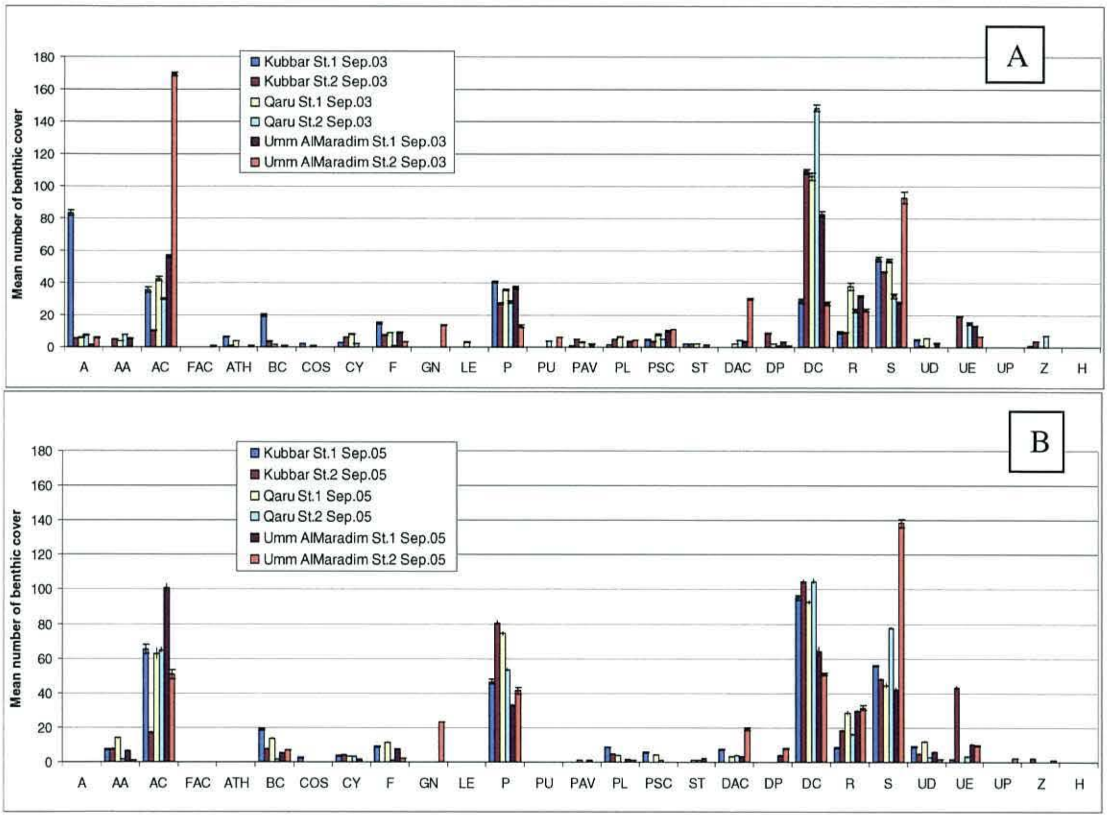

Figure 3.3.11. Mean number of benthic cover of different species on each of 4 transects at each station at each site, data collected in September 2003 (A) and data collected in 2005 (B). Key to species the same as figure 3.3.2.

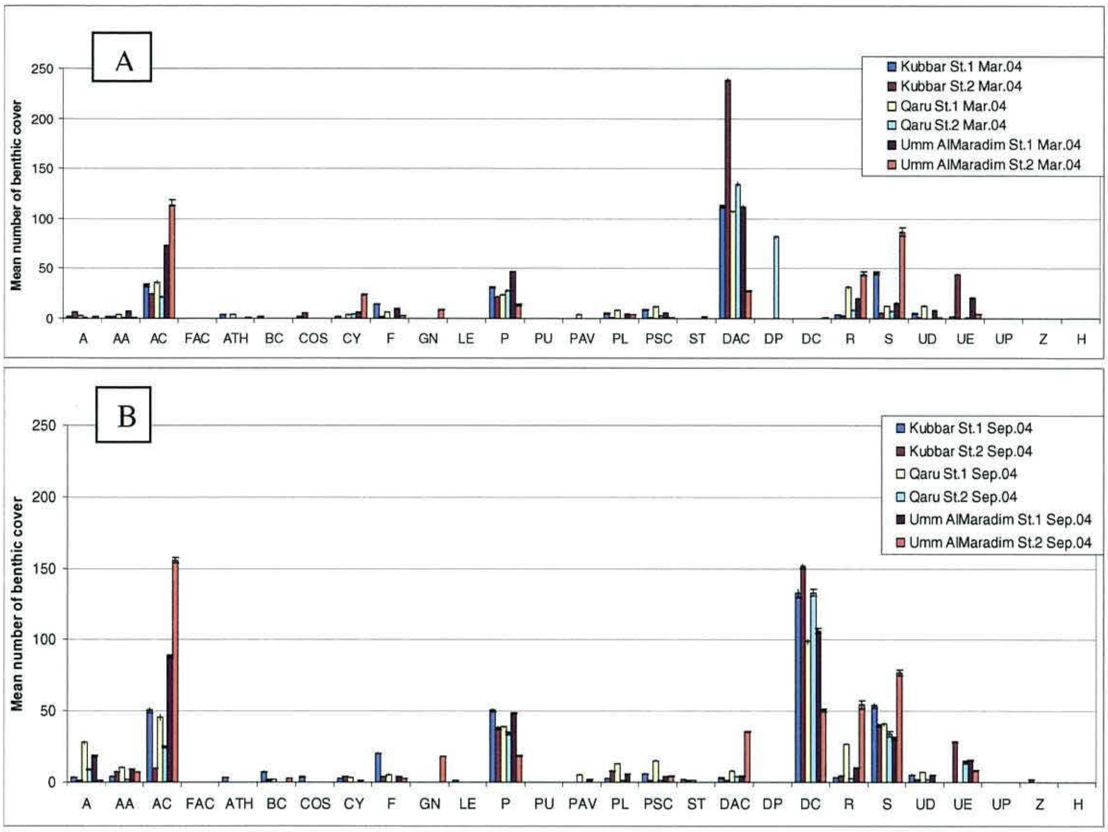

Figure 3.3.12. Mean number of benthic cover of different species on each of 4 transects in each station at each site, March 2004 (A) and September 2004 (B).

3.3.2 Statistical analysis

Differences in the benthic cover were investigated at the islands reef sites, along the transects, on the fore and back reef and at different depths; K2 (Kubbar station 2), Q2 (Qaru station 2) and Um2 (Umm AlMaradim station 2) are considered to be exposed, fore reefs, while K1, Q1 and Um1 are sheltered back reefs. The monitored transects were grouped into shallow 2 m depths (transect 4 + transect 5) and deep reef edge 8 m depths (transect 1+ transect 2) as shown in (Figures 3.3.11 – 3.3.12).

A Global test, two-way crossed anosim analysis of similarities for differences between years (averaged across all sites), to investigate differences in benthic cover were not significantly different (R = 0.14; P = 0.9%). Pairwise tests confirmed that the benthic cover at all sites in 2003 was not significantly different from 2005 (R = 0.451; P = 0.3%), but there were significant differences between 2003 and 2004 (R = 0.142; P = 2.1%) and differences between 2004 and 2005 (R = 0.102; P = 7.2%) (Table 1 in Appendix 3). A Global test for differences in benthic cover between sites (averaged across the three years), at all sites showed the sites were significantly different (R = 0.417; P = 0.1%) (Table 2 in Appendix 3). Pairwise tests confirmed that the benthic cover was significantly different between all the sites except between Kubbar station 1 and Qaru station 1 which were not significantly different (R = 0.25; P = 1.9%), and between Kubbar station 2 and Qaru station 2 (R = 0.343; P = 1.3%) and between Qaru station 2 and Umm AlMaradim station 2 (R = 0.288; P = 1.1%) (Table 2 in Appendix 3).

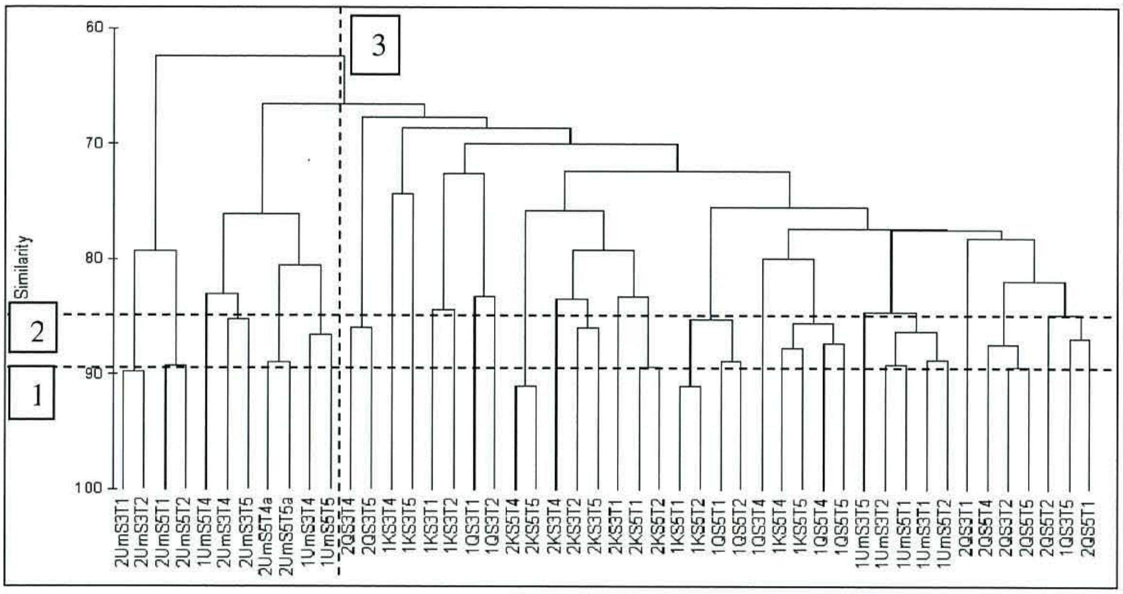

Figure 3.3.13. A dendrogram (transformed) of the number of benthic species within each transect at each of the 3 survey sites (Kubbar K, Qaru Q and Umm AlMaradim Um) with the two site stations 1, 2 and five transects 1-5 in September 2003, September 2004 and September 2005; Kubbar station 1 in September 2003 transect 1 (1KS3T1), Qaru station 1 in September 2003 transect 1 (1QS3T1) and Umm AlMaradim station 1 in September 2003 transect 1 (1UmS3T1).

The dendrogram shows a high similarity (~90% correlation) within each depth of the two transects at each site as shown by the dashed line 1 in Fig.3.3.13. The benthic cover along the 2 reef shallow transects was similar (85% correlation) to the benthic cover along the reef edge transects (dashed line 2 in Fig.3.3.13), therefore the data could be considered as four replicate transect at each station. Groups identified in the cluster analysis (Fig.3.3.13) have been superimposed on the MDS ordination (Fig.3.3.14). The two broad groups formed following analysis are positioned on the right of the MDS graph. The data were primarily from the March 2004 survey and Umm AlMaradim transects data and show the winter season effect on these sites.

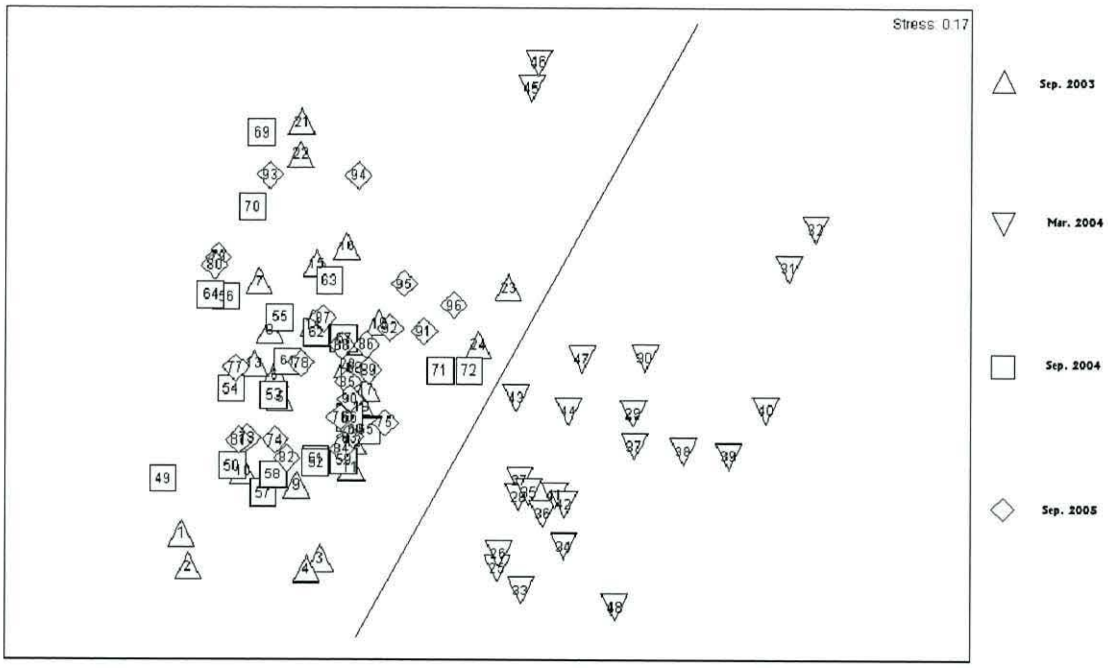

Figure 3.3.14. MDS ordinations for the benthic cover species data from within each transect at each of the 3 survey sites in 2003 & 2005 (Kruskal's stress, 0.17). Transects: 1-4 (Kubbar St.1 Sep.03); 5-8 (Kubbar St.2 Sep.03); 9-12 (Qaru St.1 Sep.03); 13-16 (Qaru St.2 Sep.03); 17-20 (Umm AlMaradim St.1 Sep.03); 21-24 (Umm AlMaradim St.2 Sep.03); 25-28 (Kubbar St.1 Mar.04); 29-32 (Kubbar St.2 Mar.04); 33-36 (Qaru St.1 Mar.04); 37-40 (Qaru St.2 Mar.04); 41-44 (Umm AlMaradim St.1 Mar.04); 45-48 (Umm AlMaradim St.2 Mar.04); 49-52 (Kubbar St.1 Sep. 04); 53-56 (Kubbar St.2 Sep.04); 57-60 (Qaru St.1 Sep.04); 61-64 (Qaru St.2 Sep.04); 65-68 (Umm AlMaradim St.1 Sep.04); 69-72 (Umm AlMaradim St.2 Sep.04); 73-76 (Kubbar St.1 Sep.05); 77-80 (Kubbar St.2 Sep.05); 81-84 (Qaru St.1 Sep.05); 85-88 (Qaru St.2 Sep.05); 89-92 (Umm AlMaradim St.1 Sep.05); 93-96 (Umm AlMaradim St.2 Sep.05). The bold line in the middle represents two groups clustering at 75% similarity and shows the transects from the March 2004 survey separate from the other groups.

Dead coral, sediment (sand), *Porites* and *Acropora clathrata* benthic cover data contributed the most to the average similarity within the sites (Appendix 2). Five to six benthic categories contributed similarily to all sites i.e. a total of 54% in 2003 (Table 1 in Appendix 1), 42% in 2004 (Table 2 in Appendix 1) and 63% in 2005 (Table 3 in Appendix 1) (Fig.3.3.13). Umm AlMaradim coral reef stations could be distinguished from the other stations by their high benthic percentage cover of *A. clathrata* and sediment (see Table 5 in Appendix 2). The factor that contributed most to the dissimilarity between the stations was the high cover of *A. clathrata* and dead coral (Table 7 in Appendix 2). Kubbar station 1 and 2 and Qaru station 1 had an average dissimilarity of 57%, 48% and 56% respectively, dead *A. clathrata* contributed the most to the dissimilarity (Table 7, 8 in Appendix 2). Kubbar station 1 and Qaru station 2 had an average dissimilarity of 54%, dead coral and dead *A. clathrata* and sediment contributed the most to the dissimilarity. Kubbar station 2 and Qaru station 2 had an average dissimilarity of 52%, and dead *A. clathrata* and dead coral contributed the most to the dissimilarity (Table 11 in Appendix 2). Qaru station 1 and 2 had an average dissimilarity of 52%, dead coral and dead *A. clathrata* and live *A. clathrata* contributed the most to the dissimilarity (Table 12 in Appendix 2). Kubbar station 1 and Umm AlMaradim station 1 had an average dissimilarity of 49%, dead coral and dead *A. clathrata* and live *A. clathrata* had contributed the most to the dissimilarity (Table 13 in Appendix 2). Kubbar station 2 and Umm AlMaradim station 1 had an average dissimilarity of 54%, dead *A. clathrata* and live *A. clathrata* and other dead coral species contributed the most to the dissimilarity (Table 14 in Appendix 2). Qaru station 1 and Umm AlMaradim station 1 had an average dissimilarity of 44%, dead coral and dead *A. clathrata* and live *A. clathrata* had contributed the most (Table 15 in Appendix 2). Qaru station 2 and Umm AlMaradim station 1 had an average dissimilarity of 49%, dead coral and dead *A. clathrata* and live *A. clathrata* contributed the most (Table 16 in Appendix 2). Kubbar station 1 and Umm AlMaradim station 2 had an average dissimilarity of 61%, live *A. clathrata* and sediment with dead coral and dead *A. clathrata* contributed the most (Table 17 in Appendix 2). Kubbar station 2 and Umm AlMaradim station 2 had an average dissimilarity of 68%, dead coral and sediment with dead *A. clathrata* and live *A. clathrata* had contributed the most dissimilarity (Table 18 in Appendix 2). Qaru station 1 and Umm AlMaradim station 2 had an average dissimilarity of 60%, sediment and live *A. clathrata* with dead coral and dead *A. clathrata* contributed the most dissimilarity (Table 19 in Appendix 2). Qaru station 2 and Umm AlMaradim station 2 had an average dissimilarity of 64%, dead coral and sediment with *A. clathrata* and dead *A. clathrata* contributed the most to the dissimilarity (Table 20 in Appendix 2). Umm AlMaradim station 1 and station 2 had an average dissimilarity of 56%, sediment and live *A. clathrata* with dead coral and dead *A. clathrata* had contributed the most to the dissimilarity (Table 21 in Appendix 2).

PRIMER ANOSIM analysis of similarities using a two way crossed analysis of the data with year as factor and pairwise tests showed there were significant differences between the 2003 and 2004 and the 2005 surveys data (Table 1 in Appendix 3). However a comparison between the 2003 and 2005 survey data showed there were no significant differences (Table 1 in Appendix 3). The values from the 2004 survey data for average generic diversity were more variable but did not indicate any major shift in the composition of the coral reef communities.

The data covariance structure was summarized using Principal Component Analysis PCA (Table 3.3.1). Scatter plots of PC2 with PC1 with 4 factorials; year (2003, 2004 and 2005), site (K, Q and Um), reef back station 1 and reef front station 2 and reef edge and shallow reef are shown in figure 3.3.15. Principal component analysis emphasized the general reef structure illustrated by SIMPER analysis, showing which benthic cover contributed most to the variation between sites and fore or exposed and back or sheltered reef. However the data did not show any significant difference between years (Fig. 3.3.16). The most variability in the data was contributed by the dead (AC) *A. clathrata* interaction as illustrated in figure 3.3.17 with the four factors. Umm AlMaradim fore and shallow reef showed the most variability with dead AC in the three years as data were grouped in the corner of the plot (see Fig. 3.3.15). The dead coral interaction plot showed that Qaru reef had the most variability in the fore reef station in 2003 (Fig. 3.3.18). The AC *A. clathrata* benthic cover plot interaction showed that the greatest variability was in the shallow Qaru reef (Fig. 3.3.19).

The benthic cover data were analyzed using ANOVA. A General Linear Model test with factor pairwise comparisons showed there were significant differences between years at all sites ($F = 3.83$; $P < 0.011$). Sites as a factor was tested at the stations and significant differences were observed ($F = 6.27$; $P < 0.005$). Reef sites acted in the same manner with differences between the fore and back reefs and between the shallow reef and reef edge except the reef site at Umm AlMaradim where a similar percentage benthic cover was found on both the fore and back edge (Fig 3.3.15) and is shown by the dashed line 3 in figure 3.3.13.

Table. 3.3.1. Principal component loadings from PCA after rotation of six principal component analysis trials for the maximum variance of benthic cover. The benthic key is: Zoanthid (Z), pencil sea urchin (UP), *Echinometra mathaei* (UE), *Diadema setosum* (UD), *Stylophora* sp. (ST), Sand (S), Rubble (R), *Psammocora contigua* (PSC), *Platygyra daedalea* (PL), *Pavona decussata* (PAV), *Porites lutea* (PU), *Porites* sp. (P), *Leptastrea* sp. (LE), *Goniopora lobata* (GN), *Favia pallida* (F), dead *Porites* (DP), dead coral (DC), dead *Acropora clathrata* (DAC), *Cyphastrea serailia* (CY), *Coscinaraea columna* (COS), brain coral (BC), *Acanthastrea echinata* (ATH), fragmented *A. clathrata* (FAC), *A. clathrata* (AC), *A. arabensis* (AA) and algae (A).

Variable	PC1	PC2	PC3	PC4	PC5	C6
Zoanthid	-0.064	-0.118	-0.215	-0.048	0.158	0.313
pencil urchin	-0.13	0.272	-0.042	0.06	-0.107	-0.086
Echinometra sp	-0.156	-0.26	-0.377	0.045	0.002	0.056
Diadema sp.	0.34	0.024	0.136	0.286	-0.09	-0.192
Stylophora sp.	0.161	0.015	-0.086	-0.318	-0.055	-0.352
Sand	-0.196	0.414	-0.013	0.01	-0.018	-0.173
Rubble	-0.03	0.318	-0.09	0.104	-0.38	0.05
Psammocora sp.	0.326	0.154	0.13	-0.071	-0.169	0.279
Platygyra sp.	0.255	-0.089	0.011	-0.146	-0.396	0.137
Pavona sp.	0.247	0.059	0.041	-0.046	-0.316	0.345
Porites lutea	-0.076	-0.087	0.08	-0.11	0.031	0.293
Porites sp.	0.183	-0.245	-0.001	0.237	0.065	-0.203
Leptastrea sp.	0.171	0.135	-0.151	-0.389	-0.024	-0.215
Goniopora sp.	-0.21	0.46	-0.112	0.129	-0.175	-0.028
Favia sp.	0.312	0.123	0.136	-0.05	0.229	-0.083
dead *Porites*	-0.121	-0.072	-0.082	-0.151	0.035	-0.112
dead coral	0.188	-0.162	-0.39	0.061	-0.032	0.039
dead *AC*	-0.205	-0.094	0.39	-0.218	-0.079	-0.041
Cyphastrea sp.	0.206	-0.02	-0.229	-0.346	-0.059	-0.312
Coscinaraea sp	0.168	0.079	0.053	0.189	0.305	-0.05
brain coral	0.151	0.13	0.163	0.274	0.202	-0.204
Acanthastrea sp.	0.197	0.226	-0.038	-0.31	0.268	0.156
fragmented *AC*	-0.118	-0.051	0.251	-0.157	-0.052	-0.016
A. clathrata	-0.126	-0.199	0.457	-0.194	-0.109	-0.127
A. arabensis	0.207	-0.181	0.094	0.253	-0.317	-0.092
algae	0.184	0.187	0.148	-0.057	0.319	0.309

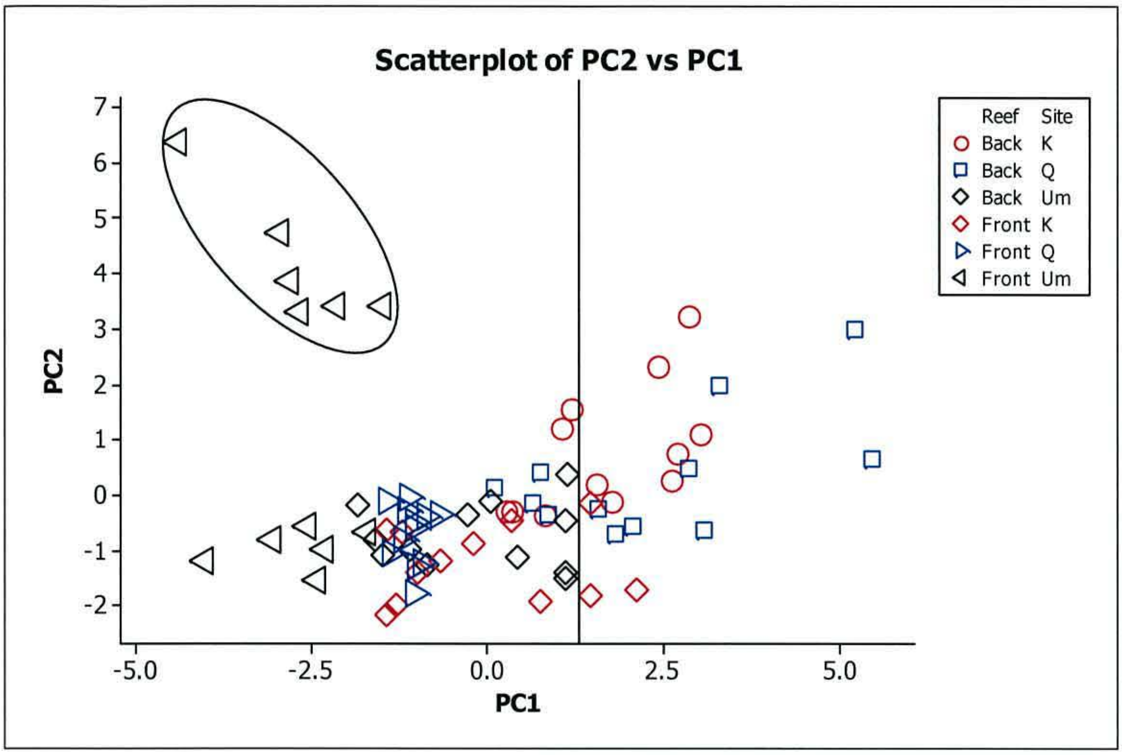

Figure 3.3.15. Principal components analysis of the benthic cover data with different years (2003-2005) scatter plot of PC2 (2[nd] analysis run) vs PC1 (1[st] analysis run) with 4 factors (year, site, reef back and front and reef edge and shallow).

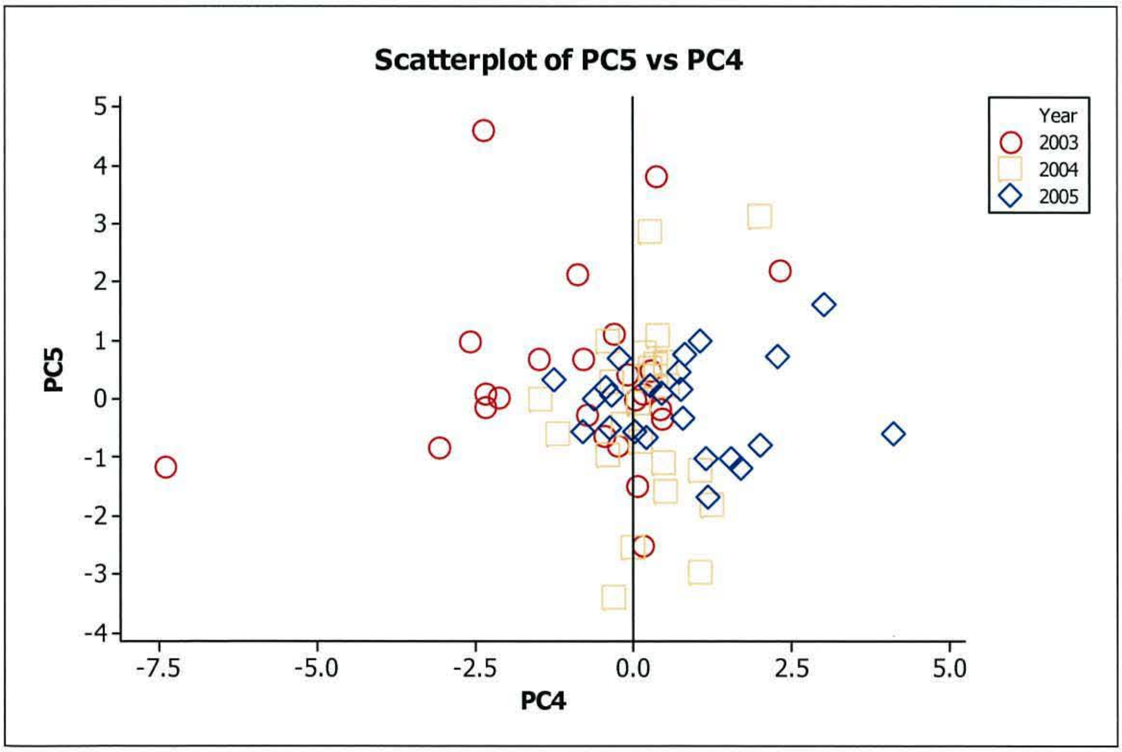

Figure 3.3.16. Principal components analysis of the benthic cover data scatter plot of

PC5 (5th analysis run) vs PC4 (4th analysis run) with year as factor (2003 – 2005).

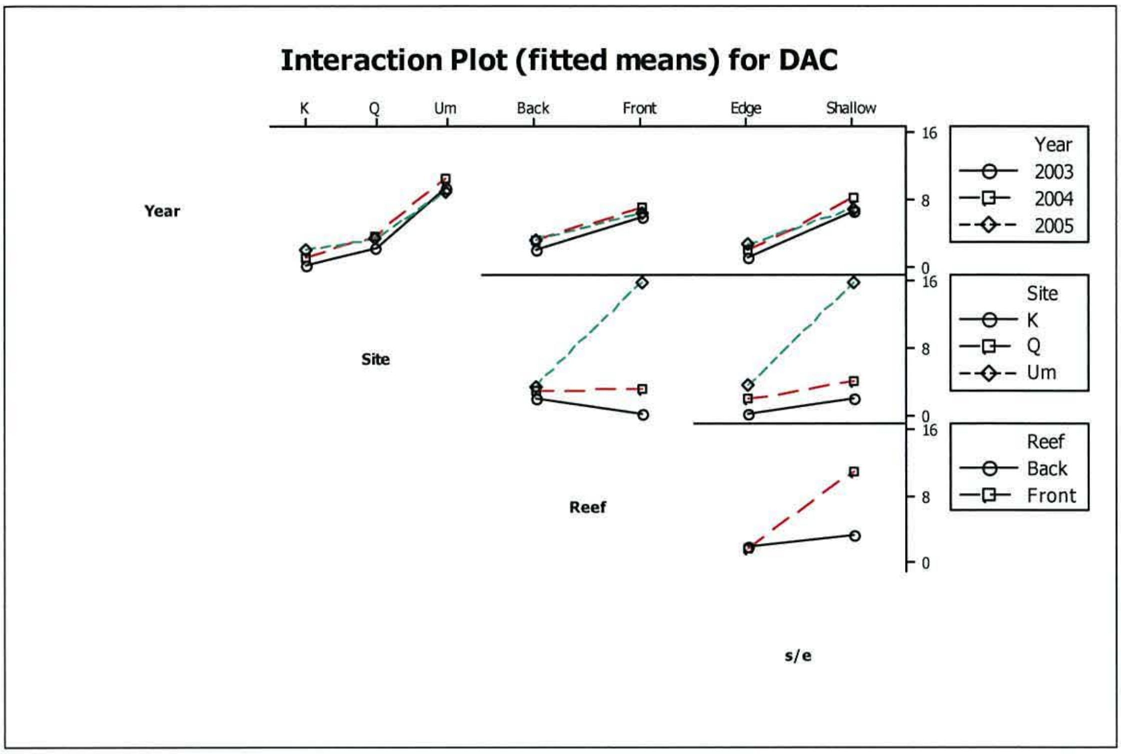

Figure 3.3.17. Interaction between the mean numbers of DAC (dead *Acropora clathrata*) on 4 transects with 4 factors (year, site, reef back and front and reef edge and shallow).

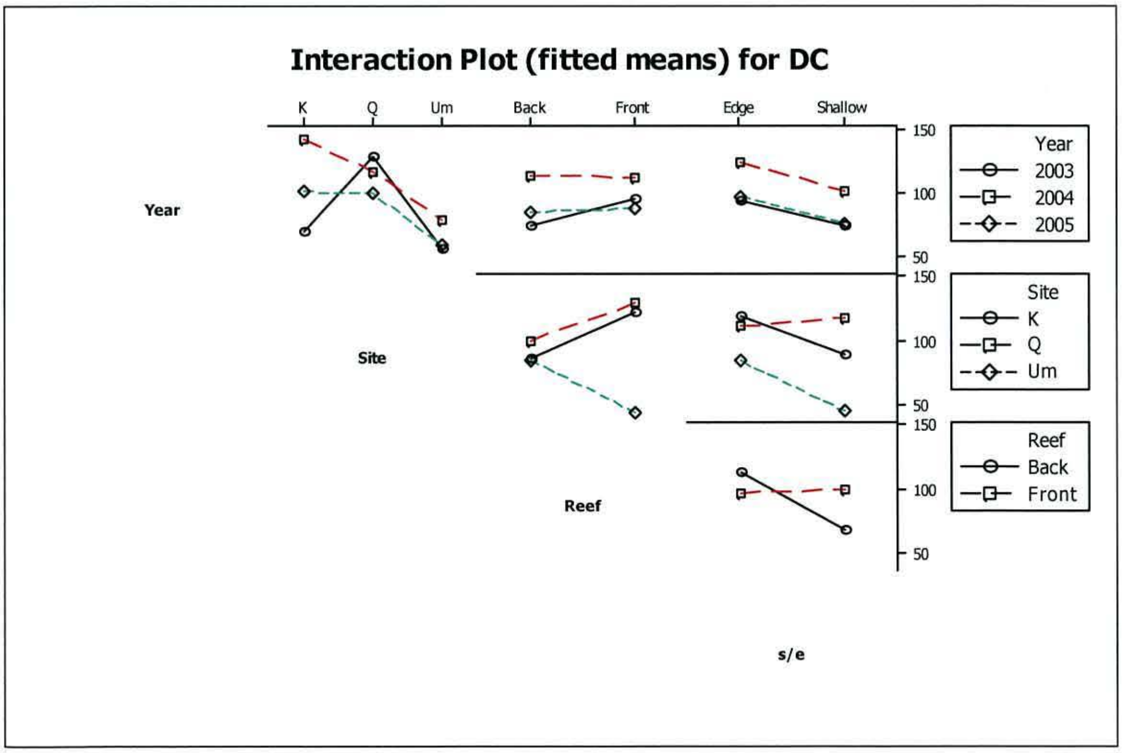

Figure 3.3.18. Interaction mean numbers of DC dead coral on 4 transects with 4 factors (year, site, reef back and front and reef edge and shallow).

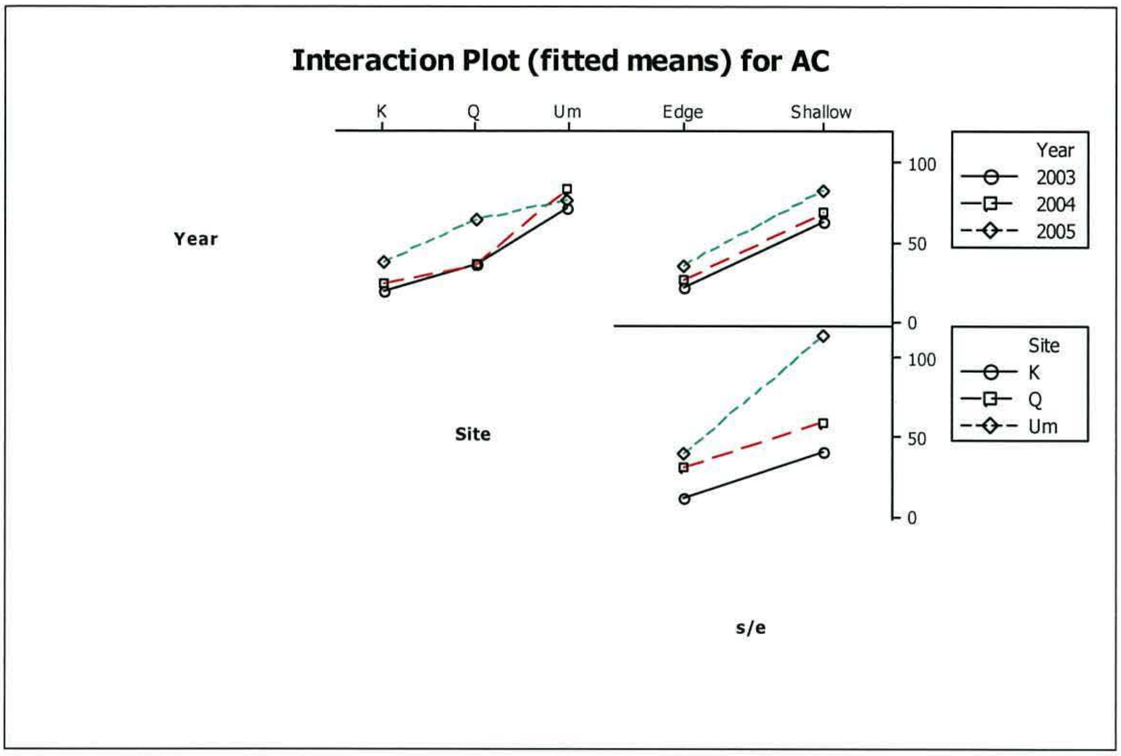

Figure 3.3.19. Interaction between the mean numbers of AC *Acropora clathrata* on 4 transects with 4 factors (year, site, reef back and front and reef edge and shallow).

3.3.3 Environmental variables and site physical status

Seawater temperature variability during the field work showed that the maximum range occurred between August and September (31° C), and the lowest range was recorded between March and April (18° C). During field work in the winter in March 42% coral bleaching was observed (Fig.3.3.8a) with normal coverage of macroalgae during April 2005 (Fig.3.3.1). Macroalgae covered the live and dead coral and were mostly seen around Umm AlMaradim reef in April 2005. Macroalgae were carefully removed to expose the coral beneath to check how many corals were alive; 9 out of 20 corals were still alive beneath the macroalgae. Dead coral *A. clathrata* AC colonies were seen around Kubbar and Umm AlMaradim in April 2005. There was also a 30cm depth of sand which had accumulated mostly at station 1 at Umm AlMaradim and covered the stands of the sediment traps to a depth of 60cm.

Water visibility was greatest around Qaru reef with depths of ~10m and ~6–8m around Umm AlMaradim and 4–5m around Kubbar reef (Table 3.3.2). Salinity was recorded as ~40 throughout the field work (Table 3.3.2). Table 3.3.2 contains some information recorded at the time of the surveys such as wind speed. Windy days occurred during most of the year. The windy days (21-25 knots) occurred mostly during winter time with Northerly winds especially during the beginning of the winter season. Calm days (0-5 knots wind speed) were experienced between March and May field work surveys (Table 3.3.2). Seawater temperatures were recorded as 18° C during the winter time.

Table 3.3.2. Average seawater temperatures recorded during the field surveys, visibility was estimated using a Secchi disc and salinity was determined using a refractometer during each survey to obtain information about the general conditions around each reef.

		Under water Visibility (M)			Salinity	
	Tem. °C	**Qaru**	**Umm AlMaradim**	**Kubbar**	**PPt ‰**	**Information**
June and July 2003	29.6	10	6.8	5	40	Med high wind
August and September 2003	31	10	6	4	40	Northerly wind
September and October 2003	28	10	5	4	39.8	High wind mostly
January and February 2004	21.5	12	5	4	40	Southerly wind
26th March – 13th May 2004	18.7	10	8	5	40	Calm wind
September and October 2004	28.8	6	6	5	42	High wind mostly
March 2005 -	18.0	8	6	5	40	Coral Bleaching CB
April 2005	20.25	10	7	5	40	CB, DC and MA
September - November 2005	25	10	7	5	39.8	30 cm sand in Um

The number of boats which anchored at the three sites (Fig.3.3.20) appeared to be the greatest contributor to the physical damage of the coral reefs (see chapter 6). Three ± 2 boats were recorded around Qaru, but 18 ± 10 boats were recorded around Umm AlMaradim and 42 ± 16 boats were seen around Kubbar (Fig. 3.3.20). In addition a local dive firm's NAUI (national association of under sea instructors) head office reported 200 divers were certified in 1995 and 9 years later in 2004 this number had risen to 800 registered divers.

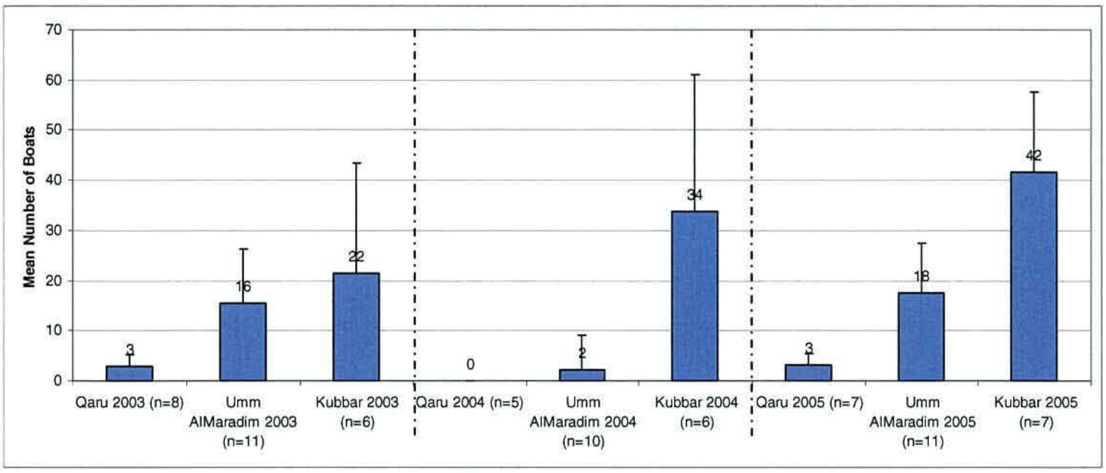

Figure 3.3.20. Mean number of speed boats (size 6-8 m long) which anchored at each reef site during the field work mostly at the weekends and during the diving season. A total of 71 boats were recorded during August-September and April-March in the 3 years of study (2003 – 2005).

3.3.4 Sedimentation onto the coral reefs

Sedimentation was measured at the three sites (Kubbar, Qaru and Umm AlMaradim) in September 2005 after the marina construction had started in April 2004 to evaluate the impacts of the marina construction on the coastal waters around the coral reef (Table 3.3.3 and Fig. 3.3.21). The first collection of sediment was carried out using 4 replicate 0.4L cups (area 314.2 cm²) placed for one week at the two stations at Umm AlMaradim. At station 1 a weight of (0.026 ± 0.004g cm^{-2}) sediment and at station 2 a weight of (0.003g ± 0.001g cm^{-2}) sediment was measured (see Table 3.3.3 and Fig.3.3.21 a). Whereas the highest accumulation of sediment in the cups collected over four weeks at Umm AlMaradim station 1 was a weight of 0.29 ± 0.141g cm^{-2} and at Umm AlMaradim station 2 a weight of 0.005 ± 0.001g cm^{-2} was collected in four weeks (Table 3.3.3 and Fig.3.3.21 b). Initially four replicate 0.4L cups were used as sediment traps to assess sedimentation rates at Umm AlMaradim, however at the other control sites, Kubbar and Qaru reefs, 8 replicate cups were used to collect sediment to highlight differences in sedimentation rates between the impacted (marina) site and the control sites (see Table 3.3.3). The highest accumulation of sediments in the cups (0.146g ± 0.143g cm^{-2}) occurred around station 1 at Umm AlMaradim (Table 3.3.3 and Fig.3.3.21 c). Sedimentation was obvious as ~30 cm of sediment had accumulated around the vertical stand of the sediment trap. At station 2 at the Qaru reef site the second highest sediment accumulation occurred

($0.059g \pm 0.051g\ cm^{-2}$) (Table 3.3.3 and Fig.3.3.21 c), $0.053 \pm 0.044g\ cm^{-2}$ was collected at station 2 on Kubbar reef (Table 3.3.3 and Fig.3.3.21 c), $0.032 \pm 0.03g\ cm^{-2}$ at station 1 Kubbar reef whereas the least weight of sediment was recorded at station 1 on the Qaru reef site ($0.02 \pm 0.015g\ cm^{-2}$) (Table 3.3.3 and Fig.3.3.21 c).

Table 3.3.3. Sediment measured ($g.cm^{-2}$) for one week using 4 cups at Umm AlMaradim, and four weeks using 8 cups at each of two stations (Qaru and Kubbar) in September 2005.

	One week			Four weeks	
		Umm AlMaradim		Qaru	Kubbar
	4 cups	4 cups	8 cups	8 cups	8 cups
St1	0.026	0.290	0.146	0.0196	0.0317
St2	0.003	0.005	0.004	0.0591	0.0531
St1 S.D.	0.004	0.141	0.143	0.0152	0.0300
St2 S.D.	0.001	0.001	0.001	0.0508	0.0439

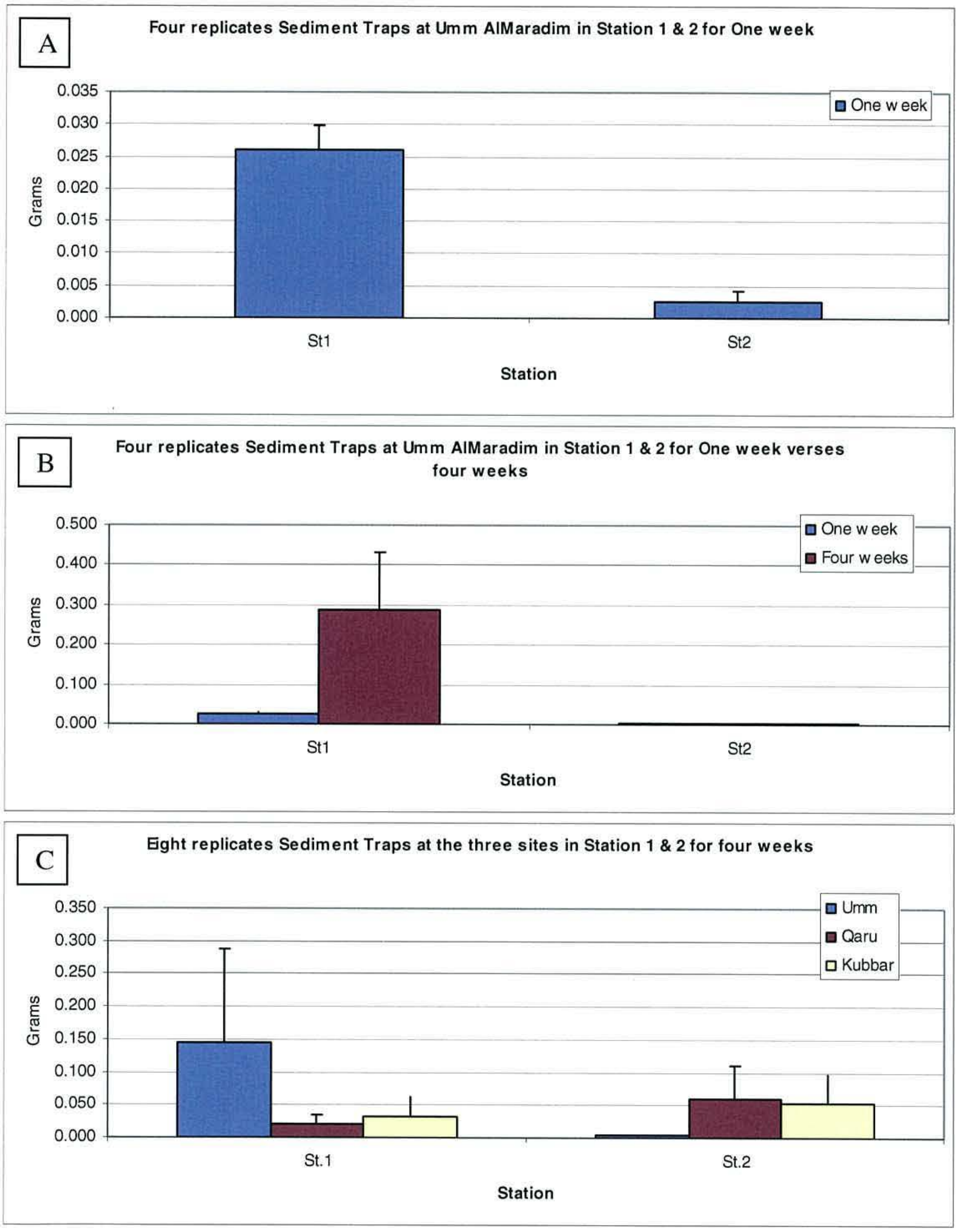

Figure 3.3.21. A. Mean sediment trapped in 4 replicate cups deployed at stations (1 & 2) at Umm AlMaradim during one week; B. mean sediment trapped in 4 replicate cups at each of two stations at Umm AlMaradim during one week verses four weeks; and C. mean sediment trapped in 8 replicate cups at two stations at the three sites during 4 weeks in September 2005.

3.4. Discussion

The survey method was carefully designed and the timing of the surveys carried out during the summer and winter and were based on methods previously documented in the literature and with prior knowledge of the settings of the reefs in Kuwait. The three sites (Kubbar, Qaru and Umm AlMaradim) were selected because the 3 different fringing reefs were different distances from the mainland and were established to highlight their natural settings and to document any changes throughout the study period between 2003 & 2005. The reefs are also situated at different distances from anthropogenic disturbances and their faunal composition and any damage to the reefs were assessed in view of associated potential human influences. The stations were chosen because they had different settings (lee and windward sides of the reef). Dives were conducted along permanent established transects with a statistically viable number of transects to represent each station with replicate transects surveyed at different depths with a limited amount of time available during each survey to cover each station during the three years of study.

The results from different numbers of two replicate transects (4 versus 9 replicate transects) showed almost identical distributions of organisms on the reefs (see Fig.3.3.2). On the basis of these initial findings only 4 replicate transects were used in all future surveys of the reefs. Since the two stations (1 & 2) at each reef site were selected as permanent survey stations, they were regularly video surveyed to save underwater time spent and to provide a permanent visual coverage of the reefs with which to assess coral recruitment along the reefs.

The precision of identification of the various organisms along the reefs was tested by analyzing the video transect coverage twice using different independent settings. The results were almost identical at one station at the 3 reefs (Fig.3.3.3). From eight different runs along the same video footage of the 50m transects using a range of point sampling up to 30 points on each image, it was found that 6 points were sufficient to produce a clear picture of the faunal distribution of the reefs and comprised in total ~300 points on images taken along the transect (Fig.3.3.1). Such an approach was used in video survey studies along the Great Barrier Reef in Australia where 350 data points were recorded per 50 m of video transect (Harriott *et al.*, 1995). In addition the dendrogram similarity test showed 85% to 90% similarity between the two transects at the reef edge and in the shallow reef respectively proving that 4 replicate transects at each station at each site were sufficient to map the faunal distributions along each of the reefs (see Harriott *et al.*, 1995).

3.4.1 Reef benthic community

The coral reef sites of Kubbar (K1 & 2), Qaru (Q1 & 2), and Umm AlMaradim (Um1 & 2) were surveyed to understand the overall faunal distribution and to investigate any differences between the three reefs. The island reefs K, Q and Um were compared and correlated using a five factorial analysis; sites, transects, fore or back reef exposure, depth level and time. The major changes which occurred in the fauna between 2003 and 2005 happened because of the establishment of new marina as shown in the dendrogram as dashed line 3 (Fig.3.3.13).

A modest significant increase of only 10% coral cover occurred around the 3 islands between 2003 and 2005 (Fig.3.3.4, and Fig.3.3.6). Using the PRIMER ANOSIM analysis of similarities the increase was only significant between 2003 and 2005, but was not significant between 2004 and 2005. However, Principal Component statistical analysis did not show any significant differences between years (Fig.3.3.16). These two statistical analysis methods have different sensitivities for detecting any significant differences. PRIMER tested for each individual benthic cover similarity contribution and detected a 10% increase in live coral cover at the three sites between 2003 & 2005. However, the three sites showed ~40% dead coral cover, ~10%, 33% and 33% at station 1, and ~45%, 48% and 15% in station 2 at Kubbar, Qaru and Umm AlMaradim respectively in 2003 (Fig.3.3.6). The dead coral cover also increased about 20% at station 1 at Kubbar, and 5% along station 2 at Umm AlMaradim, but a decrease of ~10% was recorded at the other stations in 2005 (Fig.3.3.4). The increase in dead coral correlated with the anchoring of pleasure and dive boats around the reefs. On separate occasions the number of boats anchored to fixed buoys and those anchored independently around the reefs amounted to 41 boats, 31 of them anchored at Kubbar, 18 boats, 8 of them anchored on the reef at Umm AlMaradim and 5 boats were attached to the fixed buoys at Qaru during the diving season and at weekends between 2003 and 2005 (Fig.3.3.4). The increased dead coral correlated with the extra numbers of boat anchored around Kubbar and Umm AlMaradim, although there was not an increase in the percentage dead coral at Qaru.

Probably because the number of boats did not exceed the number (10) of mooring buoys.

A series of studies were carried out between 1984 and 1988 by Downing, together with surveys by Downing (1992), Downing & Roberts (1993), Hodgson & Carpenter (1995) and Harrison *et al.*, (1997). Downing and Roberts (1993) recommended that a continued monitoring program was needed to reveal long term effects of changes in live and dead coral cover. Eighteen years have elapsed between Downing's (1986) work out the same reefs and the start of the 2003-2005 surveys. The 2005 data confirmed that no differences in percentage living coral cover were apparent between Downing's data and the 2003, 2004 and 2005 surveys along most of the transects (Table 3.4.1). Looking at the major benthic categories (Fig. 3.3.4), the following observations can be made: no significant changes were noted in the abundance of live corals along the shallower or deeper transects, except for a decrease in the deeper transects at Umm AlMaradim station 2 and an increase at Kubbar station 1 between 1989 and 2005 and no significant changes were noted in the abundance of the other major benthic categories (Table 3.4.1). Overall, the mean percentage living cover recorded in the three surveys was either higher at Kubbar (K1) or similar (K2) to that reported by Downing (1989).

Table 3.4.1. Major benthic categories of living faunal and non-living cover recorded by Downing (1989) versus the current survey conducted in 2005 along the reef edge to shallow water at the 3 coral reefs.

Mean %	K1	K2	Q1	Q2	Um1	Um2
Living cover (1989)	28.0	44.5	41.3	47	34	42
Non living (1989)	71.6	55.5	58.7		66	58
Living cover (2005)	40 – 55	37 – 28	43 – 56	42 – 32	39 – 59	14 - 47
Non living (2005)	58 – 44	55 – 51	54 – 44	56 – 66	57 – 36	84 - 52

The coral reefs in Kuwait and elsewhere continue to be under serious pressure from a variety of threats including climate change, with many reefs already showing alarming declines. Climate change is a particularly potential threat, as it's effects on coral reefs can be complex, far reaching and devastating. Warming sea temperatures associated with climate change around the world have already reportedly caused extensive coral bleaching and coral death (Catterall et al. 1992; Gleason 1993; Brown et al. 1995; Brown 1997a; McClanahan 2000 a; McClanahan et al. 2001 c; Szmant 2002). Scientists have concluded and reported that climate change will continue to have an impact on coral reefs and make them even more vulnerable to other human related stresses, such as water pollution, disease, habitat destruction and overfishing (Greenpeace 1998; Hughes et al. 2003). However, these natural factors may have developed resistant species adaptation to natural stresses recorded around the world and possibly the harsh environment along Kuwait's reefs may have had the same effect (Coles 1997; Dikoua and Woesik 2006). Bleaching was reported in Kuwait during the winter at extremely low seawater temperatures and during the summer extreme high temperature which make it a more unstable environment all year around, which requires the corals to display a greater adaptation to an all year around stressfull environment (Downing 1985; Downing 1989; Hodgson and Carpenter 1995; Gischler et al. 2005). Coral bleaching was recorded first in March 2005 and had not been seen during the previous March survey times, even though similar seawater temperatures had been recorded. During March 2005 water visibility was very low with an average visibility of 6 m depth (Table 3.3.2), with the worst visibility around the three reefs during September2004. This coincided with the start of the trawling shrimp season in August 2004. There are a few factors that may cause the 3 sites to escape bleaching events every year such as wind and currents which can interfere with the temperature intensity and turbidity, even though a seawater temperature of 18.7 C was recorded during March 2004. A one degree rise in seawater temperature is crucial, during the summer, but it is in the winter where the temperatures are not as extreme to cause a mass coral bleaching like those observed at summer high temperatures (Gates 1990).

3.4.2 Natural and anthropogenic impacts

The rainfall data showed more rain was recorded in February and March (Fig.3.1) which means there was more cloud during that time, therefore there was most likely less sun intensity during the period of rain. This may have reduced the effects of bleaching, even though similar seawater temperatures were recorded at the same in two different years (Fig.3.1). The bleaching events that have been reported around the world have involved multiple factors occurring at the same time, such as high seawater temperatures with sunlight and even elevated or lower salinity (Hoegh-Guldberg and Smith 1989). The reefs of Kuwait would not last long if the corals did not show any so they are unique to be still living in the extreme environment in Kuwait. Oliver (1985) reported a major impact on the Great Barrier Reef from recurrent seasonal bleaching and mortality of corals (Oliver 1985). Coral reefs are thus vulnerable with their health changing because of natural environment impacts arising from human impacts on the reefs (Barber et al. 2001).

The reefs of Kuwait also experience multiple anthropogenic impacts particularly at Umm AlMaradim and other reefs in general too. Coastal development causing high sedimentation disturbances and causing increases in turbidity such as the new marina construction along the reef of Umm AlMaradim are responsible for the death of living corals. Sedimentation traps showed that there was the highest sediment accumulation around station 1 in Umm AlMaradim (0.025g cm^{-2}) as a result of the accumulation of sediment carried with the dominant current northeasterly from dredging in the new marina about 200 m away. A thirty centimeter depth of sediment covering the stand of the sediment trap was extra proof of sediment movement and accumulation at this station. However station 2 at Umm AlMaradim recorded the least sediment accumulation as it was not in the direction of the current flow from the marina development. All other sediment traps recorded moderate amount of sediment probably arising from boat traffic and from the overall sedimentation stirred up from the fishing trawling activities which are undertaken so close to these reefs, especially Qaru reef due to the high fish catches (personal communication with fisheries trawler captains). Brain corals and *Porites* are capable of remaining alive beneath sediment for several weeks (personal observation) since when accumulated sediment is manually removed from these corals the coral is able to function normally. But *Porites lutea* on the other hand was observed to be mostly dead around station 2 at Qaru reef site and this could have been possibly related to the high sedimentation measured at station 2. It has been similarly reported that *Porites lutea* suffered considerable mortality as a result of increased sedimentation on an intertidal reef flat at Phuket, Thailand (Brown et al. 1990; Clarke et al. 1993).

A sedimentation impact mechanism will cover the coral polyp's mouth, so the coral defence mechanism will be to remove sediment particles with their polyp tentacles and entangle the particles in mucus which means energy would be lost but the coral can still live (Rogers 1990). In addition corals and associated zooxanthellae depend on light for rapid deposition of calcium carbonate, so high turbidity caused by sedimentation can reduce coral growth rates through lowered sunlight (Rogers 1990). Sedimentation can have immediate and long term impacts on coral reefs. An immediate impact would possibly kill the coral (Brown et al. 1990; Clarke et al. 1993) and there will be a loss in benthic cover, but in the long term this may cause a reduction in coral growth (Rogers 1990) and subsequently accumulated layers of sediment on the seabed may inhibit settlement of juveniles (Stafford-Smith and Ormond 1992). Sedimentation problems can harm the reef structure and kill corals as reported by several scientists around the world (Brown et al. 1990; Catterall et al. 1992; Richmond 1993; Gourlay and Jell 1997). Six reef sites which were chronically exposed to high sediment loads were considered to cause the most obvious form of anthropogenic stress to corals along the west coasts of Singapore's southern islands (Dikoua and Woesik 2006). Sedimentation from dredging is one of the largest potential sources of reef degradation from human activities reported in the Caribbean and in the Pacific (Rogers 1990).

The reefs of Kuwait are also becoming more popular for sea recreational activities and for the tourist industry especially around the islands reef sites. Higher numbers of boats from Khairan resort marina have been recorded visiting the islands occasionally ~100 boats visit the reefs during the summer diving season each day plus some divers camp on the islands over the weekend (personal communication with local diving Alboom company). The tourist industry is probably the major cause of reef decline in the Red Sea (Rinkevich 2005). In addition the popularity of the sport of SCUBA diving is increasing with more divers invading the coral reefs and using underwater spear guns. The local head quarters of the NAUI dive office in Alboom Company recorded 600 divers licensed in one season during the summer of 2004. These new licensed divers were reported from only one dive firm, but if about the same number of divers reported were certificated from other dive firms, it would substantially increase the impact on Kuwaits coral reefs. This human activity over time could possibly create an unbalanced ecosystem and can be considered a major cause of coral reef decline in Kuwait. Degraded coral reefs generally exhibited a shift from 48% high live coral cover at Qaru with 35% algal cover to 30% low coral cover at Kubbar with an accompanying 45% high cover of algae (food surplus for herbivores) leading to possible sea urchin breakout and leading in turn to an increase in grazing activity around the reef system which may lead to degradation of the reef (Sammarco 1982; McClanahan et al. 1996). A weakened reef system resulting from sea urchin grazing was seen around Kuwait's reefs (e.g. Fig. 3.4.1). So the excessive growing algae and overfishing appear to have caused noticeable shifts from hard coral to algal dominance and sea urchin high density around Kuwait's reefs (personal observations). Downing (1989) also concluded that normal numbers of major predators (fish) and grazers (sea urchins) increased the diversity on the reefs of Kuwait. However as I have shown sea urchins can cause intensive grazing impact on reefs leading to degradation too (see chapter 5).

The limitations of my work were the weather and the lack of a complete diving team for each field work visit. The weather was unstable most of the time around the year especially around the change from summer to winter. The windy weather would cause low visibility underwater sometimes 2 m deep, and the poor visibility would interfere with the video surveys as good visibility is required to obtain clear video surveys. Often when the time and weather were suitable to be out in the field surveying the team was often not available. For each field work visit a boat captain plus a minimum of 3 master divers including the principle investigator were needed according to University of Wales, Bangor diving rules and regulation for field work.

For future work on the coral reefs it is suggested that an investigation be carried out to check the winter season macroalgal *Colpomenia sinuosa* over-growth along the three reefs to examine how much an impact the macroalgae have on the live corals. A survey could study how many live coral heads were over-grown by the macroalgae and for how long in correlation with other substrates. Another study would be to investigate whether sedimentation from the new marina has had an immediate and long term impact on the coral reefs. Therefore, it is recommended that the long-term impact of sedimentation on the reefs should be regularly measured by a continuation of the reef monitoring program. Coral growth rates and coral reef benthic cover should be monitored to investigate whether there is a loss of benthic cover.

3.5. Conclusions

The coral reef benthic percentage cover determined using video surveying methods around Kuwait's islands and estimates of sedimentation using sediment traps were deemed efficient and successful and gave a good indication of the reefs state. The coral reef benthic cover results showed statistically that there were no significant changes over the period 2003 to 2005 at the three sites. The conclusion therefore is that the island reefs are not changing over time and they are not degrading. Even though at the beginning of the study it might have been predicted that the three reefs on the 3 islands reefs were eroding and changing over time, they infact appear to be growing and becoming restored as quickly as they are being lost over time. The coral reefs of Kuwait are in a semi-stable condition as the live coral cover increases even when the corals species are being lost. Kubbar reef appeared to undergo a 10% net loss and 5% at Umm AlMaradim but at Qaru reef there was a 5% gain in the three year study. Even though the reef at Umm AlMaradim was expected to record the worse loss in corals and benthic cover because of the new marina construction and sedimentation, only 5% of the reef was estimated to be lost. In addition Umm AlMaradim station 2 has now been changed from an exposed site in 2003 to a sheltered site because of the construction of the new marina. Unfortunately the reefs are not in a management regulation zone and there is the prediction that in the future there will be an increase in boat traffic around the coral reefs and this will lead to more coral damage if left uncontrolled. In addition anthropogenic impacts, such as the development of further new marinas may in the future take place at the other reefs and this together with the longer term impact at Umm AlMaradim reef from the marina may downgrade the biological value of the reefs as a natural asset and resource in Kuwait.

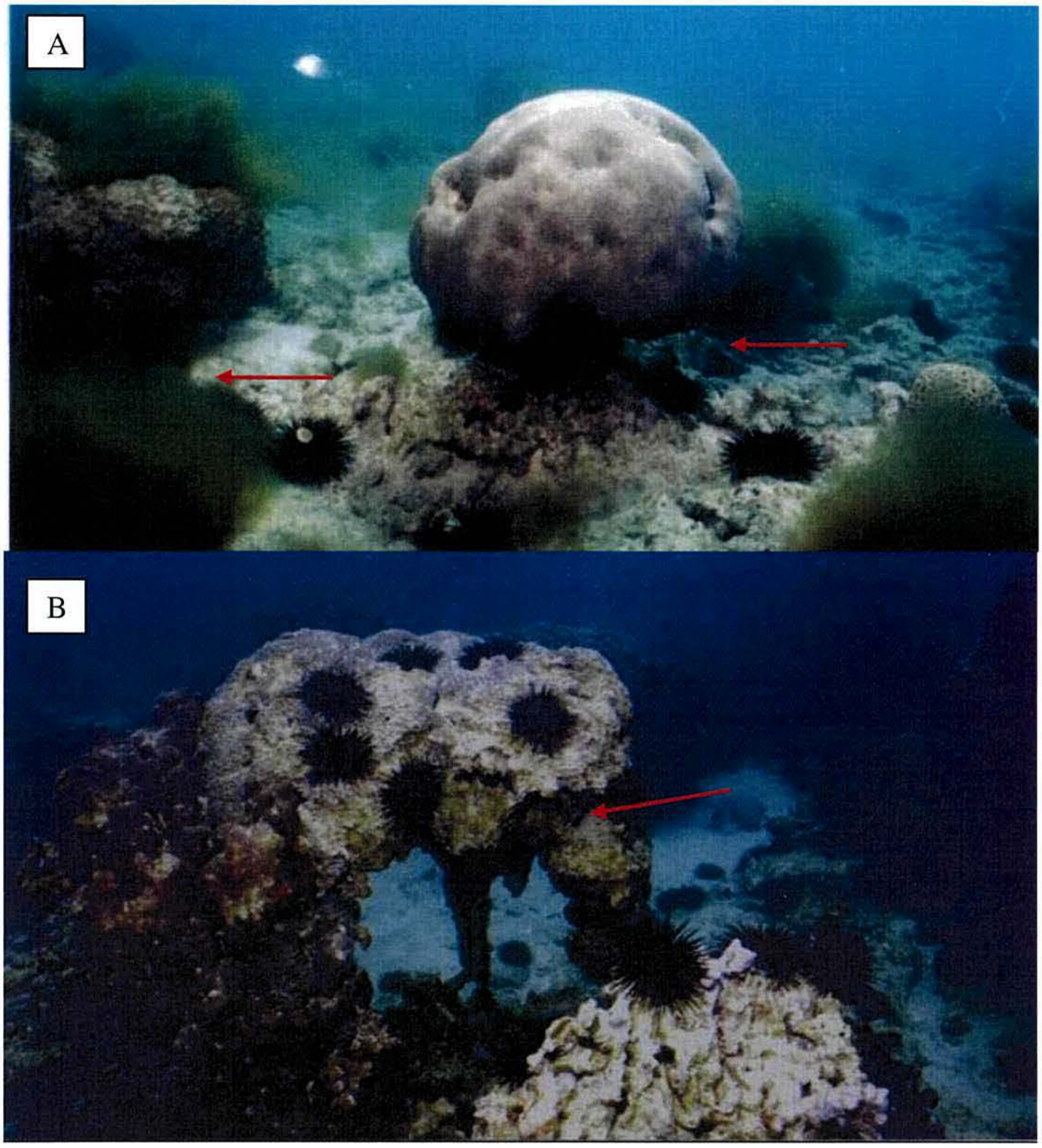

Figure 3.4.1 Macroalgae *Colpomenia sinuosa* growing at Kubbar reef in March 2003 around (A) a brain coral colony and (B) in September showing how the sea urchins grazing the algae have weakend a similar coral colony.

CHAPTER 4; Coral Recruitment patterns around Kuwait island reefs

4.1. Introduction

This chapter investigates coral recruitment, abundance and distribution from 2003 to 2005 at the three island reefs (Kubbar, Qaru and Umm AlMaradim). The recruitment of coral juveniles into a coral reef community is a major indicator of the condition of the population and the community structure of marine ecosystems. Newly settled coral recruits on a reef site indicate that the reef is in good health. However documenting coral spawning and reproduction at a site does not necessarily mean successful juvenile coral recruitment (Gittings et al. 1988; Richmond and Hunter 1990). Variation in timing of reproduction of coral species in specific populations may represent adaptations to local environmental extreme conditions (Harrison et al. 1997). Recruitment success and recruitment patterns may vary within and between sites, and maybe affected by both biotic (e.g. predation and competition) and abiotic (e.g. environmental variability and disturbance) factors. Data on coral recruitment would therefore be useful for the implementation of coral reef management practices and the data generated would be useful to predict the health of a reef site (Richmond and Hunter 1990).

Understanding the percentage cover of coral reef benthos, sea urchin abundance and coral recruitment will provide an understanding of the current health of the reef and how reefs might recover in the event of anthropogenic disturbance and allow rates of recovery of the reef to be ascertained. Observations on Kuwait's island reefs suggest that they have been degraded by extreme environmental conditions and human activities (see chapter 3). Coral, algal abundance and sea urchin abundance at the 3 island coral reefs will be controlled by extremes of sea water temperature in summer, where temperatures can reach 36° C associated with long periods of sunshine during the summer. During the winter temperatures reach as low as 16°C, followed by long recovery periods where the rate of reef recovery depends on the substratum quality for coral recruitment. Competition for space between corals, algae and sea urchins is intense and newly settling coral recruits will have to compete with the established species for space on the reefs. Synchronous periods of sexual spawning in the coral *Acropora* in June and Brain coral in August in Kuwait's island reefs has been documented in 1995 (Harrison et al., 1997). However, measurement of spawning success was not studied, and it is a key factor for the successful colonization of the reefs. Sammarco (1985) in Bermuda indicated that the rate of reef recovery may vary due to differences in the reproductive strategies of the dominant regional corals and the activity of grazing organisms such as fish and sea urchins. In addition, on Molasses reef in Florida USA, the removal of sediment and debris from areas of mechanical impact, enhanced recovery by expediting successful recruitment from coral transplantation to damaged areas (Gittings et al., 1988). Therefore, coral recruitment plays a critical role in a reefs recovery (Connell 1997 b). A normal healthy reef can also recover where there is little competition and growth amongst the fauna of the reef.

A few days or weeks after a coral spawning event coral larvae settle onto a suitable substratum e.g. a stable coral reef or the seabed (Harrison 1993). The coral larvae metamorphose to primary polyps, which soon start depositing their calcium carbonate skeleton, and add new polyps by budding (Harrison 1993). After 4-6 weeks, these recruits measuring up to about 2 mm in diameter and 1 mm in height, consist of one to six polyps (Fabricius et al. 2003). The best considered coral success recruit size is 3 cm and above, which can easily be seen and recorded as a successful recruit (Riegl 2002).

Nevertheless coral larvae were found to settle after four weeks on Kuwait's coral reefs (Harrison et al., 1997). However, the results of his study did not indicate the health of these reefs. Coral spawning and larval settlement measurements may indicate how these corals spawn and where this activity mostly occurs. A few days or weeks after a mass spawning event, coral larva settle on suitable substratum, and metamorphose to primary polyps, which soon start depositing their calcium carbonate skeleton, and adding new polyps by budding. Such observations do not allow an estimate of successful coral recruitment and the extent of recovery at these sites. Since the time taken for any recruitment to become visible occurs at about 8 to 10 months after initial settlement, and it is at this stage that a few scientists have observed recruitment to take place (Pearson, 1981; Harriott and Fisk, 1988; Tanner and Connell, 1994; Connell *et al.*, 1997). Babcock (1985) found on a subtropical reef site high rates of mortality in juveniles of the coral species *Acropora millepora*, *Goniastrea aspera* (67%) and *Platygyra sinensis* (73%) over the first eight months of their life. During the time it takes for the larvae to settle and survive until they are large enough to be visible (>10 cm), the new recruits will have had to face extreme environmental conditions in summer and winter and they may perish as a result of high grazing activity along Kuwait's reefs. It would therefore be difficult to try and find the newly settled larvae on the reef and use this as a way of estimating whether a coral reef site is beginning to recover and can be restored. Recruitment success may be applied to coral reef management practices (Richmond and Hunter 1990). In this chapter I have investigated whether there was any evidence of coral recruitment on Kuwait's island coral reefs.

4.2. Aims and objectives

The aims of this study were to investigate coral recruitment, abundance and distribution along Kubbar, Qaru and Umm AlMaradim, and on the basis of these findings to evaluate the capacity of the reefs to recover from disturbance.

The main objectives of the chapter were to investigate whether it is possible to quantify coral recruitment, abundance and distribution from video surveys taken along the island reefs. The specific objectives were:

1. To quantify the video surveys of the two permanent stations windward and leeward along each of the islands reefs.
2. To count the number of coral species that recruit at the three islands reefs through two seasons over the three year study (2003 – 2005) from the video surveys.
3. To establish whether recruitment densities are similar to those elsewhere, both in Kuwait and globally.

4.3. Material and methods

4.3.1 Abundance and distribution of coral recruits on the islands reefs

A coral larvae settlement experiment was carried out to assess larval settlement at each site. This was attempted by placing Bathroom tiles at selected sites along the three reefs. Two hundred and fifty new tiles (15 x 15 cm size) were pre-conditioned in running filtered sea water in an aquarium for 1 week at the Kuwait Institute for Scientific Research. The tiles were placed onto the coral substratum around the survey stations at each island reef during September well before coral spawning in May and June (Harrison et al., 1997). Each of 70 tiles was placed on two plastic racks which were stabilized and attached to the coral substrate so they would not tip over in the currents. Before these tiles could be removed for study the whole structure was damaged and lost. This method was abandoned. Instead a video survey was conducted and the number of visible size coral recruits that were most likely to live to adult stage were counted (see Fig.4.3.1). The number of coral recruits in 1 m^2 areas at each site would allow differences in the abundance and distribution patterns around the three reefs to be ascertained. This, in turn, would allow a prediction of whether each reef could potentially be restored to a reasonable level.

A coral recruitment survey was undertaken by divers using the Sony digital video camera. The video recording survey method has already been explained in chapter 3. Two permanent stations were monitored on each reef, one was in the north-west area of the reef (fore reef) and the second was in the south-east area of the reef (back reef), as illustrated in chapter 3 (Fig. 3.3.3). At each station four replicate 50 m long transects, the first two were along the reef edge (8 m depth) and the second two along the shallow reef (2 m depth), and one perpendicular to the beach running from the reef edge to the reef shallow. The perpendicular transect covered 30 m in September 2003 and March 2004 but it was extended to a 150 m long transect in September 2005 to allow more of the reef to be surveyed. Transects along the reef were surveyed in September 2003, March 2004 and September 2005 at Umm AlMaradim (UM1 and UM2), Qaro (Q1 and Q2) and Kubbar (K1 and K2) and are illustrated in chapter 3 (figures 3.3.1 and 3.3.3).

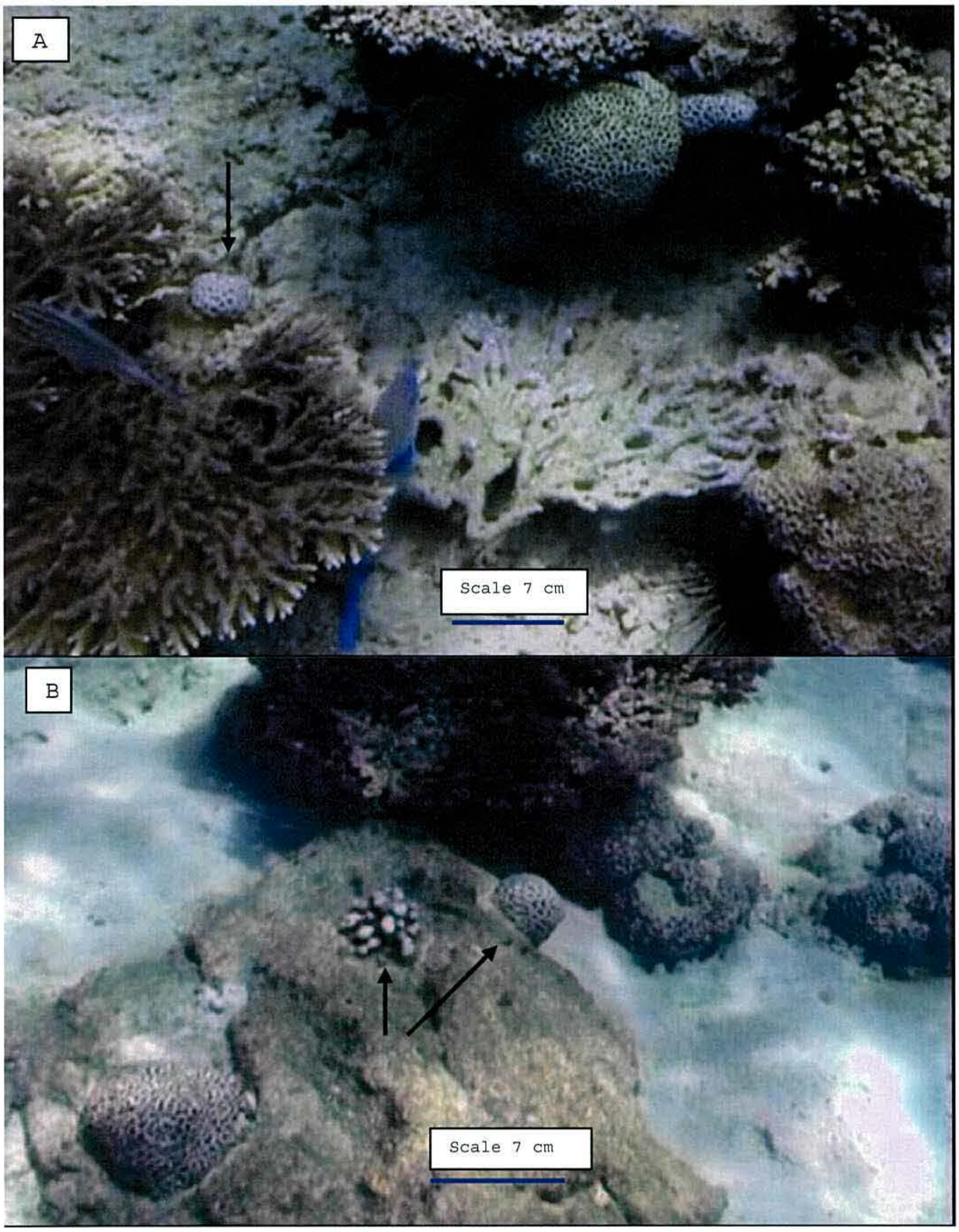

Figure 4.3.1. Two frames from the video recordings to show the coral recruits. A) *Favia pallida* (arrows) and B) *Porites* sp. and *Favia pallida* in (arrows) as an example in Umm AlMaradim and a scale of 7 cm.

The digital video coverage of the transects was viewed on a 17 inch computer monitor and subsequently digitized using Pinnacle software (ver.8). Video frames were manually selected and around 50 frames were "grabbed" in each 50 m transect. The video coverage amounted to an area of the reef of about 1 m^2. Coral recruits in each 1 m^2 frame were identified and recorded as shown earlier (Fig. 4.3.1). In many cases, identification of a recruit to species level was not possible from the video images; therefore corals were only identified to the level of genus. The survey data were recorded in an Excel spreadsheet and the numbers of recruits, the mean, standard deviation and standard error of recruit number along each transect were calculated. The recruit data for the 3 survey periods (September 2003, March 2004 and September 2005) were plotted as histograms to investigate whether there were any seasonal differences. The same approach was used to establish whether there were differences in coral recruitment between the 3 coral reefs (Kubbar, Qaru and Umm AlMaradim).

4.4. Results

4.4.1 Coral recruitment

The mean number of coral recruits m^{-2} along the islands reef sites, on the fore and back reef to investigate exposure and depth on recruitment, are shown in figure 4.4.2. The exposed reef stations are K2 (Kubbar station 2), Q2 (Qaru station 2) and Um2 (Umm AlMaradim station 2), while the fore reef stations are K1, Q1 and Um1 on the sheltered (back reef). The quadrat survey transects were grouped into reef edge 8 m (transect 1+ transect 2) and shallow 2 m depth (transect 4 + transect 5) quadrat transects as illustrated in chapter 3 (Fig 3.4.9 – 3.4.10). The mean number of coral recruits m^{-2} and standard deviation of the 5 transect means at station 1 (leeward) and station 2 (windward) at the 3 sites, in September 2003, in March 2004 and along the 150 m long transect 3 in September 2005 are shown in Table 4.4.1 & Fig.4.4.1. Cover of recruits was very low over all the sites in September 2003, March 2004 and September 2005 and shown in figure 4.4.1. The mean numbers of recruits overall at each station did not exceed 0.60 m^{-2} except Qaru at station 1 which showed a mean of 0.59 ± 0.44 m^{-2} (Table 4.4.1 & Fig.4.4.1). Also the mean number of recruits along each transect did not exceed 1 m^{-2} except at Qaru on the 150 m long transect 3 where a mean number of recruits was estimated to be 1.37±0.2 m^{-2} at station 1 leeward (Fig. 4.4.2). The highest mean number of recruits on the shallow reef was 0.12-0.35 m^{-2} (±0.6) at Qaru reef and at the reef edge was 0.05-0.11 m^{-2} (±0.05) at all the three sites. No recruits were recorded along transect 3 at Kubbar and Umm AlMaradim in September 2003 (Fig. 4.4.2). Kubbar reef recruitment of 0.52 m^{-2} (± 0.1) was exceptional at transect 5 on the shallow reef (see Fig.4.4.2). However, station 2 windward showed an opposite recruitment pattern with the lowest numbers of recruits at Qaru reef, which was similar to the number of recruits on the reef edge at station 1

(Fig. 4.4.2). Kubbar reef showed the highest number of recruits (0.25 m^{-2} (±0.1)) on the reef edge, and 0.14-0.23 m^{-2} (±0.06) at Umm AlMaradim reef edge, but with a similar number of recruits along transect 3 (0.11 m^{-2} (±0.05)) (see Fig.4.4.2).

The mean number of coral recruits m^{-2} with standard error bar of the 5 transects at each station showed almost the same average recruitment pattern at station 1 leeward in March 2004 (Fig. 4.4.3). However, the reef edge at Qaru reef along transect 1 showed 0.5 m^{-2} (±0.1) and the reef shallow at Kubbar transect 5 showed 0.2 m^{-2} (±0.09) recruits. Coral recruitment did not appear to be different in September 2005, except at Qaru along the 150m long transect 3 where there was a mean of 1.37 m^{-2} (±0.2) at station 1 leeward and 0.96 m^{-2} (±0.2) at the reef edge along transect 1 at Umm AlMaradim (Fig. 4.4.4). However, at station 2 windward an opposite recruitment pattern was recorded in September 2003 in which the highest mean number of recruits at Qaru ranged from 0.23-0.61 m^{-2} (±0.08) at the reef shallow to the edge respectively (Fig. 4.4.4). The recorded mean recruitment at transect 5 at Kubbar reef 0.52 m^{-2} (±0.1) in 2003 declined to 0.2 m^{-2} (±0.03) in 2005 (Fig. 4.4.4). In addition to a reduction in recruitment at station 2 windward a similar pattern was observed at Kubbar reef where recruitment fell to 0.05 m^{-2} (±0.03) along all transects in September 2005 (see Fig. 4.4.4).

Table 4.4.1. The mean number of coral recruits m^{-2} with standard deviation of the 5 transects at each site and at station 1 leeward and station 2 windward along the three sites, in September 2003, in March 2004 and along the extended 150 m long transect 3 in September 2005.

Site	St.1 Sep.03	St.2 Sep.03	St.1 Mar.04	St.2 Mar.04	St1 Sep.05	St 2 Sep.05
Kubbar	0.16 ± 0.21	0.13 ± 0.12	0.08 ± 0.08	0.02 ± 0.02	0.20 ± 0.05	0.04 ± 0.02
Qaru	0.18 ± 0.12	0.05 ± 0.03	0.22 ± 0.20	0.06 ± 0.06	0.59 ± 0.44	0.42 ± 0.14
Umm AlMaradim	0.09 ± 0.03	0.11 ± 0.08	0.08 ± 0.08	0.05 ± 0.06	0.33 ± 0.38	0.08 ± 0.08

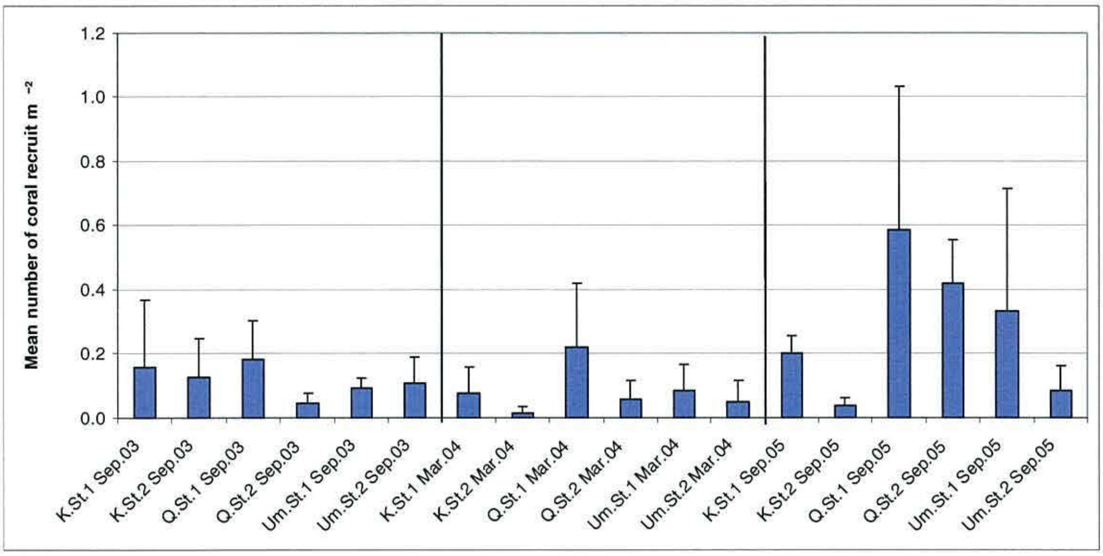

Figure 4.4.1. The distribution of the mean number of coral recruits m^{-2} with standard deviation at 2 stations (St.) along the 3 reef sites, (K) Kubbar, (Q) Qaru and (Um) Umm AlMaradim in September 2003, March 2004 and September 2005.

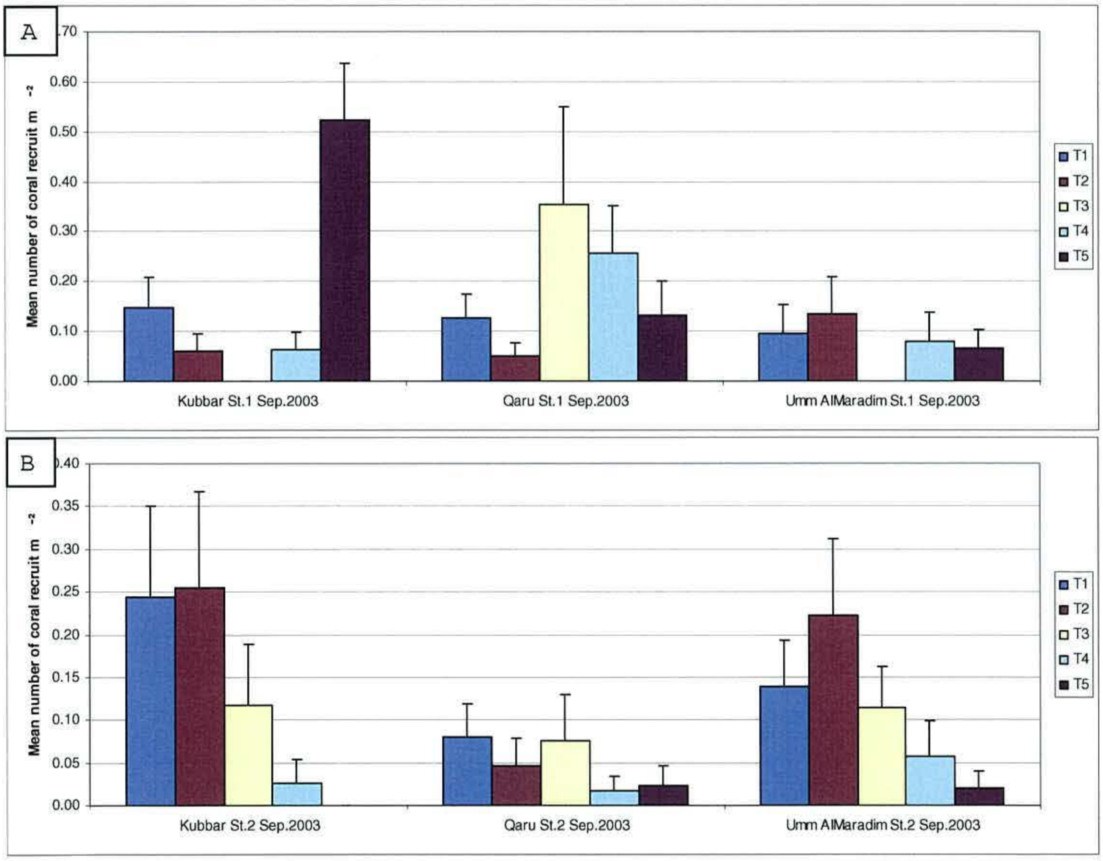

Figure 4.4.2. Mean number of coral recruits m^{-2} with standard error bar along 5 transects; two at the reef edge (T1, T2) and two at the reef shallow (T4, T5) with one between at Kubbar, Qaru and Umm AlMaradim, based on two stations; station 1 (A) and station 2 (B) in September 2003.

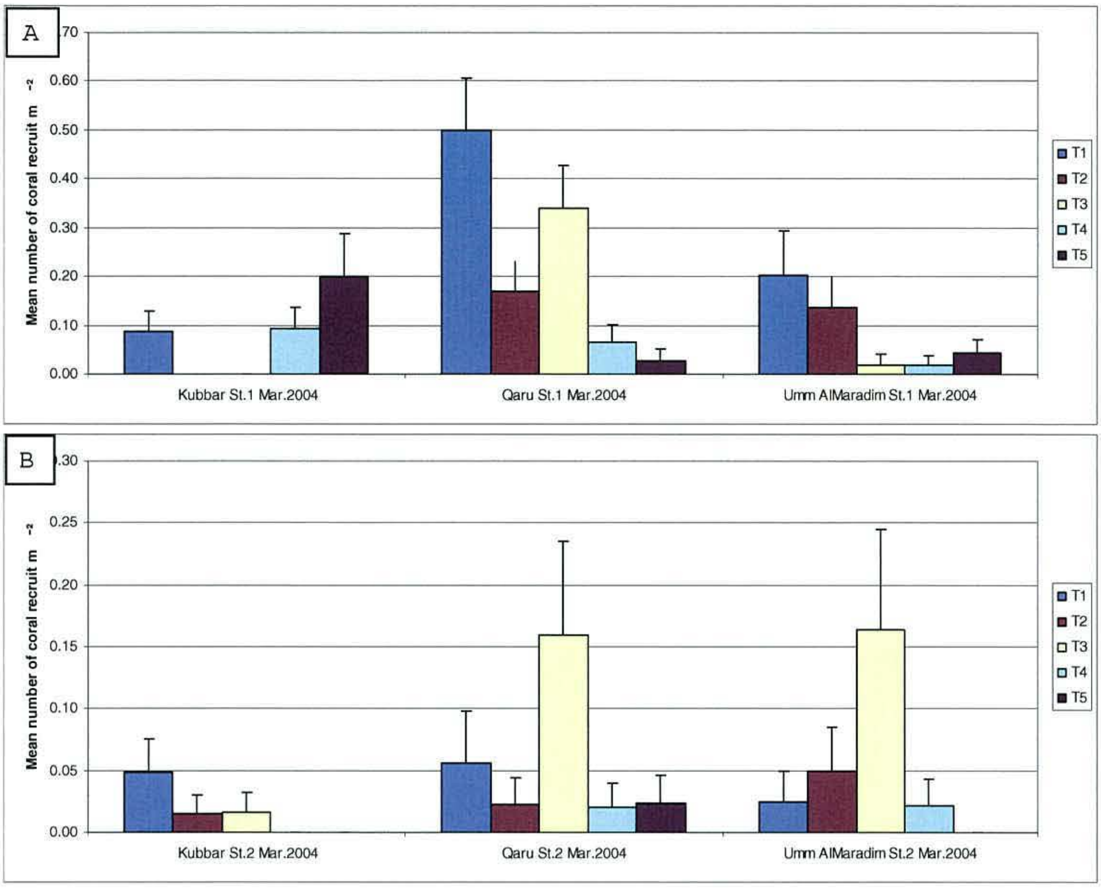

Figure 4.4.3. Mean number of coral recruits m^{-2} with standard error bar along 5 transects; two at the reef edge (T1, T2) and two at the reef shallow (T4, T5) with one between at Kubbar, Qaru and Umm AlMaradim, based on two stations; station 1 (A) and station 2 (B) in March 2004.

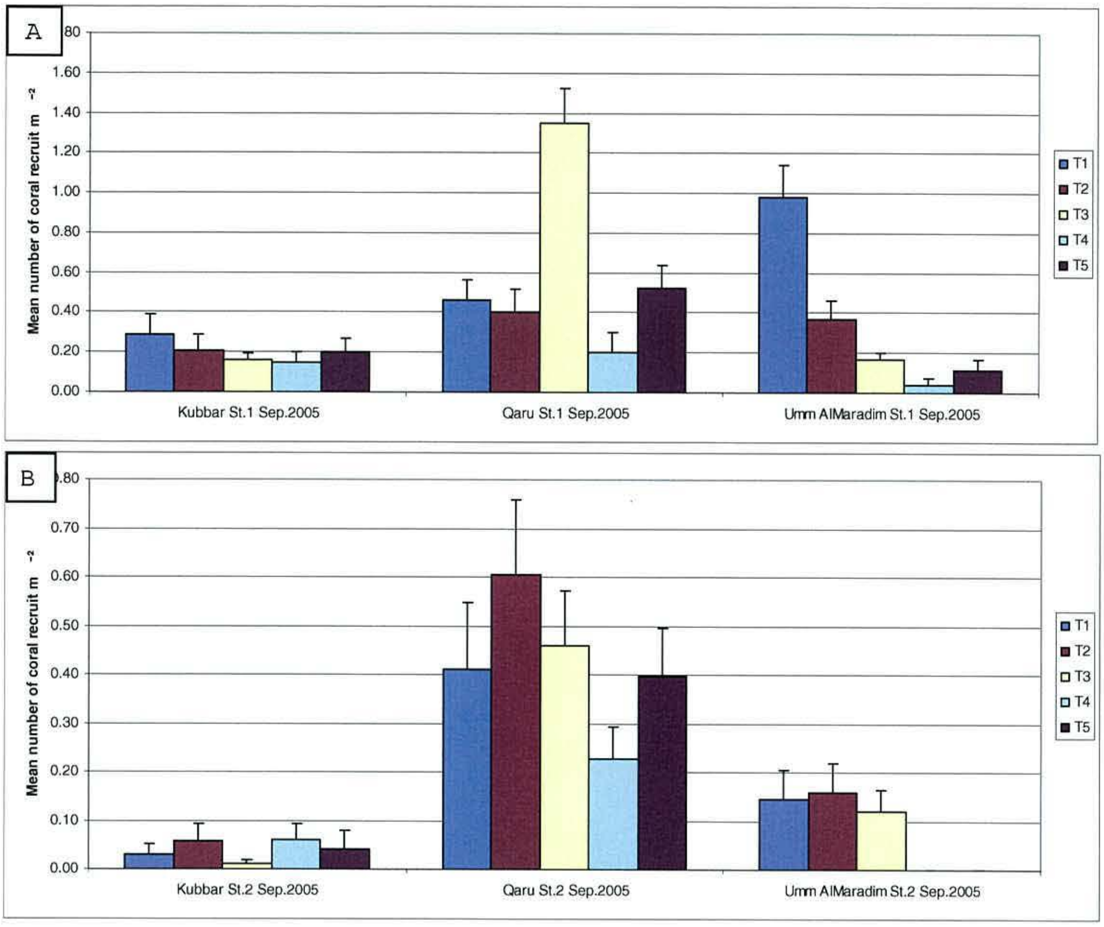

Figure 4.4.4. Mean number of coral recruits m^{-2} with standard error bar along 5 transects; two at the reef edge and two at the reef shallow along the 150 m long transect 3 at Kubbar, Qaru and Umm AlMaradim, based on two stations; station 1 (A) and station 2 (B) in September 2005.

4.4.2 Statistical analysis

Statistical analysis of the coral recruit data was undertaken to investigate whether there were differences in recruitment on the, fore (station 1) or back (station 2), and with reef exposure and reef depth. The quadrat survey along the transects (50 quadrats along each transect) were grouped into two categories, reef edge 8 m depth (transect 1+ transect 2) and shallow 2 m depth (transect 4 + transect 5). A general Linear Model test with 4 factors (site, station, year and reef depth edge and shallow) and pairwise comparisons using analysis of variance (ANOVA) for the numbers of coral recruits indicated there were significant differences between years and sites ($F = 36.30$; $P < 0.001$), between reef shallow and reef edge ($F = 20.60$; $P < 0.001$), station ($F = 29.74$; $P < 0.001$), site ($F = 29.49$; $P < 0.001$) and year ($F = 36.47$; $P < 0.001$) (Table 4.4.2 and Fig.4.4.5). In addition there was a significant difference in the three way interaction between year, station and reef shallow/edge ($F = 18.12$; $P < 0.001$). There were significant differences between year and station (F = 5.39; P <0.020), year with reef shallow/edge (F = 10.53; P <0.001) and site with reef shallow/edge (F = 5.51; P <0.004). However with site and station there were no significant differences (F = 1.53; P >0.216), station with reef shallow/edge (F = 0.13; P >0.723) and a three way interaction between year, site and station (F = 0.47; P >0.627). Although year, site and reef shallow/edge (F = 4.20; P <0.015) and site, station and reef shallow/edge (F = 4.05; P <0.017) were significantly different (Table 4.4.2 and Fig.4.4.5). In addition there was no significant difference in the four way interaction between year, site, station and reef shallow/edge (F = 0.69; P >0.502) (Table 4.4.2 and Fig.4.4.5).

Table 4.4.2. Summary of the statistical analyses of differences in coral recruitment in the different locations between 2003 and 2005.

Factorial	F value	P value	Difference
Year	36.47	0.001	significant
Site	29.49	0.001	significant
Station	29.74	0.001	significant
Shallow/Edge reef	20.60	0.001	significant
Year x Site	36.30	0.001	significant
Year x Station	5.39	0.020	significant
Year x Shallow/Edge	10.53	0.001	significant
Site x Station	1.53	0.216	not significant
Site x Shallow/Edge	5.51	0.004	significant
Station x Shallow/Edge	0.13	0.723	not significant
Year x Site x Station	0.47	0.627	not significant
Year x Site x Shallow/Edge	4.20	0.015	significant
Year x Station x Shallow/Edge	18.12	0.001	significant
Site x Station x Shallow/Edge	4.05	0.017	significant
Year x Site x Station x Shallow/Edge	0.69	0.502	not significant

An analysis using a General Linear Model test with 4 factors (site, station, season and reef depth shallow and edge) and pairwise comparisons using analysis of variance (ANOVA) for coral recruit count data showed there was significant difference between season (F = 6.46; P <0.01) between station and reef shallow/edge (F = 6.00; P <0.01), and non-significant differences between site (F = 1.80; P >0.16), between season and station (F = 0.48; P >0.48), between season and reef shallow/edge (F = 2.02; P >0.15), (Table 4.4.3 and Fig.4.4.6). In addition there was no significant difference in the three way interaction between season, site and station (F = 0.21; P >0.81), and in the four way interaction between season, site, station and reef shallow/edge (F = 1.42; P >0.24) (Table 4.4.3 and Fig.4.4.6). However, there were significant differences between station (F = 24.93; P <0.001), reef shallow/edge (F = 10.21; P <0.001), interaction season with site (F = 4.97; P <0.001), site with station (F = 6.35; P <0.001), site with reef shallow/edge (F = 5.71; P <0.001) and three way interaction between season, site and reef shallow/edge (F = 4.90; P <0.001), also season, station and reef shallow/edge (F = 15.07; P <0.001) and site, station and reef shallow/edge (F = 11.73; P <0.001) (Table 4.4.3 and Fig.4.4.6).

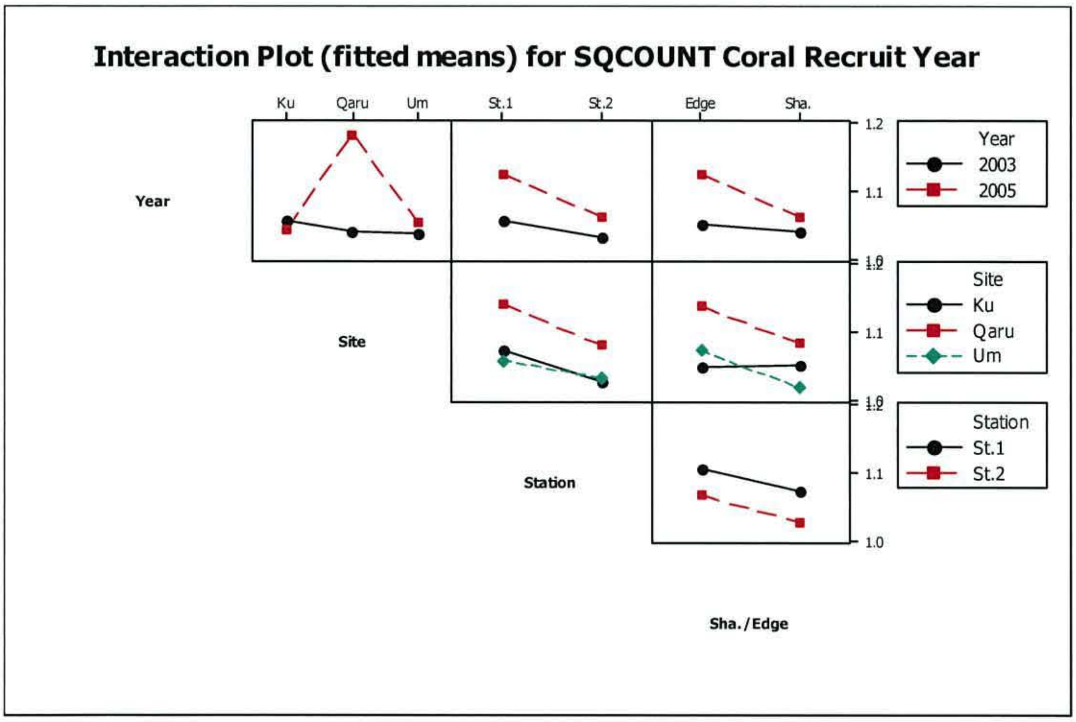

Figure 4.4.5. Interaction mean number of coral recruits with 4 factors (year, site, reef back st.1 and front st.2 and reef edge/shallow). General Linear Model count versus site, year, Station and reef Edge/Shallow. Factor; site 3 (Kubbar, Qaru, Umm AlMaradim), year 2 (2003, 2005), station 2 (station 1, 2) and reef Edge/Shallow.

The interaction plot in figure 4.4.5 showed that the number of coral recruits at Qaru reef had changed significantly between 2003 and 2005, but that at Kubbar and Umm AlMaradim recruitment appeared not to have changed (Fig.4.4.5). The edge reef showed significant change with higher coral recruitment in 2005 than in 2003, but the shallow reef showed no significant change between 2003 and 2005 (Fig.4.4.5). Station 1 back reef showed significant change with higher coral recruitment in 2005 than in 2003, but at station 2 on the fore reef no significant change was observed between 2003 and 2005 (Fig.4.4.5). Qaru and Umm AlMaradim reef recruitment data followed a similar trend of change between the shallow reef to the reef edge, but Kubbar reef did not change and the pattern of recruitment was similar at both depths (see Fig.4.4.5).

Table 4.4.3. Summary of the statistical analyses of differences in seasonal coral recruitment between March 2004 and September 2003.

Factorial	F value	P value	Difference
Season	6.46	0.011	significant
Site	1.80	0.165	not significant
Station	24.93	0.001	significant
Shallow/Edge reef	10.21	0.001	significant
Season x Site	4.97	0.007	significant
Season x Station	0.48	0.489	not significant
Season x Shallow/Edge	2.02	0.156	not significant
Site x Station	6.35	0.002	significant
Site x Shallow/Edge	5.71	0.003	significant
Station x Shallow/Edge	6.00	0.014	significant
Season x Site x Station	0.21	0.811	not significant
Season x Site x Shallow/Edge	4.90	0.008	significant
Season x Station x Shallow/Edge	15.07	0.001	significant
Site x Station x Shallow/Edge	11.73	0.001	significant
Season x Site x Station x Shallow/Edge	1.42	0.242	not significant

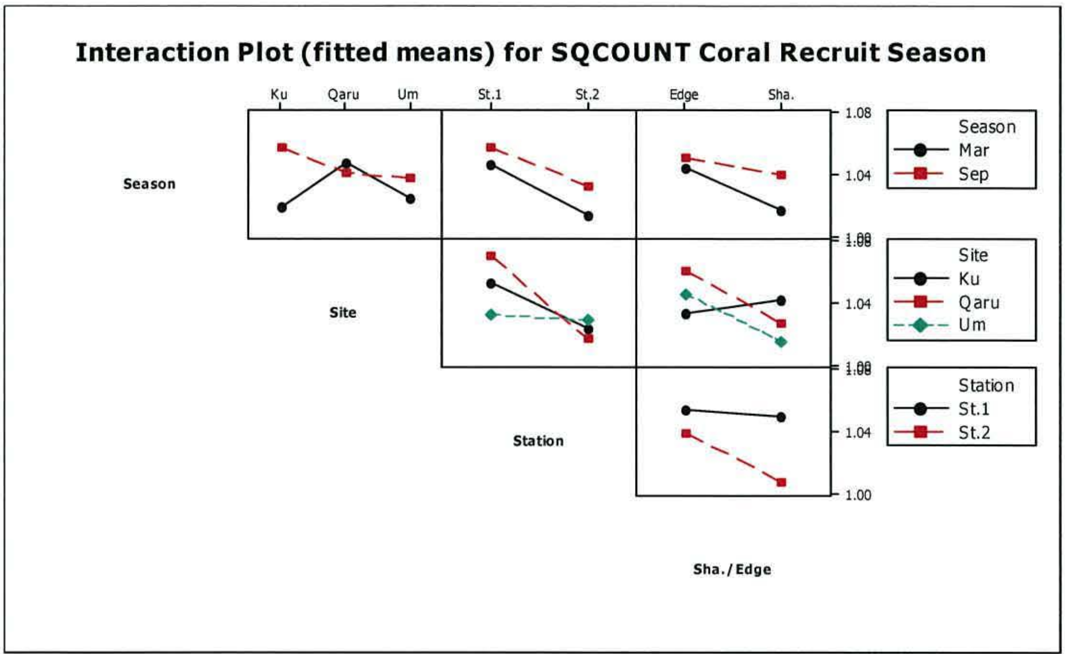

Figure 4.4.6. Interaction means number of coral recruits with 4 factors (season, site, reef back st.1 and front st.2 and reef edge/shallow). General Linear Model count versus site, season, station and reef edge/shallow. Factor; site 3 (Kubbar, Qaru, Umm AlMaradim), season 2 (March, September), station 2 (station 1, 2) and reef edge/shallow.

4.4.3 Coral species recruitment and diversity at the three reefs

The number of recruits m^{-2} of the various coral species at each site, station 1 leeward within the $1m^2$ quadrats along the 5 x 50 m long transects; 2 (T1 & T2) at the reef edge and 2 (T4 & T5) at the reef shallow with one between along transect 3, in September 2003 and in September 2005 with the 150 m long transect 3 at the six stations are presented in table 4.4.1 and station 2 windward 3 stations in table 4.4.4. Ten different coral genera were recorded as recruits into the survey areas in 2003 - 2005. The most commonly recorded coral recruits were *Acropora arabensis, A. clathrata, Porites* and brain corals at all sites, whilst *Psammocora contigua* with *Pavona decussata* were mostly recorded at Qaru at station 1 leeward at shallow reef and *Stylophora* at station 2 windward also at shallow reef (Table 4.4.4 & 5). *Goniopora lobata* was mostly often recorded at Umm AlMaradim station 2 windward (Table 4.4.5). *Cyphastrea serailia* was mostly frequently recorded at Kubbar reef station 1 leeward and *Acanthastrea echinata* at reef shallow with *Coscinaraea columna* at reef edge also at station 1 leeward (Table 4.4.4).

Table 4.4.4: Variation in the mean number of coral genera recruited m^{-2} at each site station 1 leeward with number of 1 m^2 quadrats along the 5 transects (T1 to T5) at the three sites, in September 2003 & along the 150 m long transect 3 in September 2005.

September 2003, Station 1, Transects		T1	T2	T3	T4	T5
Kubbar Station1 Sep.2003,	n =	55	51	20	48	44
Acropora arabensis AA		0	0	0	0	1
Acanthastrea echinata ATH		0	0	0	0	1
Brain Coral (Faviid unidentified) BC		3	1	0	1	11
Favia pallida (Faviid) F		0	0	0	2	2
Coscinaraea columna (Sideratreidae) COS		0	1	0	0	0
Porites compressa (Poritidae) P		5	1	0	0	8
Total number of recruits		8	3	0	3	23
Qaru Station 1 Sep.2003,	n =	70	61	48	43	45
Acropora arabensis AA		5	2	2	3	3
Acropora clathrata AC		0	0	13	0	0
Brain Coral (Faviid unidentified) BC		3	0	2	0	3
Favia pallida (Faviid) F		1	1	0	6	0
Porites compressa (Poritidae) P		0	0	0	1	0
Stylophora (Poritidae) ST		0	0	0	1	0
Total Recruits		9	3	17	11	6
Umm AlMaradim Station 1 Sep.2003,	n =	54	58	0	39	48
Acropora arabensis AA		0	0	0	0	2
Brain Coral (Faviid unidentified) BC		0	3	0	1	1
Favia pallida (Faviid) F		1	0	0	2	0
Porites compressa (Poritidae) P		4	4	0	0	0
Total number of recruits		5	7	0	3	3

September 2005, Transect		T1	T2	T3	T4	T5
Kubbar Station 1 Sep.2005,	n =	66	64	174	57	64
Acropora arabensis AA		7	4	8	2	5
Acropora clathrata AC		0	0	1	0	0
Brain Coral (Faviid unidentified) BC		1	2	1	0	4
Cyphastrea serailia (Faviid) CY		0	0	1	0	0
Favia pallida (Faviid) F		5	4	9	4	3
Porites compressa (Poritidae) P		3	0	3	0	0
Platygyra daedalea (Faviid) PL		0	1	3	2	0
Total number of recruits		16	11	26	8	12
Qaru Station 1 Sep.2005,	n =	65	47	118	60	71
Acropora arabensis AA		1	2	13	0	2
Acropora clathrata AC		7	0	4	0	5
Brain Coral (Faviid unidentified) BC		1	0	11	0	2
Favia pallida (Faviid) F		11	9	11	10	23
Porites compressa (Poritidae) P		0	1	37	2	1
Pavona decussata (Agariciidae) PAV		0	0	2	0	0
Platygyra daedalea (Faviid) PL		1	1	0	0	2
Psammocora contigua (Sideratreidae) PSC		0	0	0	0	2
Total number of recruits		21	13	78	12	37
Umm AlMaradim St.1 Sep.2005,	n =	47	64	162	50	55
Acropora arabensis AA		5	2	4	0	2
Acropora clathrata AC		3	1	2	0	1
Cyphastrea serailia (Faviid) CY		0	0	1	0	0
Brain Coral (Faviid unidentified) BC		2	1	0	0	1
Favia pallida (Faviid) F		22	10	9	1	2

Platygyra daedalea (Faviid) PL	2	0	0	0	0
Porites compressa (Poritidae) P	10	5	10	1	0
Stylophora (Poritidae) ST	0	2	0	0	0
Total number of recruits	44	21	26	2	6

Table 4.4.5: Variation in the mean number of coral genera recruited m^{-2} at each site station 2 windward with the number of 1 m^{-2} quadrats along the 5 transects (T1 to T5) at the three sites, in September 2003 & along the 150 m transect 3 in September 2005.

September 2003, Station 2, Transects		T1	T2	T3	T4	T5
Kubbar St.2 Sep.2003,	n =	49	48	36	37	45
Acropora arabensis AA		5	4	0	1	0
Brain Coral (Faviid unidentified) BC		0	2	3	0	0
Favia pallida (Faviid) F		3	0	1	0	0
Porites compressa (Poritidae) P		3	6	0	0	0
Total Recruits		11	12	4	1	0
Qaru Station 2 Sep.2003, n =		50	43	40	60	43
Acropora arabensis AA		3	1	1	1	0
Acropora clathrata AC		1	0	2	0	0
Porites compressa (Poritidae) P		0	1	0	0	1
Total number of recruits		4	2	3	1	1
Umm AlMaradim Station 2 Sep.2003,	n =	44	51	47	53	49
Acropora arabensis AA		0	0	1	0	0
Favia pallida (Faviid) F		1	5	1	2	1
Goniopora lobata (Poritidae) GON		5	3	1	0	0
Porites compressa (Poritidae) P		0	2	2	1	0
Total number of recruits		6	10	5	3	1

September 2005, Station 2, Transects		T1	T2	T3	T4	T5
Kubbar Station 2 Sep.2005,	n =	68	54	186	50	50
Acropora arabensis AA		0	2	0	1	1
Brain Coral (Faviid unidentified) BC		0	0	1	1	0
Favia pallida (Faviid) F		0	0	0	1	0
Platygyra daedalea (Faviid) PL		0	0	0	0	1
Porites compressa (Poritidae) P		2	1	1	0	0
Total number of recruits		2	3	2	3	2
Qaru Station 2 Sep.2005,	n =	56	48	80	58	59
Acropora arabensis AA		3	0	0	1	1
Acropora clathrata AC		16	12	21	6	13
Brain Coral (Faviid unidentified) BC		0	3	0	1	2
Favia pallida (Faviid) F		0	2	2	0	3
Platygyra daedalea (Faviid) PL		1	0	0	0	0
Porites compressa (Poritidae) P		3	12	13	4	4
Stylophora (Poritidae) ST		0	0	0	1	0
Total number of recruits		23	29	36	13	23
Umm AlMaradim Station 2 Sep.2005,	n =	65	63	122	66	57
Acropora arabensis AA		0	1	0	0	0
Brain Coral (Faviid unidentified) BC		2	0	0	0	0
Favia pallida (Faviid) F		5	7	10	0	0
Porites compressa (Poritidae) P		0	0	2	0	0
Goniopora lobata (Poritidae) GON		1	0	0	0	0
Turbinaria peltata (Dendrophylliidae) TUR		1	1	2	0	0
Total number of recruit		9	9	14	0	0

4.5. Discussion

4.5.1 Coral recruitment abundance and distribution patterns

The technique used to measure coral recruitment abundance and distribution at the three reefs, on balance, was a suitable one with results that could be statistically analysed and reflected how recruitment varies spatially around the three coral reefs. The study recorded very low rates of recruitment at all sites. The coral recruits were obvious to the viewer of the video images even in 3 cm^2 sized video images, but the environmental condition prevalent during the period when the corals were filmed did affect the image quality. Underwater images were out of focus if the turbidity was high at the time of filming and this made it difficult to be sure that all the coral recruits had been counted. However, the coral recruit counts showed relative little difference between sites, stations, reef depths, year and season. However it should be noted that no coral recruit counts were carried out *in situ* to compare actual observations by diving and counts of recruits on the seabed with the images obtained in the video recordings. The 3-8 cm sized coral recruits visible in the video images would most likely grow to adult size and build on the construction of the reef at each site.

The number of recruits therefore is a good indicator of the condition and state of each reef site. The interaction plot (Fig.4.4.5) showed that the main differences were between Qaru on the leeward side station 1 which had higher coral recruitment than on the windward station 2 with lower counts of coral recruits in September 2003, and these were observed to significantly increase at station 1 in September 2005. In comparison with the other sites Kubbar and Umm AlMaradim coral recruit counts were low in the two years and seasons with no significant difference between stations (Fig.4.4.5). Coral juvenile density was significantly higher along the back reef station 1, and in the deeper depth reef edge (Fig.4.4.5). By contrast *Echinometra mathaei* density showed an opposite pattern, being significantly higher along the exposed sites and at shallow reef depths (see next chapter 5 Fig.5.4.4). Therefore, the observed differences between sites may reflect localized patchy recruitments or differences in the local hydrodynamic regime near these reefs. There are several factors that are known to affect recruitment rates of corals in addition to depth (Birkeland and Randall 1981; Banks and Harriott 1996) and larval availability from the same site or transported by currents from the north sites as has been documented around three reefs along the Great Barrier Reef eastern Australia (Harriott and Fisk 1988). Grazing was obvious around these reefs as has been documented around the Kenyan coral reefs (McClanahan et al. 1996). However, variation in coral recruits around the three reefs depends on the adult species spawning at each site and the possible supplement of corals by larvae transferred by currents out from other reefs. Kuwait's reefs are the most northerly shallow reefs in the Arabian Gulf and are high latitude reefs which are characterized by a low coral species diversity, and a relatively high cover dominated by *Acropora* spp. and *Porites* spp.

4.5.2 Coral recruit species diversity

Variation in the number of coral species recruiting was characteristic of each reef by the type of species recruiting and reflecting the site dominant species. Kubbar reef was dominated by the coral species *Cyphastrea serailia, Acanthastrea echinata, Acropora clathrata, Psamocora contigua, Stylophora spp.* and *Coscinaraea columna* coral species; observations of recruitment confirmed the new recruits were mainly from these species except *Acropora arabensis* at station 1 on the leeward side (Table 4.4.4). However Qaru reef was characterized by *Psamocora contigua, Acropora arabensis, A. clathrata* and *Favia pallida*, observed recruitment was mainly from these species except *Stylophora* coral species at station 1 leeward side, and *Porities lutea* at station 2 windward side with recruitment mainly from the common species at that side except *Stylophora* species (Table 4.4.4). However, Umm AlMaradim reef was characterized by *Goniopora lobata* recruitment and coral species recruitment mainly was *G. lobata* and other common species except *Turbinaria peltata* at station 2 windward side (Table 4.4.5). There was a visible relationship between the rates of species recruitment and the abundance of adult coral species at the three reef sites as has been seen along the Great Barrier reef (Gourlay and Jell 1997; Harrison et al. 1998). Coral recruitment rates are essential for maintenance of coral communities or to assist in their recovery following devastation by extreme environmental conditions. By comparison, coral recruitment in Western Australia at Ningaloo Reef (22° S), a tropical fringing reef and at the Houtmans Abrolhos Islands (29° S), a shelf-edge, subtropical coral reef and the results obtained were consistent with those obtained from eastern Australia. Coral recruitment rate was lower at the subtropical sites (mean = 3.85 m^{-2} recruits) than at the tropical sites (means of 12 to 217 m^{-2} recruits at the 3 sites) (Harriott and Simpson 1996).

One of the most remarkable features of Qaru reef is its high scleractinian coral species richness, and at this reef the highest number of recruits were recorded. This reef had the best water visibility most of the time possibly because of its location at the most off shore reef in Kuwait (Harrison et al. 1997). Umm AlMaradim and Kubbar reefs are the closest to the shore and are therefore affected by more sedimentation from Kuwait Bay and coastal developments. Coral larvae cannot establish themselves successfully in shifting sediments as was concluded along a Hawaiin reef (Rogers 1990). Sedimentation could explain why these reefs show very low recruitment rates, because of the high sedimentation rates and other effects such as extreme environmental impacts on these reefs. Predictions of coral reef recovery times following bleaching or any catastrophic event on Kuwait's reefs will therefore be slow because of a lack of larval recruits and this may vary temporally. In addition Kubbar reef may be worse off than the other reefs because off its location along the northern site of the three reefs. Lastly low coral recruitment rates may possibly be correlated with sea urchin abundance and the distribution of recruits may therefore be a reflection of differences in grazing rate variations between the three reefs. Coral recruit density was significantly higher along the back reef station 1, and at the reef edge, whereas *Echinometra mathaei* density showed an opposite pattern, being significantly higher on the exposed fore reef than at the shallower reef (see next chapter 5).

In conclusion coral species recruitment estimated from the video surveys of the three reefs had some limitations. First of all some sites that were filmed had benthic cover deeper than 0.5 m which potentially made it more difficult to spot all the coral recruits or to identify some of the genera to species level. Secondly the timing of the video surveys often occurred when the water had a high turbidity as was the case around Kubbar and sometimes around Umm AlMaradim. The filming at these sites ended up producing video coverage of the benthic cover that was not that easy to discern. Even though there were some limitations, I have demonstrated that the results achieved were good enough to support the use of video surveys to investigate coral species recruitment. This kind of approach has not been undertaken else where in Kuwait and the Gulf.

The patterns of recruitment of juvenile coral abundance observed in the quadrats may not necessarily reflect the complete set of dynamics responses for larval settlement. The availability and abundance of coral larvae can vary according to patterns of reproductive output of the dominant adult coral species. Also factors may limit larval settlement rates which may vary at the three reefs. I would suggest a study of larval recruitment using a series of tiles anchored to the seabed and this would allow the correlation of recruitment on the tiles with natural settlement of juvenile corals in the quadrat areas. Although some attempt at using the tiles was tried this was not successful in this study.

4.6. Conclusion

In this study video survey coverage has shown that coral recruitment occurred at the three reefs over the three years and two seasons. Coral recruitment was significantly different between years ($F = 36.47$; $P < 0.001$) (Table 4.4.2), and showed significant seasonal variation ($F = 6.46$; $P < 0.011$) (Table 4.4.3). Mean coral recruit density was 1.37-0.35 m^{-2} (±0.2) at Qaru reef, and 0.05-0.11 m^{-2} (±0.03) at the other 2 reef sites. However, Kubbar reef had the lowest recruitment between 2003 and 2005. Coral recruitment rates were recorded for the first time around these reefs, therefore it was not possible to assess whether recruitment rates are generally always low for these reefs. Further studies in the future are required to assess whether successful coral recruitment is taking place on the reefs.

CHAPTER 5; Sea Urchin abundance and distribution on Kuwait Island reefs

5.1. Introduction

The aim of this chapter was to survey sea urchin abundance and distribution and to evaluate bioerosion rates around the three island reefs (Kubbar, Qaru and Umm AlMaradim). The sea urchin *Echinometra mathaei* (de Blainville) is the most abundant herbivore on many subtropical and tropical reefs world wide (e.g. Neill, 1988 at Guam; Ogden et al., 1989 at Hawaii; Mokady et al., 1996 in the Red Sea; Mills and Fontaine, 2000 at French Polynesia; Downing and El-Zahr, 1987 in Kuwait). *Echinometra mathaei*, was originally divided into four types based on morphological variations in shape, spine colour design and ecological distribution; white-tipped or entirely white - entirely brown - dark-brown or green or uniformly black (McClanahan & Muthiga, 2001). Appana *et al.* (2004) carried out research into the spatial distribution and abundance patterns of ecomorphs within *Echinometra* sp. (white-tipped or entirely white) and *Echinometra* sp. novel (dark-brown or green) in Fiji. McClanahan (1998) concluded from manipulative species interaction studies in seven reef lagoons in the Indian Ocean over a 7-year period that the top competitors in the reef environments were *E. mathaei* and herbivorous fishes. In addition, manipulated densities of sea urchins were achieved using cages in Belize by reducing macroalgae, as a technique for restoring turf and encrusting coralline algae and stony corals. McClanahan, et al. (2001c) found the best results were obtained after the reefs had been fully protected from fishing for a period long enough i.e. > 5 years to allow herbivorous fish to recover.

The black sea urchin *E. mathaei* has been identified as the agent of reef destruction on Kuwait's reefs (Downing 1985). *Echinometra mathaei* is an abundant sea urchin species on Kuwaiti reefs e.g. 20 to 80 sea urchins m^{-2} on the reefs of Kubbar, Qaru and Umm AlMaradim (Downing and Roberts 1993). Although, there are 2 types of other sea urchins on the reefs, *Diadema setosum* is less abundant and Pencil sea urchins *Heterocentrotus mammillatus,* are rare. *Diadema setosum* ranged in density from 3 to 15 m^{-2} while the density of *E. mathaei* on some areas of the reef exceeded $100m^{-2}$ (Downing and El-Zahr 1987; Downing 1992; Downing and Roberts 1993). Previous observations (Harrison et al., 1997) around Kuwait's coral reef systems and from the literature indicated that sea urchins are usually highly abundant, i.e. 5 to 100 sea urchins m^{-2} on the reefs, (Downing 1985). However data should be provided on different time scales along a permanent survey site to compare and conclude if sea urchin densities are changing with time and season and how the densities might possibly correlate with different environment variables around Kuwait's reefs. A study of the distribution and abundance of the sea urchin *E. mathaei* and other sea urchins may indicate that this organism is a bioindicator of reef health and environmental stress or that it simply occurs in high abundances.

Echinoids feed by grazing and it is this activity that has the most impact on coral reef ecosystems. Although, they feed mostly on algae around the reef, during feeding, they graze a large proportion of calcium carbonate in addition to the algae growing on dead coral and are consequently of importance in the turnover of $CaCO_3$ sediment on coral reefs (Russo 1980). Russo (1980) demonstrated that *E. mathaei* (0.1-0.2 g sea urchin^{-1} d^{-1}) and (0.2-0.4 for *E. aciculatus*) were major bioeroders in Enewetak island, Pacific and could destroy as much as 25% of the total annual $CaCO_3$ production. Downing and El-Zahr (1987) studied coral erosion by *E. mathaei* around Kuwait's reef islands, and based his estimate of erosion on an analysis of the gut contents together with measurements of gut evacuation rate and filling rate of starved sea urchins. The grazing behaviour of sea urchins contributes to the site sediment (Mokady et al., 1996). An estimation at each site of sediment accumulation using sediment traps would give only a slight indication of eroding activities, but correlated with an estimate of coral damage might given an indication of total erosion. However, these bioerosion products constitute a fraction of the total sediment in sedimentary deposits. An investigation of the carbonate budget of a fringing reef investigated in La Reunion Island (Indian Ocean) concluded that the highest sedimentation rates correlated with high densities of bioeroders in different protected zones (Conand et al. 1997). Conand *et al.* (1997) investigated bioerosion rates by sea urchins (*Echinometra mathaei*) and fish (*Scarus sordidus*) in 3 zones of La Saline reef. They recorded values showing that the highest rates 8.3 kg CaCO3 m^{-2} yr^{-1}, occurred along the outer reef flat and this correlated with the highest densities of sea urchins and fish observed, e.g. 2.9 kg at reef flat and 0.4 kg at back-reef zone. Sedimentation around Kuwait's island reefs arises from several sources as discussed in chapter 3 in addition to the feeding turnover caused by *E. mathaei*. Therefore, measuring bioerosion rates by this echinoid will be an important aim of this study.

Two different methods have been used to study bioerosion rates by echinoids, either through gut evacuation rates or by field cage experiments. Gut content measurements determine bioerosion rates through titration of acid digested calcium carbonate in sea urchin guts based on gut content (Downing and El-Zahr 1987). Downing and El-Zahr (1987) compared two methods to obtain an accurate measurement of coral erosion by *Echinometra mathaei*, through gut evacuation and gut filling. The rate of erosion was measured by an individual sea urchin to be 1.4 g $CaCO_3$ d^{-1}, based on gut evacuation rate measured d^{-1}, and 0.9 g $CaCO_3$ d^{-1} based on gut filling (Downing and El-Zahr 1987). Downing and El-Zahr (1987) calculated the gut evacuation rate through holding and isolating 66 *E. mathaei* and depriving them of food and then they sampled 30 sea urchins at three different time intervals. They estimated that the gut weight to body weight ratio over 48 hours declined from 6.8% to 2.3%. The gut evacuation rate was calculated using the linear equation $y= 0.16x + 2.57$ ($r = 0.95$) and the slope of the line gave a gut evacuation rate of 0.16 g sea $urchin^{-1}$ $hour^{-1}$. They estimated the gut $CaCO_3$ content from 10 sea urchin guts taken from the 30 sea urchin, 3 sea urchin groups, which were then dried and treated with HCL, dissolving the $CaCO_3$ and the gut weight before and after HCL treatment measured to give a value of 93.1% $CaCO_3$ dry weight gut content. They used this value to calculate an erosion rate of 1.4 g $CaCO_3$ d^{-1} sea $urchin^{-1}$.

They used 20 starved *E. mathaei*, which had been marked with an epoxy and enamel paint mixture dye, and returned back to the same dead coral heads from where they were first collected. After 48 hours they were re-captured and the percent gut weight to drained body weight calculated. This was found to be between 3.6 and 4.6% of body weight and did not return to the former 6.8% body weight. The gut filling rate experiment results could have been biased since the sea urchins may have been affected by starvation or by the marking method. Since gut filling and gut evacuation rates are similar (Downing and El-Zahr 1987) it is easier to measure objectively a gut evacuation rate than a gut filling rate. Therefore in my gut evacuation experiment, to estimate a sea urchin grazing rate, a value of 93.1% of the

$CaCO_3$ content of the dry gut weight was used to estimate the coral reef erosion rate at the three coral reefs in Kuwait.

Cage experiments have been used to calculate bioerosion rates by echinoids *in situ*. Methods of measuring sea urchin grazing or erosion rate have been undertaken using cage experiments in Fiji (Appana and Vuki 2003). Appana and Vuki (2003) reported through these cage experiments that *Echinometra sp.* bioerosion rates of 30-35 kg $CaCO_3$ m^{-2} sea urchin^{-1} d^{-1} occurred on reefs in Fiji. Cage experiments were used to measure bioerosion of the reef both in the field and laboratory and involved different densities and sizes of sea urchins, which were supplied with different levels of food, in St. John, US Virgin Islands (Levitan 1989). Kenyan reefs, at both protected and unprotected sites, which had areas caged and used large body size sea urchins *Echinothrix diadema,* reported 7.15-3.20 g $CaCO_3$ m^{-2} sea urchin^{-1} d^{-1}. This was the highest bioerosion rate, but *Echinometra mathaei* was found to be the major sediment producer and algae consumer on unprotected reefs due to its high abundance (Silva 1999; Carreiro-Silva and McClanahan 2001).

Cage experiments and gut content analysis conducted in Kenya indicated that *E. mathaei* takes in less food and a higher percentage of inorganic substratums with increasing population density and that the populations start to show signs of starvation at high population densities (McClanahan and Kurtis 1991). It has been concluded that sea urchin agonistic behaviour (pushing and biting) does not result in equilibrium between *E. mathaei* population densities and food resources in the absence of density-dependent mortality factors such as predation (Grunbaum et al. 1978; Tsuchiya and Nishihira 1985; Shulman 1990; McClanahan and Kurtis 1991). The specific cause of this behavioural (pushing and biting) switch was difficult to ascertain but it was probably a function of the three interrelated factors of increased density, decreased predators and a loss of burrow space and topographic complexity caused by high *E. mathaei*, and substratum bioerosion rates (McClanahan and Muthiga 1988; McClanahan and Shafir 1990).

McClanahan and Muthiga (1989) also experimented on three different protection sites in Kenya, and showed that sea urchin abundance was directly related to predator abundance. Where there was a reduction in sea urchins, Parrotfish increased their bite rates at protected but not unprotected sites at three different reefs in Kenya

(McClanahan and Shafir 1990; McClanahan et al., 1994; Silva, 1999). Muthiga and McClanahan (1987) also concluded that substrate degradation rates were proportional to sea urchin biomass. High densities of *Echinometra mathaei* and *E. lucunter* (12-100 sea urchins m^{-2}) have been correlated to reef damage in Kenya (McClanahan and Muthiga 1988) and at various locations around the world; Panama (Glynn 1988), Okinawa (Keesing 1992), Hawaii (Russo 1980; Ogden et al. 1989), Virgin Islands (Grunbaum et al., 1978), and Enewetak (Appana and Vuki 2003). Increases in sea urchin abundance leads to increased bioerosion and causes reef degradation and reflects the reef's health. In this study the null hypothesis that will be tested is that there was no change in the abundance and distribution of sea urchins on Kuwait Island reefs between 2003 & 2005.

5.2. Aims and objectives

The overall aim of this research was to evaluate the extent of sea urchin grazing on Kuwait's coral reefs by surveying sea urchin abundance and distribution along three islands reefs (Kubbar, Qaru and Umm AlMaradim) and to estimate bioerosion rates.

The main objective of the study was to measure sea urchin abundance changes over two years, between 2003 and 2005 and in different seasons along 3 of Kuwait's island reefs, and to apply caging to the reefs to investigate the impact of sea urchins on the reef and to undertake gut evacuation rate experiments to estimate grazing impact on the reefs. The specific objectives were:

1. To survey the number of sea urchins over two years and through 2 seasons between 2003 & 2004.
2. To survey and highlight sea urchin distribution patterns on the three reefs (Kubbar, Qaru and Umm AlMaradim).
3. To manipulate sea urchins numbers on the three reefs over two years and to investigate the impact of sea urchin densities on coral recruitment.
4. To measure sea urchin grazing impacts on the reefs by calculating gut evacuation rate and to estimate reef erosion rates by the sea urchins.
5. To measure *Echinometra mathaei* food preferences through experimentation.

5.3. Material and methods

5.3.1. Sea urchins abundance and distribution on Kuwait's Island reefs

Sea urchin abundance and distribution were measured in 2003 and 2004. Using divers the density of sea urchins was estimated by counting individuals within 1 m^2 quadrats placed along transects. The two permanent survey stations with five transects on the leeward and windward sites on each of the island reefs (Kubbar, Qaru and Umm AlMaradim) were surveyed (as described in chapter 2). Along each of the 5 transects a 1m^2 PVC pipe quadrat was placed at 5 m intervals, making 10 replicate quadrats per 50 m transect (see Fig. 5.3.1). The numbers of sea urchins in each of 50 quadrats per station (including all sea urchins that had 50% or more of their body within the quadrat) were counted and recorded. A diver with an underwater writing white slate and the quadrat, swam over each transect and placed the quadrat at the start of each transect and at 5 m intervals, care being taken to record all sea urchins, including those underneath the coral colonies. *Diadema setosum* particularly congregated underneath coral colonies, but because of their long spins, they could be seen easily from above. The survey was repeated in September 2003 and 2004, and in April 2004.

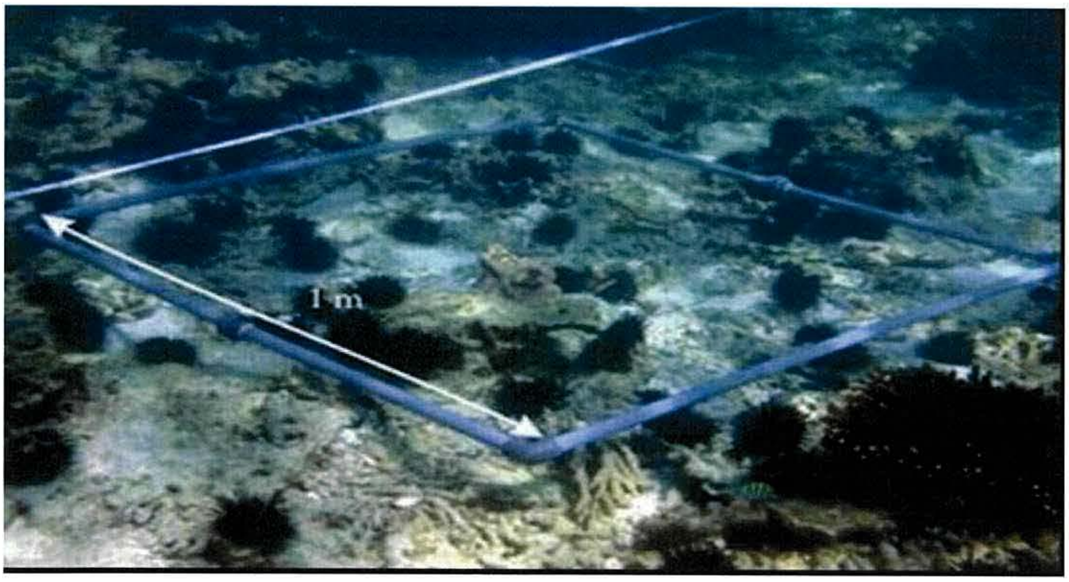

Figure 5.3.1. One m^2 PVC pipe quadrat used to survey sea urchins along the transects. The species present is mainly *Echinometra mathaei.*

5.3.2. Sea urchin gut evacuation rate experiment to quantify grazing

Gut evacuation rates of *Echinometra mathaei* were studied *in situ* to quantify grazing rates on the reefs. Sea urchin density was high (33 m^{-2}) and similar on all three coral reef islands. Qaru was selected as a suitable site because of access to a coastguard building providing space for laboratory studies. Gut evacuation rate was measured using a modification of the technique of Downing and El-Zahr (1987) described earlier in this chapter. Three hundred *E. mathaei* (size range from 3.4 to 4.4 inch) were collected off dead *Porites* heads and placed in three (0.12 m^3) square plastic cages with 1 cm size mesh on all sides of the cages. Cages were placed in mid column water using a tight 1 m rope and a small buoy which held the cage away from the substrate, such that the sea urchins trapped inside could not touch the surface of the sand or any substrate other than the mesh of the cage during the course of the experiment. The three cages were held in groups containing 100 sea urchins, to ensure there was enough space within each cage. Three samples of 20 sea urchins were removed at three different time intervals from the cages during the 25 hours of the experiment in October 2005. The first 20 sea urchins were removed at 15:30 at the beginning of the experiment and were assumed to have full guts. The second sample of 20 sea urchins were sampled after 14 hours and the last sample of 20 sea urchins removed after 25 hours. Each sample of sea urchins was placed separately in a 70% concentration of alcohol for a minute, then each sea urchin was drained by cutting the perignathic girdle (soft tissue) surrounding the Aristotle lantern and left for 30 minutes spread outside in the sun to drain. Drained sea urchins were weighed using a Status SP300 balance (±0.01 g), and the lantern size was measured using vernier calipers. Each sea urchin was weighed, dissected and the intestine removed and weighed, to calculate gut weight as a percentage of drained body weight. The first sample acted as the full gut baseline for a normal population of *E. mathaei*. The three samples were compared for gut fullness.

5.3.3. Sea urchin exclusion cage experiments to measure sea urchin grazing impact

A manipulative experiment was conducted to assess the effects of excluding sea urchins from the coral reefs using cages, size (3 x 3 m) open at the top to allow grazers, like herbivorous fish, to enter the cage and with a rolled over top to prevent sea urchins from entering. Site station cover for 3 cages was selected on the basis of an earlier model of the Kubbar reef illustrated in Figure 3.3.2 (chapter 3). The three stations at the three reefs were selected according to the general reef setting at three covers as shown earlier for the Kubbar reef. At each station to investigate the effects of caging, an area 3 m away from the 3 m^2 cages was marked with tent pegs (Fig. 5.3.3.1 b). The number of sea urchins were counted and removed from the control reef area to compare with other reef areas at the same site. The removed sea urchins were removed to a deeper reef area away from the experimental site. The cages were designed and developed to exclude sea urchins for at least three months to allow new coral larvae settlement to be visible. During the 3 months the cages were maintained and any sea urchins that moved in were removed. Different types of materials were tested, from PVC high pressure piping with strong small 1 cm size plastic mesh, to steel cages with steel coated plastic small 1 cm size mesh. The size of the cages were designed to contain a good size coral colony stabilized into the bottom of the reef with pegs at each corner to attach the cage. The nine cages were 3 x 3 m fenced (1.20 m high steel cages and 60 cm high plastic cages) with 1 cm size mesh net and allowed the fish access but excluded the sea urchins. The PVC pipes of the cages were filled with sand to increase the cage weight and mounted on the seabed at 4 m depth at each site with 1 cm thick steel tent pegs in each corner (Fig. 5.3.3.1 a). The steel cages were welded at the corners, left unpainted and covered with strong 1 cm size steel plastic coated mesh fence (Fig. 5.3.3.2 d). The steel cage had coated plastic mesh looped on the top of the cage to stop sea urchins from going into the cage (Fig.5.3.3.2 b). The cage frames were transferred to each reef site by boat (see Fig. 5.3.3.2.c). The cage was made of four welded frame walls and connected at each corner with three screws and tightened firmly with a spanner under water at each selected site. The cage was attached to the seabed using steel tent pegs in each corner to increase stability. Controlled study areas without sea urchins and without a cage required similar sized areas to compare the effects of sea urchin grazing within the caged area (Fig. 5.3.3.1 b).

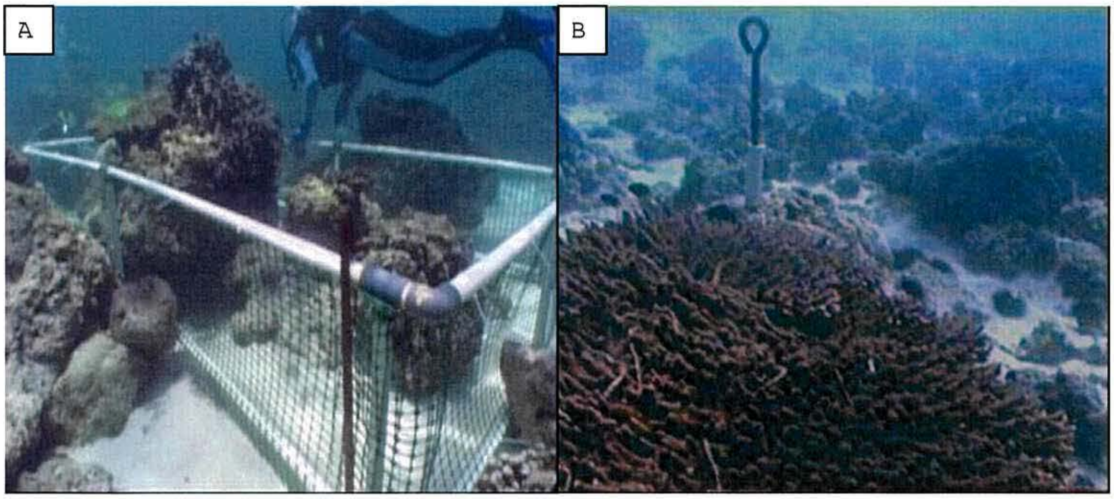

Figure 5.3.3.1. PVC pipe 3 m^2 cage with 60 cm high fence covered with strong 1 cm size plastic mesh and mounted on the seabed at 4 m depth at each site with steel tent pegs in each corner in September 2003 as show in photo A. A similar size reef area 3 m distance from the cages and marked with tent pegs acted as a control as shown in photo B.

Figure 5.3.3.2. Steel 3 m^2 cages ready to be transferred and installed at the site stations in March 2004. (A & B) The cage frames were made ready and transferred in an 8 m boat to the selected site (C) an area studied underwater acted as a control station and (D) the cage frames with a loop on the top of the cage to stop sea urchins from going into the cage.

Each study area was video surveyed using a Sony digital video camera precisely covering all the 3 m^2 area at the start of the experiment. The video survey recording was carried out. The video survey was carried out by a diver who swam over the whole area in a Zig zag pattern to cover the whole 3 m^2 area at a constant speed, approximately 50 cm above the substratum, with the camera pointed vertically downward. The swimming speed was approximately 0.2 m s^{-1} to ensure the image was in focus. Every three months the caged areas were visited and video surveyed. During every visit the cages were damaged except the one close to a mooring buoy where only the fence mesh was cut and fishing line was found attached to the cage. This cage was repaired. Three out of 9 steel cages were useable and these 3 were maintained twice in two visits every 3 months.

5.3.4. Other studies on sea urchins *Echinometra mathaei* behaviour

Three studies were carried out to understand the feeding behaviour of *Echinometra mathaei* and their food preferences.

1. The species of algae grazed by the sea urchins were investigated. About 150 *Echinometra mathaei* were examined by removing each sea urchin from the coral and assessing what type of algae and substrate the sea urchins were on at each site. In addition the video surveys of two stations along each of the 150 m reef profile, starting at 9 m depth at the reef edge to 2 m depth in the reef shallow were reviewed to quantify sea urchins numbers and type of substrate, and to identify whether the sea urchins had a feeding preference on a species of algae or substrate.
2. Diurnal sea urchin movement was observed *in situ*, 30 sea urchins were identified by location markers, and the movement from the marker was measured daily for between 1 & 2 hrs and 1 & 2 hrs at night to assess the minimum distance moved and to see if they would move from the rubble onto the top of the reef at night.
3. *Echinometra mathaei* feeding preferences were examined in laboratory aquaria to test the different reactions they had in their feeding behaviour and reaction to three types of algae which were presented to them in the glass aquaria. Two glass tanks (1.25 m long x 60 cm width x 90 cm height) were

established, with running filtered seawater and aeration. Two hundred *E. mathaei* were collected and transferred from the reefs (Fig. 5.3.4.1 a). Each glass tank contained 100 *E. mathaei* and left for 2 weeks with regular feeding with three types of algae (filamentous turf algae, *Colpomenia sinuosa* and *Padina gymnosporia*). The three types of algae were offered to the sea urchins in the tanks and their responses and different feeding behaviours observed. Other experiments were carried out using smaller glass tanks (0.75 m long x 0.30 m width x 0.40 m height). Fifty sea urchins were starved in a small cage with 0.5 cm size plastic mesh net in two separate glass tanks for 24 hours to use on the other four smaller glass tanks (Fig. 5.3.4.1 c). Into each of the four tanks tested two different algal types (filamentous turf algae and *Enteromorphe antestinalis*) were presented to five starved sea urchins held in three smaller tanks (Fig. 5.3.4.1 b). Three small glass tanks containing 5 starved sea urchins acted as a control to compare with 5 non-starved sea urchins feeding on the two different algae. The time recorded for the sea urchins in the four tanks to evacuate their guts was recorded (Fig. 5.3.4.1 c).

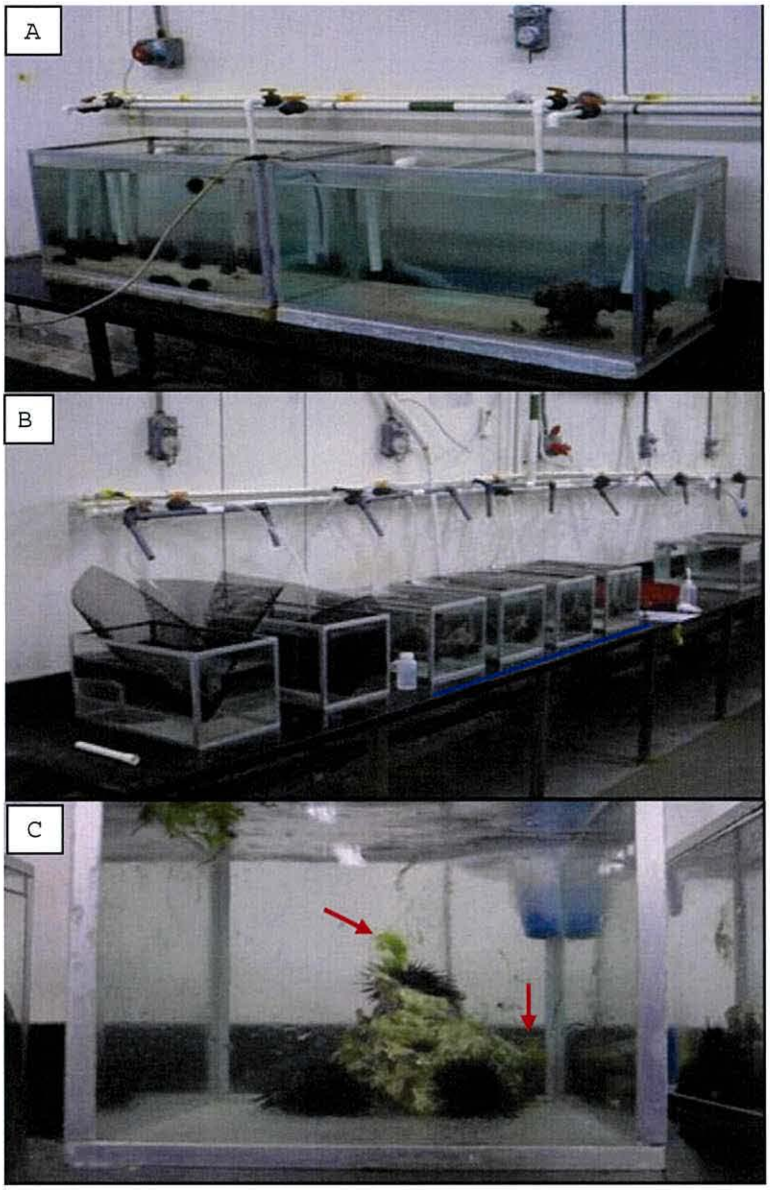

Figure 5.3.4.1. A) The aquaria used were two (300 m^3) glass tanks, (B) six (112 m^3) glass tanks and (C) a close up of one of the six glass tanks showing the algal food (red arrows).

5.4. Results

5.4.1. Sea urchin abundance and distribution

The distribution patterns of the two sea urchins have been found in the current study to be quite different, *E. mathaei* being more dense at shallow and exposed sites, while *Diadema* occurred in dense patches at the deep and sheltered sites. There was no significant difference ($F = 2.67$; $P = 0.103$) in densities between the September 2003 initial survey and the September 2004 monitoring survey results for *E. mathaei* and *D. setosum* across any of the considered study parameters (by transect, by island, by depth or by exposure) (Table 5.4.1 & Fig.5.4.1).

Three species of sea urchins were found on the Kuwait island reefs (*Echinometra mathaei*, *Diadema setosum*, and *Heterocentrotus mammillatus* Pencil sea urchin). The Pencil sea urchin was very rare, and there was an entirely white *Echinometra* sp. which was also rarely found (only 2) along the reef sites. The number of *E. mathaei* and *D. setosum* varied around the three island reefs. *E. mathaei* colonized dead *Porites* and *D. setosum* was found on hard rocky seabed. At Kubbar island reef, *D. setosum* was found mostly at the leeward site station with low mean numbers (7 m^{-2}) (±3 SE, N=50) usually at the reef edge mostly (Fig. 5.4.2 a). Qaru island reef showed the same species existence but with lower average numbers of 4 m^{-2} (±1 SE, N=52) at the reef edge at the leeward station. At Umm AlMaradim reef both species were found, but with a high density of *E. mathaei* at an average of 35 m^{-2} (±4 SE, N=48) at along the reef shallow site mostly and with an average of 8 m^{-2} (±3 SE) at the reef edge with a few *D. setosum* at an average density of 3 m^{-2} (±1 SE) (Fig. 5.4.2 b). However, abundance and distribution showed opposite trends along the leeward station at windward station 2 at all reefs sites (Fig. 5.4.2 b).

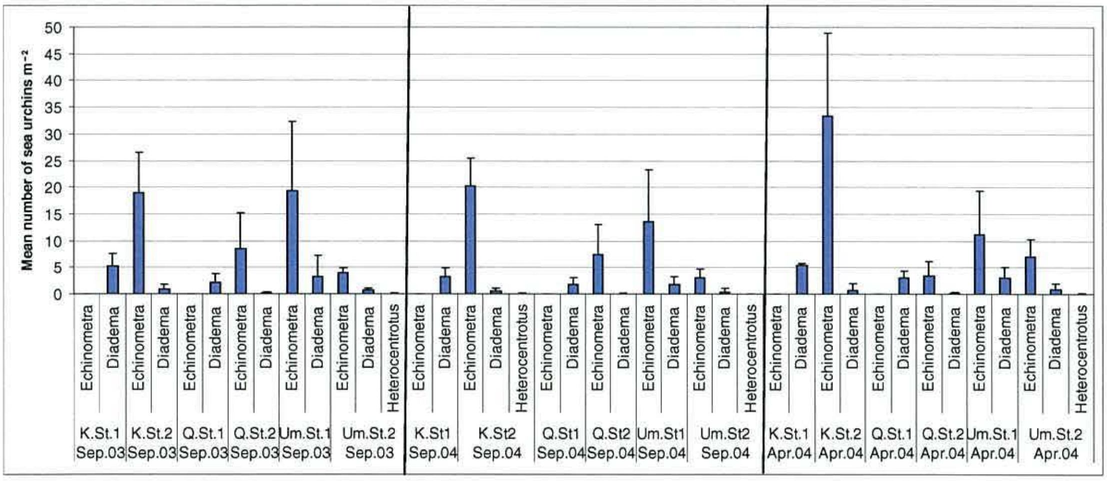

Figure 5.4.1. The mean number of sea urchins m^{-2} distribution with standard deviation at 2 stations (St.) at the 3 reef sites in September 2003, September 2004 and April 2004 at (K) Kubbar, (Q) Qaru and (Um) Umm AlMaradim.

Table 5.4.1. Sea urchins mean abundance m^{-2} and distribution with standard error at the 3 reef sites at reef edge (transect 1, 2), perpendicular transect 3 and shallow (transect 4, 5) in September 2003, April 2004 and September 2004.

Sea Urchin Abundance & Distribution	Reef	Edge		Perpendicular	Shallow	
Site	Mean ± SE	T1	T2	T3	T4	T5
Kubbar Station 1 September 2003	*Echinometra mathaei*	0.00	0.00	0.00	0.00	0.09 ±0.09
	Diadema setosum	8.18 ±1.45	5.73 ±1.24	2.17 ±1.07	6.36 ±1.92	3.55 ±0.97
Qaru Station 1 September 2003	*Echinometra mathaei*	0.00	0.00	0.00	0.00	0.00
	Diadema setosum	3.91 ±0.99	4.1 ±1.11	1 ±0.45	0.73 ±0.32	1.3 ±0.45
Umm AlMaradim Station 1 September 2003	*Echinometra mathaei*	8.73 ±2.05	7.33 ±2.77	14.38 ±6.64	31.5 ±2.89	34.8 ±3.89
	Diadema setosum	2.73 ±0.66	1.78 ±0.66	10.13 ±8.04	0.1 ±0.09	1.1 ±0.33
Kubbar Station 2 September 2003	*Echinometra mathaei*	20.83 ±3.56	13.7 ±2.88	9.14 ±2.16	23.45 ±6.1	27.8 ±4.44
	Diadema setosum	1.75 ±0.63	0.8 ±0.37	1.71 ±0.63	0.00	0.00
Qaru Station 2 September 2003	*Echinometra mathaei*	1.91 ±1.73	1.36 ±0.87	9 ±2.89	16.2 ±2.41	13.82 ±2.21
	Diadema setosum	0.55 ±0.35	0.1 ±0.09	0.08 ±0.08	0.00	0.00
Umm AlMaradim Station 2 September 2003	*Echinometra mathaei*	3.73 ±1.14	2.4 ±0.49	5 ±1.86	3.82 ±0.73	4.5 ±1.37
	Diadema setosum	1.27 ±0.85	0.5 ±0.47	1.11 ±0.48	0.36 ±0.19	0.4 ±0.21
	Heterocentrotus mammillatus	0.00	0.00	0.00	0.09 ±0.09	0.1 ±0.09
Kubbar St1 Sep.04	*Echinometra mathaei*	0.00	0.00	0.00	0.09 ±0.29	0.00
	Diadema setosum	4.36 ±3.7	5.45 ±2.45	1.17 ±0.9	2.27 ±2.49	3 ±3.54
Qaru Station 1 September 2004	*Echinometra mathaei*	0.00	0.00	0.00	0.00	0.00
	Diadema setosum	2.64 ±2.14	3.5 ±2.38	0.83 ±1.07	1.18 ±1.49	0.55 ±0.73
Umm AlMaradim Station 1 September 2004	*Echinometra mathaei*	4.36 ±3.82	6.91 ±5.27	8.3 ±4.8	23.18 ±19	24.82 ±17.6
	Diadema setosum	3.18 ±2.59	3.64 ±2	1.4 ±1.42	0.36 ±0.64	0.27 ±0.47
Kubbar Station 2 September 2004	*Echinometra mathaei*	14.82 ±10.06	20.36 ±18.56	16.33 ±15.55	22.2 ±13.8	27.82 ±8.3
	Diadema setosum	1 ±1.04	0.73 ±0.86	1 ±1	0.00	0.09 ±0.01
	Heterocentrotus mammillatus	0.00	0.18 ±0.66	0.00	0.00	0.00
Qaru Station 2 September 2004	*Echinometra mathaei*	1.18 ±2.29	1.27 ±1.48	9.89 ±5.49	12.45 ±7.5	11.8 ±4.47
	Diadema setosum	0.18 ±0.39	0.00	0.11 ±0.37	0.00	0.00
Umm AlMaradim Station 2 September 2004	*Echinometra mathaei*	3.18 ±2.98	2.17 ±1.73	5.25 ±6.4	3.91 ±2.51	1.27 ±0.92
	Diadema setosum	0.27 ±0.86	0.00	1.5 ±1.66	0.27 ±0.47	0.09 ±0.31
	Heterocentrotus mammillatus	0.09 ±0.29	0.00	0.00	0.00	0.00
Kubbar Station 1 April 2004	*Echinometra mathaei*	0.00	0.00			
	Diadema setosum	5.18 ±4.41	5.67 ±3.74	.		
Qaru Station 1 April 2004	*Echinometra mathaei*	0.00	0.00	0.00	0.00	0.00
	Diadema setosum	4 ±1.91	4.33 ±3.06	2.9 ±3.7	1 ±1.26	2.71 ±2.71
Umm AlMaradim Station 1 April 2004	*Echinometra mathaei*	5.18 ±5.57	6 ±3.12	10.89 ±12.45	22.8 ±18.3	20.44 ±10.93
	Diadema setosum	4.73 ±3.22	4 ±2.45	3.44 ±3.86	0.3 ±0.46	0.78 ±1.23
Kubbar Station 2 April 2004	*Echinometra mathaei*	22 ±19.84	19.13 ±7.75	27.7 ±21.57	42.7 ±6.1	55.67 ±7.27
	Diadema setosum	1.55 ±2.84	2.5 ±3.32	0.00	0.00	0.00
Qaru Station 2 April 2004	*Echinometra mathaei*	0.09 ±0.29	0.88 ±2.32	5 ±7.7	6.09 ±7.29	4.75 ±3.6
	Diadema setosum	0.55 ±0.89	0.00	0.00	0.09 ±0.29	0.00

Umm AlMaradim Station 2 April 2004	*Echinometra mathaei*	2.8 ±4.09	6 ±5.66	9.5 ±7.35	9.67 ±6.31
	Diadema setosum	0.1 ±0.3	2.11 ±3.03	1.5 ±1.69	0.00
	Heterocentrotus mammillatus	0.2 ±0.4	0.00	0.00	0.00

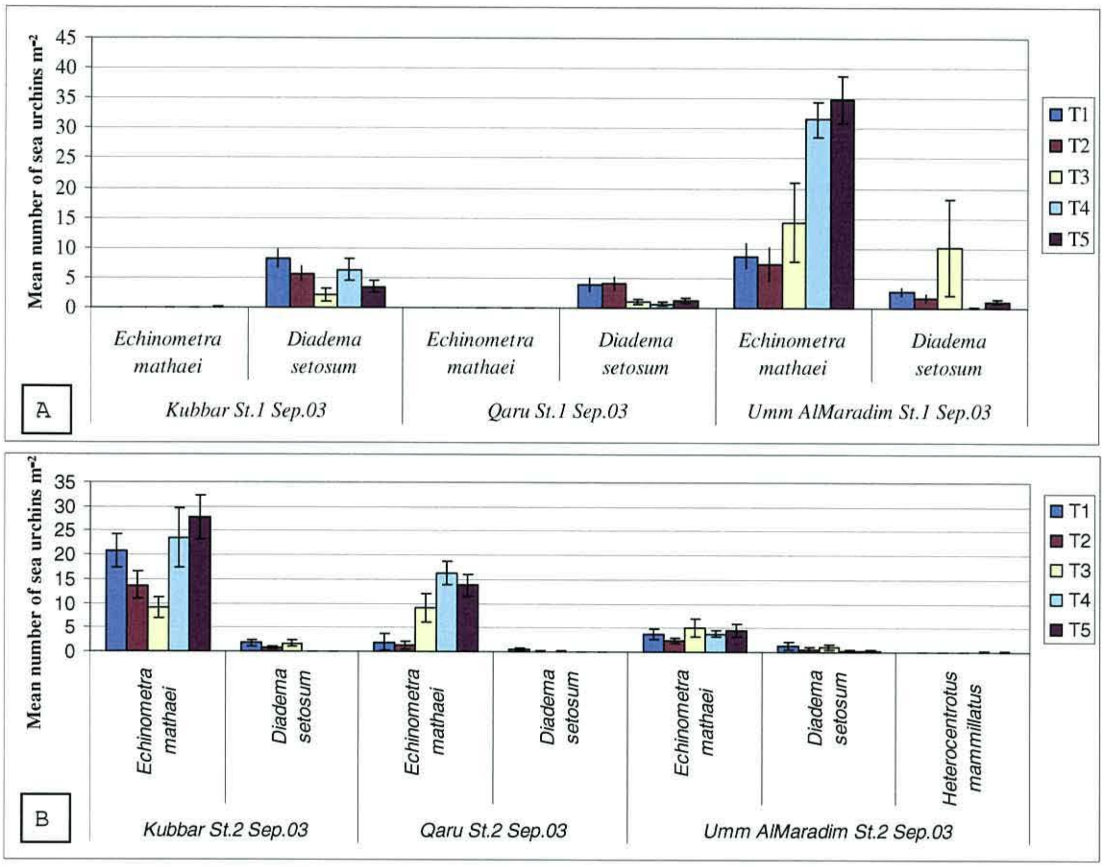

Figure 5.4.2. The density of 3 sea urchin species (mean number of individuals m^{-2} and standard error bar) along 5 transects (T) between (T1,T2) 2 and (T4,T5) 9 m depth at stations on the fore St.2 (B) and lee St.1 (A) sides of the reefs at the 3 Kuwait Islands in September 2003.

Station 2 showed a high mean number of *E. mathaei* of 14-21 m^{-2} (±4 SE, N=50) along the reef edge (Fig. 5.4.2 b) and 24-27 m^{-2} (±6 SE) along the reef shallow at Kubbar, densities of 1-2 m^{-2} (±1 SE, N=54) at the reef edge and 14-16 m^{-2} (±2 SE) at the reef shallow at Qaru were recorded. Densities of 2-5 m^{-2} (±1 SE, N=51) on the reef edge to the shallows at Umm AlMaradim were recorded regularly but very low densities of *D. setosum* of 1-2 m^{-2} (±1 SE) at all sites and Pencil sea urchins were present at Umm AlMaradim though at very low densities (a mean of 0.5 m^{-2} (±0.5 SE)) on the reef shallow (Fig. 5.4.2 b, Table 5.4.1 and Fig.5.4.1).

The data collected in September 2004 showed no difference in the average number m^{-2} of sea urchins also there was no change in distribution trend (Fig. 5.4.3;

Fig. 5.4.2). However, Pencil sea urchins appeared at Kubbar windward in September 2004 (Fig. 5.4.3 b), and also at Umm AlMaradim too (Fig. 5.4.3 b). In addition observations made in April 2004 showed no difference in the mean number of sea urchins, but *D. setosum* had disappeared from the reef shallows at Kubbar leeward site (Fig. 5.4.3 a). Station 2 at windward site showed the same distribution trend and abundance at all reef sites (Fig. 5.4.4 b).

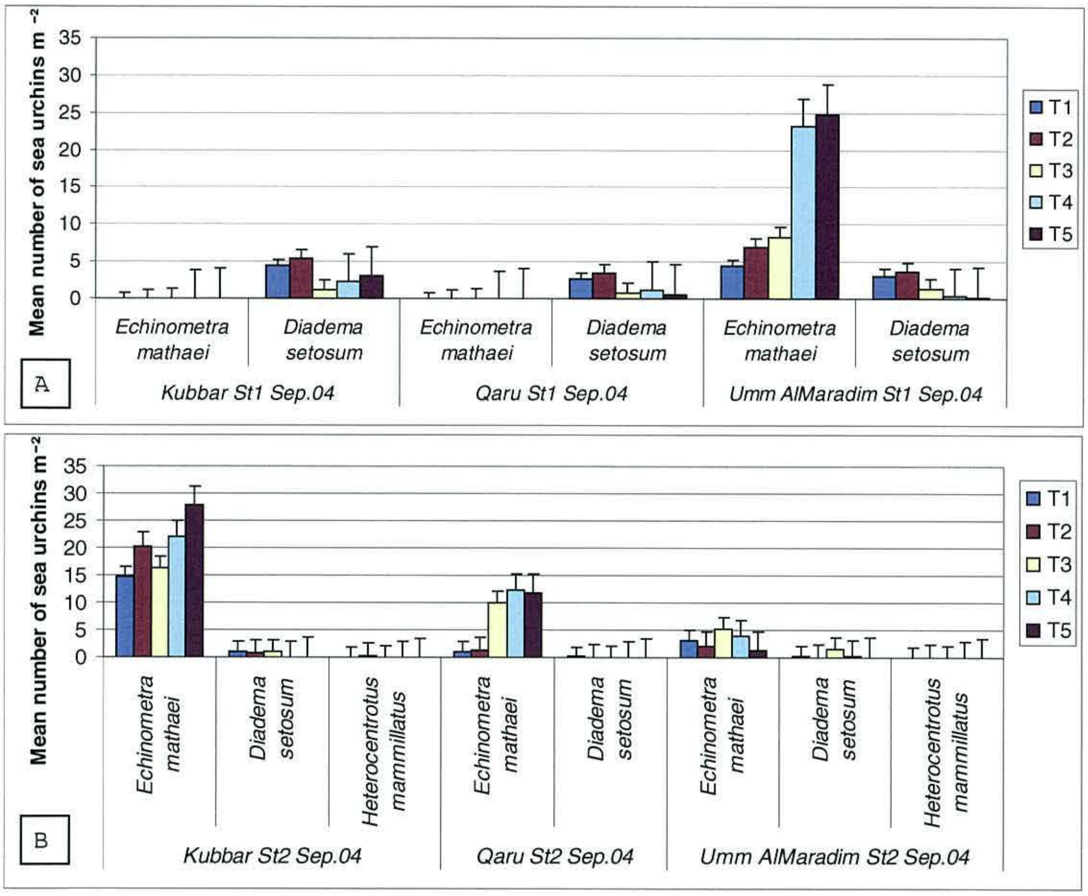

Figure 5.4.3. The density of 3 sea urchin species (mean number of individuals m^{-2} ± standard error bar) of 5 transects (T) between (T1, T2) 2 and (T4, T5) 9 m depth at stations (St.) on the lee St.1 (A) and fore St.2 (B) reefs of 3 Kuwait Islands in September 2004.

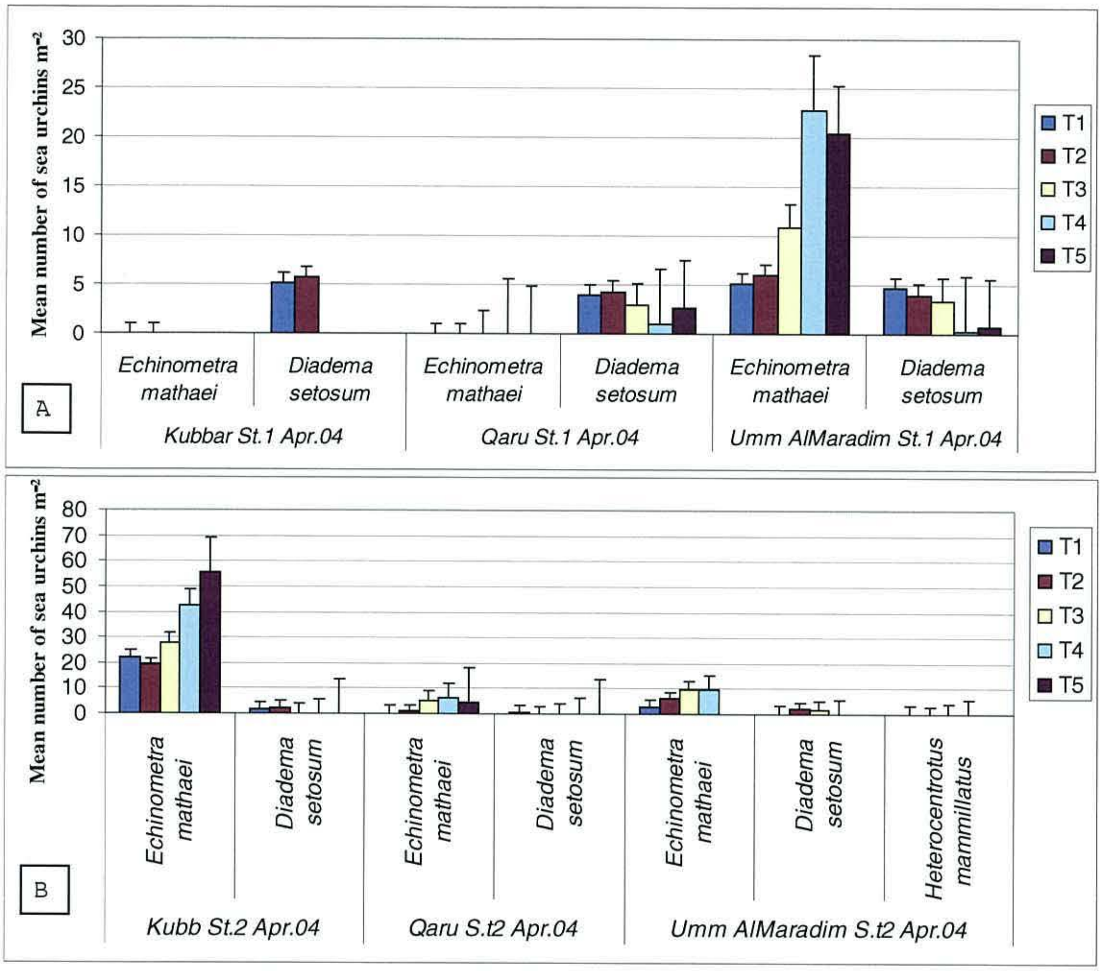

Figure 5.4.4. The density of 3 sea urchin species (mean number of individuals m^{-2} ± standard error bar; N = 50) of 5 transects (T) between (T1, T2) 2 and (T4, T5) 9 m depth at stations (St) on the lee St.1 (A) and fore St.2 (B) reefs of 3 Kuwait Islands in April 2004.

5.4.2. Statistical analysis

Statistical analysis of the sea urchin abundance and distribution data investigated differences at the islands reef sites, fore or back reef exposure; K2 (Kubbar station 2), Q2 (Qaru station 2) and Um2 (Umm AlMaradim station 2); both stations are considered exposed (fore reef), while K1, Q1 and Um1 are sheltered (back reef). The monitored quadrats in the 5 transects shown earlier in Fig 5.4.2, Table 5.4.1 and Fig.5.4.1 were grouped in each station.

A General Linear Model test with 4 factors (site, station, year and season) and pairwise comparisons analysis of variance (ANOVA) for sea urchin counts demonstrated there was no significant difference between years at all sites and stations ($F = 2.67$; $P > 0.103$) (Table 5.4.3), between season and station ($F = 0.01$; P

>0.915) (Table 5.4.2) but there was a significant three way interaction between season, site and station (F = 6.08; P <0.002) (Table 5.4.3) (Fig. 5.4.6). In addition, there was no significant difference between a three way interaction between site, year and station (F = 1.36; P >0.257) (Table 5.4.2 and Fig. 5.4.5). However, there were significant differences between season and site (F = 9.82; P <0.001) (Table 5.4.3 and Fig.5.4.6) and between site and station (F = 141.18; P <0.001). In addition, there was a significant difference with year factor between site and station (F = 128.09; P <0.001) (Table 5.4.2 and Fig.5.4.5) and between sites (F = 34.63; P <0.001) (Table 5.4.2) (Fig. 5.4.5). Umm AlMaradim reef site contributed to most of the differences with year and season as factors (Fig.5.4.5).

Table 5.4.2. General Linear Model count versus site, year, and Station. Analysis of Variance for sea urchin count. Factor; Site 3 (K, Q, Um), year 2 (2003, 2004) and Station 2 (1, 2).

Analysis of variance for sea urchin count	F value	P value	The difference
Site 3 (K, Q, Um)	34.63	0.001	significant
Year 2 (2003, 2004)	4.11	0.043	significant
Station	9.39	0.002	significant
Site x Year	2.08	0.126	not significant
Site x Station	128.09	0.001	significant
Year x Station	2.67	0.103	not significant
Site x Year x Station	1.36	0.257	not significant

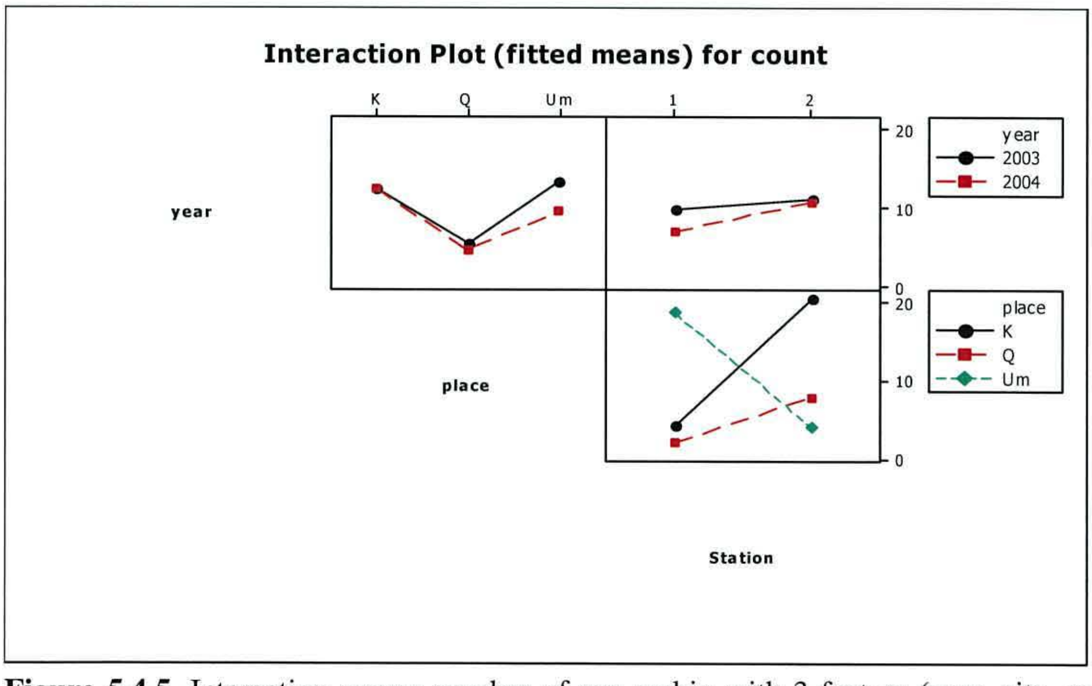

Figure 5.4.5. Interaction means number of sea urchin with 3 factors (year, site, reef back st.1 and front st.2). General Linear Model count versus site, year, and Station. Factor; Site 3 (Kubbar, Qaru, Umm AlMaradim), year 2 (2003, 2004) and Station 2 (station 1, 2).

Table 5.4.3. General Linear Model square count versus season, site, and Station. Analysis of Variance for sea urchin square count. Factor; Site 3 (K, Q, Um), season 2 (April, September) and Station 2 (1, 2).

Analysis of variance for sea urchin count	F value	P value	The difference
Site 3 (K, Q, Um)	77.26	0.001	significant
Season 2 (April, September)	15.46	0.001	significant
Station	41.27	0.001	significant
Season x Site	9.82	0.001	significant
Season x Station	0.01	0.915	not significant
Site x Station	141.18	0.001	significant
Season x Site x Station	6.08	0.002	significant

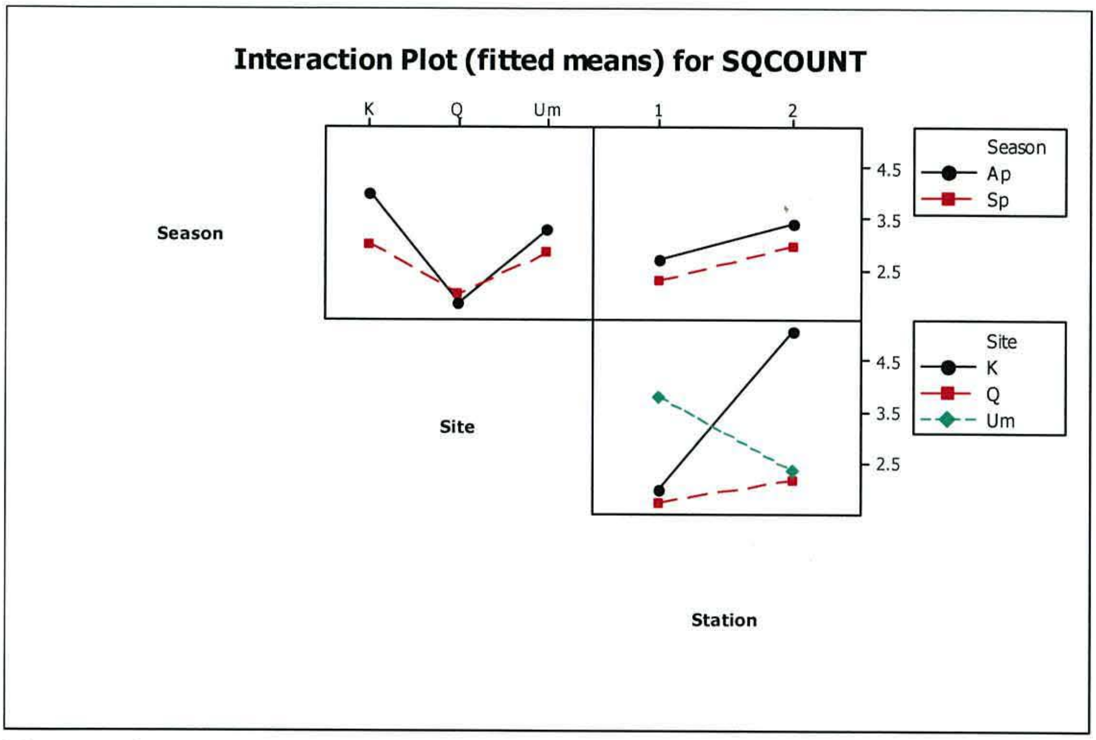

Figure 5.4.6. Interaction means number of sea urchin with 3 factors (season, site, reef back and front). General Linear Model count versus site, season, and station. Factor; Site 3 (Kubbar, Qaru, Umm AlMaradim), season 2 (April, September) and Station 2 (1, 2).

5.4.3. Sea urchin gut evacuation rate experiment

Sea urchin grazing and gut evacuation experiments were undertaken to estimate the impact of grazing sea urchins on the three reefs. Salinity during the period of the experiment was 40 and the seawater temperature was 27°C. The change in percent gut weight to drained body weight with calculated standard error is shown in table 5.4.4. The first sample showed an average gut weight of 3.32g (±0.72, N=20) and an average percent gut weight to body weight of 8.88% (±1.99%). The second sample after 14 hours showed an average gut weight of 1.40g (±0.31, N=20) and an average percent gut weight to body weight of 4.38% (±0.95%). In addition the third sample after 25 hours showed an average gut weight of 1.33g (±0.30, N=20) and an average percent gut weight to body weight of 3.62% (±0.81) (Table 5.4.3). The gut evacuation experiment was run for 25 hours. The greatest rate of change occurred during the first 14 hours. The first time period recorded that the percent gut weight to body weight had dropped from 8.88% (±1.99) to 4.38% (±0.95) (Fig. 5.4.5).

Table 5.4.4. A summary of the sea urchin percentage gut weight to drained body weight of samples of 20 *Echinometra mathaei* collected from dead *Porites* at Qaru, for 25 hours between the 29th and 30th of September 2005.

	Afternoon 3:30	Pre-dawn 5:30	Afternoon 4:30
Mean actual gut weight (g)	3.32 (±0.72)	1.40 (±0.31)	1.33 (±0.30)
Mean gut wt./body wt. %	8.88	4.38	3.62
Sample n	20	21	20
Standard Error of the Mean	1.99	0.95	0.81

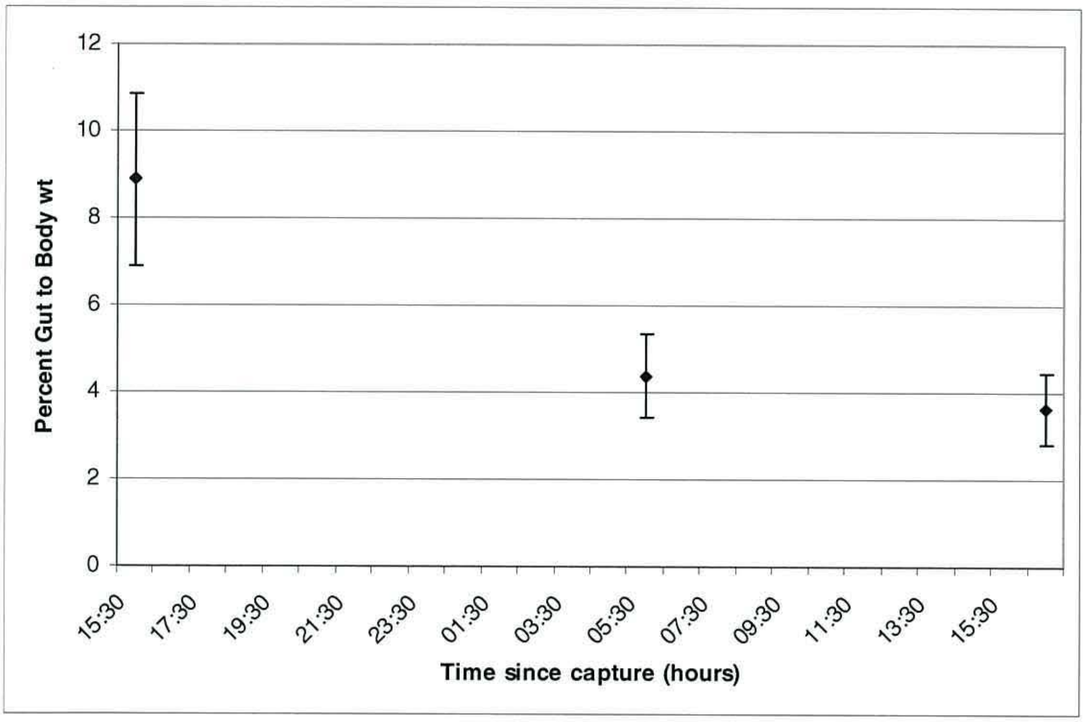

Figure 5.4.7. The mean percent gut weight/drained body weight changes with time, in 3 samples of 20 *Echinometra mathaei* removed from dead *Porites* in September 2005.

The decrease in the mean actual gut weight during the 25 hours of gut evacuation is plotted in Figure 5.4.7. From the figure, the coefficients of gut evacuation rate in the linear equation y = Ax + B, using the method of least squares was calculated. The gut evacuation line is given by the equation: y = 0.16 x + 3 (r = 0.39). The slope of the line gives the rate of gut evacuation: 0.16g dry weight^{-1} sea urchin^{-1} hour^{-1} (3.84 g weight^{-1} sea urchin^{-1} day^{-1}) (Fig. 5.4.8).

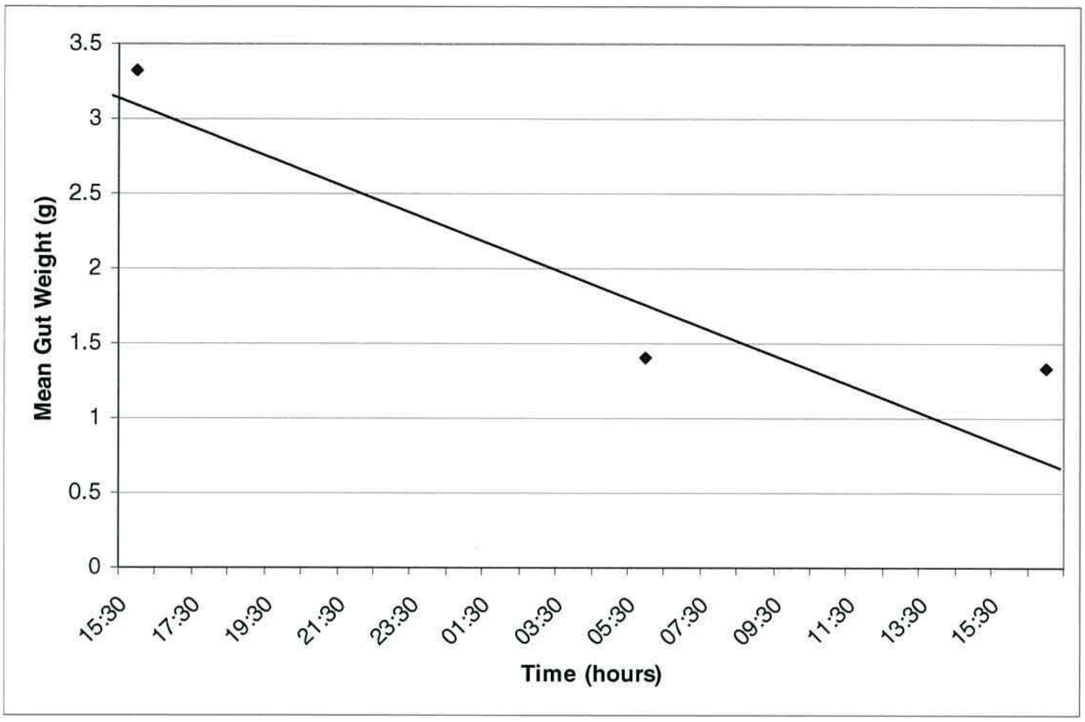

Figure 5.4.8. Slope of mean percent gut actual weight changes with time, in 3 samples of 20 *Echinometra mathaei* removed from dead *Porites* in September 2005.

5.4.4. Sea urchin exclusion experiment

An estimate of the impact of the sea urchins grazing on the three reefs was attempted using experimental cages. Unfortunately, none of the PVC cages lasted long enough as they were damaged badly after 3 months (Fig.5.4.4.4 a). The steel cages also did not last much longer (Fig. 5.4.4.4 b). The least damaged cage was next to a boat mooring buoy, but the mesh net was cut, and fishing line was left as evidence (Fig. 5.4.4.1, and Fig.5.4.4.2). Therefore there was little data except from the least damaged cage which contained good coral growth and the coral appeared to be healthier when the number of sea urchins was reduced inside the cage, and did not display any overgrowth by algae (see Fig.5.4.4.1, Fig.5.4.4.2 and Fig.5.4.4.3 a,b) as has been seen in other studies in other parts of the world (e.g. at Rottnest Island, Western Australia (Prince, 1995).

Figure 5.4.4.1. The best standing steel damaged 3 m² cage, but with cut fence mesh.

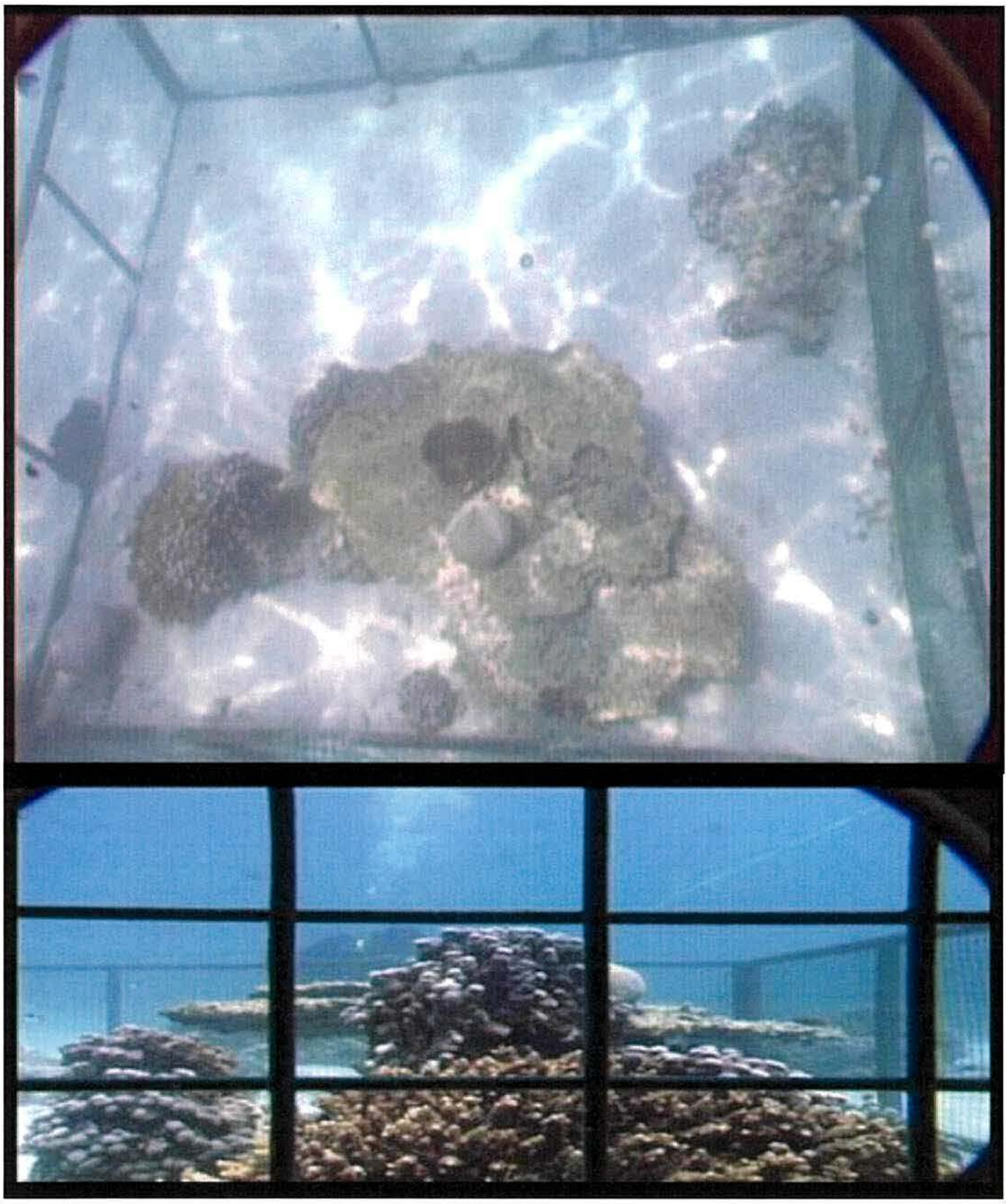

Figure 5.4.4.2. A view through the mesh of the last remaining standing steel 3 m² cage next to a mooring buoy showing good coral cover and no build up of algae can be seen in the top view and side view of the interior of the cage.

Figure 5.4.4.3. Substrate and benthos in the remaining standing steel 3 m² cage next to a mooring buoy showing A) one new *Favia* coral recruit (red arrow) and showing the coral and substrate covered by turf algae and B) one new coral recruit was found by a diver (arrow A) after 6 months including 5 cm scale blue line.

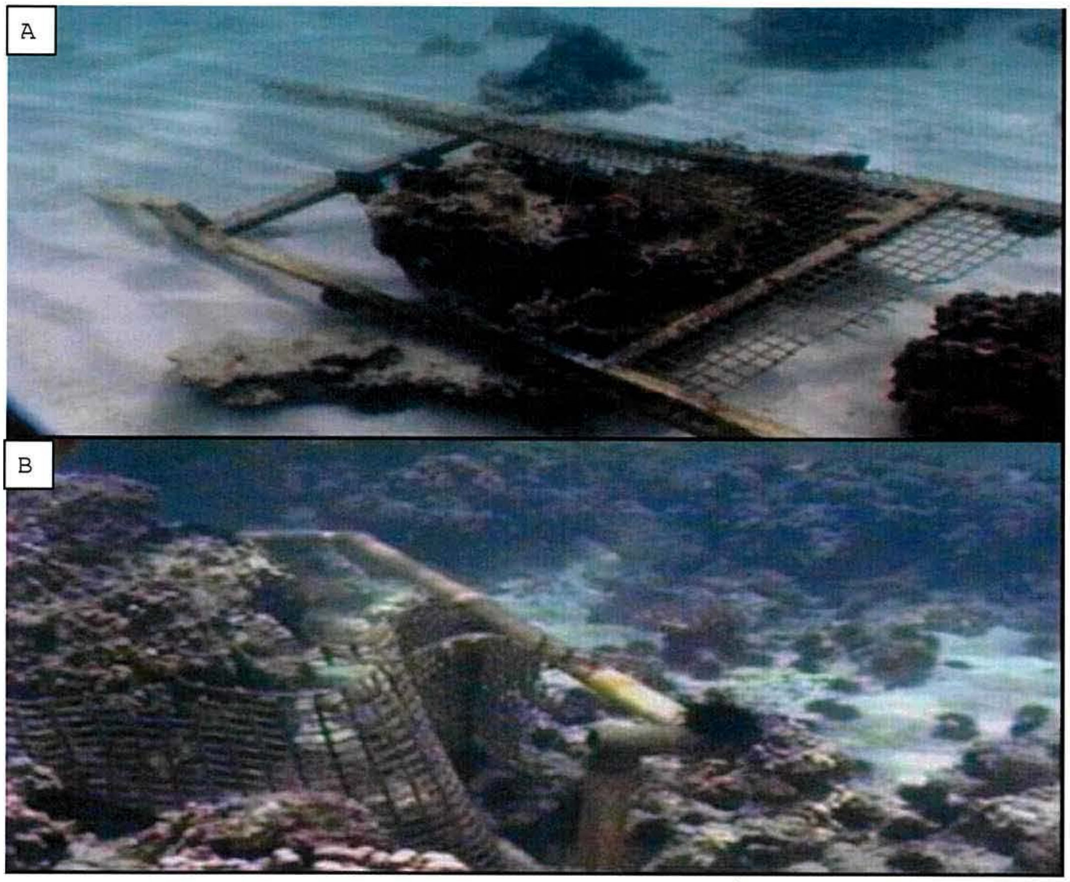

Figure 5.4.4.4. An example of one of the eighteen 3 m^2 damaged cages. (A) A PVC cage was badly damaged and (B) the steel cage was also badly damaged.

5.4.5. *In situ* sea urchin *Echinometra mathaei* feeding preference study

Sea urchins were mostly found on dead coral substrates, and all of the 150 *E. mathaei* used in the experiments were found there. *In situ E. mathaei* showed a feeding preference for a species of mostly turf algae growing on top of the dead coral. *E. mathaei* were also found feeding on the seasonally abundant large brown alga, *Colpomenia sinuosa* (see Fig.5.4.4.5). In addition, the review of the video footage taken during the surveys showed that all *E. mathaei* sea urchins were on top of dead corals and *D. setosum* were on the hard seabed. Since the survey sites did not extend into areas shallower than 2 m depths where there was rubble *E. mathaei* may have also have occurred on top of the rubble at that depth. In the shallow depths around 1 m *E. mathaei* were mostly seen covered with rubble by day and night.

5.4.6. Sea urchin *Echinometra mathaei* movements *in situ*

Echinometra mathaei remained in the same position during the day and night, and little movement occurred from the marker between 1 hr to 2 hrs during the day and 1 hr to 2 hrs during the night most of the time the sea urchins were masked by rubble during the day time and at night.

5.4.7. Sea urchin *Echinometra mathaei* feeding preference in the laboratory

Echinometra mathaei feeding preference and behaviour on the three types of algae (filamentous turf algae, *Enteromorpha antestinalis* and *Padina gymnosporia*) were examined in laboratory aquaria. The seawater temperature was ~24°C, salinity was 40 and dissolved oxygen was 6.5 mg ml^{-1}. In the main two (300 m^{-3}) glass tanks that contain all the sea urchins most of them were observed to move 30 cm in 50 sec onto all the 3 types of algal food offered to them. When the two types of algae (filamentous turf algae and *Enteromorpha antestinalis*) were placed in the four tanks (112 m^{-3}) all the *E. mathaei* preferred to move to the top of the rocks containing the filamentous turf algae. The time recorded for the first non-starved *E. mathaei* gut evacuation was 10 minutes, whereas first gut evacuation by the starved *E. mathaei* took place after 50 minutes (Fig. 5.2.4.1 b).

Figure 5.4.4.5. A 10 cm *Echinometra mathaei* feeding on the macroalga *Colpomenia sinuosa* in the spring season in March.

5.5. Discussion

One ecological approach to assessment of coral reef condition around the world is the use of sea urchin density as a proxy (Bernstein and K.H. Mann 1982; Harrold and Reed 1985; Griffin et al. 2003; Appana et al. 2004). In an early study (Faulkner and Cheshire 1979) expounded the idea that a healthy reef supports a large number of sea urchins which help to keep algae from becoming too abundant, and that the algal cover is dependant on the site condition and the type of algae occurring there. Sea urchin densities exceeding 20 sea urchins m^{-2} have a seasonal impact in regulating subtropical seagrass meadow biomass and size in St. Joseph Bay, Florida (Valentine and Kenneth 1991). However in Kuwait, sea urchin densities exceeding 35 sea urchin m^{-2} (±4) have been recorded and despite these numbers there is a seasonal occurrence of the large brown alga *Colpomenia sinuosa* and the appearance of another smaller brown alga *Padina gymnosporia.* This latter species is mainly regulated by seawater temperatures and is regularly washed up on the shore around the end of April along the coast of Kuwait and the sea urchins use this as a good food supply (Fig.5.5.1).

The peak-spawning season for sea urchins is documented to be April to May for *Diadema setosum* and in June for *Echinometra* sp. along Kuwait's coral reefs (Alsaffar and Lone 2000). The onset of spawning appears to go alongside with Kuwait's reefs at similar densities to those reported since 1983 by Downing (1985). Downing (1989) recorded maximum densities of *E. mathaei* of 32.5 sea urchins m^{-2} in 1983. However, it would be interesting to investigate the effects of changing the sea urchin densities to see if low abundances would encourage algal growth on the corals.

Figure 5.5.1. Large amounts of the macroalga *Padina gymnosporia* washed up onto the shore along the coast of Umm AlMaradim island. The appearance of the alga is regulated mainly by increasing seawater temperatures.

Sammarco (1980) kept *Diadema antillarum* in enclosures on corals at densities ranging from 0–64 individuals m^{-2} in Discovery Bay, Jamaica. Sammarco found that, despite the high algal cover, the highest coral recruitment and diversity occurred in areas where the lowest *Diadema* densities occurred. The resulting competition between the settling coral larvae and the algae was intense in the area. Competition between sea urchins and finfish on grazing algae have been studied (Silva 1999; Carreiro-Silva and McClanahan 2001). It has been suggested that if the sea urchins are overfished on some of the coral reefs sites then sea urchins would be left with no competitors for food and those sites would most likely see an increase in the abundance of sea urchins (McClanahan, et al., 1996). If sea urchin feeding is controlled by competing fish then they will limit access to the algae on the reef and this may increase the levels of bioerosion. i.e. less algae means more impact on the coral reef and bioerosion whereas more algae leads to more food for the sea urchin grazers. The removal of finfish competitors and predators on sea urchins through human fishing activities may dramatically alter the balance of the reef ecosystem e.g. denser finfish populations are found along in protected rather than unprotected reefs in Kenya (McClanahan, et al., 1996). Sea urchins have also been found to be in higher densities in unprotected rather than protected reefs (McClanahan, et al., 1996). Therefore, sea urchins can act as bioindicators of a coral reefs condition.

The most obvious form of physical disturbance observed on the coral reefs during the cage experiment study arose from anchor damage to the cages. All were damaged except the one next to a mooring buoy. However, this cage also had some damage as the mesh net was torn and fishing line attached to the cage was evidence that it had been impacted by human disturbance (Fig.5.4.3.1). In the absence of evidence for damage by waves or storms, it is apparent that most of the observed cage damage was caused as a result of anchors dropped onto, and anchor chains dragged over the cages whilst small boats were anchored on the reef (Fig.5.4.3.4 b). Branching *Acropora* and *Stylophora* colonies were most susceptible to anchor damage, although broken *Porites* colonies and overturned massive corals were also evident at some sites on the coral reefs (see Fig.5.4.3 a).

Echinoid distribution is most strongly influenced by the presence of algal food and water current movements at each depth, echinoids were mostly observed in depths of water of 1 to 3 m depth along Kuwait's reefs. Their depth distribution could be associated with more algal cover as the irradiance of the sun is more extensive in the shallow waters. Several authors have described the feeding behaviour of the sea urchin *Echinometra mathaei* (Tsuchiya and Nishihira 1985; Hart and Chia 1990; McClanahan and Kurtis 1991). At Khamala on the Kenyan coast (Hughes and Hughes 1971) assessed the distribution of *E. mathaei* along the inner reef which was mainly exposed to seaweeds washed up by wind driven waves. Along the outer reefs at Diani Beach, sea urchins were found in crevices in rock pools and under coral ledges where there was little wave and current movement (McClanahan 1995, 1998). Sea urchins *E. mathaei* were observed in slight hollows and natural pockets in the coral along the 3 Kuwait reefs. It appears that the sea urchins mode of existence is dependent upon its degree of exposure to waves and currents e.g. they are mostly found along the shallow reef transects, where sea urchins attempt to avoid wave action and current movements by burrowing into the coral along the reef shallows. However less *D. setosum* were found on the windward side of station 2 at all the reefs, these sites are commonly impacted with sand and with currents that also transport heavy loads of sediment from the coastal and northern sites. The data showed most *E. mathaei* inhabited the entire Kuwait reef and were prominently colonizing the heads of the dead *Porites* boulders on the shallow reef and occurred mostly in crevices at the reef edge. The *Porites* boulders and branching *Acropora* provided a variety of crevice sizes suitable for sea urchin inhabitation. Muthiga & McClanahan (1987) also reported a similar distribution pattern of sea urchins in Kenya. They explained this by the variable predation within reef zones, which was in turn affected by surf and current activity. However, *D. setosum* was mainly found on hard rocky substratums mostly at the reef edge. Therefore, sites with mostly sand seabed would discourage the presence of *D. setosum*. There was vigorous water movement over the reef edge and on the beach due to the constant wave action, whilst the inner shallow reef flat mostly experienced semi-calm conditions with more sun light exposure along the reef islands. In addition *D. setosum* has very fragile long spines that are likely to provide resistance to currents and become deposited with sediment where water sediment loads are highest (Edwards and Ebert 1991). However Pencil sea urchins *Heterocentrotus mammillatus* were present at Kubbar St.2 windward and Umm AlMaradim St.2 too. However, because of its rare occurrence and when it rarely did occur its strong spines probably provided protection at the windward station. If sea urchin presence was to be correlated with reef exposure, then Umm AlMaradim did not follow the same correlation pattern. Umm AlMaradim showed an opposite setting from the other two sites with exposed reef station 2 and back reef station 1 as the interaction analysis plot showed in figure 5.4.5 with year factors and figure 5.4.6 with season factors. The different setting could possibly be correlated with coral damage, following the theory that more coral damage would have more turf algae covering the dead coral and that this would provide a good food supply for the sea urchins. Coral damage abundance and distribution will be discussed in the next chapter (Chapter 6)

Sites with more dead coral especially *Porites* sp would be covered by turf algae and this would encourage *E. mathaei* to congregate to feed. However, these animals prefer to remain in one place if the conditions of food and protection are favorable (Hart and Chia 1990). Sea urchins *E. mathaei* usually were found in the coral rubble on the seabed both during the day and during the night, apparently not moving around. However, once a food supply is exhausted as it was observed in the aquaria they moved fast to any introduced algal food. Therefore on coral reefs sea urchins probably move to a fresh area where there is an algal mat covering which has grown and that the sea urchins can normally reach within a relatively short distance. This is probably why *E. mathaei* feeds more intensively in coral crevices, so that very thick coral reef colonies would develop on the top and would become weak underneath (Fig.5.5.2). These coral colonies would be very easy to break eventually by divers or occasional storms and will lead to increased reef site erosion. Clear evidence was seen in a coastal reef site called Qitat Benaiah south of Khairan resort which was highly impacted by *E. mathaei* sea urchin numbers with densities of 82 m^{-2} (±10) recorded. Thus *E. mathaei* is an important contributor to reef site erosion (bioerosion). Downing (1984) provided evidence on Kuwait reefs that *E. mathaei* removes a significant amount of coral material as it grazes and there is no reason to believe that settling coral planulae larvae are not consumed as well (Prince 1995). Therefore, less coral recruitment would most likely occur in sites where there is intensive sea urchin grazing, which would lead to a longer time for site recovery or reef growth. Sexual reproduction and the settling of planulae larvae is the most likely form that recruitment and recovery of the coral reef will take place, but there are possible problems such as the availability of the planulae. If the damage on the reef is too severe, the supplement of coral planulae must come from elsewhere. Since

Kubbar reef forms the northern-most reef of any significance in Kuwaiti waters and since the prevailing current is from the north (see chapter 1 Fig.1), it is unlikely that colonization by coral planulae from distant sources will occur. Therefore, the best way to test rehabilitation of a reef site is by sea urchin grazing measurements, and that maybe an indicator of the reef sites health.

Figure 5.5.2 At Kubbar to show the effects of sea urchin grazing undermining the stability of a colony of *Porites* in September 2004. The diameter of sea urchins mean measure ~10 cm.

Algal consumption rates of tropical Indo Pacific sea urchins vary from 0.2-8.0% of body weight day^{-1} (McClanahan 1992). Conand *et al.* (1997) used gut analysis and reported higher bioerosion rates on the reef crests than the reef flats which could be due to the fact that at Reunion, *E. mathaei* density was higher on the crest (45 m^{-2}) compared with the reef flat (19 m^{-2}). On most other reefs, *E. mathaei* occurs in low to medium densities (0-12 m^{-2}) (Ogden, 1978; Russo, 1980) depending upon the depth of the reef and the abundance of its predators and competitors (McClanahan and Shafir 1990). By contrast Kuwait reefs showed grazing impact through gut evacuation measurement of 3.84g sea $urchins^{-1}$ day^{-1} and this was 1.4g sea $urchins^{-1}$ day^{-1} calculated earlier by Downing and El-Zahr (1987). Therefore, reporting sea urchin bioerosion rates on the reef shallow, could be due to the fact that *E. mathaei* density was higher in the reef shallows (33.44 m^{-2}) than on the windward side of Kubbar and (19.35 m^{-2}) on the windward side at Umm AlMaradim and (8.46 m^{-2}) on the windward side at Qaru. However, low sea urchin activity creates a large number of reef habitats, which is an integral part of a coral reef system. Furthermore, limited grazing of algae creates the necessary space for successful coral settlement (Birkeland and Randall 1981; McClanahan and Muthiga 2001).

The study of the rates of bioerosion by the sea urchin *E. mathaei* followed the method used by (Downing and El-Zahr 1987). My study had some problems such as a lack of proper laboratory space at the field site. Nevertheless some results were obtained. The environment on the reefs of Kuwait is extremely variable with rough weather and strong currents at certain times of the year. In addition, a seasonal increase in algal cover during March in the springtime could alter the results of the sea urchin bioerosion rates as the sea urchins may become preoccupied with the increase in algal cover and the reef may not be eroded as much as when there were less algae on the rocks. Further studies in sea urchin manipulation should be carried out at the Kuwait reef site. However, cages should not be used, because they were damaged. I suggest a sea urchin manipulation experiment at the site is undertaken by removing all the sea urchins from several replicate areas of at least 200 m^2 and that would provide a buffer zone for any immigrant sea urchins entering the zone. The study area should be monitored weekly to remove any sea urchins moving into the controlled study area. The study should be conducted before the coral spawning time around June for *Acropora* and July for Brain coral as documented in 1996 (Harrison et al. 1997). The idea is to give more chance to see how coral recruitment on the control study site compared with similar sized sites, and the data produced can help to design reef site rehabilitation plans.

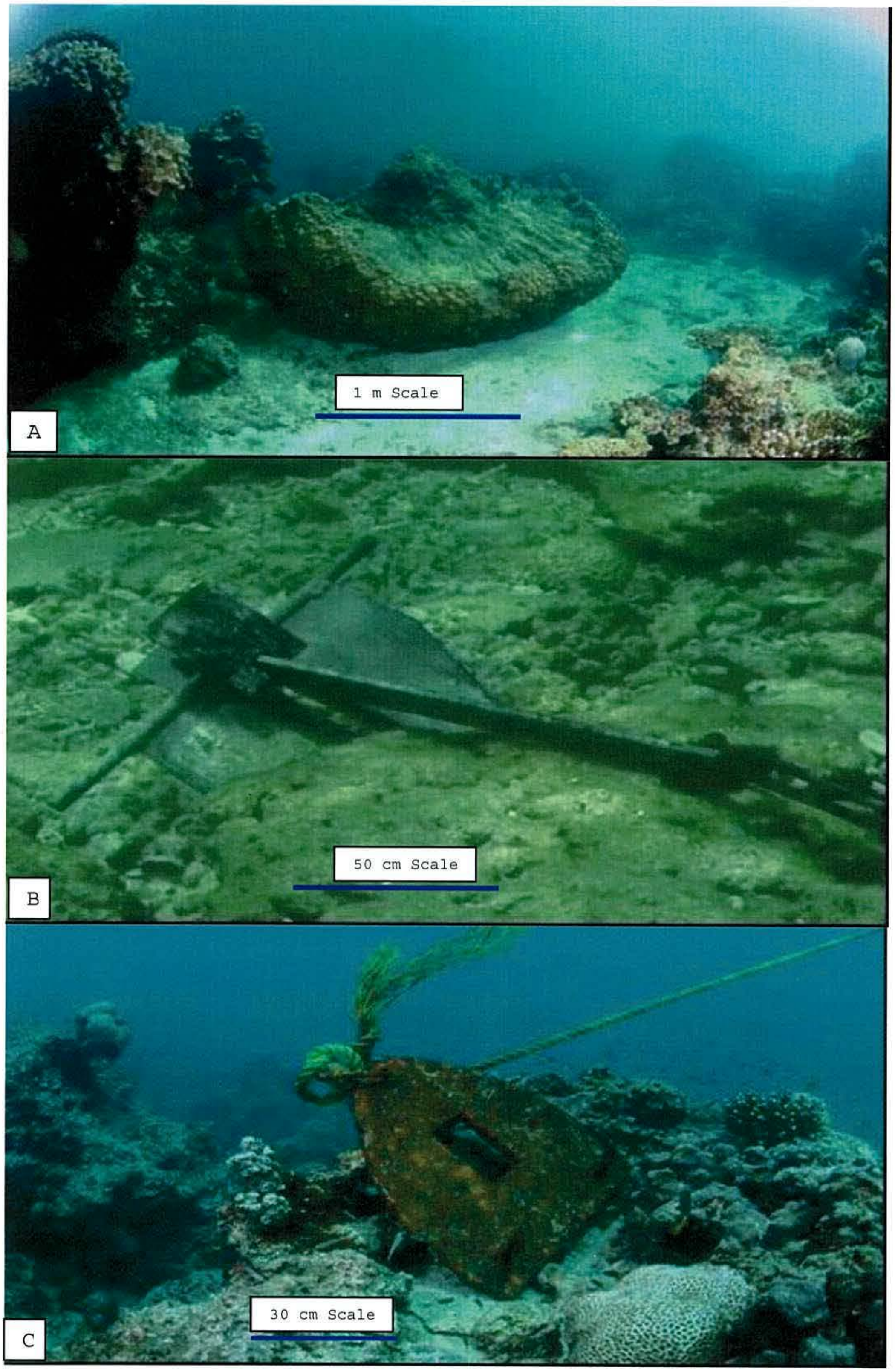

Figure 5.5.3. (A) a large *Porites* colony most likely damaged by anchor and (B & C) anchors were used in the shallow reef next to Kubbar island beach in September 2004, Each photo has its own scale reference.

5.6. Conclusion

Recorded sea urchin abundance and distribution showed no significant changes between 2003 & 2004. Therefore the null hypothesis is accepted. Reefs can be in a stable stage condition even with a high abundance of sea urchins 33.44 m^{-2} (±4). Bioerosion could be caused by multiple factors, the sea urchin grazing rates of *E. mathaei* with a gut evacuation rate of 3.84g sea $urchin^{-1}$ day^{-1} gave an indication of one possible factor affecting the loss of coral reefs. Sea urchins are therefore only one cause of reef erosion. The sea urchin *E. mathaei* had no preference for any of the three types of algae offered. Aborted cage experiments showed that Kuwait coral reefs experience extensive anchor damage (Fig.5.4.3.4, and Fig.5.5.3). Boat anchorage is therefore another cause and a consequence of reef erosion.

CHAPTER 6; Coral damage and other bioerosion impacts along the 3 coral reefs

6.1. Introduction

This chapter investigates the factors which might cause degradation of the three islands coral reefs. Coral reefs have often been described as fragile ecosystems in delicate balance with nature (Grigg and Dollar 1990). Their diversity of invertebrate, vertebrate and algal species, have been subjected to natural disturbance since their initial appearance many millions of years ago. Anthropogenic disturbance also affects the fauna and structure of the coral reefs and this is of serious concern. Sedimentation, arising primarily from dredging and coastal construction and development, oil pollution and related impacts of man's activities can cause impacts on many coastal coral reefs, these factors can cause reproductive failure and insufficient recruitment resulting in the long-term mortality of the coral reefs (Richmond 1993; Orpin et al. 2004). For example chronic exposure to sedimentation was reported to have occurred at six reef sites along the west coasts of Singapore's southern islands and was the most obvious form of anthropogenic stress (Dikoua and Woesik 2006). Sebens (1994) investigated the effects of natural and anthropogenic impacts on the biodiversity of coral reefs in the Caribbean and eastern Pacific. One of the most obvious and widespread losses to reef biota was the reduction in fish populations resulting from intense overfishing.

Anthropogenic and natural impacts need to be assessed in terms of their frequency of disturbance in relation to recovery time, and the area disturbed in relation to the total area present showing the degree of a disturbance (Grigg and Dollar 1990). Anthropogenic reversal effects which caused increases in bottom-up nutrient supply and their interactions were found to stimulate harmful fleshy algal blooms (that can alter the abundance patterns among functional groups even under intense grazing pressure). Conversely, elevated nutrients levels inhibit the growth of ecologically beneficial reef-building corals (Littler et al., 2006). Szmant (2002) has suggested that nutrient enrichment on coral reefs is the major cause of coral reef decline. Declines in coral reef health have been attributed to various anthropogenic and natural processes e.g. coral bleaching has been observed during extreme climate events and exposure to

UV radiation, air, infections microbes, and macroalgal overgrowth is usually ascribed to eutrophication (Barber et al., 2001).

The main organisms responsible for the biological destruction of coral reefs can be grouped into grazers and borers. A typical reef is subject to significant biological destruction from grazers (acanthurids and scarids, echinoids, grazing gastropods, limpets), from borers e.g. sponges, bivalves molluscs, sipunculids and polychaetes (Appana and Vuki 2003) and etchers (bacteria, fungi, algae) (Hutchings 1986). Bioerosion has been investigated at coral reefs all around the world. Polychaetes and sponges have been shown to enhance the total bioerosion rates on coral reef in Fiji (Appana and Vuki 2003). Microborers were found to be direct agents of bioerosion in both live and dead crusts of coral reefs in Moorea, French Polynesia. By removing carbonate from the coral skeletons, they indirectly increased bioerosion rates in dead coral heads since they are themselves exposed to grazing by fish, echinoderms and molluscs (Tribollet and Payri 2001).

Natural oil seeps in the Arabian Gulf have allowed the development of microorganisms which promote biodegradation of oil spills, while high temperatures and solar radiation accelerate oil degradation and rapid evaporation of light toxic compounds (Carpenter et al., 1997). However around Kuwait's island reefs, three coral species (*Acropora*, *Porites* and brain coral) have been investigated for trace metal accumulation in their body parts and Bu-Olayan *et al.*, (2005) found a high levels of metals during the summer and concluded corals can be used as bio-indicator of trace metal oil pollution levels.

Coral reef communities are mainly comprised of hermatypic scleractinians and during their growth corals build highly complex structures which are colonized by diverse communities of invertebrates including other Cnidarians, sponges and Echinodermata, as well as fish. Kuwait's coral reef ecosystem includes a range of invertebrates and vertebrate animals that may enhance the bioerosion rates of the coral colonies. Invertebrates including sponges, zoanthids and other cnidarians, worms, molluscs, crustaceans and echinoderms inhabit the coral reefs. Vertebrates are mainly fish and are one of the most diverse groups of animals on the coral reefs. Coral reefs are constantly being impacted through bioerosion and this can be seen during a visit to the reefs. However, after having looked at the effect of grazing by echinoderms the most prominent mobile herbivorous fish on these reefs, which cause bioerosion to these reefs were unfortunately not investigated for logistic reasons. Any anthropogenic impact on the coral reefs will lead to widespread losses in biodiversity of the reef biota, particularly a reduction in fish populations arising from intense overfishing. However the impact of visiting leisure boats around the reef ecosystem for fishing or diving may cause physical impact to the reef. An estimate of the area disturbed in relation to the total area of reef will show the degree of a disturbance around Kuwait's reefs. In this chapter I have investigated what other factors might be causing damage to the reefs through a study of the number of damaged coral colonies, data obtained from video surveys of the reefs, and I have estimated the degree of disturbances along Kuwait's reefs.

The impact of the new marina construction at Umm AlMaradim was investigated. A field survey was carried out along Umm AlMaradim island reef. Excavations for the marina took place ~200 m away from the leeward back reef at survey site station 1. Survey data had been collected before the marina construction began and the survey was repeated during the post-construction period to assess any possible changes that might have been caused by this new development. In order to assess whether coral reefs are affected by sediment from the new marina construction the 3 island reefs were examined for possible damage from increased sedimentation. Because of their location the reefs at Kubbar and Qaru were considered control sites for sedimentation and they could be compared with the affected reef situation at Umm AlMaradim. Two stations at each reef were investigated to find out whether the different current movements around the islands resulted in higher sedimentation rates on the fore and back reefs. Four replicate sediment traps were deployed at each station to highlight any variation between stations and reefs.

6.2. Aims and objectives

The aims of this chapter were to investigate the possible causes of reef destruction and to examine the abundance and distribution of living and damaged coral colonies at the three island reefs. To evaluate the extent of any disturbed areas of corals and to consider any possible anthropogenic causes of coral damage on the reefs.

The main objectives of the study were to find out if coral damage, abundance and distribution could be ascertained from the video surveys of the reefs. The specific objectives were:

1. To review the video surveys of the two permanent stations windward and leeward on each site of the three island reefs to ascertain the extent of coral damage.
2. To measure the abundance of the damaged coral colonies through two seasons and over three years i.e. between 2003 & 2005.

6.3. Material and methods

The number of damaged colonies was quantified by identifying broken corals in individual video frames (e.g. see Fig. 6.3.1) taken from the video survey described in chapter 3. From the video frames it was possible to see that the damaged coral colonies ranged in size from 30cm and above. The most likely cause of the damage to the corals was from human impacts. The films from each site were analysed to investigate the degree of site disturbance. The number of damaged coral colonies on each frame (~1m²) were identified and recorded (Fig. 6.3.1). In many cases, identification of damaged coral colonies to species level was possible from the video images. At each station representative video images covering 5 transects i.e. 47 x 1m² frames were analysed from each transect. The mean number and standard error of damaged coral colonies were estimated along each transect and at each station; 2 stations at the three reef sites to show differences in disturbance level. The two permanent station sites located on each reef, one was on the fore reef and the second was on the, back position (Fig. 3.3.3). The two depths covered the reef edge (8 m depth) and reef shallow (2 m depth), and one was perpendicular to the beach running from the reef edge to the reef shallow and were taken in September 2003 and March 2004 with a further 150 m long transect surveyed in September 2005 (see Fig. 3.3.1 and Fig. 3.3.3 in chapter 3).

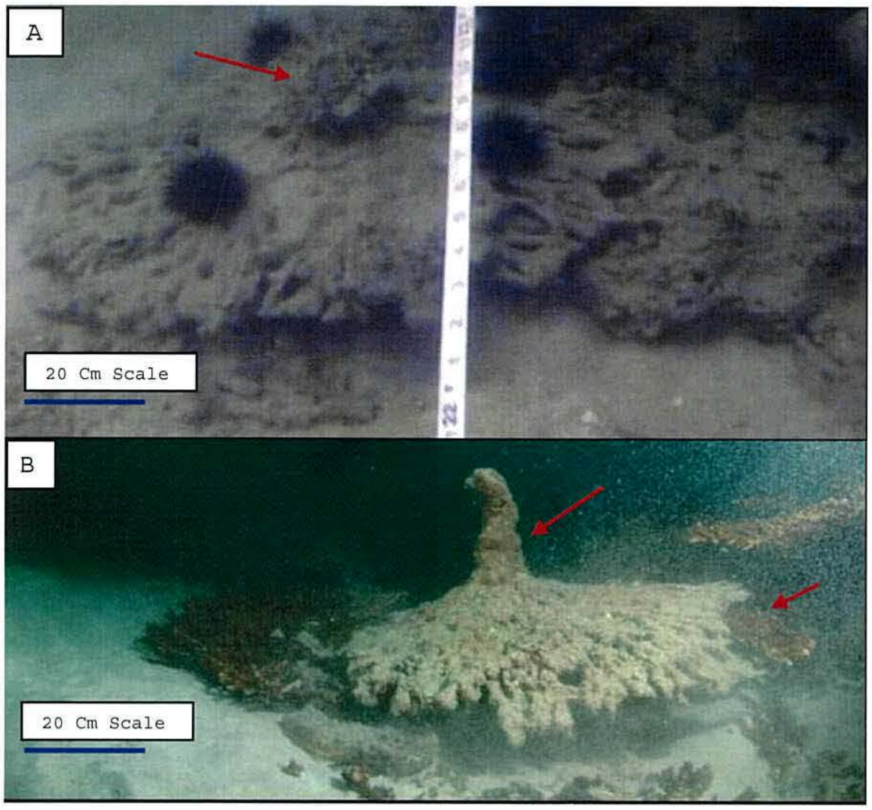

Figure 6.3.1. A portion of 1 m² video frames showing an *Acropora clathrata* colony damaged, (A) one dead completely buried in the sand upside down and (B) one half covered with sand and showing signs of regeneration at the colony edge. A coral colony has recovered and grown from an upside down position as indicated with arrows.

The mean number of coral colonies damaged along each transect surveyed during September and June 2003, March 2004 and September 2005 were estimated and the data plotted in bar chart form to find out how different the number of damaged coral colonies were between the three survey years and two seasons. The same approach was used to characterize possible differences in the appearance of the damaged coral colony structure between the 3 reefs to investigate whether anthropogenic factors were responsible. However, as well as bioerosion other distracting factors focused on Parrot fish feeding behaviour, feeding fish were observed 3 times for 30 min and a few ones occasionally.

6.4. Results

6.4.1. Damaged coral colonies

The damaged coral colonies sizes 0.3 m were considered from each m² video frame. Each transect included 50 m^{-2} video frames, and a mean of the damaged colonies calculated with standard error for each transect (see Fig.6.4.2). However the mean number of damaged coral colonies m^{-2} distribution at the 3 reefs showing data variation with standard deviation at station 1 (St.1) and station 2 (St.2) in September 2003, in June 2003 only at Qaru station 1 and Umm AlMaradim station 1, in March 2004 and in September 2005 (Fig. 6.4.1).

The mean number damaged coral colonies m^{-2} recorded were highest at Umm AlMaradim at station 1 with a mean of 0.165 m^{-2}, and at Qaru station 1 with a mean of 0.077 m^{-2} in June 2003 (Fig. 6.4.1). However the damaged coral colonies recorded were highest at Umm AlMaradim station 2 with a mean of 0.261 m^{-2}, and at Umm AlMaradim station 1 with a mean of 0.094 m^{-2} in September 2005 (Fig. 6.4.1). Also damaged coral colonies were recorded at Qaru station 2 with a mean of 0.072 m^{-2} in September 2005 (Fig. 6.4.1). However, the mean number of damaged coral colonies per 1 m^2 with standard error bars of the 5 transects (mean of 50 quadrats at each transect) at each station; two of 50 m transects at reef edge (T1,T2) and two of 50m transects at reef shallow (T4,T5) with one between at Kubbar, Qaru and Umm AlMaradim, based on two stations in September 2003 were shown in figure. 6.4.2; (a) station 1 and (b) station 2.

Damaged coral colonies showed low numbers at all sites in September 2003. However high numbers of damaged coral colonies were recorded at Qaru (at T2-4) and Umm AlMaradim (at T1-5) at station 1 as surveyed in June 2003, which was the high season of diving activities around Kuwait's reefs starting at the beginning of June to the end of August (Fig. 6.4.3). The mean damaged coral colony numbers ranged from 2-6 damaged colonies at Qaru and 4-16 damaged colonies at Umm AlMaradim in the June 2003 survey. By comparison the number of damaged colonies ranged from 3-5 damaged colonies at Qaru and 5-24 damaged colonies at Umm AlMaradim in September 2005 (Fig. 6.4.5). However, damaged colonies numbers were very low in March 2004 before the diving season, and ranged from 1-2 at all sites except at Qaru station 2 windward site (range 2-4) and at Umm AlMaradim station 1 leeward site (range 1-9) damaged colonies in March 2004 (Fig. 6.4.4).

Kubbar and Umm AlMaradim reefs showed a mean of 0.02 ± 0.02 m^{-2} in transects at the reef edge at both stations and at Kubbar $0.02 - 0.04 \pm 0.02$ m^{-2} in transects at reef edge station 1 and 0.04 ± 0.02 m^{-2} in transects at reef shallow at Umm

AlMaradim in September 2003 (Fig. 6.4.2). However, Qaru and Umm AlMaradim reefs damaged coral colonies ranged from a mean of 0.05 – 0.14 ± 0.03 m^{-2} in transects at the reef edge and shallow at Qaru and 0.08 – 0.32 ± 0.05 m^{-2} in transects at reef edge and shallow at Umm AlMaradim in June 2003 (Fig. 6.4.3).

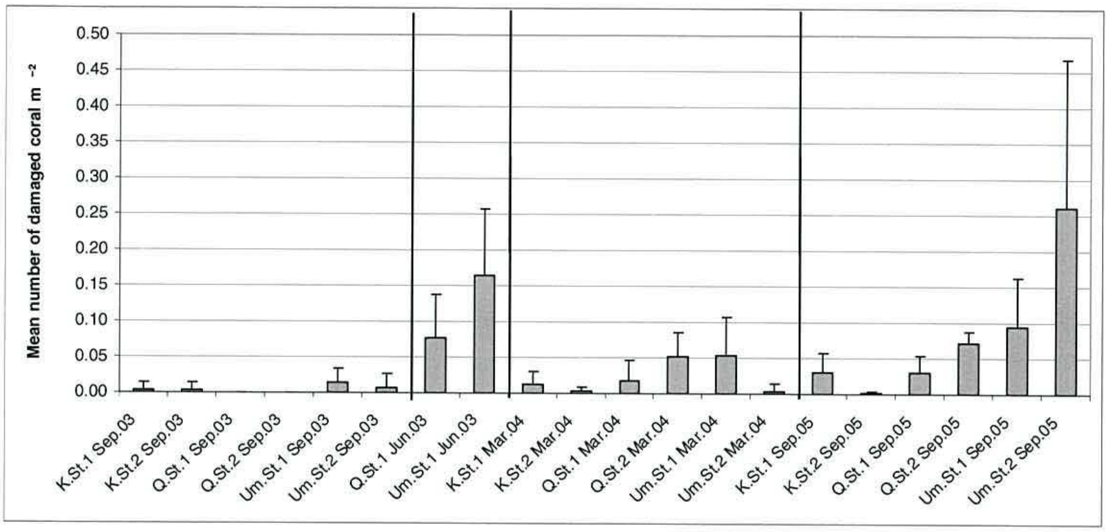

Figure 6.4.1. The mean number of damaged coral colonies m^{-2} distribution with standard deviation at 2 stations (St.) at the 3 reef sites in September 2003, Jun 2003 (only at Qaru St.1 and Umm AlMaradim St.1), March 2004 and September 2005. (K Kubbar, Q Qaru and Um Umm AlMaradim)

The damaged coral colony data showed higher numbers than September 2003 at all sites in March 2004. Kubbar reef showed a range of means (0.02-0.04 ± 0.02 m^{-2}) in transects at reef shallow station 1 leeward and 0.02 at reef edge station 2 windward in March 2004. However Qaru showed 0.03-0.06 ± 0.03 m^{-2} in transects in the reef shallow and ranged from 0.04-0.08 ± 0.04 m^{-2} in transects at reef shallow and edge station 2 windward. Umm AlMaradim reef showed a range from 0.02-0.14 (± 0.02-0.04 respectively) m^{-2} in transects at the reef shallow and edge station 1 leeward and 0.02 ± 0.02 m^{-2} in transects at reef shallow station 2 windward in March 2004 (Fig. 6.4.4).

The damaged coral colony data of means in September 2005 showed as in March 2004, but with same damaged coral colonies extending around Kubbar and Qaru at station 1 leeward sites (Fig. 6.4.5). The damaged coral colonies ranged from 0.02-0.07 ± 0.02 m^{-2} in transects at all depths. However Kubbar reef at station 2 windward had a mean of 0.02 ± 0.02 m^{-2} in transects at the reef shallow, and ranged from 0.05-0.1 ± 0.03 m^{-2} in transects at all depths at Qaru reef. However, Umm AlMaradim reef had a mean ranging from 0.02-0.2 ± 0.02-0.04 m^{-2} in transects at all depths; station 1 leeward site, but damaged coral colonies had with mean ranges from 0.09-0.5 ± 0.03m^{-2} in transects at all depths station 2 windward. The most documented coral species damaged was *Acropora clathrata*.

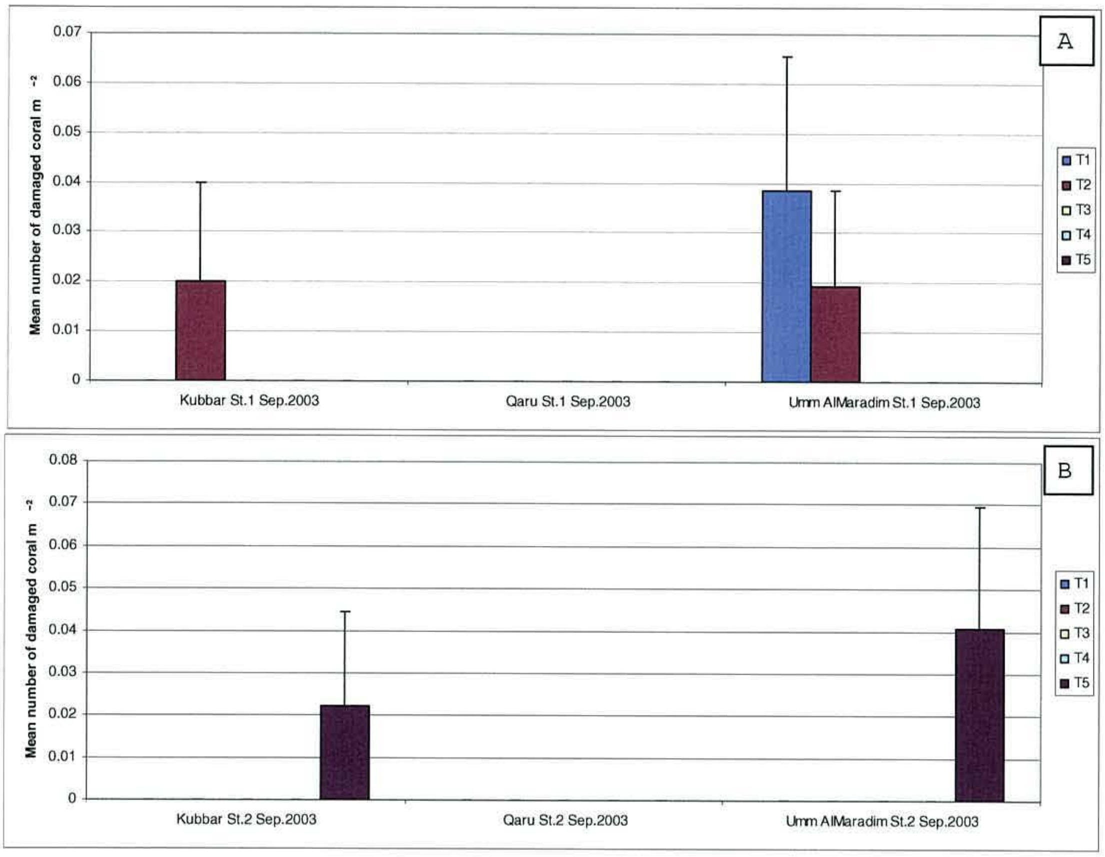

Figure 6.4.2. The mean number of damaged coral colonies per m² with standard error bar of 5 transects; 2 at reef edge (T1,T2) and 2 at reef shallow (T4,T5) with one between (T3) at Kubbar, Qaru and Umm AlMaradim, based on two stations; (a) St.1 and (b) St.2 in September 2003.

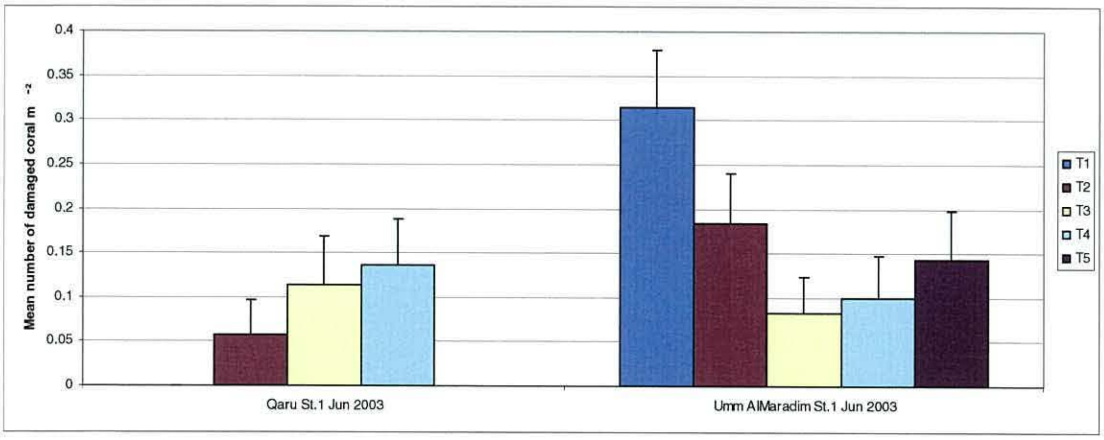

Figure 6.4.3. The mean number of damaged coral colonies per m² with standard error bar of 5 transects; 2 at reef edge (T1,T2) and 2 at reef shallow (T4,T5) with one between (T3) at Qaru and Umm AlMaradim station 1 in June 2003.

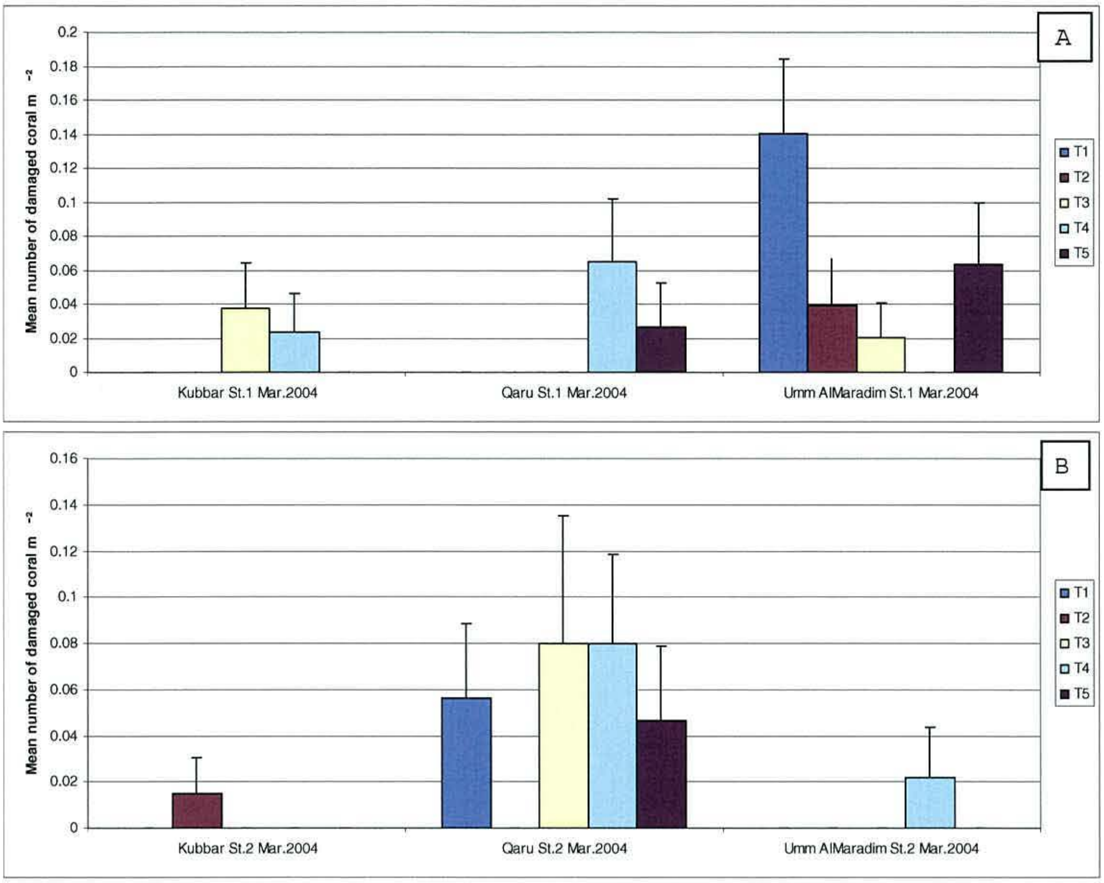

Figure 6.4.4. The mean number of damaged coral colonies per m² with standard error bar of 5 transects; 2 at reef edge (T1,T2) and 2 at reef shallow (T4,T5) with one between (T3) at Kubbar, Qaru and Umm AlMaradim, based on two stations (a) St.1 (b) St.2 in March 2004.

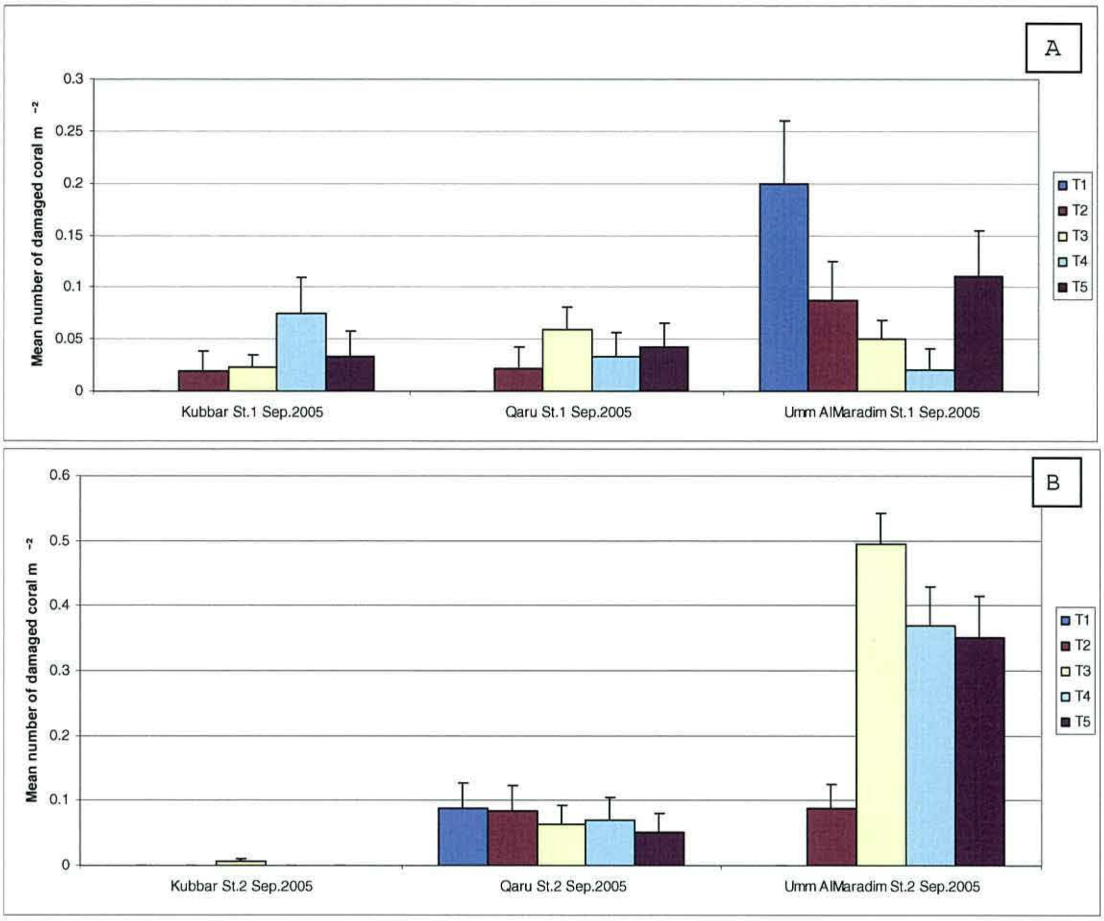

Figure 6.4.5. The mean number of damaged coral colonies per m² with standard error bar of 5 transects; 2 at reef edge (T1,T2) and 2 at reef shallow (T4,T5) with (T3) extended to a 150 m long transect at Kubbar, Qaru and Umm AlMaradim, based on two stations (A) St.1 (B) St.2 in September 2005.

6.4.2. Statistical analysis

Statistical analysis of the damaged coral colony data testing for differences at the islands reef sites, fore reef (station 1) or back (station 2) reef exposure and depth level was undertaken. The quadrat survey in transects were grouped in each station, but also quadrat survey transects were grouped in reef edge 8 m (transect 1 & transect 2) and reef shallow 2 m depth (transect 4 & transect 5). A General Linear Model test with 4 factorial (site, station, year and depth). Pairwise comparison analysis of variance (ANOVA) for damaged coral colonies showed counts there was a significant difference in year ($F = 118.48$; $P < 0.001$), in site ($F = 57.47$; $P < 0.001$), in station ($F = 28.43$; $P < 0.001$) (see Table 6.4.1 and Fig. 6.4.6). In addition there was significant difference in two way interaction between year and station ($F = 29.66$; $P < 0.001$), between site and station ($F = 26.89$; $P < 0.001$) and in three way interaction between year, site and station ($F = 29.66$; $P < 0.001$) (see Table 6.4.1 and Fig. 6.4.6). However there was no significant differences in depth (shallow and edge) (F = 0.77; P > 0.381) and in two way interaction between year and depth (F = 0.98; P > 0.323), between site and depth (F = 0.94; P > 0.392), between station and depth (F = 2.33; P > 0.127) and in three way interaction between year, site and depth (F = 1.28; P > 0.280), between year, station and depth (F = 0.00; P > 0.999), but a significant difference between site, station and depth (F = 3.59; P > 0.028) and a non-significant four way interaction between year, site, station and depth (F = 1.35; P > 0.258) (see Table 6.4.1 and Fig.6.4.6).

Table 6.4.1. Damaged coral colonies count differences between years 2003 and 2005 with 3 factorials (site, reef back st.1 and front st.2 and reef depth edge/shallow).

Factorial	F value	P value	Difference
Year	118.48	0.001	Significant
Site	57.47	0.001	Significant
Station	28.43	0.001	Significant
Shallow/Edge reef	0.77	0.381	Not Significant
Year x Site	46.28	0.001	Significant
Year x Station	29.66	0.001	Significant
Year x Shallow/Edge	0.98	0.323	Not Significant
Site x Station	26.89	0.001	Significant
Site x Shallow/Edge	0.94	0.392	Not Significant
Station x Shallow/Edge	2.33	0.127	Not Significant
Year x Site x Station	29.66	0.001	Significant
Year x Site x Shallow/Edge	1.28	0.280	Not Significant
Year x Station x Shallow/Edge	0.00	0.999	Not Significant
Site x Station x Shallow/Edge	3.59	0.028	Not Significant
Year x Site x Station x Shallow/Edge	1.35	0.258	Not Significant

General Linear Model test with 4 factorial (site, station, season and reef depth shallow and edge reef) pairwise comparisons analysis of variance (ANOVA) for damaged coral colony counts there was a significant difference in season (F = 16.73; P < 0.001) (see Table 6.4.2 and Fig.6.4.7) and between site (F = 3.70; P > 0.025). However, there were no significant differences in all other interaction, between station (F = 0.97; P > 0.324) and depth (F = 0.32; P > 0.572), and other factorial interactions (see Table 6.4.2 and Fig.6.4.7).

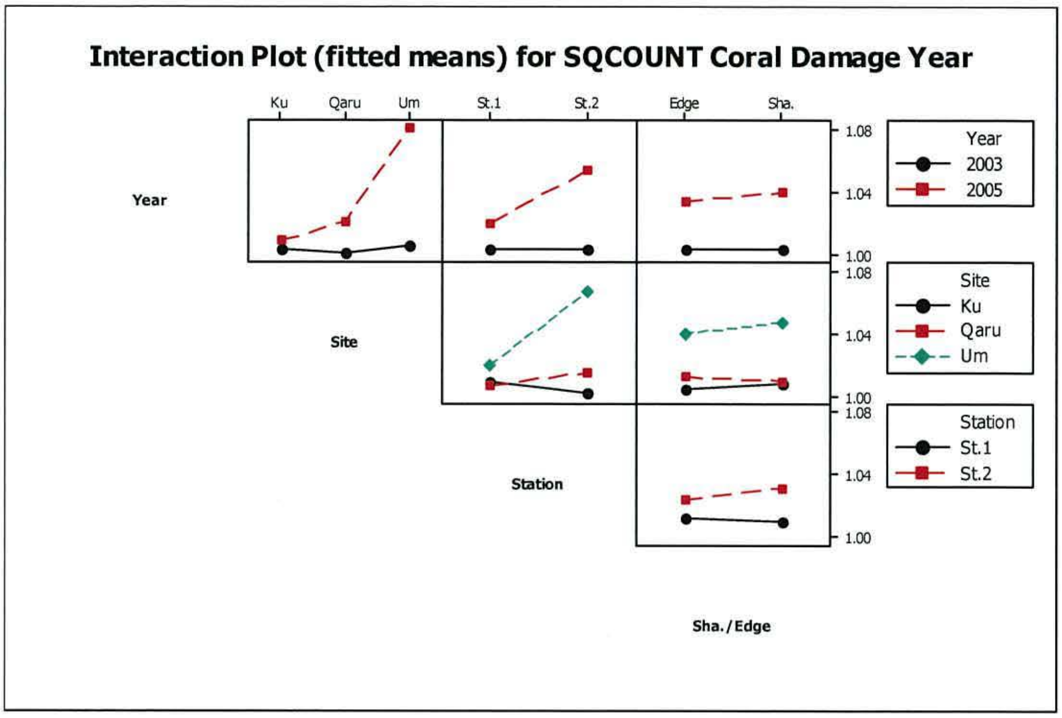

Figure 6.4.6. Interaction means number of damaged coral colonies with 4 factorials (year, site, reef back st.1 and front st.2 and reef depth edge/shallow). General Linear Model count versus year, site, station and reef depth Edge/Shallow. Factor; site 3 (Kubbar, Qaru, Umm AlMaradim), year 2 (2003, 2005), station 2 (station 1, 2) and reef depth Edge/Shallow.

Table 6.4.2. Damaged coral colonies counts differences between season (September 2003 and March 2004) with 3 factorials (site, reef back st.1 and front st.2 and reef depth edge/shallow).

Factorial	F value	P value	Difference
Season	16.73	0.001	Significant
Site	3.70	0.025	Significant
Station	0.97	0.324	Not Significant
Shallow/Edge reef	0.32	0.572	Not Significant
Season x Site	4.79	0.008	Significant
Season x Station	0.65	0.419	Not Significant
Season x Shallow/Edge	0.55	0.457	Not Significant
Site x Station	5.51	0.004	Significant
Site x Shallow/Edge	2.82	0.600	Not Significant
Station x Shallow/Edge	2.99	0.084	Not Significant
Season x Site x Station	4.36	0.013	Significant
Season x Site x Shallow/Edge	2.30	0.100	Not Significant
Season x Station x Shallow/Edge	0.46	0.499	Not Significant
Site x Station x Shallow/Edge	4.01	1.018	Not Significant
Season x Site x Station x Shallow/Edge	0.33	0.719	Not Significant

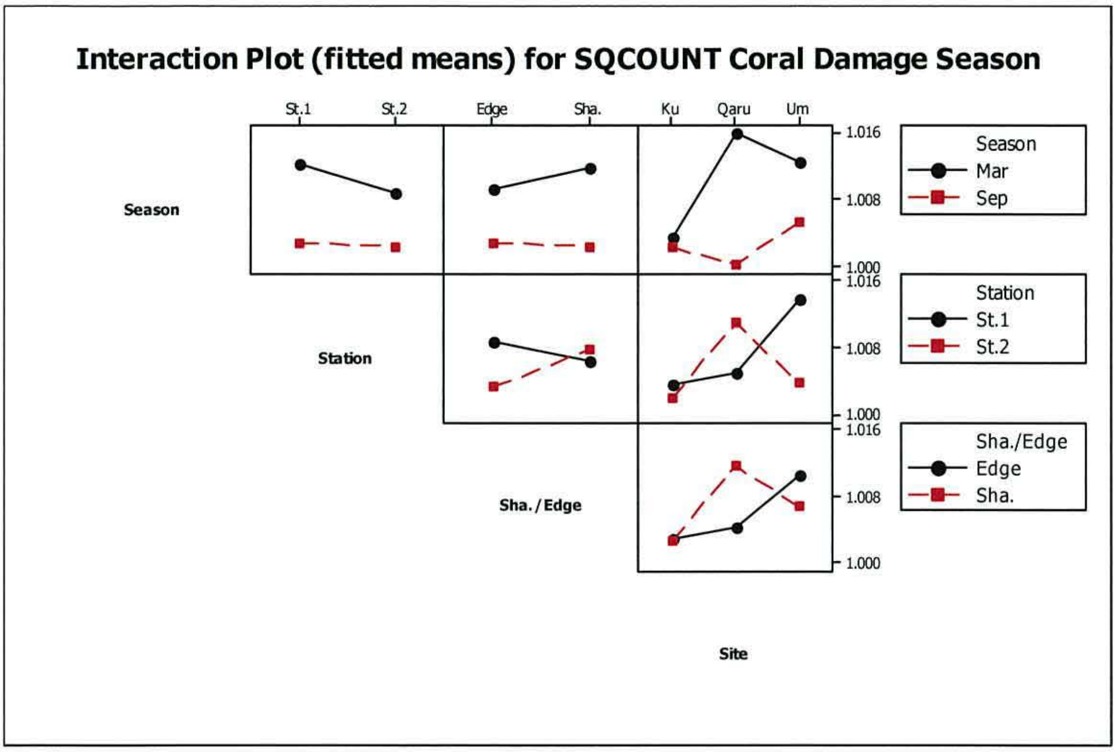

Figure 6.4.7. Interaction means number of damaged coral colonies with 4 factorials (season, site, reef back st.1 and front st.2 and reef depth edge/shallow). General Linear Model count versus year, site, station and reef depth Edge/Shallow. Factor; site 3 (Kubbar, Qaru, Umm AlMaradim), season 2 (September 2003, March 2004), station 2 (station 1, 2) and reef depth Edge/Shallow.

The interaction plot showed Umm AlMaradim reef had changed significantly from 2003 damaged coral colonies data to 2005, but Kubbar and Qaru have not changed (Fig.6.4.6). The reef depth was showing no significant change from 2003 damaged coral colonies data to 2005 (Fig.6.4.6). Station 2 fore reef was showing significant changes with higher counts of damaged coral colonies in 2005 than in 2003 only in Umm AlMaradim, but station 1 back reef showed no significant change from 2003 damaged coral colonies data to 2005 in the 3 sites (Fig.6.4.6). Kubbar Qaru and Umm AlMaradim reef damaged coral data had a similar trend of change from shallow to edge reef, but Umm AlMaradim reef had more damaged coral colonies (Fig.6.4.6). However, only Qaru reef had a significant difference between seasons from summer season in September to winter season in March (Fig.6.4.7).

6.4.3. Coral colony species damaged at the three reefs

The coral colony species damaged were *Acropora clathrata* except at Umm AlMaradim station 1 back reef where *Porites compressa* was recorded damaged during the diving season in June 2003. *P. compressa* was recorded at the reef edge and reef shallow, yet more damaged coral colonies *A. clathrata* were recorded at the reef edge and ranged from 4-5 colonies and the reef shallow ranged from 9-15 colonies.

6.4.4. Damage from the marina construction

A new marina constructed at Umm AlMaradim reef in April 2004 was a major anthropogenic impact on the coral reef. Some coral colonies were removed from the new marina planned reef area to the beach and a lot of building materials were dumped into the reef (Fig.6.4.8). In addition to dumping materials, dredging was done to the marina area disturbing sediments around the reef causing high turbidity and reduced light intensity. Large quantities of suspended sediment were seen to flow out of the harbour as a plume, especially on a falling tide, and the prevailing currents then picked this up and carried it in an easterly direction along the reef edge and over the reef shallow east of the harbour. (Fig.6.4.9).

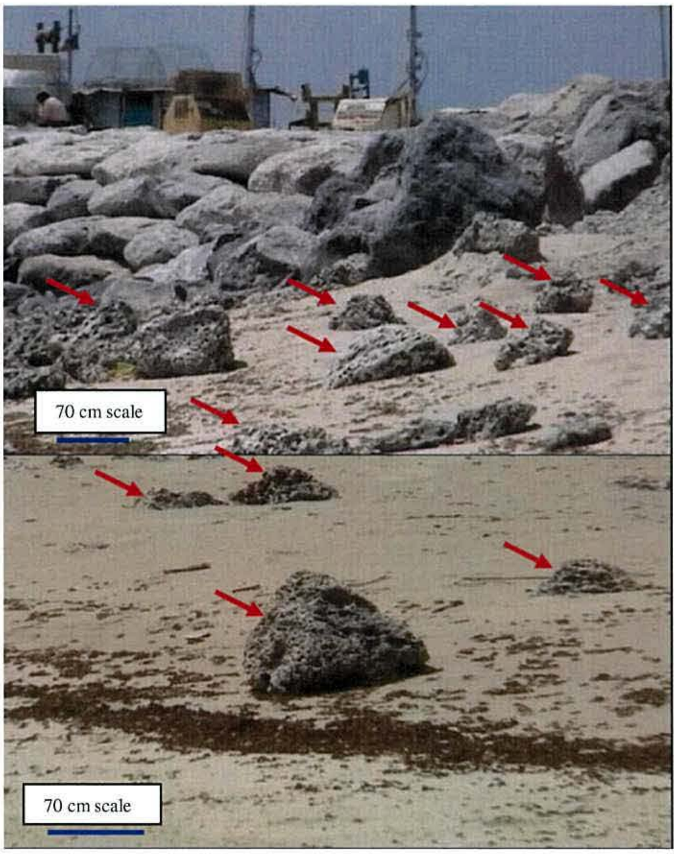

Figure 6.4.8. Large dead coral colonies pointed with red arrows were removed from the marina reef area to the beach as dredging activity for the new marina construction at Umm AlMaradim in April 2005 (scale blue line 70 cm).

Figure 6.4.9. The new marina during construction showing dredging activities with red arrows were causing high turbidity at Umm AlMaradim in December 2005.

6.5. Discussion

6.5.1. The number of damaged coral colonies abundance and distribution

Many coral colonies had suffered broken branch tips, and some dead standing coral skeletons had collapsed. However in many cases the small corals pieces that had settled on the dead corals crevices were still alive. However the large coral damaged pieces with size larger than 70 cm were mostly found dead and covered by sand. Other large damaged coral colonies were found as whole colonies upside-down. The data were tested for differences between years and seasons. Between years damaged coral colonies were significant with most coral damage at Umm AlMaradim. The significant difference was most likely caused by the new marina development impacting on the reef. Station 2 fore reef at Umm AlMaradim is the most affected in the calculated difference, that could also be correlated to the same impact but with personal observation of a large barge was stationed close to that station. Reef depth did not contribute to the difference between years, so the damaged coral colonies were not localized by depth but by station.

The damaged coral colony data showed significant differences between seasons. However the seasonal data differences were contributed most by Qaru back reef at station 1. The likely difference is the reef position as most offshore reefs can be impacted by large fetch waves driven by the strong prevailing common northern winds in winter and by the presence of recreational boats around the shallow reefs at the time. The effect of strong prevailing seasonal Northern winds in winter can be very high especially on plate type corals (Downing 1985). The north-west area of the fore reef or windward station would be less impacted by human impact as it is a less stabile zone for divers or boat anchorage. However the back reef station 1 was in south-east area of the reef as a back or leeward reef position more damaged zone, so this reef position is favoured for divers and was more vulnerable to boat anchorage. Because Qaru reef number visiting boats are most of the time less than the number of mooring buoys available around (see Fig.3.3.18 in chapter 3) there is less damage. In addition damage is possible from artisanal fishery trawler activities close to the reefs, as was observed personally. The environmental impacts of artisanal fishing gear on coral reef ecosystems were studied in multi-gear fishery of southern Kenya and the results indicated that fishers using beach seines, spears and gill nets cause the most direct physical damage to corals (Mangi and Roberts 2006). The other factors could be reef depth although the data did not change significantly with depth. However the physical impact factors were damaging certain coral species such as *Acropora clathrata*.

6.5.2. Species damaged colonies distribution

Acropora clathrata was damaged as shown in the data and only 2 of the damaged *Porites* colonies were documented during the diving season. The coral colony plate species were damaged as they are the most fragile because of their characteristic morphology colonies consist of a small attachment trunk (Tanner et al. 1996). Damage was recorded at all sites except at Umm AlMaradim station 1 leeward back reef where *Porites compressa* was recorded as damaged during the diving season in June 2003. Reef edge recorded less damage than reef shallow most likely because of the mooring buoys around and most of the time boats use, but they use anchorage instead in the reef shallows. The shallow site can be more vulnerable from anchorage during rough seas making the anchor chain move around and cause more damage (Fig. 6.5.1).

Figure 6.5.1. Long metal chain used with anchor at back reef in Qaru reef in June 2003 with that may increase damage around the reef.

6.5.3. Umm AlMaradim marina

Marina construction and dredging on the Umm AlMaradim reef caused damage and the damage covered a large area of the reef (Fig. 6.4.9). The development of a harbor in Diego Garcia lagoon similarly caused damage to the resident reef colonies (Sheppard 1980). A number of studies have reported on the effect of dredging on coral reef (e.g. Sheppard 1980; Smith 1988; Brown et al. 1990; Grigg and Dollar 1990; Fisk 1991; Neil 1996). However with development, construction and dredging of the reefs, they can recover via coral recruit and regrowth of fragments (Smith 1988). The effect of the harbour construction and dredging at Umm AlMaradim reef had impact at the time with sedimentation and removal of large coral colonies from the harbour area and long term impact on the reef. This happened at Heron Island in Australia, a harbour was constructed in 1945 and dredging was carried out a few times. The effects of dredging initiated a long term monitoring program (Lawn and Preker 1993; Hacker and Gourlay 1996; Gourlay and Jell 1997). Long-term changes following a dredging event after 10 years were investigated in Botany Bay (NSW, Australia), and impact was concluded (Fraser et al. 2006). However dredging and blasting for military construction in an enclosed lagoon in Diego Garcia atoll in Indian Ocean with poor cover, was surveyed and the coral were found to be unaffected by the construction, i.e. to the construction process appears to have had no major or lasting effect on coral diversity (Sheppard 1980). In general the construction outcomes can be related to the general reef morphology and setting, in addition to the construction process. The construction had continuance impact on Heron Island reef had no impact at Diego Garcia atoll. Overall the most important approach should be well planned and impact assessment studies carried out before any action is taken. Military explosive was found at the fore reef at Umm AlMaradim and it was exploded after moving the explosive to shallow reef by military personal in March 2005 (Fig. 6.5.2), such explosives can create coral damage around this reef.

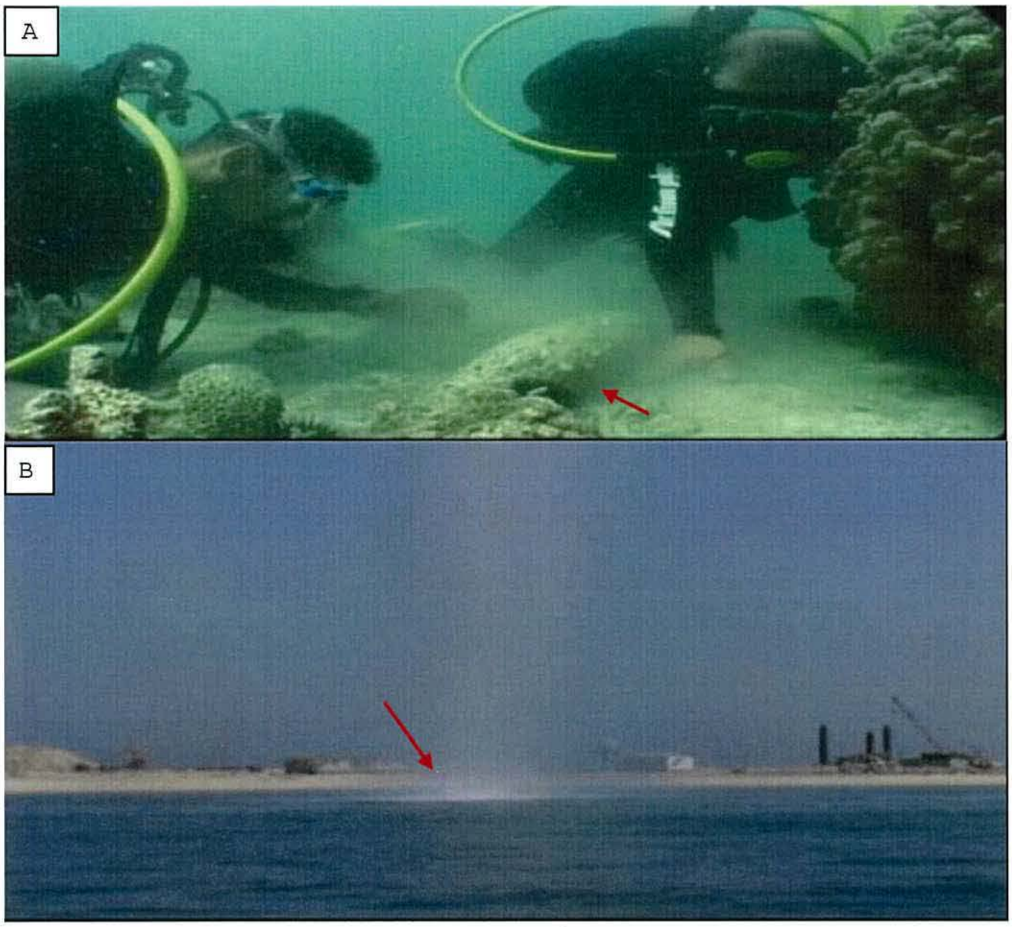

Figure 6.5.2. Military explosive was found pointed by red arrow at fore reef at Umm AlMaradim reef (B) and it was exploded (A) after moving the explosive to shallow reef pointed by red arrow by military personal in March 2005.

6.5.4. Parrot fish feeding behavior as a Bioerosion factor

There are a few herbivorous fish around these reefs and also boring polychaete, sponges family *Clionidae* and Bivalves *lithophaga* were also found. The two herbivores had effects, but one has more effect than the other. The coral skeleton eroding polychaete *Lumbrinereis* sp. inhabits a soft tube exteriorly attached to the host and can causes deep erosion of the coral skeleton, as was seen personally during a coral coring study in 2002 (Gischler et al. 2005). The boring sponges were seen to be very dense around Kuwait reefs, and thus could be related to the extreme seawater temperatures, found associated with warm El Nino events. Fleshy algae and sponges being higher than previously reported on Maldivian reefs (McClanahan 2000). However, the effects of polychaetes, sponges and bivalves were not considered in this Kuwait reef study (Fig. 6.5.3). However, parrot fish were observed for about 30 min three times and few others were seen for a short time. Coral reef fish species reported in the Indo-Pacific number 3000, in the parrotfish family and produce significant bioerosion. One of 2 species of parrotfish *Bolbometopon muricatum* occurs on the Great Barrier Reef. Each parrotfish is estimated to remove 2.33 m^3 or 5.69 tonnes of carbonate a year and that is the highest erosion rate recorded on coral reefs (Bellwood et al. 2003). However other herbivorous fish do not have the same effect as parrot fish, but they graze some of the algae around leaving clear substrates as areas for possible new coral larvae settlement (Soong et al. 2003). Parrot fish on Kuwait's reefs did not have selective type substrate to graze on, and were not seen feeding on the seasonal macroalgae in March and April.

Future studies should investigate the possibility of transplanting damaged large fragments of corals that have been displaced onto the sand flats especially after the dive season ends in August. Removing these colonies from sand benthic to affixing them with epoxy to the reef may increase survival rate. This procedure would contribute greatly to a reef rehabilitation scheme that management should grant. Other bioerosion effects by parrot fish (number of feeding marks m^{-2}), polychaetes and sponges that may enhance the total bioerosion rates should also be measured and quantified (number of sponges and polychaetes m^{-2}). These data would help develop a contingency plan. The sponges in the field either have a brown colour *Cliona viridis* or a yellow colour *Cliona celata* pick up possible trends in bioeroding sponge abundances and how that would impact on the carbonate balance. A bioeroding sponge that is evenly penetrating spreading into the substrate instead of making the single-cavity pattern, eroding may be to 1 cm in depth, and it has continuous tissue covering the substrate surface. Line-intercept transect surveys recorded the abundance of sponges and found them living right next to live coral tissue.

6.6. Conclusion.

Damaged coral colonies abundance and distribution was determined from the initial video surveys on the three island reefs. The degree of disturbance to Kuwait islands reefs was measured by the number of damaged coral colonies. The most recorded disturbed reef was around Umm AlMaradim, and it was significant between years. Qaru reef was found disturbed second most as it was significant between seasons and Kubbar third. The site with the most damaged coral colonies correlated with the site used by recreational boats and other anthropogenic impact e.g. the new marina, as it appeared at Umm AlMaradim was the most visited and Kubbar as second and Qaru the least visited.

CHAPTER 7; General discussion: assessing ecological changes along Kuwait's coral reefs

7.1. General discussion and aims

The aim of this chapter was to generate a general conceptual model (see Fig.7.1) leading to a management plan which would consider the future of the reef. Either the management plan can be applied to predict various scenarios or the plan will not be useable. The model will include the results from the current study of Kuwait's coral island reefs (Kubbar Qaru and Umm AlMaradim) that were surveyed between 2003 & 2005. Data that were collected to investigate changes in the benthic percentage cover, from 2 established permanent survey stations at the three sites islands over two seasons were used. It is hoped the output from the model will allow predictions to be made of the future of the reefs.

In chapter 2 a general view of the structure of the three islands coral reefs was described and quantified by mapping the reefs. The extent of the reef around each island was classified using aerial photographs and from video surveys of the reefs showing depth profiles. This was achieved by establishing two permanent marked stations at each reef. Mean live coral ranged between 39-59% on the leeward sides of the three reefs and ranged between 12-47% on the windward sides of the reef (see Table 3.4.1 in chapter 3). Therefore I concluded that the windward sides of the three reefs had less live coral cover than the leeward sides of the reefs. The observed variations between the windward with leeward sides is most likely correlated to the North easterly dominated currents (see Fig.1.1 in chapter 1) and its impact on the windward sides of the reef was more than on the leeward sides. Several investigations along the Australian Great Barrier Reef concluded that there was an effect of current flow on the Heron Island coral reef communities (Lawn and Preker 1993; Berkelmans et al. 1997; Gourlay and Jell 1997). Kuwait's island reefs were dominated by *Porites* spp., but most of it appeared dead on the surface and covered with the sea urchin *Echinometra mathaei* particularly in the reef shallows. Beside the *Porites* colonies there was a mixed assemblage of *Acropora*, *Platygyra*, *Pavona*, *Goniastrea*, and *Favides* species. Dead coral surfaces could be caused by multiple factors such as sedimentation on the coral surface or simply the most exposed surfaces died as a result of being exposed to the extensive daily sunlight or exposed during the lowest low tides with low temperatures as has been documented by Downing (Downing 1985). Early surveys of Kuwait's reefs indicated that significant periods of stress, bleaching and coral mortality occurred in 1982-83 and 1984-85, and in the winter of 1991-92 (Downing, 1985, 1989, 1992; Downing and Roberts, 1993). There was also unpublished data documenting a coral bleaching event in the summer of July 2000. In addition, Kuwait's coral reefs are known for marginal reef development, being located at high latitudes and in naturally environmentally stressed areas, where sea temperatures are cold (16° C) in winter, and very hot (36° C) during the summer, with the extensive striking sunlight which causes coral bleaching, events which often occur both during winter and summer (Downing 1985).

I have demonstrated (Chapter 5) that there is no correlation between sea urchins, coral damage and coral recruitment. It was demonstrated that the recruitment of corals onto both undamaged and damaged coral colonies indicated a wide variation in recruitment success. Both damaged and undamaged corals had newly settled recruits on their colonies. However the benthic percentage cover data detected a trend for the appearance of algae on the back reef but not on the fore reef. Because of the variation within the data the appearance of the algae could not be correlated with sea urchin abundance as might have been expected. The reason for this might perhaps be the infrequent sampling of the sites (only twice a year); more frequent sampling may have picked up short-term changes in algal cover. For example when the algae were abundant in September 2003 it is possible that the sea urchins had moved onto the coral reefs and grazed the alga fronds and then moved back to their original reef position. Therefore, it is suggested that the coral reefs should be surveyed once every month to investigate if there is variation in the number of sea urchins over short time periods which might correlate with algal cover. The data collected during my study between 2003 & 2005 (Table 7.1) can now be used as base line data with which to compare any future data collected from the coral reefs. In a model of the coral reef system the data can be treated as a negative or positive contribution to live coral cover, for example coral recruitment would be considered a positive measurement on the health of the reef, but coral bleaching would be a negative measurement of the health of the reef.

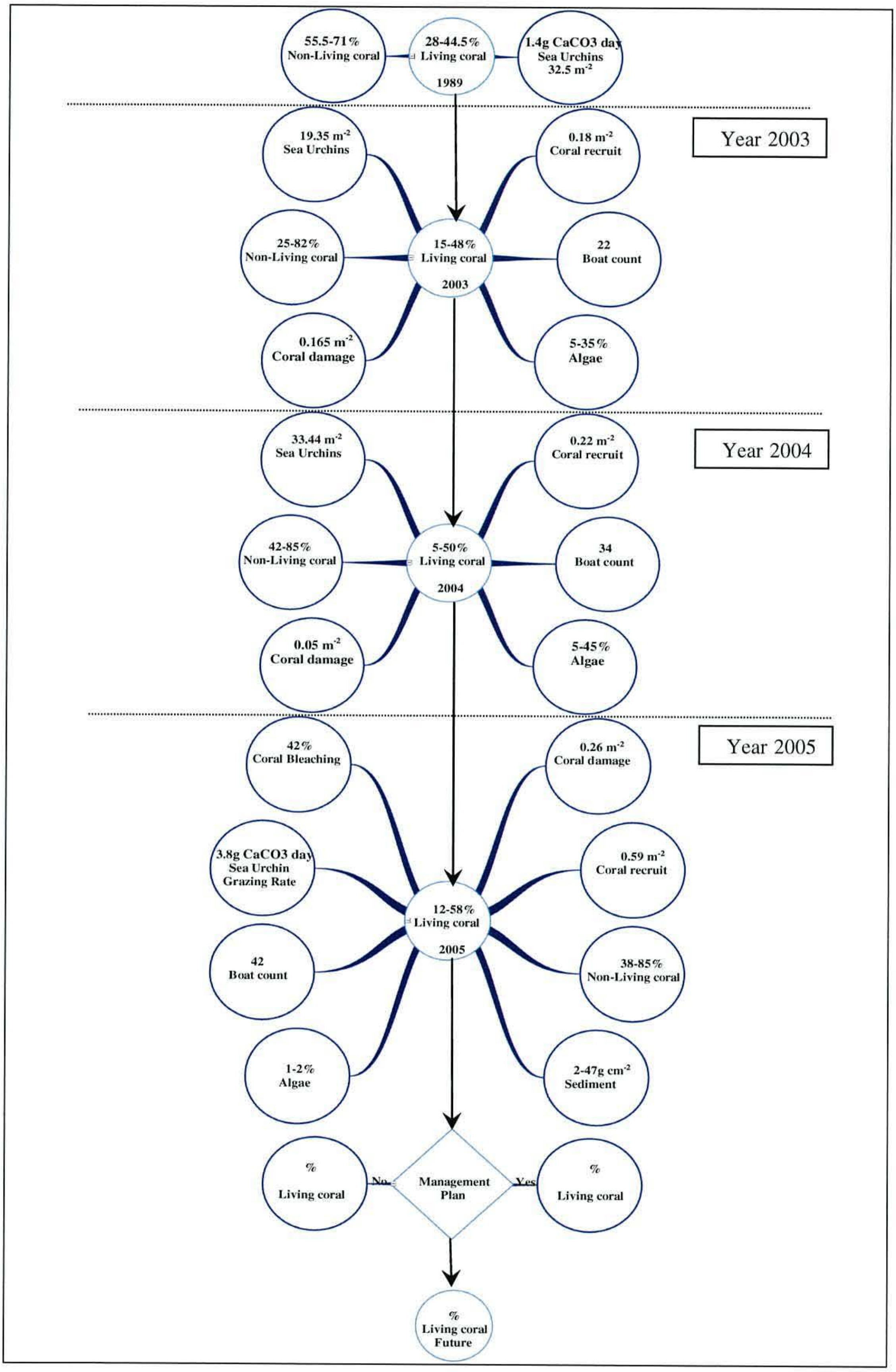

Figure 7.1. Conceptual model using data collected between 1989 & 2005 which would lead to a management plan which predicts coral reef condition in 2003, 2004 & 2005 during the 3 years of the current study.

Table 7.1. Summary of data collected on the health of a coral reef (from Downing 1989) and in October 2005 sedimentation was measured ranging from 2-47g cm^{-2} d^{-1}.

Coral reef Health	Living coral	Algae	Coral Recruit	Non living	Sea urchin	Damage	Sea urchin Grazing $CaCO_3$	Coral Bleach ing	No. of boats
1989	28–44.5	- -	- -	55.5-72	32.5	- -	1.4g day^{-1}	- -	- -
2003	15-48	5-35	0.18	25-82	19.35	0.165	- -	- -	22
2004	15-50	5-45	0.22	42-85	33.44	0.05	- -	- -	34
2005	12-58	1-2	0.59	38-85	- -	0.26	3.8g day^{-1}	42	42

The data I have collected needs to be pooled, but not so close together that there is effectively not a long history of data to form a conceptual model (e.g. Fig.7.1) (see Tanner et al. 1996). The data census interval however should also not be less than the interval between any major disturbances such as the recent construction of the new marina at Umm AlMaradim, or any other natural or anthropogenic events that have a substantial impact on the reef community. However long periods of historical data censuses are required to form a model (Tanner et al. 1996). Since my study is of comparatively short duration I can only consider a model in the form of a flow chart to illustrate the data flow. Ideally the data should be used to produce equations which can calculate data change trends so that the model can be used to predict the future reef ecosystem condition by changing one variable at a time in the model.

The data represented in the conceptual flow chart shown in figure 7.1, summarizes the available data each year including data collected by Downing in 1989 with which to compare the present study data from 2003 to 2005 (Table 7.1). The data changes through the years should give a better understanding of the value of the baseline data and lead to a management plan that is adequately supported by the available data. The flow chart also shows the consequences of considering and not considering the management plan leading to the future reef health (Fig.7.1). If the reef was to be impacted by a new development, such as the marina at Umm AlMaradim, it would be desirable to investigate how such a large perturbation would lead to changes in the short term and long term recovery of the reef and how the reef was ultimately controlled by differential rates of coral recruitment, growth, and the persistence of individual species (see Tanner et al. 1994).

The changes observed during my study were not found to be significant as the coral reefs I studied showed resilience to change. Coral growth has latitudinal limits which do not differ greatly between reefs (Johannes et al. 1983), so this factor can be used in the conceptual model of Kuwait's reefs. Linear growth of *Acropora* colonies was measured to be 145mm in two years at Heron Island reef, Australia (Hacker and Gourlay 1996). However this growth rate would have different impacts around Kuwait's reefs. Other factors such as the seasonal macroalgal development, sedimentation rates and anchorage (caused by the arrival of 34 boats, only 10 of them anchoring to a mooring buoy at each reef will damage the corals). Seasonal development of some macroalgal species in the Gulf has been considered to be sufficiently high that reef corals have become overgrown and killed by algal shading (Coles 1988).

But along Kuwait's reefs there has been no significant reduction in live coral coverage over the three years (see chapter 3). An increase in the number of boats around the coral reefs will have a negative effect on the reef through the effects that anchors will have damaging the coral colonies. The effect is illustrated by the red arrows running from 2003 to 2005 (see Fig.7.1). The increase in damaged corals did not show any correlation with the percentage algal cover as was expected since the algae covered the dead coral. However the percentage algal cover increased slightly from 35% in 2003 to 45% in 2004 but then it dropped down to 2% in 2005 possibly because of the extreme low sea water temperatures recorded during 2005. These low temperatures also caused 42% coral bleaching along the reefs and the extreme temperatures probably also depleted the algal cover at the site as illustrated by the purple arrows in figure 7.1. Gleason (1993) reported a mass coral bleaching event which began in March, 1991 on reefs in Moorea, French Polynesia and the low temperatures affected the cover of filamentous algae, much of which covered the plate-like and branching corals species that had died during the bleaching event. McClanahan (2000) reported the effects of warm El-Nino events along the Maldives Chagos reefs in the 1990s compared with studies before 1980. The event caused large losses in coral cover and the dead corals became dominated by coralline and turf algae (68%) with fleshy algae and sponges being higher in abundance than had been earlier reported (McClanahan 2000). Increases in algal cover apparently provided a food surplus for sea urchins around the reef, but his data did not support this assumption.

Sea urchin density and distribution was found to be very high (33.44 m^{-2}) and variable at the three Kuwait reefs. The black sea urchin *Echinometra mathaei* was the most abundant, the long spined sea urchin *Diadema setosum* and the pencil sea urchin *Heterocentrotus trigonarius* also occurred, but at lower numbers. The pencil sea urchin *H. trigonarius* was usually found in deeper areas, beyond the depth of the studied area (personal observations). However, the distribution trend of *D. setosum* was higher on the reef edge and decreased toward the reef flat. The distribution trend of *E. mathaei* was higher on the shallow reef and decreased towards the reef edge, especially at Umm AlMaradim. These trends had been previously observed in earlier studies on these coral reefs (Downing 1989), hence, this trend in abundance has not changed since the earlier 1980s studies.

The high densities of 33.44 m^{-2} *E. mathaei* m^{-2} along Kubbar reef contrast the previous findings by Downing (1989) that Umm AlMaradim reef hosted the highest number of sea urchins (i.e. 32.5 m^{-2}). Downing (1993) reported that the density of the sea urchin *E. mathaei* was highest at Umm AlMaradim reef and higher than at the other two reefs in 1991 and 1992 (Downing 1992; Downing and Roberts 1993). The second highest density of 21 m^{-2} *E. mathaei* was found at Kubbar reef. Furthermore, mean sea urchin percentage cover at the different reef sites in 1995 indicated that Umm AlMaradim reef also hosted the highest number of *E. mathaei*, followed by Kubbar reef (Harrison et al. 1997). High sea urchin abundances were seen on reefs close to the shore at Kubbar and Umm AlMaradim, compared with the offshore fore reef at Qaru reef. However investigations into the relationship between sea urchin abundance and coral recruitment showed there was no correlations at either of the 3 coral reefs studied (r_s =-0.035; P = 0.387 (r_s = spearman rank correlation). The correlation showed a weak negative relationship, so as sea urchin numbers increased the coral recruits decreased (as discussed in chapter 5). The mean density of 33.44 sea urchins m^{-2} showed a negative correlation with a mean of 0.59 coral recruits m^{-2} and provided an indication of coral reef degradation.

The investigated distribution and abundance of sea urchins, coral recruits and damaged coral colonies along the three coral island reefs and the benthic percentage cover data both form valuable base line data. The base line data obtained during my investigation have been used to formulate a management and protection plan suggested for the reefs maintenance and future restoration. My original tested hypothesis proposed that the dominant high abundance of the sea urchin *E. mathaei* on Kuwait's southern island coral reef ecosystems indicates that either the coral reef ecosystem is degrading due to coral erosion caused by man or by natural impacts from grazing organisms. The Kuwait reef ecosystems, however, appear to be resilient, with low live coral abundance and the recruitment of new corals neither of which appears to be affected by sea urchins abundance. It is much more likely that major anthropogenic perturbations such as human developments at Umm AlMaradim during the construction of the new marina, are much more likely to cause significant and direct damage to the coral colonies. The sea urchin *E. mathaei* is an indirect cause of coral reef damage but they apparently have little effect on Kuwait's coral reefs. The state of Kuwait's coral reef level can be considered as being healthy with the living coral percentage cover as the main factor reflecting the reefs health (Fig.7.1). The living coral percentage cover recorded varied between 28 & 44.5% in 1989 (Downing 1989) whereas 15-48% was recorded in this study in 2003, (as discussed in chapter 3) with no significant difference between 1989 and 2005.

Sea urchin abundances on the reefs close to the mainland of Kuwait are close to centres of human populations, and will be most subject to damage. A higher abundance of sea urchins might give an indication of degradation due to human and environmental impacts, for example over-fishing, boat anchor damage and temperature extremes. These kinds of reefs are threatened, since there has been an increase in scuba diving, spear-fishing and they have been more regularly visited in recent years. There has been a noticeable decrease in fish populations (personal observation) and their decrease may have failed to regulate sea urchin densities since some of these fishes feed on the sea urchins. The periodic changes in live coral cover may be a natural phenomenon but any induced pressure by humans, such as anchor damage, alters the natural balance of this ecosystem.

E. mathaei is an important contributor to the erosion (bioerosion) of coral reefs. The effects of bioerosion by sea urchins have been documented through calculations of the gut evacuation rates of 3.8 g. sea urchin^{-1} day^{-1}. Downing (1984) presented evidence on Kuwait reefs that *E. mathaei* removes a significant amount of coral material as it grazes and that they are likely to consume any settling planulae larvae.

Therefore, a low success of new coral recruits is most likely to happen in those sites where there is high sea urchin grazing activity. High densities of sea urchins and their distribution led me to examine the relationship between coral recruitment density and distribution and the presence of sea urchins. The correlation of sea urchin densities (Fig. 4.4.1) with coral recruit abundance and distribution (Fig. 5.4.1) showed there was a correlation between the September 2003 data. Even though the number of coral recruits recorded was very low at all sites, the lowest numbers were found at Umm AlMaradim and Kubbar and these numbers coincided with the highest numbers of sea urchins at station 1 on the back reef. However station 2 on the windward side of the reefs at Kubbar and Qaru showed that although these reefs had the highest sea urchin abundance, recruitment of coral colonies was almost the same along all of the three reefs. The windward side of these reefs appear to be receiving coral recruits from other patches of the coastal reefs in northern Kuwaiti waters. The reefs also receive more sedimentation, transported by the dominant currents, which then smothers the surfaces of the dominant coral species, *Porites*. The dead coral surfaces may then in turn stimulate more sea urchins to graze on the turf algae growing on the dead coral surfaces (observed personally).

The data on the number of damaged coral colonies on the windward sides of the reefs showed that none were damaged in 2003 as these are not favourable sites for recreational boats to anchor. However if boats were to anchor on the windward sides then it might be expected that damage to the colonies would be substantial from the long lines of anchors going all around the coral colonies at the anchor position (see Fig.6.3.1, in chapter 6). Most boats usually anchor on the leeward sides of the coral reefs although anchored boats were seen around the windward sides on good days especially during the diving season in the summer and at weekends all year around. Despite the anchoring of leisure boats around the reefs, sea urchin density and distribution did not correlate with damaged coral colonies (see Fig.5.4.1.in chapter 5 & Fig.6.4.1in chapter 6).

The impact of sea urchins was examined on the three reefs using strong exclusion cages and their grazing impact was estimated by calculating their gut evacuation rates. The sea urchin exclusion cages were however not successful because of the high numbers of boats anchoring in the areas around the reefs, the cages sustaining damage from the anchors. I provided evidence of the impact of the anchoring pleasure boats and noted that the number of mooring buoys were too few for the number of boats visiting each reef. For example the average number of boats recorded around the three reefs at the weekends was 42 ± 15 at Kubbar, 3 ± 2 at Qaru and 17 ± 10 at Umm AlMaradim. With only 10 mooring buoys available at each reef site there was insufficient mooring buoys around each reef. If the exclusion cages had worked then it might have been expected to highlight the impact of the sea urchins grazing on the number of coral recruits. Despite the loss of the cages, when sea urchins were removed from areas of the coral reef and transferred away to deeper sites the areas without sea urchins did not appear to be different from the areas impacted by the sea urchins grazing. The majority of damage to the reefs is probably not from sea urchin grazing but from boats anchoring along the reefs. The extent of the anchor damage could be seen from the number of damaged coral colonies which had been flipped upside down. One other possible cause of damage is that caused by divers on the reefs; recently the reefs have been receiving an increase in the number of divers around the reefs as has been seen by the increase in new certificated divers. Each year very high numbers of newly registered divers are being recorded e.g. 800 new registered divers were recorded in 2004. In view of the anchor and diver induced damage these reefs need to be continually monitored both from bioerosion and from human impacts and their effects need to be included in any reef protection and restoration plans. It is very important to quantify all bioerosion and human impact effects and continue with a regular monitoring program and implement any suggested management plans for the sustainable development of the three islands reefs as marine parks. Recovery on these reefs can then be continued to be monitored after the implementation of a management plan.

In the short-term, the reaction to the increased recreational use of the islands, has been the establishment of mooring buoys around the three island reefs. These buoys which are regularly used by visiting boats may reduce the damage from anchors. However other human impacts have recently been a problem. The marina constructed on Umm AlMaradim Island reef during the 2004 survey has had a direct effect through the physical destruction of corals due to the anchorage of large barges and building work and indirectly through increased turbidity from dredging activities around the reef. During the third year of my study, coral reef surveys at Umm

AlMaradim estimated the impact of this marina construction on the fauna of the reef. The development of the marina went ahead without any of the usual mitigation measures being taken to protect the reef. More importantly, special precautions should have been planned and implemented before any construction work proceeded near the coral reefs and this will need to be carried out in the future. The result of the marina construction was the extensive death of many coral colonies (see Fig.6.3.1 in chapter 6), and the removal of large coral colonies onto the beach where they died (see Fig.6.4.8 in chapter 6).

Coral damage was significantly different between the three reefs and years as discussed in chapter 6, and the number of boats visiting the reefs was also variable with 3 boats at Qaru reef and 22 at Kubbar in 2003 with a small increase to 20 boats at Kubbar and 2 boats at Umm AlMaradim in 2005 with no change in the number of boats at Qaru (see Table 7.1). During the marina construction at Umm AlMaradim in 2004 there was a reduction in the number of boats from 16 boats in 2003 to 2 boats (Table 7.1). The mean number of damaged coral colonies also reflected the increased boat traffic with a higher number of damaged coral colonies where boat traffic was highest (see chapter 6). However marina construction and anchor damage from visiting boats both caused damage to the coral colonies and it is difficult to distinguish which activity had the greatest effect on the coral reef. Umm AlMaradim showed a decrease in the number of damaged coral colonies and the number of boats in 2004 during the construction work, but an increase in damaged coral and number of boats after the marina construction was completed in 2005.

Future proposals have been outlined, including the need for the implementation of active restoration measures. First of all the management role of the coral reefs should be the implementation of a long-term plan for monitoring the condition of Kuwait's reef and to eventually formulate a conceptual model for these reefs. A survey of the permanent transect survey sites should be undertaken regularly, perhaps if not monthly at least twice a year during the two seasons (winter and summer). With a frequent survey in both seasons, natural events such as coral bleaching could be detected and their extent reported. The coral bleaching extent reported highlights how it is very important to understand the over all reef health and future condition of Kuwait's reefs. Such reporting of coral bleaching highlighted the event in the

Maldives (McClanahan 2000) in Mauritius (Ahamada et al. 2002) and the events have been used in a view of global warming (Hughes et al. 2003).

The current study has produced recommendations and a management plan for protecting Kuwait's coral reefs. The coral reefs of Kuwait have many values for eco-tourism and biodiversity as shown by the number of divers from local dive operation firms. The proposed management plan for protecting and restoring the coral reefs of Kuwait will help in the sustainable use of these scientifically and economically valuable resources. On the 17th of January 2002 Kuwait ratified the Convention on Biodiversity which called for the protection of coral reef habitat and species diversity. By protecting the coral reefs, Kuwait will meet its obligations to the convention and it will strengthen its position in conserving its resources for the benefit of future generations.

7.2 Recommendations for the future monitoring of Kuwait's Coral Reef Systems

Management tools and action plans are essential to help coral reef users and managers to reduce the impacts of natural environmental changes by reducing human impacts on these sensitive and valuable coral ecosystems. Hence the following measures are proposed to reduce human impacts on Kuwait's coral island reefs. There is an immediate requirement to reduce damage from anchoring, overfishing, pollution, coastal developments and other activities in order that the reefs can be given the best possible conditions for a fast recovery. My recommendations which are based on my scientific study are:

1. That the three coral islands of Kubbar, Qaru and Umm AlMaradim and the surrounding reef should be declared protected Marine Parks. This will remove fishing pressures from the reefs and reduce the effects of any direct damage to the remaining corals reefs, such as those inflicted by boat anchors, and it will encourage restoration of the normal ecological balances along the reefs; such as the recovery of the predators of sea urchins which will in turn help to increase coral recruitment along the reef.
2. To restrict boats movements in the shallow coral reef areas of the islands. The restriction area will reduce the movement of sand and its effects on corals and

avoid anchorage on the shallow reef areas. Each islands existing jetty and mooring buoys should be maintained and should only be used to access the island and the surrounding reef. The number of mooring buoys should be increased to more than double the number of buoys which exist already and they should be connected to each other to make up a reef border similar to that illustrated in the classified maps of the reefs (see chapter 2, Fig.2.3.1, Fig.2.3.2 and Fig.2.3.3) for diving operations around the reef. Permission and the issue of a permit to visit and work around the coral reefs should be compulsory if access to each island's marine park is required. In this way it will be possible to control the number of boats visiting each site each time of day, and to monitor daily the number of boats visiting each reef.

3. A monitoring program of the coral reefs should be continued using regular underwater video surveys and aerial photography. These surveys should be conducted on a regular basis such as monthly or at least twice a year covering the winter and summer seasons. The identification of all existing problems should be continued. Any changes in the "health" of these reefs should be reported immediately, such as bleaching and coral disease. Therefore, more frequent regular visits, at least once per month are desirable and encouraged.
4. It is recommended that a research facility is established by the Kuwait Institute for Scientific Research and that all experiments are supervised at each island particularly with regard to documenting any coral spawning at each reef site at each island and for regular monitoring purposes too.

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Appendix 2.1.
Ground truthing reference points as GPS co-ordinate and its conversion to decimal Y and X points at Umm AlMaradim Island in April 2005.

Reference points around on Umm AlMaradim Island				Y	X
1	28°40.765	48°39.175	On the southwest corner of the new tower fence	28.6794167	48.6529167
2	28°40.778	48°39.174	On the southeast corner of the new tower fence	28.6796333	48.6529000
3	28°40.779	48°39.163	On the northeast corner of the new tower fence	28.6796500	48.6527167
4	28°40.767	48°39.161	On the northwest corner of the new tower fence	28.6794500	48.6526833
5	28°40.820	48°39.120	On the light tower	28.6803333	48.6520000
6	28°40.714	48°39.085	On new building	28.6785667	48.6514167
7	28°40.784	48°39.094	On the northeast corner of the old tower fence	28.6797333	48.6515667
8	28°40.786	48°39.089	On the northwest corner of the old tower fence	28.6797667	48.6514833
9	28°40.782	48°39.087	On the southwest corner of the old tower fence	28.6797000	48.6514500
10	28°40.780	48°39.091	On the southeast corner of the old tower fence	28.6796667	48.6515167

Point	Lat.	Long.	depth	benthic	time		
1	28°40.879	48°38.998		Dead *Porities*		28.6813167	48.6499667
2	28°40.887	48°39.000		*Porities*		28.6814500	48.6500000
3	28°40.899	48°39.005		Dead *Porities*		28.6816500	48.6500833
4	28°40.988	48°39.011		Dead *Porities*		28.6831333	48.6501833
5	28°40.915	48°39.013		*Porities*		28.6819167	48.6502167
6	28°40.927	48°39.016		Dead *Porities*		28.6821167	48.6502667
7	28°40.940	48°39.029		Dead *Porities*		28.6823333	48.6504833
8	28°40.945	48°39.038		*Porities*		28.6824167	48.6506333
9	28°40.950	48°39.044		Sand		28.6825000	48.6507333
10	28°40.957	48°39.053		Sand		28.6826167	48.6508833
11	28°40.961	48°39.059		*Acropora*	12:01	28.6826833	48.6509833
12	28°40.968	48°39.065		Dead *Porities*		28.6828000	48.6510833
13	28°40.981	48°39.075		*Porities*		28.6830167	48.6512500
14	28°40.985	48°39.083		Sand		28.6830833	48.6513833
15	28°40.990	48°39.095		*Porities*		28.6831667	48.6515833
16	28°40.991	48°39.103		*Acropora*		28.6831833	48.6517167
17	28°40.992	48°39.116		*Acropora*		28.6832000	48.6519333
18	28°40.994	48°39.126		Sand		28.6832333	48.6521000
19	28°40.199	48°39.135		*Porities*		28.6699833	48.6522500
20	28°41.001	48°39.146		Dead *Porities*		28.6833500	48.6524333
21	28°40.999	48°39.157		Sand		28.6833167	48.6526167
22	28°40.993	48°39.168		*Porities*		28.6832167	48.6528000
23	28°40.988	48°39.176		Sand		28.6831333	48.6529333
24	28°40.981	48°39.184		*Porities*		28.6830167	48.6530667
25	28°40.973	48°39.190		Sand		28.6828833	48.6531667
26	28°40.969	48°39.192		Dead *Porities*		28.6828167	48.6532000
27	28°40.955	48°39.209		*Porities*		28.6825833	48.6534833
28	28°40.953	48°39.224		*Porities*		28.6825500	48.6537333

29	28°40.948	48°39.237	Dead *Porities*	28.6824667	48.6539500
30	28°40.939	48°39.245	Dead *Porities*	28.6823167	48.6540833
31	28°40.927	48°39.250	Dead *Porities*	28.6821167	48.6541667
32	28°40.919	48°39.253	Dead *Porities*	28.6819833	48.6542167
33	28°40.911	48°39.256	Dead *Porities*	28.6818500	48.6542667
34	28°40.904	48°39.260	Sand	28.6817333	48.6543333
35	28°40.896	48°39.266	Dead *Porities*	28.6816000	48.6544333
36	28°40.885	48°39.267	Porities	28.6814167	48.6544500
37	28°40.874	48°39.268	Dead *Porities*	28.6812333	48.6544667
38	28°40.863	48°39.274	Dead *Porities*	28.6810500	48.6545667
39	28°40.853	48°39.275	Dead *Porities*	28.6808833	48.6545833
40	28°40.845	48°39.277	*Platygyra*	28.6807500	48.6546167
41	28°40.838	48°39.281	*Porities*	28.6806333	48.6546833
42	28°40.831	48°39.285	Dead *Porities*	28.6805167	48.6547500
43	28°40.822	48°39.289	*Porities*	28.6803667	48.6548167
44	28°40.815	48°39.287	Dead *Porities*	28.6802500	48.6547833
45	28°40.808	48°39.285	Dead *Porities*	28.6801333	48.6547500
46	28°40.801	48°39.284	Dead *Porities*	28.6800167	48.6547333
47	28°40.789	48°39.285	Dead *Porities*	28.6798167	48.6547500
48	28°40.777	48°39.280	*Porities*	28.6796167	48.6546667
49	28°40.768	48°39.278	Dead *Porities*	28.6794667	48.6546333
50	28°40.759	48°39.276	Sand	28.6793167	48.6546000
51	28°40.752	48°39.274	*Porities*	28.6792000	48.6545667
52	28°40.741	48°39.272	*Porities*	28.6790167	48.6545333
53	28°40.733	48°39.271	Dead *Porities*	28.6788833	48.6545167
54	28°40.724	48°39.270	*Porities*	28.6787333	48.6545000
55	28°40.714	48°39.268	*Porities*	28.6785667	48.6544667
56	28°40.707	48°39.265	*Porities*	28.6784500	48.6544167
57	28°40.694	48°39.262	*Porities*	28.6782333	48.6543667
58	28°40.685	48°39.260	Dead *Porities*	28.6780833	48.6543333
59	28°40.675	48°39.256	Dead *Porities*	28.6779167	48.6542667
60	28°40.668	48°39.252	*Porities*	28.6778000	48.6542000
61	28°40.659	48°39.251	*Porities*	28.6776500	48.6541833
62	28°40.648	48°39.249	*Porities*	28.6774667	48.6541500
63	28°40.635	48°39.245	Dead *Porities*	28.6772500	48.6540833
64	28°40.629	48°39.244	Dead *Porities*	28.6771500	48.6540667
65	28°40.620	48°39.240	Dead Coral	28.6770000	48.6540000
66	28°40.615	48°39.237	Dead Coral	28.6769167	48.6539500
67	28°40.608	48°39.233	Dead Coral	28.6768000	48.6538833
68	28°40.598	48°39.229	Dead Coral	28.6766333	48.6538167
69	28°40.585	48°39.227	Dead Coral	28.6764167	48.6537833
70	28°40.575	48°39.224	*Acropora*	28.6762500	48.6537333
71	28°40.568	48°39.219	*Acropora*	28.6761333	48.6536500
72	28°40.557	48°39.210	*Acropora*	28.6759500	48.6535000

73	28°40.548	48°39.197	Dead Coral		28.6758000	48.6532833
74	28°40.648	48°38.946	Dead Coral		28.6774667	48.6491000
75	28°40.652	48°38.941	Dead Coral		28.6775333	48.6490167
76	28°40.665	48°38.943	Rubble		28.6777500	48.6490500
77	28°40.675	48°38.954	Dead Coral	11:52	28.6779167	48.6492333
78	28°40.708	48°38.968	Rock		28.6784667	48.6494667
79	28°40.717	48°38.971	Rock		28.6786167	48.6495167
80	28°40.725	48°38.975	Sand		28.6787500	48.6495833
81	28°40.730	48°38.976	*Acropora*		28.6788333	48.6496000
82	28°40.738	48°38.979	*Porities*		28.6789667	48.6496500
83	28°40.738	48°38.981	*Acropora*		28.6789667	48.6496833
84	28°40.752	48°38.984	*Acropora*		28.6792000	48.6497333
85	28°40.761	48°38.982	Dead *Acropora*	11:55	28.6793500	48.6497000
86	28°40.772	48°38.988	Dead *Acropora*		28.6795333	48.6498000
87	28°40.780	48°38.986	Dead *Acropora*		28.6796667	48.6497667
88	28°40.788	48°38.984	Dead *Acropora*		28.6798000	48.6497333
89	28°40.795	48°38.980	Dead *Acropora*		28.6799167	48.6496667
90	28°40.800	48°38.977	*Porities*		28.6800000	48.6496167
91	28°40.810	48°38.976	*Porities*		28.6801667	48.6496000
92	28°40.824	48°38.980	*Porities*		28.6804000	48.6496667
93	28°40.832	48°38.981	*Porities*		28.6805333	48.6496833
94	28°40.842	48°38.984	*Porities*		28.6807000	48.6497333
95	28°40.850	48°38.989	*Porities*		28.6808333	48.6498167
96	28°40.862	48°38.994	Dead *Porities*		28.6810333	48.6499000

Appendix 2.2.
Ground truthing reference points (RPs) as GPS co-ordinate and its conversion to decimal Y and X points at Qaru Island in April 2005.

Reference points around on Qaru Island				Y	X
1	28°49.027	48°46.530	On the start of the Pier on island	28.8171167	48.7755000
2	28°49.097	48°46.538	On the northeaster rock beach	28.8182667	48.7756333
3	28°49.081	48°46.623	On the beach northern of the island	28.8180167	48.7770500
4	28°49.015	48°46.613	On the start of southeast beach rock	28.8169167	48.7768833
5	28°49.004	48°46.567	On the start of southwest beach rock	28.8167333	48.7761167
6	28°49.048	48°46.556	On the bias of the flag pole	28.8174667	48.7759333
7	28°49.063	48°46.544	On the southwest corner of the building	28.8177167	48.7757333
8	28°49.070	48°46.550	On the northwest corner of the tower fence	28.8178333	48.7758333
9	28°49.078	48°46.551	On the northeast corner of the tower fence	28.8179667	48.7758500
10	28°49.060	48°46.575	On the Helicopter base on the meddle	28.8176667	48.7762500
11	28°49.098	48°46.601	On the southeast sand arch beach	28.8183000	48.7766833

Point	Lat.	Long.	depth	benthic	time		
1	28°48.907	48°46.551		*Acropora*		28.8151167	48.7758500
2	28°48.908	48°46.566		Dead *Porities*		28.8151333	48.7761000
3	28°48.908	48°46.558		*Acropora*		28.8151333	48.7759667
4	28°48.910	48°46.542		*Acropora*		28.8151667	48.7757000
5	28°48.911	48°46.592		Dead *Porities*		28.8151833	48.7765333
6	28°48.911	48°46.580		Dead *Porities*		28.8151833	48.7763333
7	28°48.912	48°46.604		Dead *Porities*		28.8152000	48.7767333
8	28°48.914	48°46.614		Dead *Porities*		28.8152333	48.7769000
9	28°48.916	48°46.624		*Acropora*		28.8152667	48.7770667
10	28°48.917	48°46.635		Dead Coral		28.8152833	48.7772500
11	28°48.918	48°46.533		*Acropora*		28.8153000	48.7755500
12	28°48.919	48°46.535		*Acropora*		28.8153167	48.7755833
13	28°48.921	48°46.645		*Acropora*	11:32	28.8153500	48.7774167
14	28°48.925	48°46.531		*Acropora*		28.8154167	48.7755167
15	28°48.930	48°46.654		Dead *Porities*		28.8155000	48.7775667
16	28°48.932	48°46.528		Dead Coral		28.8155333	48.7754667
17	28°48.934	48°46.667		Dead *Porities*		28.8155667	48.7777833
18	28°48.937	48°46.526		*Acropora*	11:36	28.8156167	48.7754333
19	28°48.938	48°46.674		*Acropora*		28.8156333	48.7779000
20	28°48.941	48°46.679		Dead Coral		28.8156833	48.7779833
21	28°48.944	48°46.519		Dead *Porities*		28.8157333	48.7753167
22	28°48.947	48°46.687		*Porities*	11:30	28.8157833	48.7781167
23	28°48.949	48°46.509		*Acropora*	11:37	28.8158167	48.7751500
24	28°48.951	48°46.501		Dead Coral		28.8158500	48.7750167
25	28°48.953	48°46.693		*Porities*		28.8158833	48.7782167
26	28°48.954	48°46.494		*Acropora*		28.8159000	48.7749000

27	28°48.957	48°46.485		*Acropora*		28.8159500	48.7747500
28	28°48.957	48°46.699		Dead *Porities*		28.8159500	48.7783167
29	28°48.960	48°46.475		*Porities*		28.8160000	48.7745833
30	28°48.962	48°46.470		Sand		28.8160333	48.7745000
31	28°48.967	48°46.712		*Porities*		28.8161167	48.7785333
32	28°48.969	48°46.474		*Porities lutea*		28.8161500	48.7745667
33	28°48.970	48°46.490		Dead Coral	11:40	28.8161667	48.7748333
34	28°48.973	48°46.485		*Porities*		28.8162167	48.7747500
35	28°48.973	48°46.716		Dead *Porities*		28.8162167	48.7786000
36	28°48.981	48°46.485		*Porities*		28.8163500	48.7747500
37	28°48.984	48°46.459		*Acropora*		28.8164000	48.7743167
38	28°48.985	48°46.483		*Acropora*		28.8164167	48.7747167
39	28°48.989	48°46.465		Dead *Porities*		28.8164833	48.7744167
40	28°48.990	48°46.721		Dead *Porities*		28.8165000	48.7786833
41	28°48.991	48°46.469		*Acropora*		28.8165167	48.7744833
42	28°48.999	48°46.725		Dead *Porities*		28.8166500	48.7787500
43	28°49.004	48°46.491		Dead *Porities*	11:46	28.8167333	48.7748500
44	28°49.006	48°46.733		Dead *Porities*		28.8167667	48.7788833
45	28°49.008	48°46.491		*Porities*		28.8168000	48.7748500
46	28°49.012	48°46.742		Dead *Porities*		28.8168667	48.7790333
47	28°49.016	48°46.505		Sand		28.8169333	48.7750833
48	28°49.017	48°46.739		*Porities*		28.8169500	48.7789833
49	28°49.020	48°46.455		Dead Coral	11:07	28.8170000	48.7742500
50	28°49.023	48°46.734		Dead *Porities*		28.8170500	48.7789000
51	28°49.030	48°46.739		Dead *Porities*		28.8171667	48.7789833
52	28°49.031	48°46.465		*Porities*		28.8171833	48.7744167
53	28°49.037	48°46.743		Dead *Porities*		28.8172833	48.7790500
54	28°49.040	48°46.467		Dead *Porities*	11:08	28.8173333	48.7744500
55	28°49.047	48°46.740		Dead *Porities*		28.8174500	48.7790000
56	28°49.048	48°46.466		Dead *Porities*		28.8174667	48.7744333
57	28°49.056	48°46.468		*Acropora*		28.8176000	48.7744667
58	28°49.056	48°46.742		Dead Coral		28.8176000	48.7790333
59	28°49.065	48°46.473		Sand	11:09	28.8177500	48.7745500
60	28°49.066	48°46.746		Dead *Acropora*		28.8177667	48.7791000
61	28°49.074	48°46.747		Dead *Acropora*	13:25	28.8179000	48.7791167
62	28°49.075	48°46.474		Sand		28.8179167	48.7745667
63	28°49.081	48°46.473		Sand		28.8180167	48.7745500
64	28°49.083	48°46.748		Dead Coral		28.8180500	48.7791333
65	28°49.091	48°46.477		Sand		28.8181833	48.7746167
66	28°49.091	48°46.743		Dead Coral	11:24	28.8181833	48.7790500
67	28°49.106	48°46.744		Sand		28.8184333	48.7790667
68	28°49.108	48°46.487	5	Sand		28.8184667	48.7747833
69	28°49.112	48°46.741		*Acropora*		28.8185333	48.7790167
70	28°49.115	48°46.492		Rubble	11:10	28.8185833	48.7748667

71	28°49.124	48°46.739	*Acropora*	11:23	28.8187333	48.7789833
72	28°49.129	48°46.506	Rubble	11:11	28.8188167	48.7751000
73	28°49.134	48°46.729	*Porities*		28.8189000	48.7788167
74	28°49.142	48°46.723	*Porities*		28.8190333	48.7787167
75	28°49.144	48°46.503	Rubble	11:12	28.8190667	48.7750500
76	28°49.152	48°46.718	Sand		28.8192000	48.7786333
77	28°49.155	48°46.495	Dead Coral		28.8192500	48.7749167
78	28°49.161	48°46.713	*Acropora*		28.8193500	48.7785500
79	28°49.168	48°46.488	*Acropora*	11:13	28.8194667	48.7748000
80	28°49.169	48°46.706	*Acropora*		28.8194833	48.7784333
81	28°49.176	48°46.489	*Porities*		28.8196000	48.7748167
82	28°49.181	48°46.702	*Porities*		28.8196833	48.7783667
83	28°49.189	48°46.492	*Porities*	11:14	28.8198167	48.7748667
84	28°49.196	48°46.495	Dead *Porities*		28.8199333	48.7749167
85	28°49.196	48°46.693	*Acropora*	11:20	28.8199333	48.7782167
86	28°49.203	48°46.682	*Acropora*		28.8200500	48.7780333
87	28°49.205	48°46.671	*Acropora*		28.8200833	48.7778500
88	28°49.207	48°46.660	*Acropora*		28.8201167	48.7776667
89	28°49.209	48°46.527	Dead *Porities*		28.8201500	48.7754500
90	28°49.210	48°46.514	Dead *Porities*		28.8201667	48.7752333
91	28°49.210	48°46.544	*Porities*	11:15	28.8201667	48.7757333
92	28°49.212	48°46.557	Dead *Porities*		28.8202000	48.7759500
93	28°49.212	48°46.635	Dead Coral		28.8202000	48.7772500
94	28°49.213	48°46.622	Dead Coral		28.8202167	48.7770333
95	28°49.213	48°46.647	Dead Coral		28.8202167	48.7774500
96	28°49.216	48°46.572	Dead *Porities*		28.8202667	48.7762000
97	28°49.217	48°46.609	Dead Coral		28.8202833	48.7768167
98	28°49.222	48°46.597	Dead *Porities*		28.8203667	48.7766167
99	28°49.227	48°46.584	Dead *Porities*		28.8204500	48.7764000

Appendix 2.3.
Ground truthing reference points (RPs) as GPS co-ordinate and its conversion to decimal Y and X points at Kubbar Island in April 2005.

Reference points around on Kubbar Island

	Lat.	Long.	Location	Y	X
1	29°04.321	48°29.540	On the southwest corner of the new tower	29.0720167	48.4923333
2	29°04.314	48°29.549	On the southeast corner of the new tower	29.0719000	48.4924833
3	29°04.321	48°29.559	On the northwest corner of the new tower	29.0720167	48.4926500
4	29°04.331	48°29.552	On the northwest corner of the new tower	29.0721833	48.4925333
5	29°04.344	48°29.548	On the northeast corner of the old tower	29.0724000	48.4924667
6	29°04.352	48°29.541	On the northwest corner of the old tower	29.0725333	48.4923500
7	29°04.344	48°29.529	On the southwest corner of the old tower	29.0724000	48.4921500
8	29°04.332	48°29.538	On the southeast corner of the old tower	29.0722000	48.4923000
9	29°04.306	48°29.565	On the light tower	29.0717667	48.4927500
10	29°04.385	48°29.548	On top of the Trig Point	29.0730833	48.4924667
11	29°04.402	48°29.471	On the northeast beach rock	29.0733667	48.4911833
12	29°04.363	48°29.445	On the med northern beach rock	29.0727167	48.4907500
13	29°04.337	48°29.436	On the northwest beach rock	29.0722833	48.4906000
14	29°04.224	48°29.515	On the southwest beach rock	29.0704000	48.4919167
15	29°04.218	48°29.555	On the med south beach rock	29.0703000	48.4925833
16	29°04.251	48°29.634	On the southeast beach rock	29.0708500	48.4939000
17	29°04.348	48°29.710	On the southeast sand arch tip	29.0724667	48.4951667

Point	Lat.	Long.	depth	benthic	time		
1	29°04.303	48°29.352	6.8	*Acropora*	12:06	29.0717167	48.4892000
2	29°04.316	48°29.362	3.5	Dead big coral	12:11	29.0719333	48.4893667
3	29°04.329	48°29.367	3	Sand	12:16	29.0721500	48.4894500
4	29°04.336	48°29.302	2.8	*Acropora*	12:19	29.0722667	48.4883667
5	29°04.345	48°29.380	3	Dead big coral	12:17	29.0724167	48.4896667
6	29°04.356	48°29.382	2.8	*Acropora*	12:19	29.0726000	48.4897000
7	29°04.366	48°29.390	2.6	Dead Coral	12:21	29.0727667	48.4898333
8	29°04.375	48°29.394	2.6	Sand	12:21	29.0729167	48.4899000
9	29°04.384	48°29.403	2.8	Dead Coral	12:22	29.0730667	48.4900500
10	29°04.392	48°29.406	3	Sand	12:24	29.0732000	48.4901000
11	29°04.397	48°29.411	3	Sand	12:24	29.0732833	48.4901833
12	29°04.405	48°29.420	3	Dead Coral	12:25	29.0734167	48.4903333
13	29°04.412	48°29.425	3	Sand		29.0735333	48.4904167
14	29°04.417	48°29.430	3	Sand	12:26	29.0736167	48.4905000
15	29°04.424	48°29.434	3	Dead Coral	12:26	29.0737333	48.4905667
16	29°04.428	48°29.438	3	Dead Coral	12:27	29.0738000	48.4906333
17	29°04.435	48°29.449	3	Sand	12:28	29.0739167	48.4908167
18	29°04.432	48°29.458	3	Dead Coral	12:29	29.0738667	48.4909667
19	29°04.438	48°29.469	2.6	Dead Coral	12:31	29.0739667	48.4911500
20	29°04.442	48°29.475	2.6	Brain coral	12:31	29.0740333	48.4912500

21	29°04.442	48°29.487	2.6	Dead Coral	12:31	29.0740333	48.4914500
22	29°04.442	48°29.493	2.6	Dead *Porities*	12:32	29.0740333	48.4915500
23	29°04.444	48°29.504	2.6	*Platigyra*	12:33	29.0740667	48.4917333
24	29°04.449	48°29.515	2.6	Dead Coral	12:34	29.0741500	48.4919167
25	29°04.450	48°29.528	2.6	*Porities*	12:34	29.0741667	48.4921333
26	29°04.450	48°29.537	2.7	Dead *Porities*	12:35	29.0741667	48.4922833
27	29°04.450	48°29.550	2.7	*Platigyra*	12:36	29.0741667	48.4925000
28	29°04.446	48°29.560	2.5	*Porities*	12:37	29.0741000	48.4926667
29	29°04.446	48°29.572	2.5	Dead *Porities*	12:38	29.0741000	48.4928667
30	29°04.445	48°29.583	2.5	*Porities*	12:38	29.0740833	48.4930500
31	29°04.443	48°29.594	2.5	Sand	12:39	29.0740500	48.4932333
32	29°04.439	48°29.604	2.5	*Porities*	12:39	29.0739833	48.4934000
33	29°04.442	48°29.618	2.5	Dead *Porities*	12:41	29.0740333	48.4936333
34	29°04.440	48°29.633	2.5	Dead *Porities*	12:42	29.0740000	48.4938833
35	29°04.434	48°29.640	2.5	Sand	12:43	29.0739000	48.4940000
36	29°04.433	48°29.652	2.5	Sand	12:44	29.0738833	48.4942000
04/03/2005							
37	29°04.461	48°29.603	1.9	Dead Coral	10:32	29.0743500	48.4933833
38	29°04.432	48°29.657		Sand	10:40	29.0738667	48.4942833
39	29°04.431	48°29.667		Sand	10:41	29.0738500	48.4944500
40	29°04.435	48°29.687		Sand	10:42	29.0739167	48.4947833
41	29°04.418	48°29.702		Sand	10:48	29.0736333	48.4950333
42	29°04.425	48°29.706		Dead Coral	10:52	29.0737500	48.4951000
43	29°04.412	48°29.718		Sand	10:54	29.0735333	48.4953000
44	29°04.408	48°29.725		Sand	10:56	29.0734667	48.4954167
45	29°04.384	48°29.758		Dead Coral	11:00	29.0730667	48.4959667
46	29°04.364	48°29.778		Dead Coral		29.0727333	48.4963000
47	29°04.144	48°29.543		Rock	11:27	29.0690667	48.4923833
48	29°04.142	48°29.531		Rock	11:29	29.0690333	48.4921833
49	29°04.138	48°29.532		Rock	11:30	29.0689667	48.4922000
50	29°04.144	48°29.514		Rock	11:31	29.0690667	48.4919000
51	29°04.150	48°29.501		Rock		29.0691667	48.4916833
52	29°04.156	48°29.491		Rock		29.0692667	48.4915167
53	29°04.160	48°29.486		*Acropora*	11:33	29.0693333	48.4914333
54	29°04.173	48°29.483		*Acropora*		29.0695500	48.4913833
55	29°04.174	48°29.458		Rock		29.0695667	48.4909667
56	29°04.189	48°29.452		Rock		29.0698167	48.4908667
57	29°04.210	48°29.768		Sand	11:11	29.0701667	48.4961333
58	29°04.202	48°29.757		*Porities*	11:12	29.0700333	48.4959500
59	29°04.192	48°29.748		Brain coral		29.0698667	48.4958000
60	29°04.188	48°29.734		Brain coral		29.0698000	48.4955667
61	29°04.185	48°29.721		Dead Coral		29.0697500	48.4953500
62	29°04.176	48°29.709		Dead Coral		29.0696000	48.4951500
63	29°04.174	48°29.698		Dead Coral		29.0695667	48.4949667

64	29º04.172	48º29.682		Dead Coral	11:17	29.0695333	48.4947000
65	29º04.167	48º29.671		Rock	11:18	29.0694500	48.4945167
66	29º04.161	48º29.662		Dead Coral	11:19	29.0693500	48.4943667
67	29º04.347	48º29.787		Dead Coral	11:03	29.0724500	48.4964500
68	29º04.338	48º29.787		*Platigyra*		29.0723000	48.4964500
69	29º04.329	48º29.791		Dead Coral		29.0721500	48.4965167
70	29º04.312	48º29.789		Dead Coral		29.0718667	48.4964833
71	29º04.300	48º29.791		Dead *Porities*		29.0716667	48.4965167
72	29º04.278	48º29.788		Dead *Porities*		29.0713000	48.4964667
73	29º04.262	48º29.787		Dead *Porities*	11:08	29.0710333	48.4964500
74	29º04.245	48º29.776		Dead *Porities*		29.0707500	48.4962667
75	29º04.228	48º29.771		Dead *Porities*		29.0704667	48.4961833
76	29º04.222	48º29.770		Dead *Porities*		29.0703667	48.4961667
77	29º04.158	48º29.648		Dead Coral		29.0693000	48.4941333
78	29º04.157	48º29.638	1.4	Dead Coral		29.0692833	48.4939667
79	29º04.155	48º29.631	1.4	Dead Coral	11:21	29.0692500	48.4938500
80	29º04.157	48º29.623		Dead Coral		29.0692833	48.4937167
81	29º04.149	48º29.613		Sand		29.0691500	48.4935500
82	29º04.154	48º29.604		Dead Coral		29.0692333	48.4934000
83	29º04.149	48º29.595		Rock		29.0691500	48.4932500
84	29º04.149	48º29.585		Rock		29.0691500	48.4930833
85	29º04.151	48º29.570		*Acropora*		29.0691833	48.4928333
86	29º04.151	48º29.565		*Acropora*		29.0691833	48.4927500
87	29º04.193	48º29.441	3	*Acropora*		29.0698833	48.4906833
88	29º04.215	48º29.423	3	Rock	11:39	29.0702500	48.4903833
89	29º04.226	48º29.416		Rock		29.0704333	48.4902667
90	29º04.240	48º29.409		Rock		29.0706667	48.4901500
91	29º04.249	48º29.410		Dead Coral		29.0708167	48.4901667
92	29º04.275	48º29.398		Rock		29.0712500	48.4899667
93	29º04.286	48º29.393	2.6	Rock		29.0714333	48.4898833
94	29º04.304	48º29.395	2.4	Rock	11:43	29.0717333	48.4899167
95	29º04.333	48º29.396	2	Rock	11:45	29.0722167	48.4899333

Appendix 2.4

Habitat descriptive information recorded in 5 m² quadrats (N = 36) at Kubbar reef in April 2005. (BC brain coral; PC *Porites* coral; A *Acropora* sp.; DC dead coral; S sand; R rubble; EU *Echinometra mathaei*; DU *Diadema setosum*)

Kubbar 36 St	Lat.	Long.	depth	BC	PC	A	DC	S	R	EU	DU	Surge Fish	Parrot Fish	m Visibility
					20		25	35		20		1		3
1	29°04.266	48°29.474	1.8		20		30	30		20				
					30		25	30		15				3
2	29°04.225	48°29.470	2	5	25		25	25		20				
				10	25		20	30		15				3
3	29°04.190	48°29.476	1.9	10	25		25	25		15				
					20		30	30		20				4
4	29°04.175	48°29.512	2		30	10	25	20		15				
				5	10	15	30	25		15				4
5	29°04.169	48°29.544	2.4	5	20	30	20	15		10				
				10		30	25	25		10		2	2	4
6	29°04.164	48°29.572	2.9	10	5	30	25	10		20				
				5	5	10	30	40		10				4
7	29°04.082	48°29.327	2.6	5	5	10	30	40		10				
					5	5	30	50		10				4
8	29°04.083	48°29.327	2.4		5	25	30	30		10			1	
					20	5	40	20		10				4
9	29°04.311	48°29.184	1.3		20	5	40	20		15				
					10		30	55		15				4
10	29°04.301	48°29.192	1.2		10		30	55		15				
					20		20	40		20				4
11	29°04.284	48°29.201	1.3		20		20	40		20				
					15		55	10		20				4
12	29°04.251	48°29.191	1.6		15		55	10		20				
					15	20	40	15		10				4
13	29°04.229	48°29.199	3.4		15	20	40	15		10				
				5	20	5	40	20		10				4
14	29°04.208	48°29.216	1.3	5	20	5	40	20		10				
					10		20	50		20				4
15	29°04.325	48°29.207	1.2		10		20	50		20				
					15		50	20		15				4
16	29°04.328	48°29.224	0.9		15		50	20		15				
					10	5	65	5		20				4
17	29°04.335	48°29.249	2		10	5	65	5		20				
				5	15	10	45	10		15				4
18	29°04.266	48°29.266	2.2	5	15	10	45	10		15				

Appendix 2.5

Habitat descriptive information recorded in 5 m² quadrats (N = 36) at Qaru reefs in April 2005. (BC brain coral; PC *Porites* coral; A *Acropora* sp.; DC dead coral; S sand; R rubble; EU *Echinometra mathaei*; DU *Diadema setosum*)

Qaru 38 St	Lat.	Long.	depth	BC	PC	A	DC	S	R	EU	DU	Surge Fish	Parrot Fish	Visibility
					10	5	40	20	5	20			2	
1	28°48.894	48°46.652	2.6	5	25	10	35	20	5	10			20	9
					15	5	55	10	10	5				
2	28°48.905	48°46.676	2.6		15	5	55	10	10	5			1	9
					5	5	5	20	10	60			2	
3	28°48.923	48°46.684	2.6		5	5	10	15	5	60			5	9
					35		45	15	5	5			5	
4	28°48.922	48°46.683	2.7	5	40	5	30	10	5	5			15	9
					10	40	20	5	15	10		5	4	
5	28°48.874	48°46.673	3.2		10	60	10	20					5	9
				5		60	15	10	5		5	4	9	
6	28°48.848	48°46.689	4.6	5	15	30	20	20			5		7	9
				5	5	45	20	20	5				7	
7	28°48.909	48°46.815	3.6	2	10	65	10	10			3		4	3.5
				25	5	15	45	10				3	2	
8	28°48.872	48°46.831	4.2	7	10	35	20	25			3		6	5
					10	10	20	35	15		10	3	2	
9	28°48.950	48°46.776	2.7	5	10	20	35	20			10		4	7
				5	20	20	40	10	5		5	5	7	
10	28°48.116	48°46.773	7.9	5	20	10	40	20			5		2	6
					10	25	40	25				5	3	
11	28°48.114	48°46.743	3.6	8	30	15	20	25			2		8	9
					5	5	60	5	20	5		7	3	
12	28°48.108	48°46.695	2.6	5	10	5	70	10		10		8		6.5
				2	10	5	18	30	35			5	2	
13	28°48.143	48°46.570	2.4	1	3	1	20		70	5			10	6.5
				5	5	45	30	10	3		2	3	2	
14	28°48.302	48°46.512	4.0	9	50	9	10		20		3		3	6.5
				2	20	25	20	20	13				3	
15	28°48.314	48°46.506	5.4	2	50	10	15		20		3		4	6.5
				3	45	2	30		5	20			1	
16	28°48.249	48°46.502	2.2	10	20		40		10	20				9
					35	10	40	5		20				
17	28°48.081	48°46.433	2.7	5	20	5	45	10		15				6.5
					10	20	45	5	22		3			
18	28°48.995	48°46.448	5.0	5	15	5	35		35				2	9
					20		65			15				
19	28°48.001	48°46.491	2.1		25		70		5	10				6.5

Appendix 2.6

Habitat descriptive information recorded in 5 m² quadrats (N = 13) at Umm AlMaradim reef in April 2005. (BC brain coral; PC *Porites* coral; A *Acropora* sp.; DC dead coral; S sand; R rubble; EU *Echinometra mathaei*; DU *Diadema setosum*)

Umm AlMaradim	Lat.	Long.	depth	BC	PC	A	DC	S	R	EU	DU	Surge Fish	Parrot Fish	Visibility
1	28°40.539	48°39.255	8.3	35	5		10	40		10				
2	28°40.566	48°39.236	3.5		10	25	20	40		5				
3	28°40.578	48°39.287	1.5	5	5	55	20	5		10				
4	28°40.600	48°39.314	2	5	20	25	20	20		10				
5	28°40.612	48°39.352	3.5		5	20	20	40		15				
6	28°40.664	48°39.405	3.5	10	5	20		40	10	15				
7	28°40.756	48°39.451	2.8			10	55	10	30	5				
8	28°40.805	48°39.431	1.5	10				80		10				
9	28°40.965	48°39.472	3.5			15		80		5				
10	28°40.029	48°39.478	4.1	10	5	20	10	5	40	5				
11	28°40.149	48°39.388	3.5	5	5	20	20	35	10	5				
12	28°40.195	48°39.208	3.5				10	25	60	5				
13	28°40.156	48°39.111	3.1	5	10	10		15	50	10				

Appendix 3.1 . SIMPER Similarity Percentages for benthic cover contributions; in 6 grouping and tables showing similarity percentage and benthic contribution in the three years factorial, and testing the data for normality first.

Standardise data: No
Transform: None
Cut off for low contributions: 90.00%

Factor groups (2003, 2004, 2005)

1. Group 2003, Average similarity: 53.98

Benthic	Ave Abund.	Ave Sim.	Sim./SD	Contrib.%	Cum.%
DC	83.79	18.44	1.45	34.17	34.17
S	51.42	12.00	2.17	22.24	56.40
P	30.17	7.63	1.88	14.13	70.53
AC	41.79	6.35	0.81	11.77	82.30
R	22.29	3.83	1.20	7.09	89.39
UE	8.96	1.30	0.63	2.41	91.81

2. Group 2004, Average similarity: 41.50

Benthic	Ave Abund.	Ave Sim.	Sim./SD	Contrib.%	Cum.%
P	32.79	7.97	2.08	19.20	19.20
DAC	63.31	7.96	0.56	19.17	38.37
DC	56.06	6.85	0.51	16.49	54.86
AC	43.06	6.82	0.86	16.42	71.29
S	35.31	5.90	0.93	14.21	85.50
R	16.35	1.81	0.61	4.36	89.86
UE	11.21	1.18	0.50	2.85	92.71

3. Group 2005, Average similarity: 63.27

Benthic	Ave Abund.	Ave Sim.	Sim./SD	Contrib.%	Cum.%
DC	85.42	19.93	2.33	31.49	31.49
S	67.63	13.94	2.37	22.03	53.52
P	54.79	11.63	1.98	18.38	71.90
AC	58.79	9.55	0.95	15.09	86.99
R	22.13	3.99	1.41	6.30	93.29

4. Groups 2003 & 2004, Average dissimilarity = 57.54

Benthic	Ave 03 Abund.	Ave 04 Abund.	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	83.79	56.06	12.28	1.48	21.35	21.35
DAC	3.75	63.31	10.68	0.88	18.56	39.91
AC	41.79	43.06	7.76	1.09	13.49	53.40
S	51.42	35.31	6.46	1.10	11.24	64.64
R	22.29	16.35	3.80	1.02	6.60	71.24
A	17.25	4.38	3.10	0.61	5.38	76.62
P	30.17	32.79	2.87	1.35	5.00	81.61
UE	8.96	11.21	2.23	1.03	3.87	85.48
DP	2.21	6.79	1.50	0.39	2.62	88.10
F	7.21	5.63	1.22	1.22	2.12	90.22

5. Groups 2003 & 2005, Average dissimilarity = 43.64

Benthic	Ave 03 Abund.	Ave 05 Abund.	Ave Diss.	Diss./SD	Contrib.%	Cum.%
AC	41.79	58.79	8.46	1.31	19.39	19.39
DC	83.79	85.42	7.77	1.44	17.79	37.18
S	51.42	67.63	6.22	1.05	14.25	51.43
P	30.17	54.79	4.93	1.39	11.30	62.73
R	22.29	22.13	3.05	1.16	7.00	69.73
A	17.25	0.00	2.74	0.55	6.28	76.00
UE	8.96	10.92	2.12	0.90	4.85	80.85
BC	4.00	7.25	1.35	0.90	3.08	83.94
F	7.21	4.42	1.09	1.25	2.51	86.44
DAC	3.75	4.63	1.02	0.70	2.33	88.77
AA	1.63	5.71	0.90	1.04	2.06	90.83

6. Groups 2004 & 2005, Average dissimilarity = 55.31

Benthic	Ave 04 Abund.	Ave 05 Abund.	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	56.06	85.42	10.73	1.68	19.39	19.39
DAC	63.31	4.63	9.83	0.87	17.78	37.17
AC	43.06	58.79	8.11	1.30	14.65	51.82
S	35.31	67.63	7.40	1.21	13.38	65.21
P	32.79	54.79	4.81	1.37	8.70	73.90
R	16.35	22.13	3.43	1.07	6.20	80.10
UE	11.21	10.92	2.43	0.89	4.39	84.50
DP	6.79	1.29	1.25	0.35	2.27	86.76
BC	1.08	7.25	1.12	0.92	2.02	88.78
F	5.63	4.42	1.01	1.09	1.83	90.61

Appendix 3.2 . SIMPER Similarity Percentages for benthic cover contributions; in 21 grouping and tables showing similarity percentage and benthic contribution in the three sites with the two station each, and testing the data for normality first.

Standardise data: No
Transform: None
Cut off for low contributions: 90.00%
Factor name: Site groups (1K, 2K, 1Q, 2Q, 1Um, 2Um)

1. Group 1K, Average similarity: 53.19

Benthic	Ave 1K Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
S	52.44	13.71	3.55	25.78	25.78
P	42.19	10.86	4.34	20.42	46.20
DC	64.13	9.10	0.77	17.10	63.30
AC	40.75	6.66	0.88	12.53	75.83
F	14.56	3.48	1.70	6.54	82.38
DAC	29.25	2.09	0.26	3.93	86.31
BC	11.63	1.66	0.85	3.13	89.43
A	22.13	1.43	0.29	2.70	92.13

2. Group 2K, Average similarity: 52.30

Benthic	Ave 2K Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
DC	91.38	19.48	1.06	37.24	37.24
P	41.81	8.38	1.68	16.02	53.26
UE	33.75	8.20	2.48	15.68	68.94
S	35.25	8.00	1.26	15.29	84.23
DAC	59.69	3.28	0.23	6.28	90.51

3. Group 1Q, Average similarity: 55.72

Benthic	Ave 1Q Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
DC	74.38	13.35	1.08	23.96	23.96
P	43.06	9.62	3.57	17.27	41.23
AC	46.69	8.34	1.20	14.96	56.19
S	37.94	7.52	1.87	13.49	69.68
R	31.25	5.67	1.45	10.17	79.86
DAC	28.69	2.40	0.29	4.31	84.16
F	7.94	1.74	2.36	3.13	87.29
PSC	9.69	1.74	1.39	3.13	90.42

4. Group 2Q, Average similarity: 51.29

Benthic	Ave 2Q Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
DC	96.56	20.63	1.03	40.23	40.23
P	35.94	9.07	2.21	17.69	57.92
AC	35.31	7.85	2.10	15.31	73.22
S	37.56	6.67	0.94	13.00	86.23
DAC	35.88	2.68	0.31	5.23	91.46

5. Group 1Um, Average similarity: 63.05

Benthic	Ave 1Um Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
AC	79.63	21.15	4.76	33.54	33.54
P	41.25	11.10	3.65	17.60	51.13
DC	63.31	11.07	0.91	17.55	68.69
S	28.06	5.42	1.12	8.59	77.28
R	22.81	4.83	1.71	7.66	84.94
UE	14.75	3.33	2.00	5.28	90.23

6. Group 2Um, Average similarity: 49.17

Benthic	Ave 2Um Abundance	Ave Sim.	Sim./SD	Contrib.%	Cum.%
S	93.25	19.62	1.29	39.90	39.90
AC	67.50	8.53	0.54	17.34	57.24
R	35.56	5.63	0.91	11.45	68.69
DC	32.25	5.30	0.92	10.78	79.47
P	21.56	3.66	1.26	7.44	86.91
DAC	18.69	3.39	0.78	6.90	93.81

7. Groups 1K & 2K, Average dissimilarity = 56.97

Benthic	Ave 1K Abundance	Ave 2K Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DAC	29.25	59.69	12.03	0.83	21.11	21.11
DC	64.13	91.38	11.86	1.37	20.82	41.93
AC	40.75	10.19	5.91	1.16	10.37	52.30
UE	0.44	33.75	5.51	2.08	9.68	61.98
S	52.44	35.25	4.03	1.37	7.08	69.06
P	42.19	41.81	4.03	1.32	7.08	76.13
A	22.13	1.19	3.70	0.60	6.49	82.62
F	14.56	3.00	2.00	1.86	3.52	86.14
BC	11.63	2.44	1.76	0.98	3.08	89.22
R	5.56	8.25	1.29	1.07	2.27	91.49

8. Groups 1K & 1Q, Average dissimilarity = 48.10

Benthic	Ave 1K Abundance	Ave 1Q Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	64.13	74.38	10.01	1.36	20.81	20.81
DAC	29.25	28.69	7.29	0.84	15.15	35.97
AC	40.75	46.69	6.24	1.42	12.97	48.93
R	5.56	31.25	4.25	1.27	8.83	57.77
S	52.44	37.94	4.15	1.41	8.64	66.40
A	22.13	8.63	4.06	0.75	8.45	74.85
P	42.19	43.06	3.09	1.19	6.43	81.28
BC	11.63	3.31	1.74	0.99	3.61	84.89
F	14.56	7.94	1.44	1.66	2.99	87.88
PSC	6.25	9.69	1.07	1.20	2.22	90.10

9. Groups 2K & 1Q, Average dissimilarity = 55.63

Benthic	Ave 2K Abundance	Ave 1Q Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DAC	59.69	28.69	11.81	0.84	21.23	21.23
DC	91.38	74.38	10.20	1.27	18.34	39.58
AC	10.19	46.69	6.24	1.25	11.22	50.80
UE	33.75	0.00	5.46	2.07	9.82	60.62
P	41.81	43.06	4.24	1.25	7.61	68.23
R	8.25	31.25	3.96	1.19	7.12	75.36
S	35.25	37.94	3.88	1.51	6.98	82.34
PSC	0.63	9.69	1.47	1.35	2.64	84.97
A	1.19	8.63	1.39	0.72	2.50	87.48
UD	1.56	9.00	1.33	1.08	2.38	89.86
AA	3.25	7.13	1.11	1.01	1.99	91.85

10. Groups 1K & 2Q, Average dissimilarity = 54.04

Benthic	Ave 1K Abundance	Ave 2Q Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	64.13	96.56	12.78	1.36	23.65	23.65
DAC	29.25	35.88	8.52	0.84	15.77	39.42
AC	40.75	35.31	5.62	1.42	10.41	49.83
S	52.44	37.56	5.42	1.65	10.04	59.87
A	22.13	3.13	3.87	0.64	7.17	67.03
DP	0.00	20.44	3.43	0.56	6.35	73.38
P	42.19	35.94	3.01	1.29	5.57	78.95
F	14.56	0.13	2.43	2.12	4.49	83.45
BC	11.63	0.19	1.93	0.99	3.57	87.02
R	5.56	12.25	1.82	1.03	3.36	90.38

11. Groups 2K & 2Q, Average dissimilarity = 52.31

Benthic	Ave 2K Abundance	Ave 2Q Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DAC	59.69	35.88	12.79	0.83	24.46	24.46
DC	91.38	96.56	11.37	1.26	21.73	46.19
S	35.25	37.56	5.14	1.60	9.82	56.00
UE	33.75	7.88	4.65	1.60	8.89	64.89
AC	10.19	35.31	4.53	1.24	8.66	73.55
P	41.81	35.94	4.20	1.27	8.02	81.57
DP	2.19	20.44	3.65	0.62	6.98	88.54
R	8.25	12.25	1.78	1.09	3.40	91.94

12. Groups 1Q & 2Q, Average dissimilarity = 51.55

Benthic	Ave 1Q Abundance	Ave 2Q Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	74.38	96.56	11.24	1.31	21.80	21.80
DAC	28.69	35.88	8.20	0.83	15.91	37.71
AC	46.69	35.31	5.30	1.31	10.29	48.00
S	37.94	37.56	4.97	1.47	9.64	57.64
R	31.25	12.25	3.94	1.19	7.63	65.28
DP	0.13	20.44	3.36	0.56	6.53	71.81
P	43.06	35.94	3.35	1.21	6.49	78.30
A	8.63	3.13	1.51	0.82	2.93	81.22
PSC	9.69	0.88	1.46	1.32	2.84	84.06
UD	9.00	0.63	1.40	1.10	2.72	86.78
UE	0.00	7.88	1.31	0.72	2.54	89.32
F	7.94	0.13	1.26	2.06	2.45	91.77

13. Groups 1K & 1Um, Average dissimilarity = 49.24

Benthic	Ave 1K Abundance	Ave 1Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	64.13	63.31	9.84	1.35	19.98	19.98
AC	40.75	79.63	7.86	1.50	15.97	35.96
DAC	29.25	30.31	7.36	0.85	14.96	50.91
S	52.44	28.06	4.69	1.54	9.52	60.43
A	22.13	2.63	3.75	0.63	7.61	68.04
R	5.56	22.81	3.06	1.42	6.21	74.25
P	42.19	41.25	2.48	1.36	5.03	79.28
UE	0.44	14.75	2.35	1.79	4.77	84.05
BC	11.63	0.75	1.83	0.98	3.72	87.77
F	14.56	6.94	1.54	1.52	3.13	90.90

14. Groups 2K & 1Um, Average dissimilarity = 53.72

Benthic	Ave 2K Abundance	Ave 1Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DAC	59.69	30.31	11.82	0.82	21.99	21.99
AC	10.19	79.63	11.39	2.42	21.20	43.19
DC	91.38	63.31	10.65	1.37	19.83	63.02
P	41.81	41.25	3.86	1.36	7.18	70.21
S	35.25	28.06	3.83	1.45	7.13	77.34
UE	33.75	14.75	3.35	1.29	6.24	83.58
R	8.25	22.81	2.75	1.29	5.12	88.70
AA	3.25	7.00	0.98	1.54	1.82	90.52

15. Groups 1Q & 1Um, Average dissimilarity = 44.19

Benthic	Ave 1Q Abundance	Ave 1Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	74.38	63.31	8.76	1.35	19.82	19.82
DAC	28.69	30.31	7.10	0.85	16.07	35.88
AC	46.69	79.63	6.95	1.38	15.74	51.62
S	37.94	28.06	3.84	1.45	8.70	60.32
R	31.25	22.81	3.26	1.18	7.37	67.68
P	43.06	41.25	2.91	1.25	6.58	74.26
UE	0.00	14.75	2.37	1.82	5.37	79.63
A	8.63	2.63	1.48	0.77	3.34	82.97
PSC	9.69	3.06	1.32	1.26	2.99	85.97
UD	9.00	3.19	1.23	1.06	2.79	88.76
AA	7.13	7.00	1.09	1.27	2.46	91.22

16. Groups 2Q & 1Um, Average dissimilarity = 49.36

Benthic	Ave 2Q Abundance	Ave 1Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	96.56	63.31	11.72	1.40	23.74	23.74
DAC	35.88	30.31	8.21	0.82	16.63	40.36
AC	35.31	79.63	7.95	1.57	16.10	56.46
S	37.56	28.06	5.03	1.48	10.20	66.66
DP	20.44	1.31	3.51	0.60	7.12	73.78
R	12.25	22.81	2.80	1.28	5.67	79.45
P	35.94	41.25	2.73	1.30	5.52	84.97
UE	7.88	14.75	2.16	1.62	4.37	89.34
F	0.13	6.94	1.13	1.45	2.30	91.64

17. Groups 1K & 2Um, Average dissimilarity = 61.38

Benthic	Ave 1K Abundance	Ave 2Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
AC	40.75	67.50	11.16	1.35	18.18	18.18
S	52.44	93.25	9.83	1.47	16.02	34.20
DC	64.13	32.25	9.27	1.20	15.10	49.30
DAC	29.25	18.69	6.40	0.96	10.43	59.73
R	5.56	35.56	5.33	1.03	8.68	68.41
P	42.19	21.56	4.73	1.70	7.71	76.12
A	22.13	1.31	3.77	0.60	6.15	82.26
F	14.56	1.75	2.20	1.94	3.59	85.85
BC	11.63	1.81	1.84	0.96	2.99	88.85
GN	0.00	7.88	1.29	0.91	2.10	90.95

18. Groups 2K & 2Um, Average dissimilarity = 67.85

Benthic	Ave 2K Abundance	Ave 2Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	91.38	32.25	12.97	1.56	19.11	19.11
S	35.25	93.25	11.30	1.49	16.66	35.77
DAC	59.69	18.69	11.25	0.79	16.58	52.35
AC	10.19	67.50	11.05	1.03	16.28	68.63
R	8.25	35.56	5.14	1.01	7.57	76.20
P	41.81	21.56	5.11	1.24	7.54	83.73
UE	33.75	6.63	4.65	1.59	6.86	90.59

19. Groups 1Q & 2Um, Average dissimilarity = 59.81

Benthic	Ave 1Q Abundance	Ave 2Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
S	37.94	93.25	10.99	1.43	18.38	18.38
AC	46.69	67.50	10.92	1.44	18.25	36.63
DC	74.38	32.25	9.40	1.54	15.71	52.34
DAC	28.69	18.69	6.15	0.96	10.28	62.62
R	31.25	35.56	5.05	1.21	8.44	71.06
P	43.06	21.56	4.75	1.44	7.94	79.00
UD	9.00	0.25	1.45	1.12	2.42	81.42
PSC	9.69	1.56	1.44	1.30	2.41	83.83
A	8.63	1.31	1.43	0.72	2.39	86.22
GN	0.00	7.88	1.26	0.91	2.11	88.33
AA	7.13	0.56	1.12	0.91	1.88	90.20

20. Groups 2Q & 2Um, Average dissimilarity = 63.66

Benthic	Ave 2Q Abundance	Ave 2Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
DC	96.56	32.25	14.11	1.54	22.17	22.17
S	37.56	93.25	11.90	1.46	18.70	40.87
AC	35.31	67.50	11.25	1.38	17.68	58.54
DAC	35.88	18.69	7.33	0.86	11.52	70.06
R	12.25	35.56	5.17	1.03	8.11	78.17
P	35.94	21.56	4.30	1.58	6.76	84.93
DP	20.44	1.56	3.64	0.59	5.71	90.64

21. Groups 1Um & 2Um, Average dissimilarity = 56.12

Benthic	Ave 1Um Abundance	Ave 2Um Abundance	Ave Diss.	Diss./SD	Contrib.%	Cum.%
S	28.06	93.25	11.90	1.52	21.20	21.20
AC	79.63	67.50	11.57	2.01	20.62	41.82
DC	63.31	32.25	8.55	1.39	15.24	57.05
DAC	30.31	18.69	5.97	0.97	10.65	67.70
R	22.81	35.56	4.69	1.14	8.35	76.05
P	41.25	21.56	4.62	1.93	8.23	84.29
UE	14.75	6.63	1.56	1.13	2.78	87.07
GN	0.00	7.88	1.28	0.91	2.28	89.35
AA	7.00	0.56	1.11	1.65	1.98	91.33

Appendix 3.3 . ANOSIM, Analysis of Similarities in percentages for benthic cover, two-way crossed analysis.
Factor: Year (2003, 2004, 2005)
Factor: Site (1K, 2K, 1Q, 2Q, 1Um, 2Um)

Tests for differences between year groups, (averaged across all Site groups)

Sample statistic (Global R): 0.14
Significance level of sample statistic: 0.9%; (P>5%, there is no significant difference between groups)
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 8

1. Pairwise Tests

Groups	R Statistic	Significance Level %
03, 04	0.142	2.1
03, 05	0.451	0.3
04, 05	0.102	7.2

Tests for differences between site groups, (averaged across all year groups) Global Test

Sample statistic (Global R): 0.417
Significance level of sample statistic: 0.1%; (P<5%, there is a significant difference between groups)
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

2. Pairwise Tests

Groups	R Statistic	Significance Level %
1K, 2K	0.481	0.2
1K, 1Q	0.25	1.9
1K, 2Q	0.511	0.1
1K, 1Um	0.481	0.1
1K, 2Um	0.512	0.1
2K, 1Q	0.51	0.3
2K, 2Q	0.343	1.3
2K, 1Um	0.44	0.2
2K, 2Um	0.375	0.1
1Q, 2Q	0.499	0.2
1Q, 1Um	0.361	0.9
1Q, 2Um	0.492	0.1
2Q, 1Um	0.394	0.4
2Q, 2Um	0.288	1.1
1Um, 2Um	0.366	0.1