Khaled bin Sultan Living Oceans Foundation

Habitat Mapping and Characterization of Coral Reefs of the Saudi Arabian Red Sea

2006-2009

Final Report

Part II

Ras Qisbah, Al Wajh, Yanbu, Farasan Banks and Farasan Islands

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Front cover: Close-up of a colony of *Acropora* spp. in Al Wajh Bank. Photo by Andrew Bruckner

Back cover: Hemispherical colony of *Lobophyllia corymbosa* surrounded by shingle-like plates of *Hydnophora exesa*. Reef slope community in the Farasan Banks. Photo by Andrew Bruckner

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Executive Summary

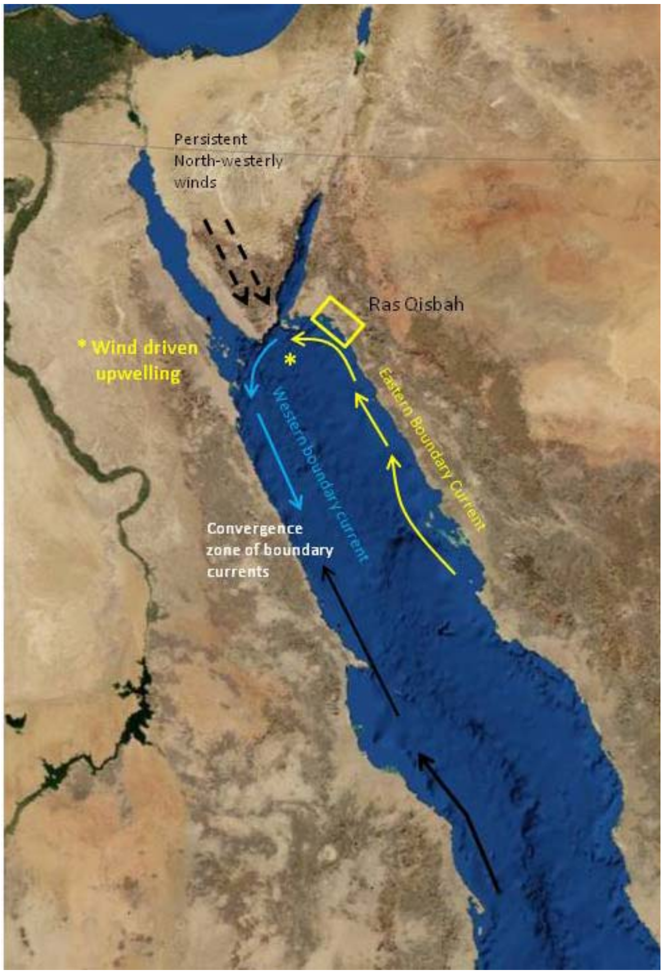
The Khaled bin Sultan Living Oceans Foundation implemented four research missions in the Saudi Arabian Red Sea from 2006-2009 using the M/Y Golden Shadow as a research platform. The research was undertaken to improve the understanding of the spatial distribution, size and condition of shallow marine habitats, and to identify options to enhance the conservation and management of Saudi Arabian coral reef ecosystems. The research focused on three priorities: 1) characterization and mapping of shallow marine habitats off the Saudi Arabian Red Sea coastline; 2) assessment of the composition, population structure, cover and health of key reef species, including stony corals and soft corals, algae, and fishes; and 3) characterization of past impacts, patterns of recovery, ongoing stressors, and resilience indicators. Products generated by this research include the *Khaled bin Sultan Living Oceans Foundation Atlas of Shallow Marine Habitat in the Saudi Arabian Red Sea*, a hardcover book containing the habitat maps and digital copies of the maps in HTML format; a Geographic Information System (GIS) database containing the satellite imagery, bathymetric maps, habitat maps and additional data layers including coral reef data, photographs, and videos; the *Coral Reef Conservation in the Red Sea* Symposium, held in January 2012 in Jeddah; a movie on the Farasan Islands; numerous scientific presentations and publications; three Ph.D. theses; and an upcoming hardcover book on coral reefs in the Red Sea entitled "*Conservation of Coral Reef Ecosystems of the Saudi Arabian Red Sea*".

QuickBird multispectral satellite imagery (DigitalGlobe Inc.) was acquired for 25,000 km^2 of coastal and offshore marine habitats in the Saudi Arabian Red Sea, from the shoreline to depths of 20-30 m, extending up to 100 km offshore. Satellite imagery was supplemented with hyperspectral imagery in the Farasan Islands (3200 km^2) and Al Wajh lagoon (approximately 2000 km^2). Groundtruthing efforts used to classify habitats covered 19,754 sq km, with 2,711,893 depth soundings, 3530 groundtruth points and 14.7 hours of video footage. The resulting habitat maps subdivide shallow marine areas into 12-15 distinct marine habitat types, to depths of 20-30 m, including specific reef environments, grassbeds, mangroves, algal flats, and sand-bottom communities. Detailed SCUBA assessments, including photo-transects, quantitative belt transects to characterize coral population structure, recruitment, mortality and health and fish diversity, abundance and biomass, and assessments of over 50 biological, ecological, and physical resilience parameters were completed in 128 locations. In each location, the coral reef community structure was characterized. This included quantification of 1) the diversity, abundance, and size structure of corals; numbers of coral recruits; condition of corals; and threats affecting corals; 2) population dynamics of reef fishes, with emphasis on abundance and size structure of ecologically-relevant and commercially important fishes, and fisheries impacts; and 3) the identification of Red Sea indicators of resilience on a landscape scale, including the spatial distribution of factors that promote and degrade resilience; ecological areas that exhibit high resilience; and major factors that degrade resilience of these ecosystems. Recommendations on conservation actions for each region are presented.

Coral reefs off the Saudi Arabian Red Sea coastline are unique and include many different reef structures, including some found nowhere else on the planet. These ranged in condition from excellent to poor. There were many sites that were fully live, with a high diversity of corals, high living coral cover, low levels of macroalgae and pest species, and flourishing communities of reef fishes and motile invertebrates. Such sites were represented in offshore locations on the Yanbu *Little Barrier Reef*, the Al Wajh barrier reef system, midshelf bank reefs and offshore tower reefs in the Farasan Banks, and bank reef systems in the northwestern end of the Farasan Islands, seaward of the major islands. There were also nearshore locations in Al Wajh and the Farasan Banks that were highly turbid, but still contained flourishing coral communities (e.g *Acropora* thickets in shallow habitats). Environmental conditions in these locations (e.g. turbidity) may have lessened bleaching impacts during periods of unusually high seawater temperatures, and their location may have protected them from devastation by crown of thorns (COTs, *Acanthaster*) seastars, two of the greatest natural stressors affecting reefs in other locations in the Red Sea. There is evidence of several large scale mortality events that were clearly visible in all regions examined. This includes the 1998 thermal anomalies and subsequent bleaching event, localized recent bleaching events, and outbreaks of coral-eating predators (COTs seastars and *Drupella* gastropods). In disturbed locations, few large corals survived; high numbers of dead corals in growth position were noted and remaining live colonies were greatly reduced in size due to partial mortality. Often, the underlying framework was undergoing regeneration, with many early colonizing species occurring on dead corals. In some locations (especially the Farasan Banks), sites that appeared largely dead had unusually high numbers of coral recruits. These were surviving and rapidly growing, even in areas with dense carpets of macroalgae, turf algae and soft corals. Other sites, especially in Ras Qisbah, were of more concern, as dead corals were common, recruitment was fairly low, and recovery was limited to isolated reefs located near channels. While human impacts associated with pollution, sedimentation, and development were apparent only in a few locations (e.g. nearshore areas in the Farasan Islands and Yanbu), the greatest direct human impact appears to be unsustainable fishing pressure. Sharks, large groupers and other top predators were absent, or of a very small size (juveniles and subadults); commercially important lobsters, giant clams, sea cucumbers and other high value fisheries species were also uncommon, or populations were dominated by small individuals or non-preferred species. Herbivorous fishes were usually abundant and diverse, although these were also predominantly small (< 30 cm total length) and dominated by juveniles and sub-adults. Nuisance species were low in most locations, with exception of certain boring and encrusting sponges that were overgrowing corals, higher macroalgal cover in southern locations, and high numbers of *Drupella* molluscs and COTs seastars on certain reefs in Yanbu, Al Wajh, the Farasan Banks and the Farasan Islands. Bleaching was rarely observed (isolated corals) during this study.

The Farasan Islands. The extensive system of banks in the northwest Farasan Islands contained many unique and highly productive shallow marine habitats. The coral reefs vary from high coral cover, *Acropora*-dominated and massive *Porites*-dominated systems, to low cover rubble and sand environments with isolated corals. Reefs located at the seaward extent of the Farasan Islands system, offshore (west and northwest) from the largest emergent islands, have extensive, diverse and healthy coral reefs. These provide the best high-relief habitat for associated fishes and invertebrates, and appear to have the highest resilience. Most of the best sites, with the highest living coral cover, were located to the west and northwest of Farasan Kabir, especially those sites on Al Baghlah Bank, Massad Island, Shuma and Lajhan. They are located far enough offshore that siltation from terrestrial areas is minimal, and water clarity is much higher than nearshore habitats. In contrast, reefs off the main islands, including Zufaf Island and Dushuk Island were much more degraded. These sites had higher abundances of soft corals, encrusting and bioeroding sponges, macroalgae and cyanobacteria, all of which may be signs of nutrient loading and/or reduced herbivory. While many sites showed signs of a previous disturbance, as evidenced by extensive rubble and dead coral, and colonization by early recruiting soft corals, the high proportion of small colonies throughout these disturbed sites is indicative of recent successful recruitment events and progressive regeneration. Fish communities formed three distinct groupings, outer reefs, back islands and front islands, with the highest diversity and biomass occurring on outer reefs at the northwest end of the bank system. Although reef fish populations were diverse, they showed signs of stress from fishing pressure, with significantly lower diversity and biomass than that seen in the Farasan Banks. This included a lack of large predators, a low abundance of herbivores, high numbers of juvenile and subadult fishes, and a dominance by small omnivores, especially damselfishes. Two key measures to protect Farasan Islands reefs and promote high resilience are: 1) expansion of the Farasan Islands MPA to encompass the offshore reef systems currently outside the park boundaries; 2) new fishery measures that limit the take of reef-associated species, especially herbivores and top predators, within these important reef habitats.

Ras Qisbah. Coral reefs examined in the Al Farshah region of Ras Qisbah exhibited a moderate diversity of coral species, few active diseases or signs of predation, and low levels of recent tissue mortality, but living coral cover was generally low, and long-dead corals were common. The region has been subject to several episodes of mass mortality in the last decades. Evidence for this include a coral community dominated by small colonies, larger colonies containing extensive patches of previously denuded skeleton atop extensive dead coral frameworks, high cover of early colonizing soft corals, and large areas of uncolonized reef framework. The resilience of the region may be somewhat lower than the nearby reefs in the Tiran area of Ras Qisbah (to the West). Unlike the areas examined in this study, reefs in the Tiran area have been minimally affected by coral bleaching primarily because the area is exposed to upwelling of cool deep waters driven by year-round winds blowing offshore out of the north-west (Fig. 1). Geographically, the area examined should also experience upwelling. However, the Eastern Boundary Current flowing northwards up the Saudi coastline serves to suppress the wind-driven



upwelling. One consequence is that the corals in the area are exposed to positive temperature excursions without the protective buffering afforded by cool upwelling. Mortality will therefore be higher than expected during periods of unusual thermal anomalies, and more severe than the relatively more healthy neighboring Tiran area of the Sinai Peninsula. The richest coral cover and diversity remains in areas near channels, as tide-driven flow through restricted channels promotes flushing. These areas would benefit from protection from human activities, especially fishing, as they may provide an important source of larvae necessary to reseed degraded reefs.

Fig. 1. Current and wind direction in the northern red Sea. Currents move away from the coast near Ras Qisbah, with upwelling (*) occurring west of study site.

Al Wajh: Al Wajh bank is one of the largest shallow marine environments in the Saudi Arabian Red Sea, containing a large (>1400 sq km) central lagoon, an elongate barrier reef, islands and associated reef formations, and numerous associated grassbeds, mangroves, and algal communities that are integrally linked to the reef systems. The best developed reefs were located on the barrier reef and in reticulate reef systems at the southern end, where 52 genera of corals were documented. A large platform within the lagoon also supports healthy coral reef communities. As in other locations, the framework consisted of columnar *Porites*, and this genus was often the dominant live taxon, followed by *Acropora*, *Millepora*, *Montipora*, *Goniastrea*, *Favia*, *.Pocillopora*, *Stylophora* and *Echinopora*, respectively. The highest coral cover occurred in the shallow reef crest and fore reef on the outer barrier reef (1-5 m depth; 30-70%). Dense *Acropora* thickets were also identified on shallow inner patch reefs in the northern sector (1-3 m depth, 50-80% cover), in very turbid water. Moderate cover was observed at mid depths (7-12 m depth; 20-30%) and low cover at the base of the reef slope (<5-30%) on outer sites. Many patch reefs and fringing reefs located within the lagoon experienced several major recent disturbances and had low cover (0-5%). The framework in these areas was mostly dead, and it had been colonized by massive, plating and branching corals that had also subsequently died; surviving corals were small, with a high proportion of larger colonies that were reduced to small tissue remnants. The one exception was those reefs located near channels, possibly due to greater flushing of lagoonal waters which helped maintain cooler temperatures. In areas showing regeneration, small colonies of massive corals (*Goniastrea* and *Echinopora*) and branching corals (*Pocillopora* and *Acropor*a) were abundant. In all nearshore and lagoonal sites reef fish communities were depauperate; there was a notable absence of top predators, and most other species occurred in low numbers and were of a small size. Fish communities in offshore barrier reef locations were richer, and included many commercially-important groupers, occasional sharks, snappers, wrasse and other species, although these were also usually juveniles and subadults (< 30 cm total length). A management program that would help conserve Al Wajh reef systems would include establishment of MPAs on the outer barrier reef, and new fishery measures that regulate the use of fish traps, protect populations of herbivores, and limit the take of predators, especially species that may control populations of lower trophic organisms (e.g. COTs and *Drupella*) that are destructive to coral communities. The Al Wajh region also exhibits a high potential for disturbances from climate change, due to the shallow, calm lagoonal habitats that heat up during periods of unusual thermal anomalies. Elimination of human stressors and protection through designation as a network of no-take MPAs can help promote the survival of the reef communities, by enhancing recovery rates from past disturbance events and ensuring that communities resist degradation during future sea water warming events.

Yanbu: The Yanbu region is a unique area, in having both extensive shallow coastal marine habitats with large stands of mangroves and submerged grassbeds and a complex offshore barrier reef system separated from nearshore habitats by a major shipping channel. The distribution of corals on these reef systems was extremely patchy, with a dominance of small corals (up to 20 cm diameter), except for the offshore locations where large colonies of *Porites, Acropora, Favia stelligera, Lobophyllia* and other species were abundant. The best reefs, in terms of high cover of corals, were offshore locations at the northern end of Yanbu. In these areas, the major functional groups of corals included unusually large, massive *Porites* colonies, thickets of branching *Acropora*, and dense assemblages of table acroporids. In contrast, many inner, central and southern locations show signs of extensive die-offs of corals, including the *Porites* framework and corals that subsequently settled on the dead *Porites* skeletons. These areas tended to have fewer large corals, most of which were found in very shallow water. They also had a high abundance of small faviids and small colonies of other species on inner reefs. The variation in size structure of live corals between reefs and the patchy distribution of intact dead corals suggest that these reefs may have been affected by diseases, predator outbreaks, and other factors, while temperature-related bleaching was less of a cause for the widespread mortality. While nearshore reefs, and reef systems located adjacent to the shipping channel are most likely to experience impacts from human stressors, including marine pollution and grounding, land-based pollution, and sedimentation, Yanbu's barrier reef system exhibits many factors that promote high resilience. These sites had high topographic complexity, strong currents and wave energy, minimal ponding and pooling of water, lower temperature extremes than Al Wajh, and shading by reef structures associated with north/south direction of growth of the reef system.

Yanbu's barrier reef system, especially the outer, offshore reefs and the northern end of the system should be considered for protection as no-take MPAs, as these reefs may provide an important source of larvae to inner reefs and reef systems to the north. Economic impacts of this measure are likely to be minimal, as fishing is already prohibited in areas near the shipping channel and few offshore areas have island masses large enough to support development. Conservation efforts designed to reduce human impacts associated with land-based activities, including industrial expansion in coastal areas, pollutant discharges and run-off, and destruction of nearshore grassbed and mangrove habitats would enhance the resilience of nearshore and central coral reef communities and protect critical nursery areas. Care must also be taken to minimize the potential for ship strikes, groundings and anchoring on reef structures near the shipping channel as these areas are most vulnerable to physical impacts. Offshore locations used by recreational dive operators would benefit from the installation of moorings at preferred dive locations.

The Farasan Banks The Farasan Banks support more diverse reef systems than anywhere else in the Red Sea, and these are generally separated by deep water channels. These sites were most dramatic, often exhibiting sheer (near vertical) drop-offs from the shallow reef crest subject to 300-500 m, with ledgers, ridges and caves perforating the wall. In addition, many of the atoll-like tower reefs had flourishing coral communities on the outer rim as well as the leeward lagoonal (inward) face. The site experiences large latitudinal and seasonal extremes in temperature (up to 38º C), and above-average salinities, two factors that would typically contribute to high mortality of corals. Nevertheless, the presence of flourishing coral communities in many of the locations we examined suggests local populations are adapted to temperature stress, but the environmental extremes in this region are likely to be close to their physiological tolerance maxima, which may make them particularly vulnerable to climate change. Our surveys also documented evidence of widespread coral mortality affecting 20 of the 58 sites examined, including the near total loss (>95%) of adult colonies at five sites that extended from the reef flat to depths of 30 m or more. These die-offs appear to have occurred over the last 1-5 years, possibly due to crown-of-thorn-starfish (COTs, *Acanthaster planci*) outbreaks and/or coral bleaching. Predation by COTs was observed at many sites, with outbreaks and extensive ongoing coral mortality documented in three locations. Nevertheless, the reefs appear to be highly resilient, both in terms of physical, biological and environmental attributes of these sites and positive signs of recruitment and recovery. Factors that are suggestive of high resilience include:

The dominant reef frame builders in the Farasan Banks are massive and submassive colonies of *Porites*. This taxon is more tolerant of thermal stress than most other genera and also less susceptible to mortality from disease, bleaching and predation by COTs. These growth forms account for most of the three-dimensional architectural complexity of the region, which differentiates these reefs from reefs in the adjacent Indian Ocean. The midshelf and offshore reefs were surrounded by deep water, strong currents that seasonally change directions, and numerous physical attributes such as steep vertical walls and overhangs; all of which will moderate temperature extremes and UV penetration, and reduce the potential for bleaching, Substrate quality was high and conducive to coral settlement, with low amounts of unstable rubble, very low macroalgal cover, relatively low cover of soft corals and higher amounts of crustose coralline algae than observed in other areas along the Saudi Arabian Red Sea coastline. Human pressure on the reefs in the Farasan Banks was low. The majority of reefs are very remote from land-based pollution and other stressors. Despite the presence of commercial fishing activity in the Banks, populations of fish and echinoderm herbivores remain high. A high diversity of reef building corals exists, including multiple growth forms and resistant taxa, many functional groups and a wide size range extending from the smallest (juvenile and recruits) to largest colonies. In areas with widespread mortality of adult corals, the dead colony structure remained largely intact, turf algae and macroalgae cover was low, and juvenile corals were present in unusually high numbers; Overall recruitment levels that were 2-10X higher than that observed anywhere else in Saudi Arabia during the four year study and much higher than adjacent Indian Ocean sites. Because of their remote nature and low population density, the Farasan Banks can be considered "de facto marine reserves", and they present an ideal natural "control" site for monitoring responses and recoveries of coral reefs to these types of large scale natural disturbances and climate change impacts in absence of local human impacts. Conservation actions that would benefit the Farasan Banks include fishery restrictions, especially a reduction in the use of fish traps in reef environments, implementation of a mooring system for outer reefs that are utilized by recreational dive operators, and efforts to reduce discharge of wastes from recreational vessels in reefal environments.

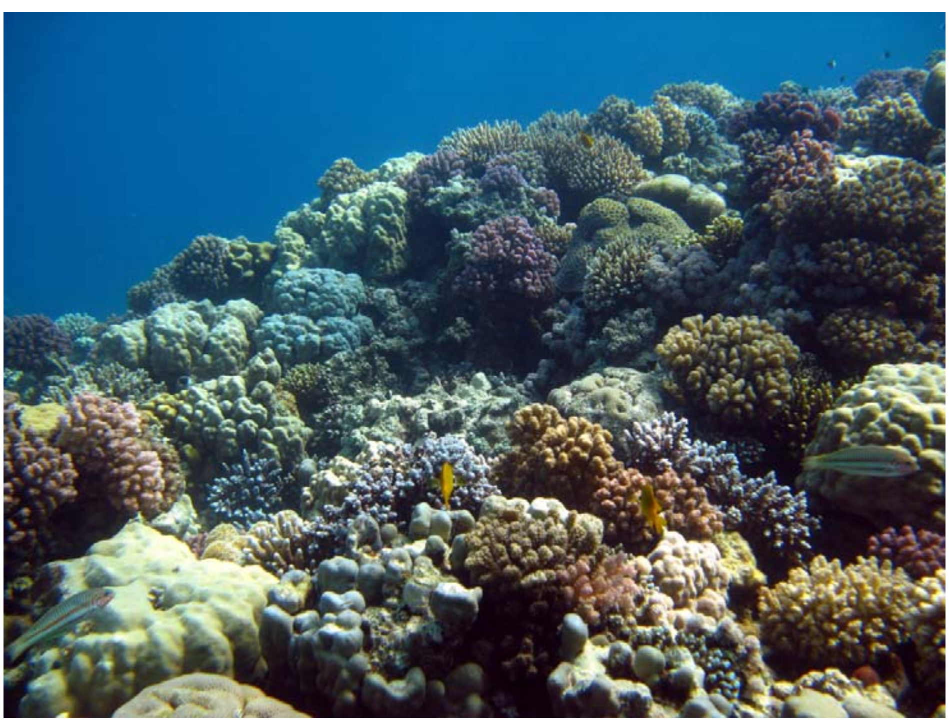


Fig. 1b. Shallow reef slope on the Al Wah barrier reef.

Contents

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Preface

The following sections detail the work done in each region within the Saudi Arabian Red Sea during the four year research mission. The major findings are compiled from research performed by various scientists or teams during each missions. Data and figures are provided from the Nova Southeastern University National Coral Reef Institute (NCRI) habitat mapping efforts and modeling studies, IUCN resilience assessments, University of Cambridge's Cambridge Coastal Research Unit's hyperspectral mapping studies, Saudi Wildlife Commission (SWC) marine mammal and turtle surveys, and Living Oceans Foundation coral reef assessments. The sections are presented in the sequence of each research mission, beginning with the Farasan Islands (2006), Ras Qisbah (2007), Al Wajh Bank and Yanbu Barrier Reef (2008), and Farasan Banks (2009).

For each location an overview of the work is presented, with emphasis on mapping and habitat characterization and coral reef SCUBA surveys. The major habitat features for each region and a habitat map are presented. This is followed by an evaluation of the coral community structure, fish assemblages, threats, and resilience indicators. When available, additional information is provided on other habitats (mangroves/grass beds), modeling outputs and other parameters. Field data are complemented with an assessment of coral reef resilience completed by regions with comparisons among regions. Conclusions and recommendations are detailed in the final section. These involve application of the data to potential future conservation and management initiatives. The appendices list: 1) partners; 2) participating scientists and their role; 4) habitat classification scheme; and 5) final list of fishes identified as key contributors to coral reef resilience.

1. Introduction

Coral reef assessments and habitat maps were completed within four regions in Saudi Arabia (the Farasan Islands (2006), Ras Qisbah (2007), Al Wajh Bank and Yanbu Barrier Reef (2008), and Farasan Banks (2009). These regions were selected due to the complexity of marine habitats found here, the presence of extensive offshore reef systems, and the occurrence of unique habitat types and unusual biodiversity. With the exception of reefs in the immediate vicinity of coastal cities and towns (particularly Jeddah and Yanbu), these reefs generally have low levels of human use and impact. While classic fringing reefs extend along both the east and west sides of the Red Sea, the systems examined in this study extend several kilometers to over 100 km from the shore. The reef systems and islands often support extensive mangroves, seagrass beds and back reef habitats, along with a wide range of reef morphologies, deep water lagoons and raised islands. Major reef types include mainland fringing reefs, island fringing reefs, platform patch reefs, ‘pinnacles’ tower reefs, reticulate reef systems, and barrier reefs (Sheppard 1985, Guilcher 1988). Reefs also developed in sharms along the mainland coast, a characteristic reef-form largely restricted to the Red Sea. Levels of reef development vary widely, ranging from subsurface patch reefs that largely lack a reef flat community, to large platform and barrier reefs with reef flats often > 100 m wide, to tower reefs similar in structure to atolls. These reef types support coral communities with highly variable levels of living and dead coral cover, species diversity and unique community composition, and they are of high global biogeographic importance, with about 10% species level endemism (DeVantier et al. 2000a). Furthermore, the central Red Sea, including the Farasan Islands and Farasan Banks, contains many species that are absent from either the northern or southern Red Sea. These offshore reefs are reported to act as important regional stepping stones for gene flow within the southern Red Sea (DeVantier & Pilcher 2000, Turak et al. 2007).

Studies in the Red Sea have examined the ecology of coral reefs, mangroves, seagrasses and other ecosystems (reviewed by Edwards & Head 1987; Sheppard et al. 1992), as well as environmental pressures and coastal management options (Child & Granger 1990, Sheppard et al. 1992, Gladstone 2000). The first major broad-scale surveys were undertaken in 1980s (Bemert & Ormond 1981, Ormond et al. 1984a-c) These studies identified nearly 70 key sites as conservation priorities, and also recommended establishment of larger multiple-use marine protected areas (MPAs) that included the Tiran Island chain, Al Wajh Bank, the Outer Farasan Bank and part of the Farasan Islands. Reef types, composition of the coral fauna of and stressors including diseases and crown of thorns sea stars were also assessed in the early-mid 1980s (Sheppard & Sheppard 1985, 1991, Antonius et al. 1990), resulting in the first comprehensive coral species inventory for the Saudi Arabian Red Sea. Monitoring of coral reef health and surrounding water quality along the Saudi Arabian Red Sea was conducted during 1987-1988 (Awad 2000). These efforts identified coral diseases (black and white band diseases, shut-down-reaction and tissue bleaching) and more than twenty hydrographic, chemical and pollution parameters were used for describing the surrounding environment (Antonius 1985, Dicks 1987).

During 1997-99, the distribution and composition of coastal and marine habitats of the central-northern Red Sea, from north of Jeddah to Haql in the Gulf of Aqaba were assessed in a joint project by the National Commission for Wildlife Conservation and Development (NCWCD) and Japanese International Co-operation Agency (JICA) (DeVantier & Pilcher, 2000, JICA/NCWCD 2000). This study produced detailed bioinventories for corals, fish, algae, seagrasses, coastal vegetation and birds, and assessed the distribution and abundance of marine mammals and turtles. By incorporating socio-economic assessments of patterns of human use and detailed habitat mapping prepared from aerial photos and satellite images, the data were used to define key reefs and larger reef areas of high conservation significance for MPA planning (NCWCD-JICA 2000, DeVantier et al. 2000).

In 1998-99, most reefs of the central-northern Saudi Arabian Red Sea were reported to be in good to excellent condition with living cover of reef-building corals ranging from <10% to >75% (Pilcher & Alsuhaibany 2000). The highest coral cover was usually present on the shallow reef slopes of exposed fringing, patch and barrier reefs, especially reefs of relatively high exposure to wave energy and high water clarity. Reef slopes (> 10 m) as well as reefs in low wave energy environments and reefs with low water clarity usually had lower living coral cover. (DeVantier & Pilcher 2000). The 1998 bleaching event was highly variable. At the peak of the event, bleaching extended north from the Farasan Islands to reefs around Jeddah and Yanbu. Reefs offshore from Rabigh and north to Yanbu experienced intense bleaching, causing high levels of coral mortality, while Al-Wajh Bank reefs were little affected. In some cases, bleaching occurred at the base of the reef-slopes (> 20 m depth), but was usually most intense in depths < 6 m where recently dead and bleached corals accounted for up to 90 % of the total cover of hard corals, soft corals and fire-corals (DeVantier et al. 2000b). At this time, predation by crown-of-thorns starfish *Acanthaster planci* and muricid snails *Drupella* spp. had minimal effects on coral cover or community composition on most reefs, with exception of some patch reefs in the Al-Wajh Bank and Farasan Islands, where outbreaks of seastars were noted (Rouphael & Al Yami 2000a,b). In a study from 2002, the best reefs examined were reported to have from 40% live cover (Al Wajh), 28% (Farasan Islands) and 20% (Jeddah) at 5 m depth (Kotb et al. 2004). This study notes the 1998 bleaching event as the only major recent disturbance. However, contrary to reports by DeVantier et al. (2000b), it indicates that bleaching caused localized losses of corals that were restricted largely to the southern reefs, patchy damage in central areas and virtually no damage in the north. In more recent reports, reefs were still reported to be in good condition with exception of those adjacent to major cities of Jeddah, Yanbu and Jizan (Mohamed et al. 2004, Kotb et al. 2008). No recent disturbances were noted in this report.

Recent work (2006-2009, by the Khaled bin Sultan Living Oceans Foundation presented in this document provides an update on the status of reefs within five regions off the Saudi Arabian Red Sea coastline, Ras Qisbah, Al Wajh Bank, Yanbu, Farasan Banks and Farasan Islands. To the best of our knowledge this is the most expansive recent updated assessment of these reefs since the JICA (2000) surveys. The work includes a comprehensive mapping and habitat characterization component, using QuickBird multispectral satellite imagery as a platform, along with detailed SCUBA assessments and phototransects. Observations and data are presented in chronological order of the surveys, beginning with the Farasan Islands (2006), Ras Qisbah (2007), Al Wajh and Yanbu (2008) and Farasan Banks (2009) (Fig. 1). Additional background information and general observations are presented in part 1 of the final report. High resolution habitat maps and bathymetric maps created for each of these regions are compiled into the *Khaled bin Sultan Living Oceans Foundation Atlas of Saudi Arabian Red Sea Marine Habitats* and available in a georeferenced format on an associated GIS database.

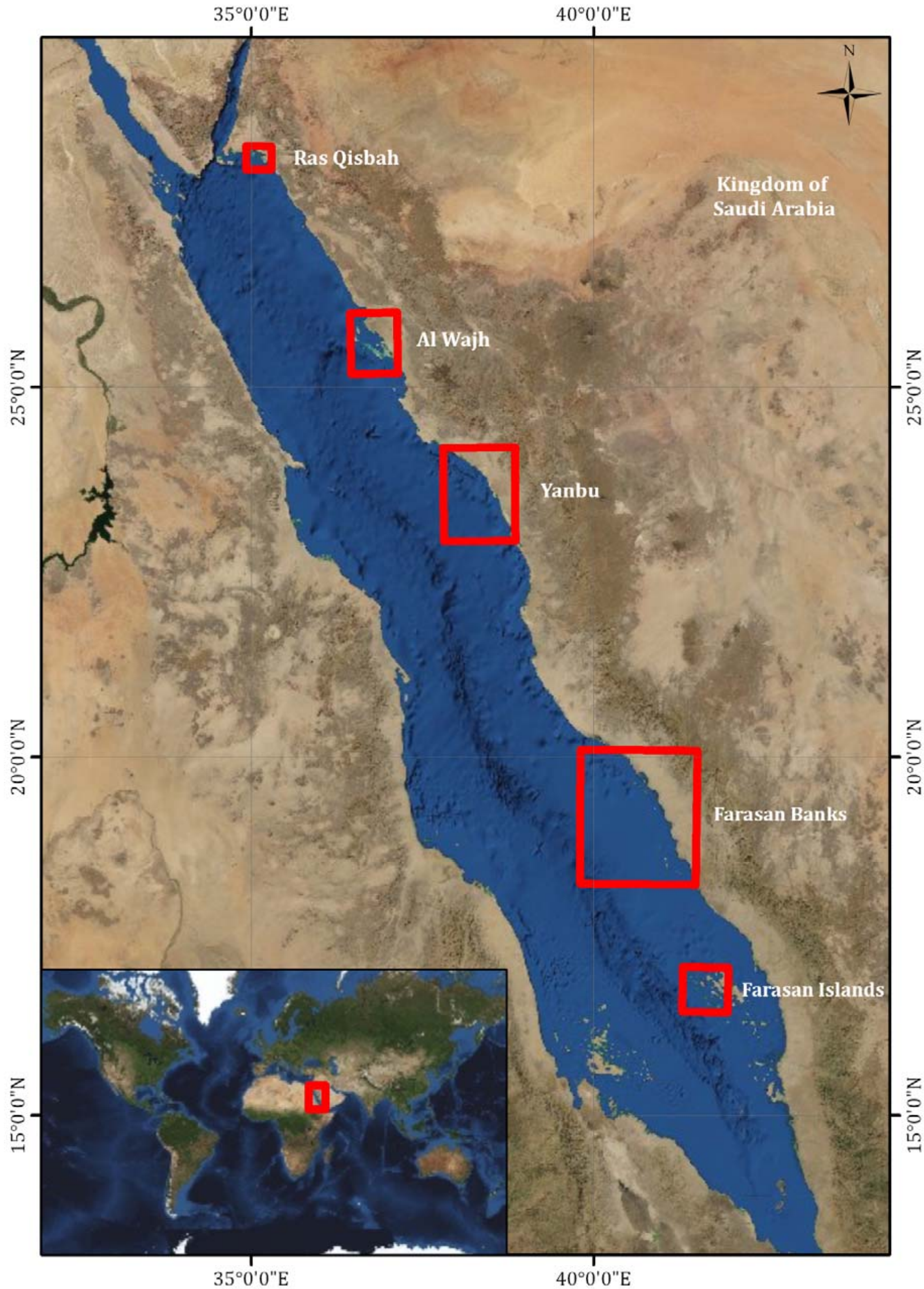


Fig. 1. Location of research sites examined by the Khaled bin Sultan Living Oceans Foundation.

2. Farasan Islands

2.1 Background

The Farasan Islands are situated in southern Saudi Arabia at $16^{o}20'$-$17^{o}20'$N, $41^{o}24'$-$42^{o}26'$E, beginning approximately 40 km from the coastal town of Jizan[1], Saudi Arabia. The region sits atop a relatively flat carbonate shelf located at about 600 m depth. This shelf is about 130 km wide, stretches from Jeddah to the southern border of Saudi Arabia and extending into Yemen. The archipelago extends approximately 100 km offshore. On its seaward edge, the shelf slopes steeply towards the central axial trough, while the landward edge connects to the Tihama plain.

Extensional tectonic movements, perpendicular to the direction of horst-and-graben features, exert a major influence on the geomorphology of the Farasan Islands (Purser & Bosence 1998). The influence of evaporites is also apparent in the gross geomorphology of the Farasan shelf, with islands forming in areas where sediments are intact and pushed upwards during the Miocene, by enlarging salt domes. The seabed was subsequently cut by deeper troughs; these depressions occur where exposed salt deposits have dissolved. Several phases of tectonic uplift also pushed old coral reefs upward, raising these structures above current sea level to form part of the Farasan Islands. During the Pleistocene (30,000-17,000 years ago), sea level dropped by 120-150 m; sea level began to rise again about 15,000 years ago. Present day coral reefs formed as sea level approached modern day levels, around 7,000 years ago (Sheppard et al. 1992).

The Farasan Islands archipelago consists of about 176 islands, the largest being Farasan Kabir (66 km long, 5-8 km wide, maximum elevation = 72 m). This region also contains the Farasan Island Marine Protected Area, established in 1996. The MPA covers an area of approximately 3,310 km^2 and includes about 128 islands and 18 shoals, including the three largest and only permanently inhabited islands (Farasan al-Kebir, Sajeed and Gumah[2]). Total human population in the Farasan Islands is about 20,000.

[1] Also called Gizan
[2] Alternate English spellings for place names are common and include Farasan Kabir, Saqid, Segid, Gummah

2.2. Research completed

During the Farasan Islands research mission, the bulk of the effort focused on habitat mapping and characterization. Hyperspectral surveys were undertaken using a CASI sensor and the Golden Eye sea plane to obtain data on habitat types within 15 areas in the Farasan Archipelago. Concurrently, extensive groundtruthing was completed to georectify the imagery, improve accuracy, and characterize the different habitats. A second component of the mission focused on coral reef assessments using SCUBA surveys. One team conducted belt transects to characterize fish communities, while a second team completed benthic photo-transects. Photo-transects were subsequently analyzed using NCRI's Coral Point Count (CPCE) software to estimate benthic cover of major functional groups including coral genus, algae (macroalgae, coralline algae and filamentous algae), other benthic organisms such as sponges and non-coral cnidarians, and four major substrate categories (pavement, rubble, sand, dead coral).

Fig. 2.2a. A sandy beach in the Farasan Islands showing large rocky outcrops consisting primarily of uplifted coral reefs.

2.21 Mapping

During May 2006, 3,168 km^2 of CASI image data were collected in the Farasan Islands using the Golden Eye, a Cessna floatplane. The floatplane, with a mounted hyperspectral sensor (CASI) and differential Global Positioning System (dGPS) integrated to a gyroscope measuring aircraft position and movement, was flown in straight, parallel lines in a grid system to map the marine environment to a depth of 20 m. The CASI sensor was operated for a maximum period of two hours in the morning and two hours in the afternoon, during pre-selected times based on times of sun-rise and sun-set. These times enabled the highest level of accuracy to be achieved in the CASI data collection by ensuring a high sun angle, and thus minimising sun-glint. CASI data were recorded from 15 areas within the Farasan archipelago, covering a total of 3,168 km^2 (Fig. 2.21a,2.21b).

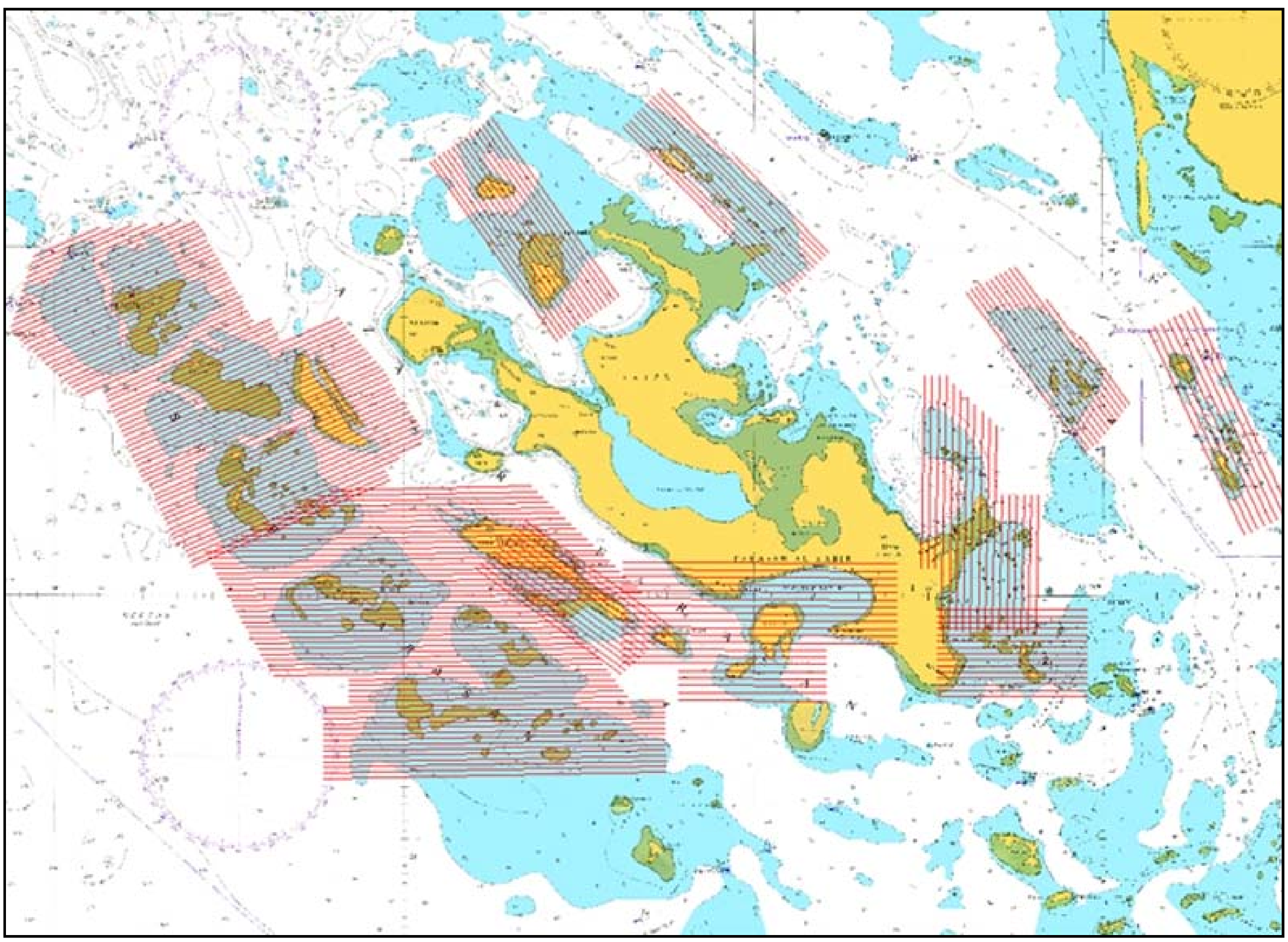


Fig. 2.21a. Flight lines of the Cessna aircraft within the Farasan Islands.

CASI data were collected at 1.5 m pixel resolution, with 19 bands assigned between 400 and 660 nm and 2 bands within the near-infrared (NIR) region, representing a non-contiguous 21 band hyperspectral dataset. Band width (FWHM) ranged from 3-7.6 nm. Augmenting this, 1,637 km^2 of high resolution QuickBird multispectral satellite data (eight scenes dating March 2004 through October 2006) were also acquired. QuickBird imagery has high spatial resolution (2.4 m pixel) comparable to CASI, but with fewer bands (4 vs. 21) and greater band width (60-140 nm).

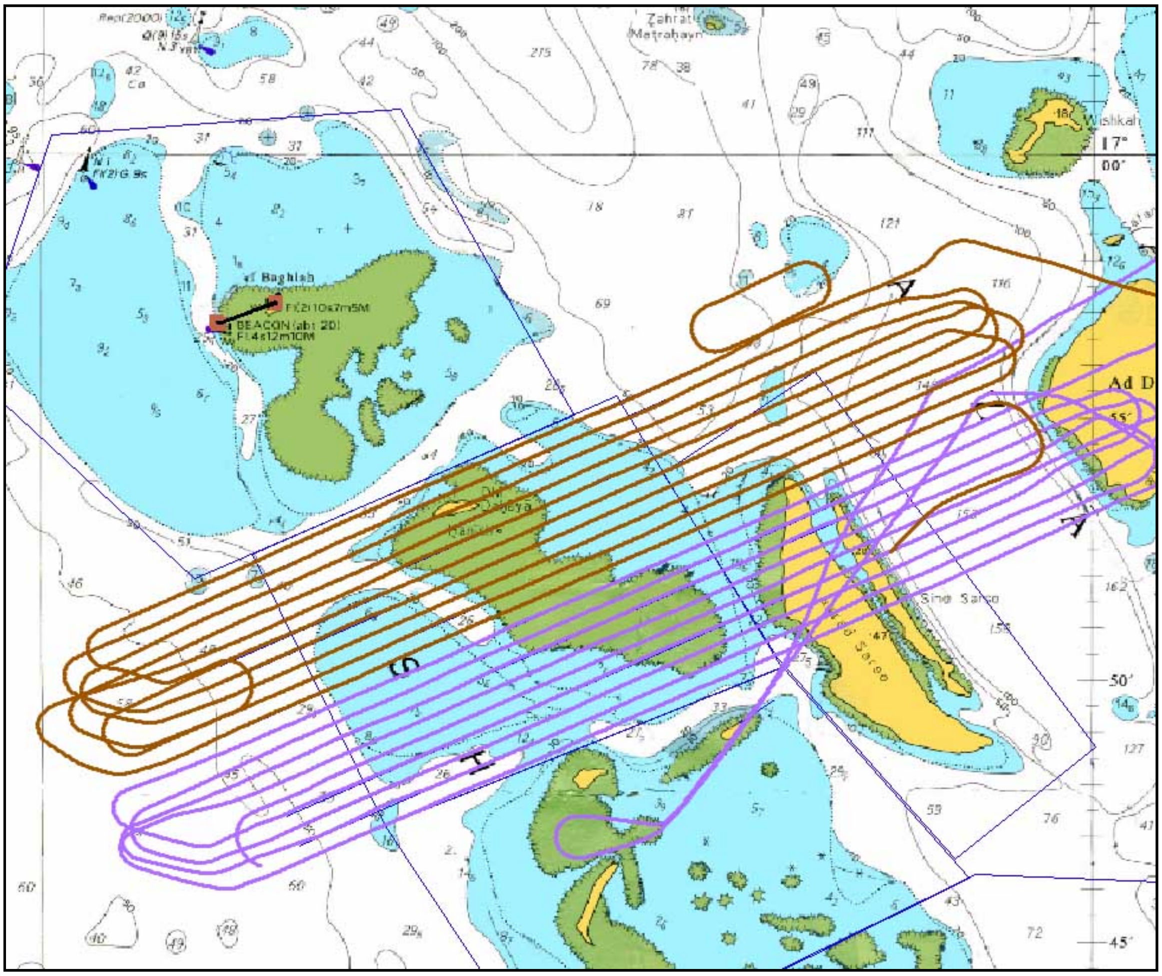


Fig. 2.21b. Detail of 'area 5' flight lines.

In order to classify color images produced by CASI into different habitat types, *in situ* measurements and observations were made at the same time as the CASI surveys. Using Landsat imagery as a guide, ground tracks bisecting areas of high spectral heterogeneity, depth and exposure regimes were selected. This maximized the representativeness and diversity of habitat sampling. Single-beam acoustic sonar linked to dGPS was run continuously during the survey process, producing ~160,000 soundings, later adjusted for tidal height. A subset of 2,967 soundings were then set aside from model development and utilized exclusively for test purposes. A visual census incorporating percentage covers of major habitat contributors (corals, macro-algae, seagrass, sponges, etc) and base substrates was carried out using glass-bottom buckets, snorkel and SCUBA. Sites were chosen at random along the pre-selected ground tracks, though some spectrally distinct features were specifically targeted, producing 1604 ground truth points. Optical data described the water as intermediate between Jerlov type II and type III, indicative of a slightly turbid tropical environment.

Spectral signatures (readings of the amount of light reflected by an object) were collected for numerous benthic habitat types (e.g. coral, seagrass, algae, sand, bare rock etc.) using a hand-held Dive-Spec underwater spectrometer (NightSea LLC). This spectrometer utilizes both artificial and incident light sources, calibrated against a white Spectralon panel (99% reflectance). It was used to measure diffuse attenuation, marine and terrestrial end member spectra, and deep water reflectance. By knowing what type of habitat is on the seabed at an exact position, this ground-control data allowed classification of the entire CASI dataset and enabled accurate habitat maps to be produced.

Data collected by the hand held spectroradiometer was not available at all sites, so instead, white and blue targets were placed underwater and on land. These targets, visible on the CASI imagery, were used for subsequent depth correction and geo-referencing of the CASI data. The targets consisted of 3 m x 3 m square sheets of plastic placed at depths of 15 m, 10 m and 5 m. The targets were laid as horizontally as the reef allowed, so that the shape could easily be picked up by the CASI sensor. The targets were secured onto the reef in order to withstand underwater currents. Metal stakes were hammered into dead coral substrate or sand and each corner of the target was tied onto a metal stake. On land, white and dark blue targets were laid out on a flat area and secured with metal stakes (Fig. 2.21c). The land targets were used for atmospheric correction of the CASI data.

Fig 2.21c. Deploying a white target on beach.

The ground-truthing team also collected bathymetric and current data at various locations using a grid sampling method across the area of interest. Current data was collected using an Acoustic Doppler Current Profiler (ADCP), which recorded both the speed and direction of water flow. In total, 138 km of bathymetric and current data were collected.

2.22 Map Production

Image processing followed the methodologies outlined in Fig. 2.22a. A thematic map product was produced by first performing independent supervised classifications of the processed CASI and QuickBird imagery and then merging the results into an integrated product. Field data were categorized into distinct habitat classes based on the dominant benthic coverage. A total of 800 points were used to train a maximum likelihood classification. When either sensor lacked adequate spatial coverage (or in cases where the distortion from the CASI abnormality was too high), the other sensor was used. The red and NIR bands from each sensor were used for mangrove classification and land masking, and benthic classification was based on bands from the blue-green region of the spectrum (CASI: 13 bands; QuickBird: 2 bands). A preliminary analysis was carried out for flight Areas 8 and 9 before expanding the mapping protocols to the whole study area. Comparison of tau accuracy coefficients from 185 randomly chosen field observations suggested higher discriminatory ability using CASI in habitats shallower than 6 m (79% vs. 74%) while QuickBird was the more accurate of the two sensors for habitats deeper than 6 m (80% vs. 76%). Accordingly, two classifications were performed for each sensor, one classification for depths from 0-6 m and one classification for depths from 6-15 m. In the final map product, the various classifications were merged with reference to image availability, depth priority and context. For accuracy assessment of the final map, 300 points independent from the training process, distributed across the study area, were used. Most points (86%) were less than 6 m in depth, reflecting the dominance of shallow bank-top habitat.

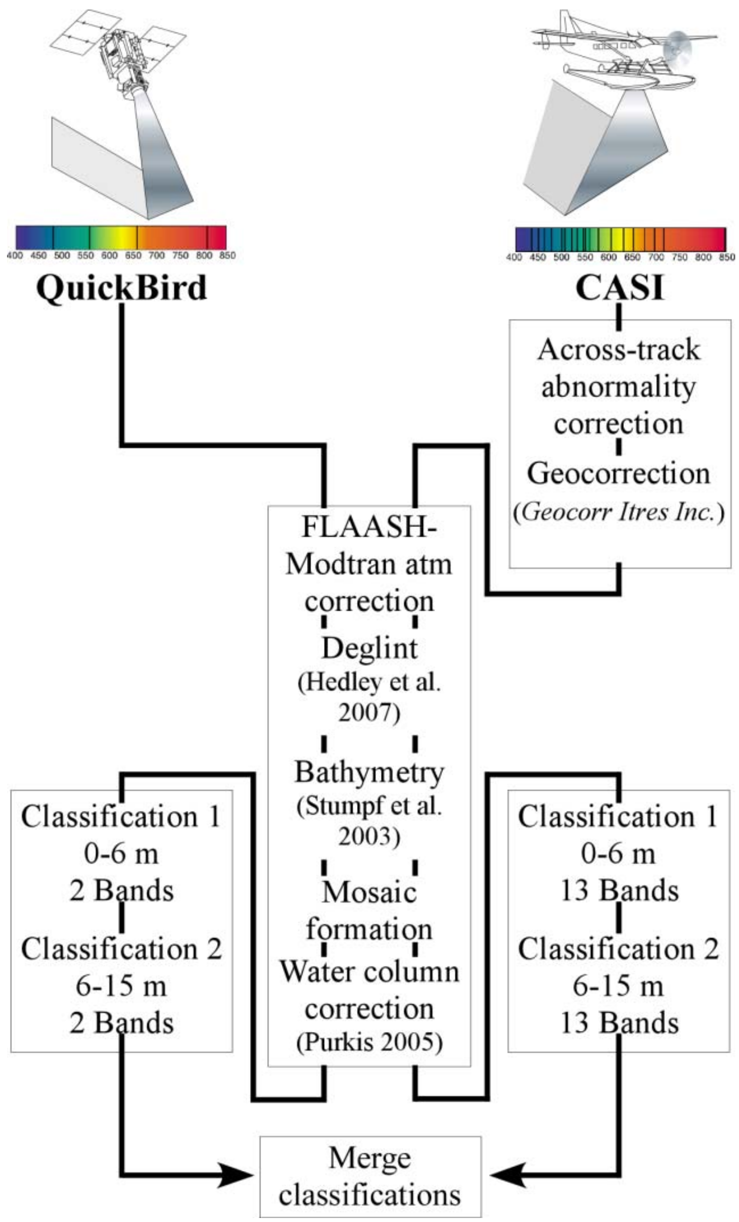


Fig. 2.22a. Processing stream for CASI and QuickBird data in producing thematic map product.

2.23 SCUBA Assessments

A total of 58 photo-transects and 28 fish surveys were conducted within coral reef habitats during the expedition. Benthic surveys were conducted using a 50 m long transect tape, laid down on the seabed at a pre-determined depth. The transect line followed the depth contour, thus a constant depth was retained throughout each survey. These transects were placed in coral reef environments, although due to their length they frequently ran through sand flats, rubble fields and other non-coral habitats. A 1 m long piece of PVC piping was used as a guide along the transect tape and photographs were taken along the 50 m length at 0.5 m intervals (Fig. 2.23a). Approximately 100 photographs were taken along each transect line, allowing for some overlap between adjacent photographs. Two photo transects (each 50 m in length) were conducted during each dive, as shown in Fig. 2.23b. The positions of all transects were recorded by deploying a buoy to the surface and taking a GPS (Global Positioning System) reading All photo transects were completed by Annelise Hagan and Ben Stobart with assistance from Phil Renaud.

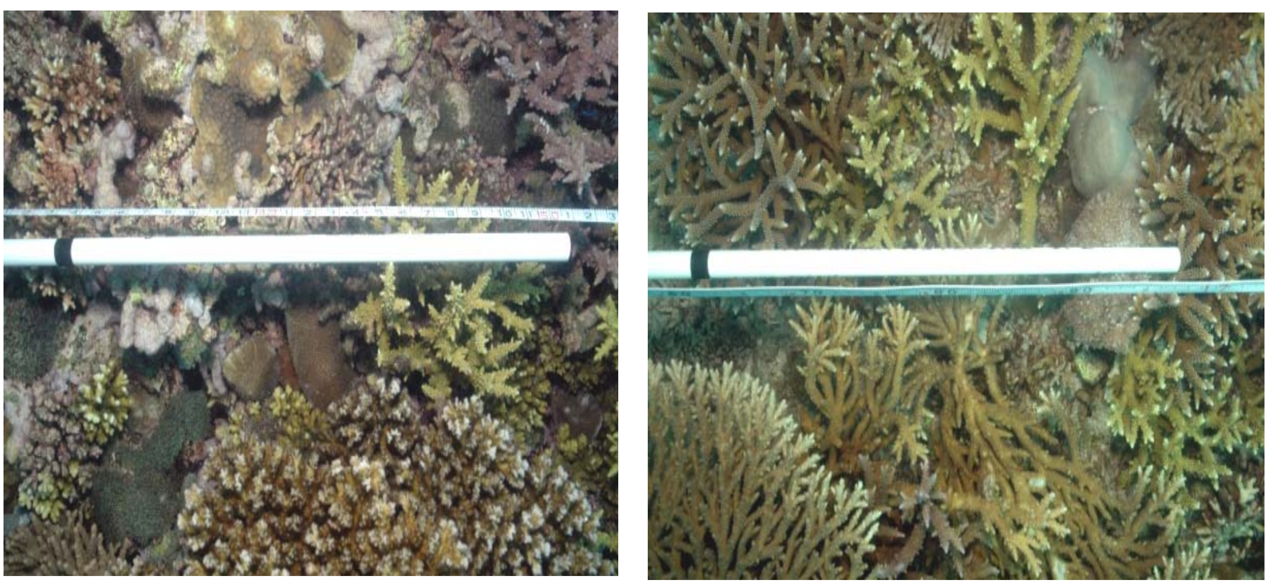


Fig 2.23a. Examples of photographs taken at 0.5 intervals along the transect line. Note use of PVC piping along transect line and overlap at either end of the 0.5 m section. Black marker on PVC piping represents the 0.5 m point. Photos by Annelise Hagan/Ben Stobert.

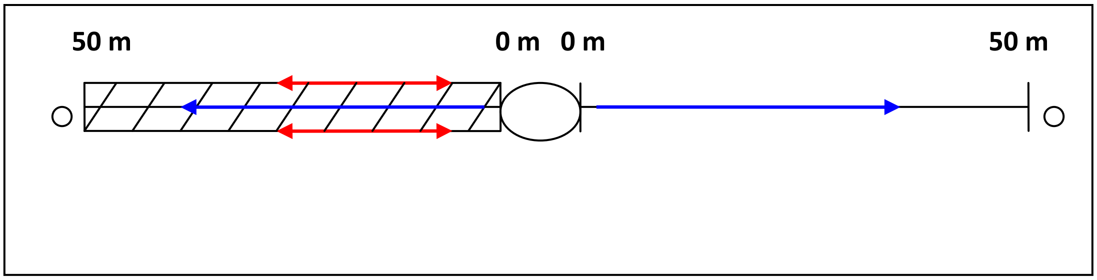


Fig. 2.23b. Plan view of benthic and fish survey transects. Oval indicates central buoy marked by GPS, small circles represent buoys deployed at end of transect line. Blue arrows indicate direction of benthic survey (photo transect methods), red arrows indicate direction of fish surveys. Shaded area represents area of fish survey (2 m either side of central transect line).

2.24 Fish assessments

Fish-census surveys were conducted during 2-22 May 2006 in the southern Red Sea off the coast of Saudi Arabia. On 2 May, a random-search survey was conducted at the Jeddah shipwreck to identify local reef fishes. From 4-22 May, quantified Belt Transect fish-census surveys were conducted to assess the abundance and biodiversity reef fishes in the Farasan Islands Marine Park. These were biodiversity-based surveys that assessed all fishes encountered in the transect, as opposed to surveys that assess only target groups of fishes. A Belt Transect fish-census survey laid along the depth contour selected for the habitat survey, starting from a central point that was marked by a surface buoy. The fish-census survey protocol was to use the tape extending to the left (facing shoreward) of the buoy location, and to start the fish survey at least 20 minutes after the start of the habitat survey. This delay allowed time for the habitat survey to be completed, and for the fish community to recover from the minor disturbances caused by the habitat survey divers.

A fish-census survey was conducted by a diver swimming along the transect line, recording the fishes observed in the 2 m-wide column of water on the left side of the tape, that extended from the benthic habitat to the surface. The survey first counted the fishes above the substrate and in the water column along the 50 m length of the transect line, and then counted the cryptic fishes by searching carefully in caves and crevices when returning back along the transect line. For transects with large numbers of species, this method was modified by leaving some substrate-associated species to be counted entirely on the return leg of the transect. The fish-census data was recorded by species, by number, in six total length (TL) intervals of <1-5 cm, 6-10 cm, 11-

20 cm, 21-30 cm, 31-40 cm and >40 cm. The underwater form used to record the survey data was prepared with appropriate headings for the survey parameters (i.e., date, location, depth, etc), and columns for the length intervals and rows for the species data. The species were entered on the form as they were encountered along the transect line, using a shorthand code (developed by the survey diver) to identify the genus and species. This avoided the time it would have taken to write-out the Latin name for each species. The count for a species could be added to the shorthand identification code for that species already entered on the data form, or the code could be entered again to save time.

The six length intervals were a sub-set of the intervals recommended for coral reef fish surveys following the standard rapid assessment protocols (RAP; Lang 2003) that are used internationally. The use of length intervals facilitated rapid accurate counting of the fish in groups that were ecologically meaningful. The <1-5cm and 6-10cm intervals segregated the information on juvenile fishes and those species that are small as adults. The 10cm intervals up to 40cm were easy to estimate, and for most species delineated the sub-adult and adult (reproductive) life-phases. The >40cm length interval included all of the large, terminal-phase reef fishes. There were typically either few fishes >40cm in length seen in reef surveys, or the fish of this size occurred in large schools of a single species that were of the same (maximum) size. For both situations, the counts included additional notations on the survey data form of the actual length estimates. To facilitate accurate estimations of the lengths intervals, the fish survey diver carried a reference gauge that was a “T” made from plastic pipe, with the 40cm T-end marked-off in the six length intervals.

The fish counts by species followed the general procedures recommended for highly variable numbers of fishes in the RAP method (Lang 2003) and for surveys of tropical marine resources (English et al. 1997). The number of each species in each length interval was tallied cumulatively for the entire transect. Fish present individually or in groups (approximately) <50 were counted directly. For larger groups of fish, a part of the volume of the group (usually comprised of no more than 50 fish) was quickly counted and then the number of these “parts” required to equal the total volume of the group was estimated. The total count of the group of fish was recorded on the data form as either the product of these two numbers, or as the “part-count” x “total-parts”, which ever was easier.

Following the quantified survey along the transect line, the survey diver would make a check-list of any additional species (i.e., fishes not recorded in the transect count) by searching in the vicinity of the transect location, but outside of the defined transect area. The check-list could also include species that had moved into the transect area after the completion of the transect count. This was done to estimate if the transect included a representative number of the fishes in the area, and to add to the database (species list) of fishes at the survey location. The duration, and thus the completeness, of the search for additional species, was determined by the amount of bottom-time remaining in the dive after completion of the fish-census survey. This time-limit was highly variable between transect locations, and thus the check-list data represented a very conservative estimate of the fishes in the area.

After the completion of each fish-census survey dive, the underwater survey data form was reviewed for clarity, and any species identification questions are resolved using fish identification resources (e.g. FishBase 2000). This timely data review protocol was vital to maintain the highest possible level of accuracy in the visual census data. The survey data was later entered in to the Excel spreadsheet data storage system (Microsoft 2000) for analyses.

2.3 General habitat attributes

The western Farasan Islands contains a submerged bank system located seaward of Sarad Sarso, Zufaf and Farasan Al Kabir (Fig. 2.3a). Marine habitats are predominantly sedimentary in nature with 55% of benthos comprised of sand, or sand with sparse algae. The habitats represented in the Farasan Islands include algae-covered pavements located close to shore, sand flat communities, seagrass meadows, mangroves, patch reefs, and fringing reefs. In most cases hardground areas consist of either patch reef or fringing reef environments with very little live coral cover, with a dominance by rubble and algae. Macroalgae communities with sponges occupied 22% of the rubble hardgrounds, while 6% was rubble with sparse coral cover. Patch reef and fringing reefs were coral-dominated on windward and leeward coral crests, and in *Porites* framework habitats. The highest live coral cover was found in habitats referred to as "dense *Acropora* thickets". These made up 3% of the submerged habitats found in the north-west. With exception of *Acropora*, coral was only classifiable as a mixed assemblage. These mixed coral assemblages comprised only (2%) of the substrate, mostly located in microatoll formations of 1-20 m diameter.

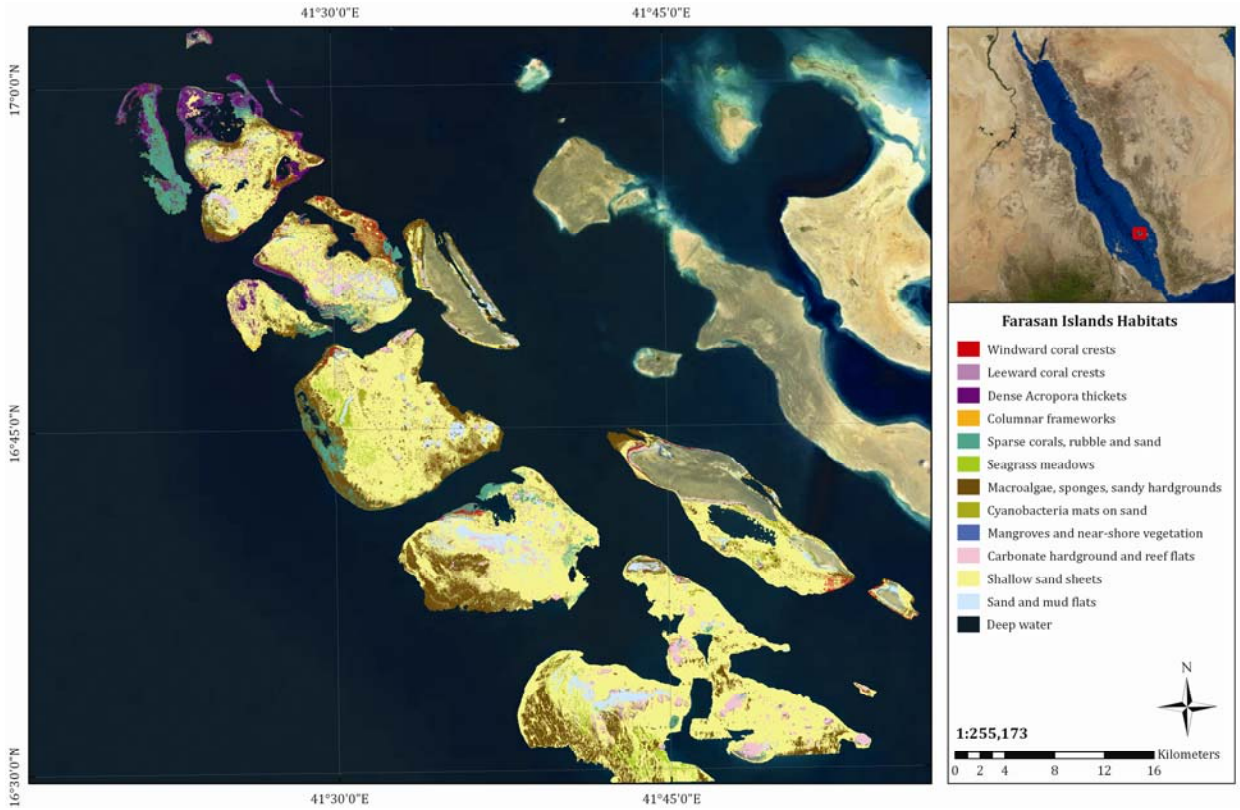


Fig. 2.3a. A habitat map for the western Farasan Islands developed from the CASI hyperspectral data and groundtruthing information. A total of 12 different habitat types were discriminated. White areas are deep water (>20 m).

Rather than a coral-dominance, many of the hardground areas consisted of accumulations of crustose coralline algae, colonized by *Sargassum* and *Turbinaria* (brown macroalgae). Algal-dominated fringing reefs tended to occur close to the shoreline, and in areas with high sediment loads; the benthos in these areas was colonized primarily by macroalgae (mostly *Sargassum* and *Turbinaria*) growing atop a crustose coralline algae (red algae) substrate.

Subtidal sea grass beds occurred in several locations in the Farasan Islands. Mangrove biotopes were also identified, these being dominated by *Avicennia marina* and *Rhizophora mucronata*. Soft bottom communities that were not colonized by mangroves or sea grasses included shallow sand sheets, sand and mud flats, and sandy areas colonized by cyanobacteria, as well as areas with isolated corals, rubble and algae. A habitat map for the western portion of the Farasan Islands illustrating the distribution of various benthic habitats is shown in Fig. 2.3a.

2.4 Coral community structure

The 58 photo-transects conducted in the Farasan Islands were located on 22 reefs (Fig. 2.4 a) These transects generally targeted both deeper reef habitats (12-17 m) and shallow habitats (3-8 m) within an individual reef, although some transects were completed in either deep or shallow water, depending on the structure of the reef environment. Coral cover on fringing reefs ranged from very low (<1%) to very high (>80%), with numerous sites having over 60% live coral cover at depths of 3-8 m. Most coral reefs consisted of a dead *Porites* framework with a mix of living massive and branching corals and other taxa. Areas with dense *Acropora* thickets were dominated by large tabular growth forms of these species. *Acropora* spp. colonies were often layered in tiers resulting in a structurally complex reef system. These were mostly located on the northern and northwestern end of the bank system, facing into the Red Sea and offshore (northwest) from Sarad Sarso. In non-acroporid habitats the dominant taxa was *Porites*. This coral was typically the largest coral observed on these reefs, with some unusually large colonies measuring over 1.5 m in diameter. Shallow reef crest and reef flat communities had low cover of coral, and colonies were often competing for space with macroalgae.

In general, deeper transects (10-17 m depth) had low amounts of live coral cover. These more typically consisted of pavements covered in sediment with macroalgae and isolated corals, and a dominance by soft corals (especially *Xenia*). While some deeper sites did have a high cover of massive corals with a predominance of *Porites* (e.g. dive # 19, 18 May, 2006, 12 m depth), and *Acropora* thickets occasionally were found at these depths, more often the best coral was seen in shallow water (4-7 m).

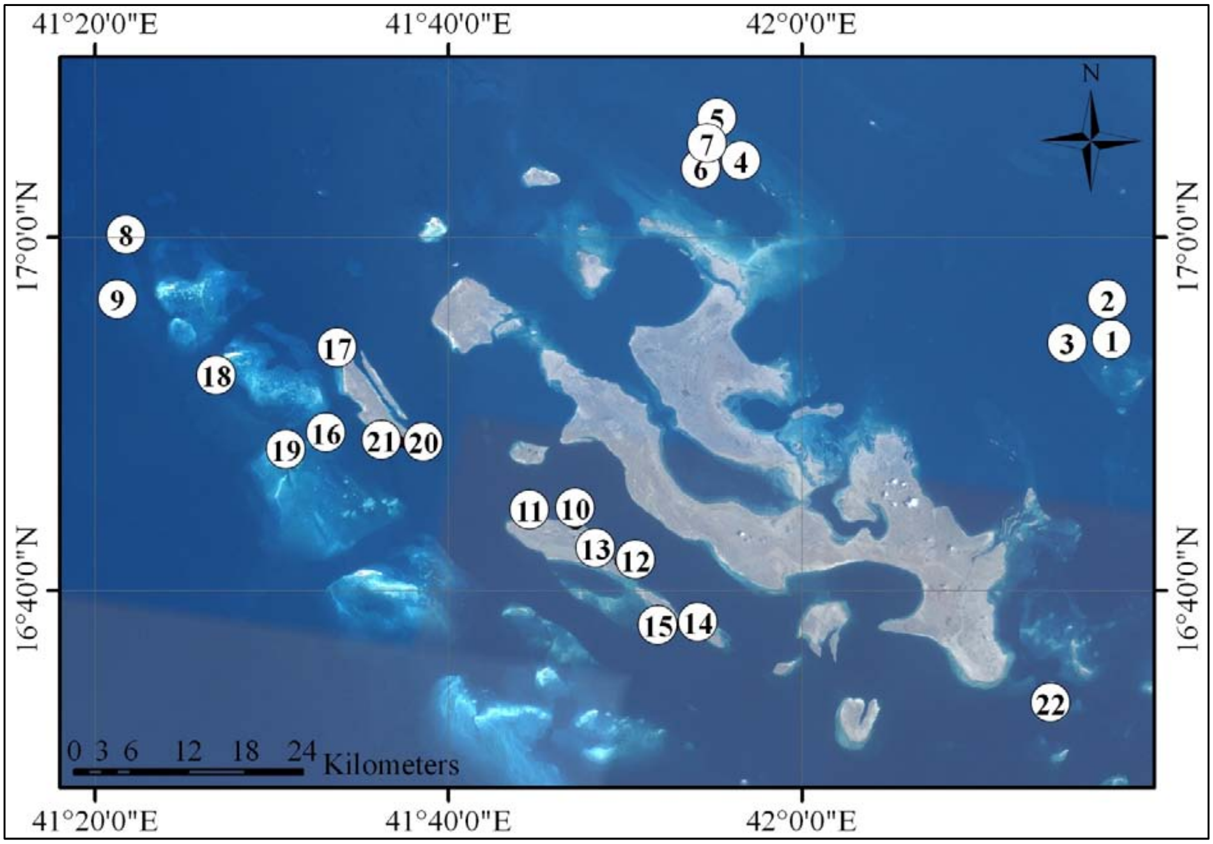


Fig. 2.4a. Location of dive sites in the Farasan Islands.

Table 2.4. Coordinates of dive locations surveyed in the Farasan Islands

Site #	Latitude, N	Longitude, E	Date	Location
1	16.91612	42.29254	5/4/2006	Abu Shuqar Bank
2	16.92904	42.28852	5/5/2006	Abu Shuqar Island
3	16.89894	42.25025	5/6/2006	W side Abu Shuqar Bank
4	17.07091	41.93261	5/7/2006	Island W of Akbayn Island (south)
5	17.09743	41.91989	5/7/2006	N tip Akbayn Island
6	17.06367	41.90481	5/8/2006	shoal SW of Akbayn Islands
7	17.08736	41.91079	5/8/2006	Island W of Akbayn Island (north)
8	17.00145	41.36283	5/9/2006	N Al Baghlah Bank
9	16.94038	41.35460	5/11/2006	W side Al Baghlah Bank
10	16.73097	41.78627	5/12/2006	N Zufaf Island
11	16.74176	41.74350	5/12/2006	N Zufaf Island
12	16.69473	41.82946	5/13/2006	Zufaf Island
13	16.70569	41.80913	5/13/2006	Zufaf Island
14	16.63576	41.88818	5/14/2006	S tip Dushuk Island
15	16.63294	41.87719	5/14/2006	S tip Dushuk Island
16	16.81433	41.54255	5/16/2006	Massad Island
17	16.89461	41.56198	5/16/2006	N tip Sasuh (Sarad Sarso)
18	16.86874	41.44787	5/17/2006	Lajhan (Dhi Dahaya)
19	16.79890	41.51369	5/18/2006	Shuma
20	16.80602	41.62758	5/19/2006	SW Sasuh (Sarad Sarso)
21	16.80747	41.61946	5/19/2006	SW Sasuh (Sarad Sarso)
22	16.55966	42.23502	5/22/2006	shoal SW of S Kulam Island

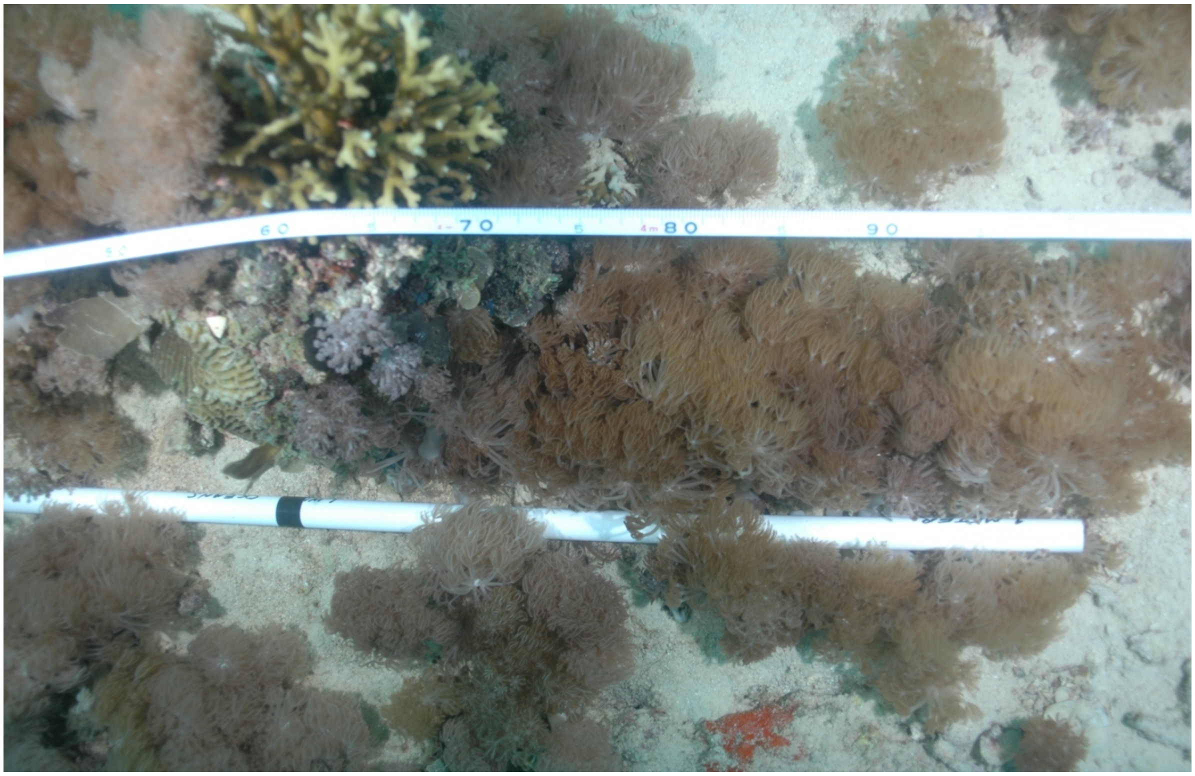


Fig. 2.43a. Typical photoquadrats taken along a 50 m transect at 17 m depth at Abu Shuqar Bank. The sediment-covered pavement was dominated by *Xenia* soft corals.

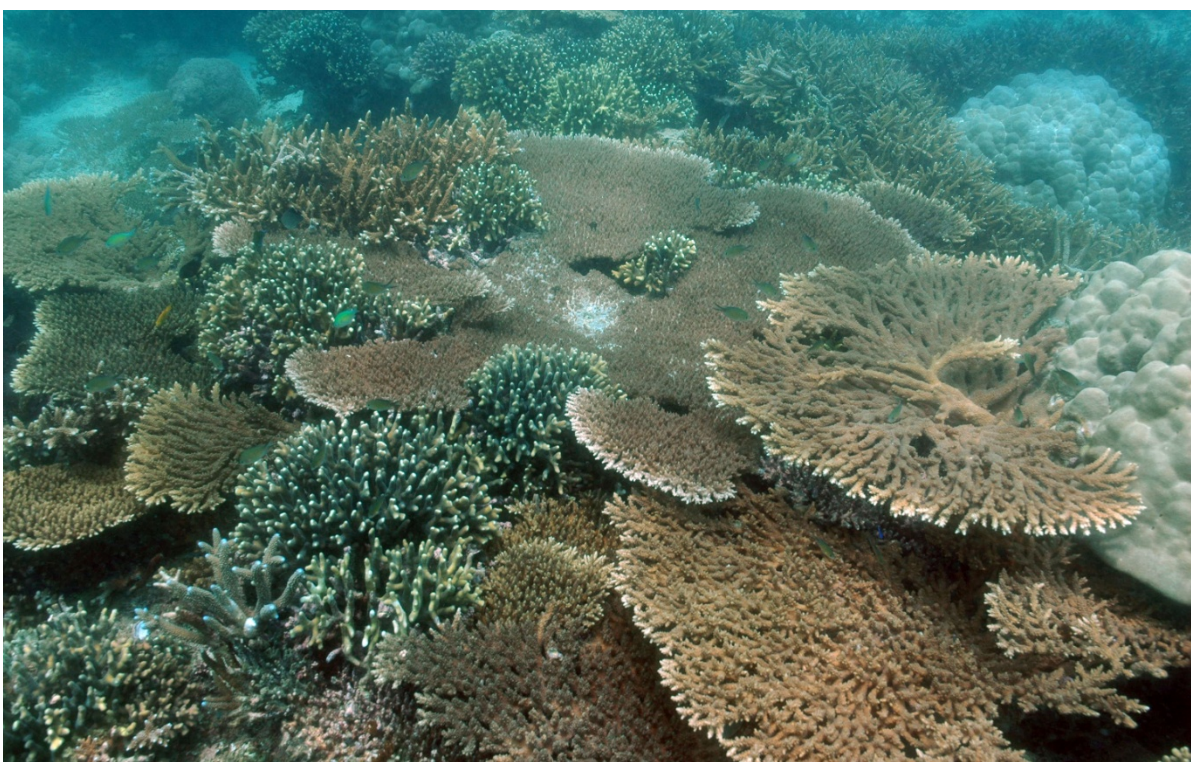


Fig. 2.43c. *Acropora* dominated reef at 4 m depth with several canopy layers of *Acropora* and isolated *Porites* colonies. Photos by Annelise Hagan.

2.41 Abu Shuqar Bank and Island

Coral assessments were conducted on Abu Shuqar Bank and off Abu Shuqar Island at 5, 10, 12 and 15 m depths. These sites were characterized by low living coral cover from 10-15 m depth (0.1-5%) and much higher cover in shallow water (20-70%), with some shallow areas dominated by *Acropora* thickets. The substrate included patches of rubble, sandy areas and pavement, with higher cover by rubble in deeper areas. The dominant benthic organisms observed from 10-15 m depth were soft corals (primarily *Xenia)*, with low cover by sponges and gorgonians. Old dead coral was recorded at all depths, but the cover of dead corals was fairly low (0-5%). Isolated recently killed corals (0.33%) and bleached corals (0.12%) were also noted. The substrate and dead corals were colonized by macroalgae (3-5%), cyanobacteria (0.1-5%), turf algae with trapped sediments (5-43%), and crustose coralline algae (0.9-6.5%). In general, macroalgae was more abundant in shallow transects and cyanobacteria increased with depth.

Coral diversity was relatively low, with a dominance by *Acropora* spp. (cover= 63% at 5 m depth) and *Porites* (7%) in shallow water. Other corals seen within transects, generally making up less than 1% cover, included *Stylophora, Psammocora, Platygyra, Pavona, Oulophyllia, Montipora, Millepora, Lobophyllia, Goniastrea, Favia, Echinopora, Coscinarea, Favites, Fungia, Herpolitha/Ctenactis,* and *Leptastrea*.

2.42 Akbayn Island

Coral assessments were conducted in reef environments off Akbayn Island at 4, 12 and 17 m depth. These sites all exhibited low coral cover at mid and deep sites (0.1-11%) and lacked *Acropora* thickets, as seen in other areas. Shallow areas (4 m depth) did, however, have isolated colonies of *Acropora* (1-23% cover) along with a higher cover of branching *Stylophora* colonies (2-20% cover) and massive *Porites* (2-15% cover). In one transect, coral-dominated areas were dispersed among pavements with a sediment covering. The coral areas had 25-33% live coral cover, with 15% *Acropora*, 12% *Stylophora*, and about 2% *Porites* and *Goniastrea*. Substrates were predominantly pavements covered in a fine layer of sediment, with some rubble areas colonized by coralline algae, interspersed with sand patches. *Xenia* soft corals were once again a dominant member of the community in deeper water, but not at 4 m depth. Other prominent invertebrates included an encrusting sponge (seen carpeting the reef and dead coral skeletons), a colonial anemone (*Palythoa*) and didemnid tunicates. Algae was dominated by fine turfs (up to 15% cover) and fine turfs with trapped sediments (up to 21% cover), with lower cover of macroalgae at mid depths, and crustose coralline algae and cyanobacteria (1-5% cover each). Shallow areas (4 m), however, had a much higher cover of macroalgae (up to 18% cover), especially around the margins of stony corals. Pavement and rubble were colonized in isolated patches by crustose coralline algae, while substrates exhibited a dominance by turf algae and trapped sediments. Overall, shallow areas consisted of about 52% algal-colonized pavement, 5% rubble and <1% sand, with isolated colonies of long dead corals (3% cover), living soft corals (2% cover), and encrusting and rope sponges (2%).

2.43 Al Baghlah Bank

All coral reef assessments conducted on Al Baghlah Bank were in deeper water (12-18 m depth). Reef environments had patches with stony corals, separated by large expanses of pavement colonized by turfs, soft corals and macroalgae. The 18 m deep transect had a mean live coral

Fig. 2.43. Photoquadrat from Al Baghlah bank, 16 m depth. The dominant space occupiers are *Dictyota* (macroalgae), *Xenia* (soft coral) and stony corals (*Echinophyllia, Platygra, Acropora* and *Porites* are visible in this image). Scale bar is 0.5 m.

cover of about 33% (within coral areas), although coral-dominated habitats were also separated by expanses of pavement, sand and rubble patches and soft coral communities. Corals consisted predominantly of massive and plating growth forms interspersed with low-relief tabular and branching acroporids. Corals often formed encrustations or small hemispherical colonies, with their margins surrounded by macroalgae. The dominant genera were *Porites* (8% cover), *Hydnophora* (5%), *Platygyra* (3%), *Diploastrea* (1.5%), *Echinopora* (1.3%), *Galaxea* (0.9%), *Favites* (0.7%), *Favia* (0.5%), *Echinophyllia* (0.4%), and *Goniastrea* (0.4%), with patches of *Acropora* (9% cover) and isolated small branching corals in the genus *Stylophora* (0.5%). Much of the bottom that was not colonized by invertebrates consisted of coral rubble and dead massive coral colonies colonized by soft corals (especially *Xenia*, 9% cover and *Sinularia,* 4% cover), turf algae (17%), turfs with trapped sediment (6%), red crustose coralline algae (3.6%), macroalgae (3.5%), encrusting sponges (2%), and cyanobacteria (1.5%). The most abundant taxa of macroalgae was *Dictyota* spp.

Old dead coral was relatively common (4% cover) at these sites. Coral diseases (white syndrome) were observed on several massive *Porites* colonies within the transects, although the amount of recently killed tissue was minimal. Several taxa also had bleached tissue, although no completely white colonies were noted.

2.44 Zufaf Island

Reefs examined off Zufaf Island (10-18 m depth) had a sand or sand and rubble substrate with numerous large (0.3-0.5 m diameter) massive and plating corals, isolated patches with acroporids, and a high number of free living fungid corals in sandy areas. The larger corals often formed overlapping shingle-like structures interspersed with flattened massive corals. Species diversity was high, with a dominance by large colonies of *Astreopora, Favia, Goniastrea, Montipora, Porites, Platygyra, Mycedium, Diploastrea, Oxypora, Turbinaria* and *Pavona*. Coral cover was highly variable, ranging from areas with 20-40% living coral to areas with <5% living coral, extensive patches of rubble and sand, and areas dominated by soft corals (especially *Xenia*).

Macroalgae was much less prevalent on these reefs, possibly due to a high abundance of *Diadema* sea urchins. Turf algae was common on hard substrates, while sand and rubble were often uncolonized, with a notable absence of crustose coralline algae and cyanobacteria, suggesting the sediments were unstable and periodically resuspended. Stressors to corals included 1) burial by sediments, with margins of corals often covered in sand; 2) competition with other invertebrates especially soft corals; and 3) several cases where encrusting sponges were observed overgrowing and killing corals. In particular, a red boring sponge in the family clionidae (*Pione* spp.) was very common (Fig. 2.44a). Coral diseases and signs of predation were rare, as was bleaching.

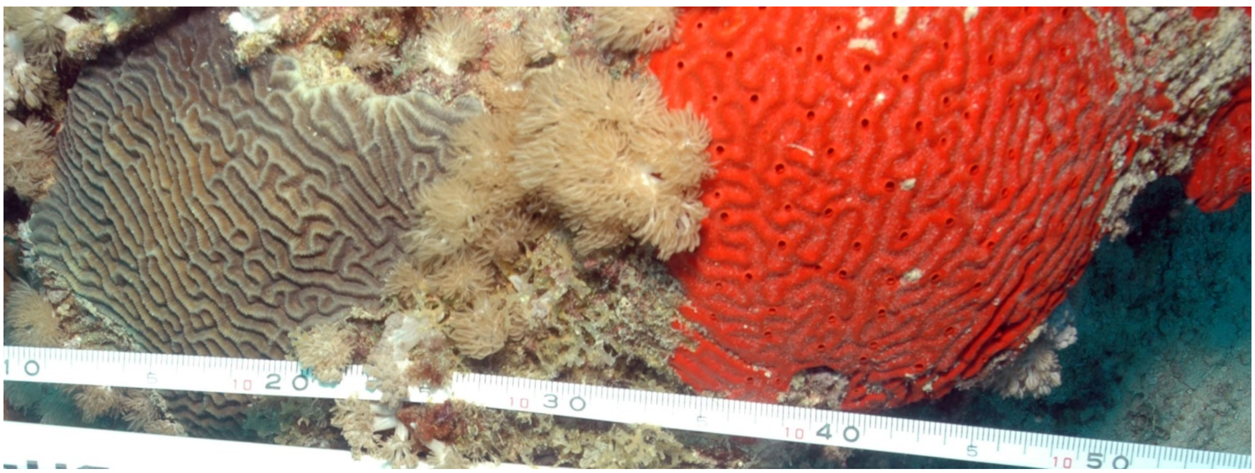


Fig. 2.44a Colony of *Platygyra daedalea* brain coral being overgrown by *Xenia* soft coral and an encrusting clionid sponge in the genus *Pione.*

2.45 Dushuk Island

Transects conducted on the southern tip of Dushuk island were located in shallow water (4-6 m depth). The two sites examined were vastly different. The first, at 5-6 m depth, consisted of a pavement covered with fine sediment, patches of rubble and extensive colonization by cyanobacteria (Fig. 2.45a). Most of the corals were small (5-20 cm diameter), with isolated larger colonies (50-120 cm) of *Astreopora, Echinopora, Diploastrea* and *Porites*. Other important corals included *Millepora*, *Favia*, *Stylophora*, *Goniastrea*, and *Platygra*. Many of the colonies had experienced partial mortality, and coral skeletons were colonized by thick turf algae, cyanobacteria and *Xenia*. Cover of live coral in this location ranged from about 3%-10%, with isolated patches containing up to 20% live coral, and large areas colonized by *Xenia*.

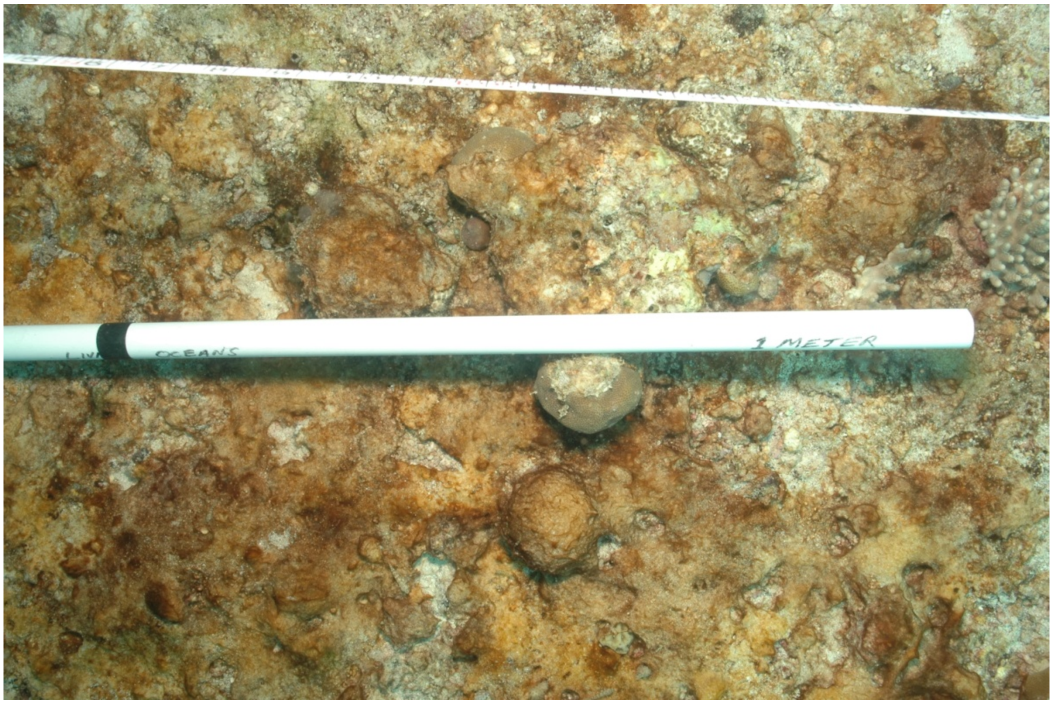


Fig. 2.45a. Representative photo from the southern tip of Dushuk Island at 5 m depth. The bottom consisted of a pavement with a layer of sediment, patches of rubble and extensive mats of a reddish cyanobacteria.

The second site, at 4m depth, was dominated by large massive colonies of *Porites* along with isolated tabular acroporids and massive *Echinopora*. These corals were often several meters in diameter, most were in excellent condition, and they accounted for most of the living coral cover, which covered between 30-40% of the bottom. The other important corals were *Millepora, Stylophora*, *Acropora,* and *Platygyra*, most of which were 15-30 cm in diameter. Soft corals were relatively common at this site (5-10% cover). Most of the substrate was colonized by fine turf algae, although there was a considerable amount of crustose coralline algae and macroalgae; cyanobacteria was rare. A number of *Porites* colonies had patches of recently denuded skeleton associated with *Acanthaster* (COTS) sea star predation, and COTS were observed actively feeing on this coral. In addition, this was the only site with an unusually high abundance of *Coralliophila* snails, a genus that is known to feed on stony corals. The snails most commonly formed aggregates with depressions and at the margins of lesions on massive *Porites* colonies, although fresh feeding scars were small. Herbivorous sea urchins (*Diadema*) were very common.

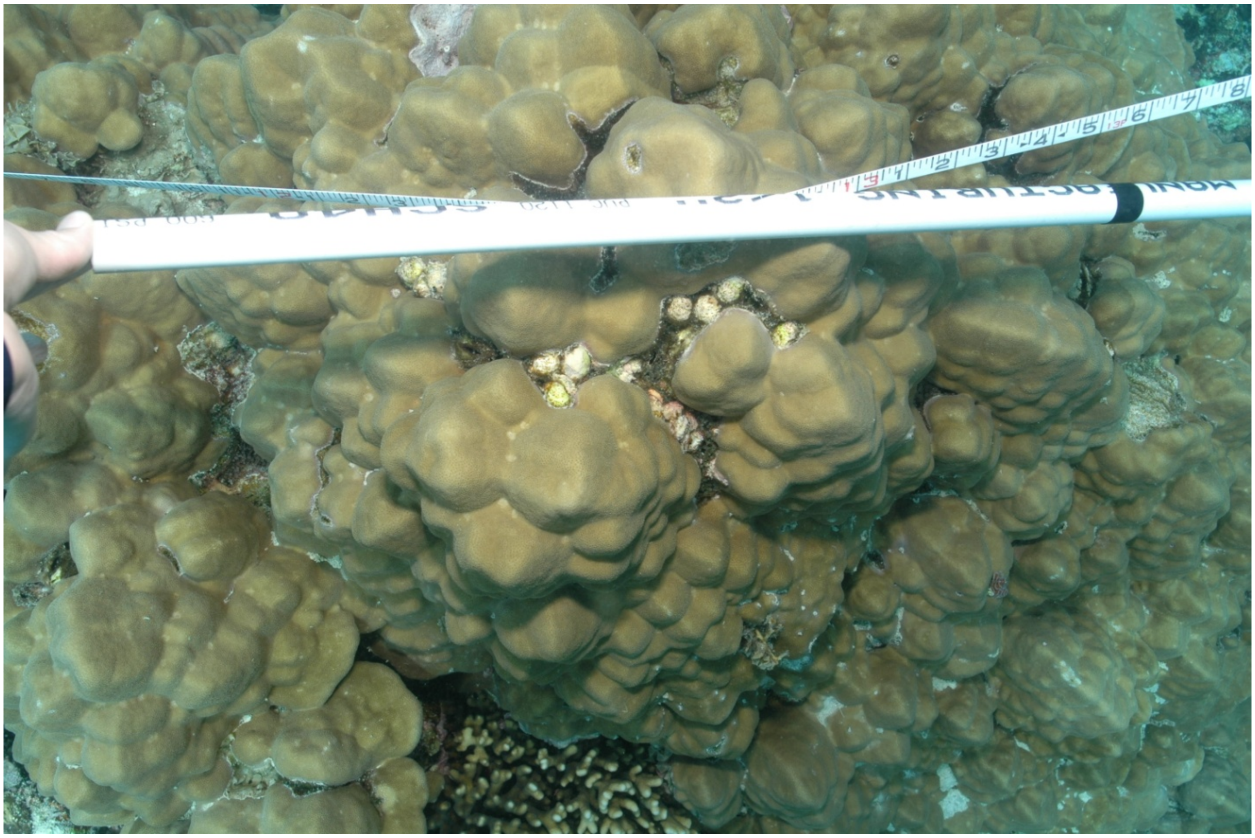


Fig. 2.45b. Large *Porites lobata* colony within a transect off Dushuk Island at 4 m depth. An aggregation of Coralliophila snails is visible in the depression in the middle of the coral below the PVC scale bar.

2.46 Massad Island

Transects conducted off Massad Island were in shallow water (5-6 m depth). The reef was in a protected environment behind the island, seaward from Sarad Sarso. It had a sandy bottom with patches of rubble and large boulders colonized by stony corals and soft corals. Sandy areas had an abundance of free living fungiid corals. In places soft corals covered 50-60% of the bottom, and were encroaching on stony corals, while other areas were dominated by massive and plating corals in the genus *Echinopora, Porites, Platygyra, Lobophyllia, Galaxea, Favia, Montipora, Plerogyra* and other taxa. Other common taxa included *Stylophora* and *Acropora*. Some of the largest corals (*Porites*) were over 2 m in diameter. Several large sponges (primarily in the genus *Ircinia*) were abundant.

While macroalgae were uncommon on this reef, turf algae was very thick and often carpeted the margins of corals and dead colonies. Numerous dead, algal encrusted acroporids colonies were observed. In addition, corals appeared to be suffering from sediment stress.

2.47 Sasuh (Sarad Sarso)

Photo transects were conducted on reefs located off the northern tip and the southwestern end (10 m and 14 m depth) of Sasuh (Sarad Sarso) island. The northern tip had dense thickets of *Acropora* in shallow (5 m depth) water. These were patchy, interspersed with large massive *Porites* lobata colonies, and separated by large expanses of sand. Living coral cover within the coral thickets ranged from 30-80%, while areas between these thickets had 0-5% coral. Dead *Acropora* colonies were colonized by dense growths of *Xenia*. Other important corals included *Platygyra*, *Stylophora*, and *Goniastrea*. The surrounding substrate was a mix of sand, dead coral skeletons and dead *Acropora* rubble; substrates were fairly clean with fine filamentous algae and little macroalgae.

The first site examined in the south was a high relief coral reef site with 30-50% living coral cover. It was dominated by large massive *Porites* colonies and massive *Echinopora* colonies, and numerous other corals. Together, these two corals made up 20-30% living coral cover. This was one of the most diverse reefs examined in the Farasan Islands, and also the reef with the largest corals overall. The next most dominant corals, with most colonies typically of a large size (30-100 + cm) included *Lobophyllia, Favia, Goniastrea, Echinophyllia, Stylophora*, *Montipora, Favites,* and *Mycedium.* Much of the hard substrate without corals was colonized by *Xenia*. Also, an encrusting sponge covered much of the substrate and was actively overgrowing living corals.

The second dive (10 m depth) in the south consisted of large expanses of sand with isolated hard ground areas colonized by a high diversity of coral species. The site had many large (40-80 cm) *Diploastrea, Echinopora, Goniastrea, Favia, Montipora* and *Porites* colonies, although most corals were small to medium sized (10-25 cm). This site had a high number of *Seriatopora* colonies and *Stylophora,* including a species not seen elsewhere. Coral cover was much lower (15-30%) than the deeper area. *Xenia* and the gray encrusting sponge were also abundant at this site, especially in areas with coral rubble.

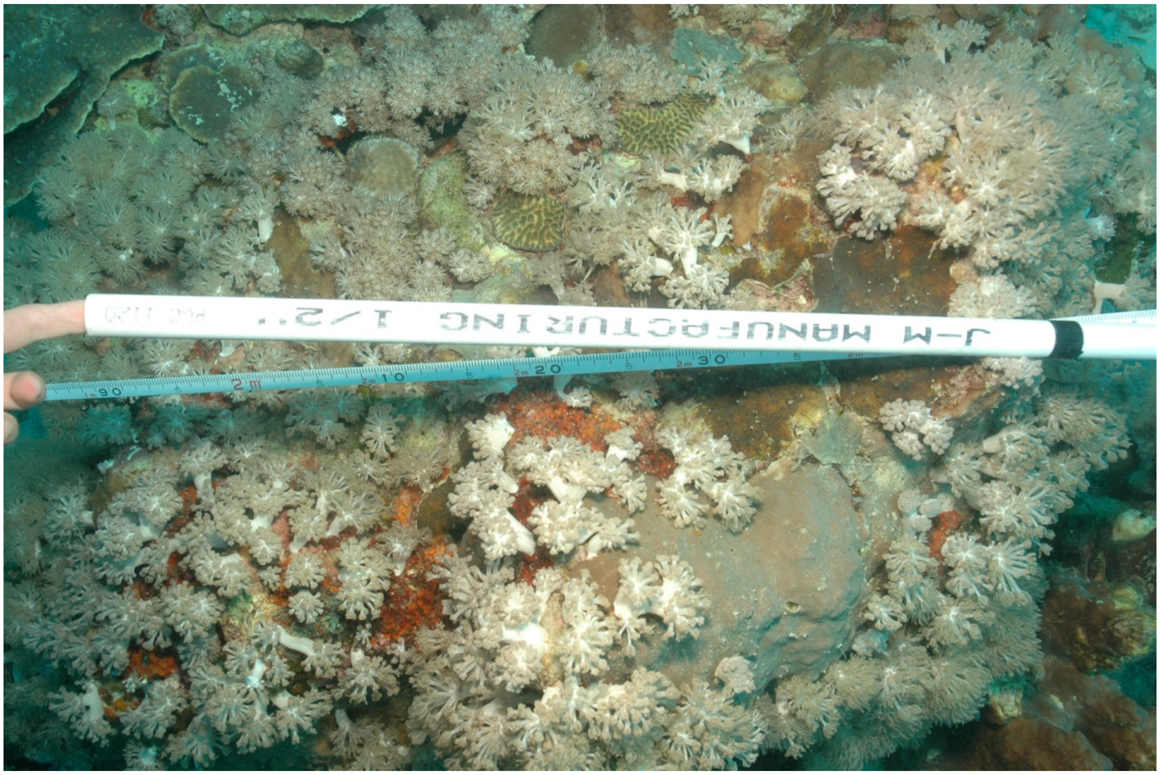


Fig. 2.47a. Xenia soft corals outcompeting stony corals at Sasuh (Sarad Sarso), 14 m depth

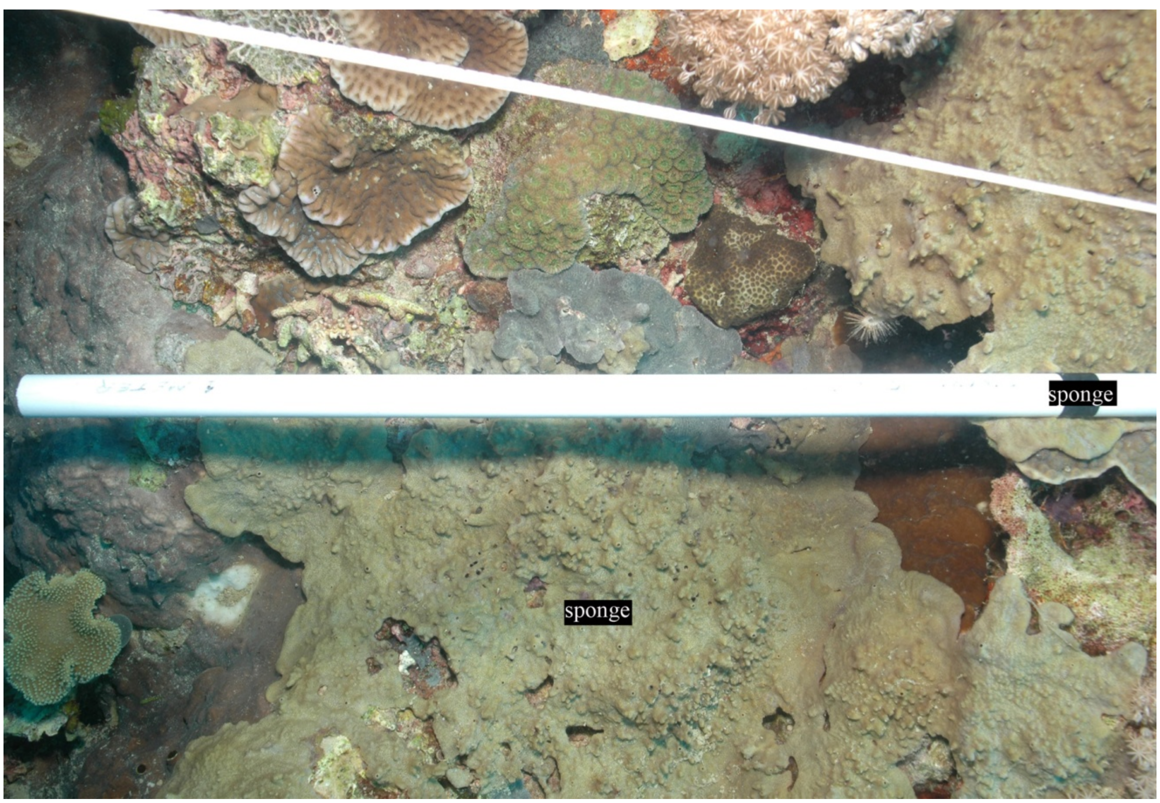


Fig. 2.47b. Encrusting sponge overgrowing live corals.

2.48 Shuma

Two depths were examined off Shuma, 12m and 4 m. Both sites had large expanses of reef with moderately high coral cover (30-70%) separated by sand patches. The deeper site was dominated by massive and plating growth forms, with a high abundance of unusually large colonies of *Galaxea* (50-400 cm diameter) and *Porites* (50-200 cm), and many other species including *Lobophyllia*, *Acropora*, *Echinophyllia*, *Platygyra*, *Goniastrea*, *Favia*, *Favites* , *Mycedium* and many other species. Hardground areas also had patches colonized by dense assemblages of soft corals, especially *Xenia* and *Sinularia*. Many corals in this site also experienced partial mortality, and in particular, the red encrusting clionid (*Pione* spp.) was commonly overgrowing corals. The site appeared to have high levels of sediment transport and resuspension, as many of the corals had a film of fine sediments on their surface.

The shallow site (4 m) consisted of a hardground area with patches of sand and coral rubble. Large *Acropora* thickets were common throughout this area, interspersed with massive *Porites* colonies, *Stylophora*, *Montipora* and *Pocillopora*. There were also large clumps of *Xenia*. Although macroalgal abundance was low, there were small patches of Dictyota and cyanobacteria.

2.49 S Kulam Island

A single dive was conducted on a shoal SW of S. Kulam Island in about 5 m depth. This reef consisted of hardground areas intermixed with extensive sand patches and smaller rubble patches. Stony corals were mostly small (5-20 cm diameter) branching corals, especially Stylophora separated by large expanses of sand, rubble and hardground. The dominant invertebrates were soft corals in the genus *Xenia* and moderate cover (up to 20%) by *Dendronepthya*. This is the only site in the Farasan Islands that had such high abundances of this soft coral. *Dendronepthya* is often an early colonizing species, which suggests that this site may have undergone a past disturbance that eliminated many of the stony corals, and pioneer species are recolonizing the area.

Fig. 2.49a. Coral reef community off S. Kulam Island. The dominant invertebrates on this reef were *Xenia* soft corals and *Dendronepthya* soft corals, with isolated hard corals (e.g. *Stylophora)*.

2.5 Fish

The 28 quantified fish-census surveys provide a baseline of all reef-associated species present in the Farasan Islands, as well as their abundance and size. The total transect counts of 20,491 fish represented 151 species from 40 families (Table 2.51). Off-transect observations recorded an additional 22 species giving a check-list of 173 species. The surveys were dominated by small damselfish (Family Pomacentridae), fusiliers (Family Caesionidae) and wrasse (Family Labridae). The most specious families were the pomacentrids with 27 species and the labrids with 24 species, followed by the acanthurids and serranids with nine species each, and the chaetodontids with eight species. The species distributions of the remaining 34 families ranged from three families with six species each, to 14 families with one species each. The 10 most abundant species were *Caesio striata* (Caesionidae; 4,321), *Chromis viridis* (Pomacentridae; 3,781), *Pomacentrus trichrourus* (Pomacentridae; 922), *P. leptus* (Pomacentridae; 862), *C. lunaris* (Caesionidae; 855), *C. ternatensis* (Pomacentridae; 737), *Neopomacentrus xanthurus* (Pomacentridae; 733), *Cheilodipterus quinquelineatus* (Apogonidae; 693), *Dascyllus marginatus* (Pomacentridae; 647), and *Abudefduf sexfasciatus* (Pomacentridae; 461).

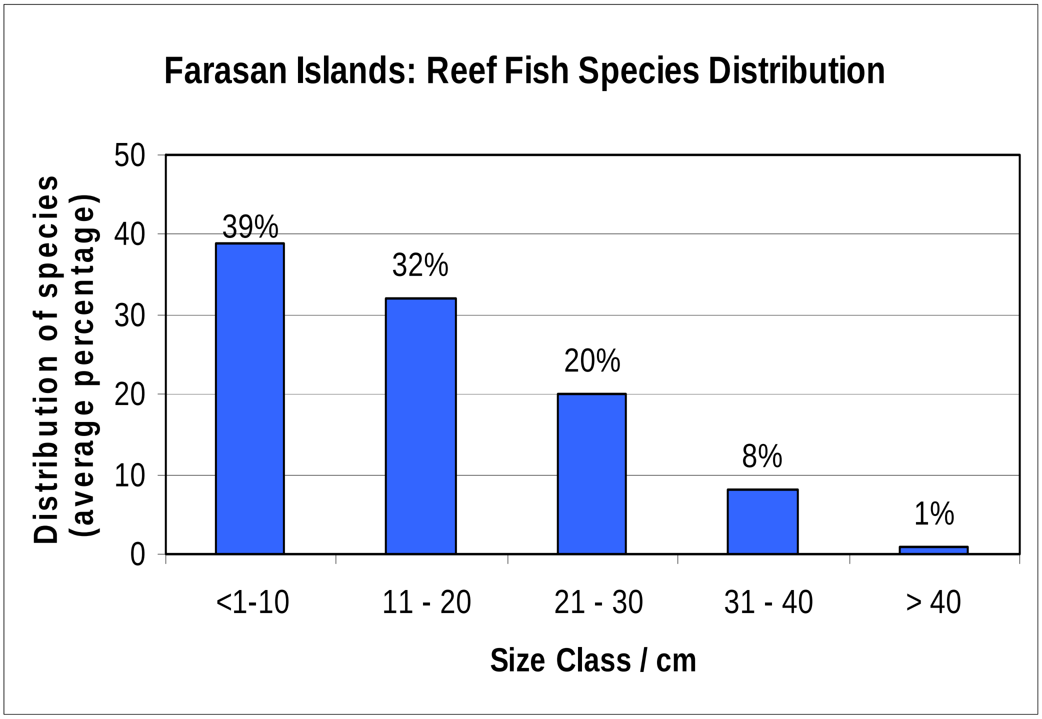


Fig. 2.5a. Distribution of fishes across each size class. Data from all survey sites and species are combined.

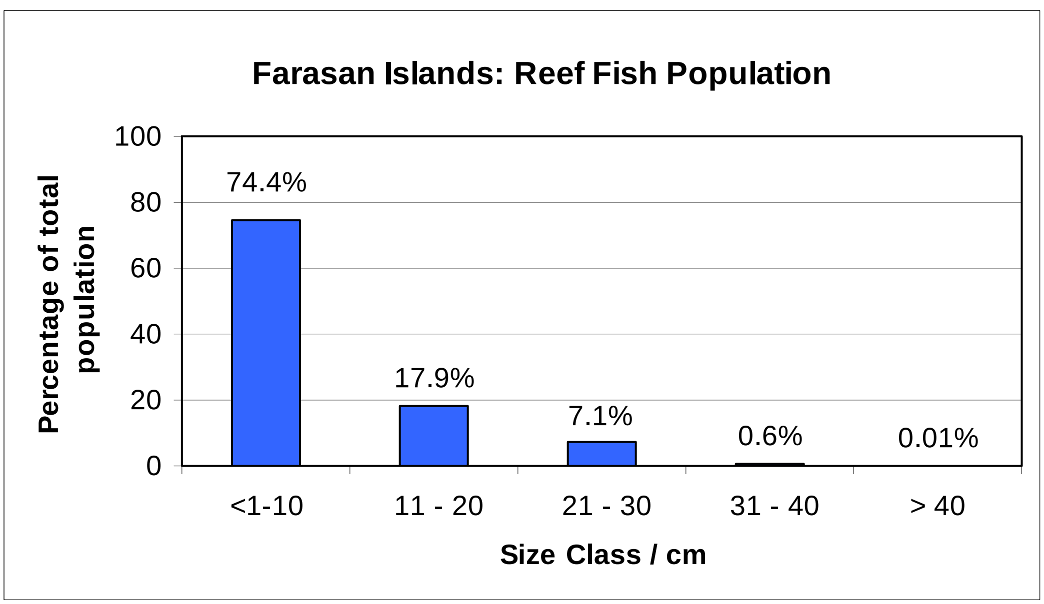


Fig. 2.5b. Farasan fish population distribution across size classes. Data from all survey sites combined

There were few large reef fish observed throughout the fish surveys (Fig. 2.5b), indicative of a reef system that has been subjected to intense fishery harvests. Only 105 fish counted (<0.5% of the total) were in the 31-40cm total length (TL) interval, and only two fish were in the >40cm TL interval (a moray eel and a parrotfish). Comparisons with a previous (1999) survey of 22 species of reef fish important in artisanal and industrial fisheries found close agreement in the percentages for each species, indicating that their relative abundances have likely changed little over the intervening six years. However, it is important to note that the dominant species observed in these transects were damselfish (Fig. 2.5c), which tend to be small. The sheer numbers of damselfish are likely to have skewed the size structure to the left (small size).

Fig. 2.5c. a) Damselfish (Family Pomacentridae), one of the most abundant fish on the reefs of the Farasan Islands and b) parrotfish (Family Scaridae), one of the few larger fish observed.

Table 2.51. Summary of fish species recorded on transects in the Farasan Islands in May 2006.

Family	Genus/species	Number	Off Transect
Acanthuridae	*Acanthurus gahhm*	47	
Acanthuridae	*Acanthurus nigricans*	63	
Acanthuridae	*Acanthurus sohal*	16	
Acanthuridae	*Ctenochaetus striatus*	209	
Acanthuridae	*Naso lituratus*		X
Acanthuridae	*Naso hexacanthus*		X
Acanthuridae	*Naso unicornis*	1	
Acanthuridae	*Zebrasoma desjardinii*	16	
Acanthuridae	*Zebrasoma xanthurum*	12	
Apogonidae	*Apogon cookii*	9	
Apogonidae	*Apogon nigrofasciatus*	10	
Apogonidae	*Archamia fucata*	81	
Apogonidae	*Cheilodipterus arabicus*	25	
Apogonidae	*Cheilodipterus macrodon*	35	
Apogonidae	*Cheilodipterus quinquelineatus*	693	
Balistidae	*Balistapus undulatus*	5	
Balistidae	*Pseudobalistes fuscus*	4	
Balistidae	*Sufflamen albicaudatus*	19	
Belonidae	*Tylosurus choram*		X
Blenniidae	*Aspidontus taeniatus*	2	
Blenniidae	*Ecsenius gravieri*	9	
Blenniidae	*Meiacanthus nigrolineatus*	31	
Blenniidae	*Plagiotremus rhinorhynchos*	1	
Blenniidae	*Plagiotremus tapeinosoma*		X
Caesionidae	*Caesio caerulaurea*	1	
Caesionidae	*Caesio lunaris*	855	
Caesionidae	*Caesio striata*	4321	
Caesionidae	*Caesio suevica*	12	
Carangidae	*Carangoides bajad*	16	
Carangidae	*Carangoides ferdau*	3	
Carangidae	*Carangoides fulvoguttatus*	116	
Carangidae	*Caranx melampygus*		X
Carangidae	*Trachinotus blochii*		X
Carcharhinidae	*Carcharhinus amblyrhynchos*		X
Chaetodontidae	*Chaetodon auriga*		X
Chaetodontidae	*Chaetodon austriacus*	2	
Chaetodontidae	*Chaetodon fasciatus*	8	
Chaetodontidae	*Chaetodon larvatus*	115	
Chaetodontidae	*Chaetodon melannotus*		X
Chaetodontidae	*Chaetodon mesoleucos*	18	
Chaetodontidae	*Chaetodon semilarvatus*	5	
Chaetodontidae	*Heniochus intermedius*	32	
Cirrhitidae	*Cirrhitichthys oxycephalus*	1	
Cirrhitidae	*Paracirrhites forsteri*		X
Dasyatidae	*Taeniura lymma*	9	

Table 2.51 (cont)			
Family	**Genus/species**	**Number**	**Off Transect**
Echeneidae	*Echeneis naucrates*	2	
Ephippidae	*Platax orbicularis*	7	
Ginglymostomatidae	*Nebrius ferrugineus*		X
Gobiidae	*Amblygobius albimaculatus*	11	
Gobiidae	*Amblygobius hectori*	83	
Gobiidae	*Bryaninops natans*	5	
Gobiidae	*Lotilia graciliosa*	4	
Haemulidae	*Diagramma pictum*	2	
Haemulidae	*Plectorhinchus flavomaculatus*		X
Haemulidae	*Plectorhinchus gaterinus*	20	
Haemulidae	*Plectorhinchus pictus*	2	
Holocentridae	*Myripristis murdjan*	64	
Holocentridae	*Myripristis xanthacrus*	14	
Holocentridae	*Neoniphon sammara*	12	
Holocentridae	*Sargocentron caudimaculatum*	10	
Holocentridae	*Sargocentron diadema*	16	
Holocentridae	*Sargocentron spiniferum*	6	
Labridae	*Bodianus anthoides*		X
Labridae	*Bodianus axillaris*	4	
Labridae	*Cheilinus abudjubbe*	12	
Labridae	*Cheliinus fasciatus*	57	
Labridae	*Cheilinus lunulatus*	5	
Labridae	*Coris caudimacula*	2	
Labridae	*Coris variegata*	71	
Labridae	*Epibulus insidiator*	9	
Labridae	*Gomphosus caeruleus*	68	
Labridae	*Halichoeres hortulanus*	29	
Labridae	*Halichoeres marginatus*	11	
Labridae	*Halichoeres scapularis*	234	
Labridae	*Hemigymnus fasciatus*	18	
Labridae	*Labroides dimidiatus*	20	
Labridae	*Larabicus quadrilineatus*	423	
Labridae	*Macropharyngodon bipartitus*	2	
Labridae	*Novaculichthys taeniourus*	1	
Labridae	*Oxycheilinus mentalis*	389	
Labridae	*Paracheilinus octotaenia*	243	
Labridae	*Pseudocheilinus evanidus*	2	
Labridae	*Pseudocheilinus hexataenia*	21	
Labridae	*Thalassoma klunzingeri*	3	
Labridae	*Thalassoma lunare*	418	
Labridae	*Thalassoma purpureum*	3	
Lethrinidae	*Lethrinus borbonicus*	28	
Lethrinidae	*Lethrinus harak*		X
Lethrinidae	*Lethrinus mahsena*		X
Lethrinidae	*Lethrinus nebulosus*		X

Table 2.51 cont.

Family	Genus/species	Number	Off Transect
Lethrinidae	*Lethrinus olivaceus*	3	
Lutjanidae	*Lutjanus bohar*	1	
Lutjanidae	*Lutjanus ehrenbergii*	251	
Lutjanidae	*Lutjanus fulviflamma*	20	
Lutjanidae	*Lutjanus kasmira*	103	
Monacanthidae	*Cantherhines pardalis*	1	
Monacanthidae	*Oxymonacanthus halli*	4	
Monacanthidae	*Pervagor randalli*	9	
Nemipteridae	*Scolopsis ghanam*	290	
Mullidae	*Mulloidichthys flavolineatus*	7	
Mullidae	*Parupeneus cyclostomus*	43	
Mullidae	*Parupeneus forsskali*	48	
Mullidae	*Parupeneus macronema*	1	
Muraenidae	*Gymnothorax javanicus*	1	
Myliobatidae	*Aetobatus narinari*		X
Nemipteridae	*Scolopsis ghanam*	1	
Ostraciidae	*Ostracion cubicus*	1	
Ostraciidae	*Ostracion cyanurus*	11	
Pempheridae	*Pempheris vanicolensis*	6	
Pinguipedidae	*Parapercis hexophthalma*	20	
Pomacanthidae	*Centropyge mulitspinis*	16	
Pomacanthidae	*Pomacanthus asfur*	76	
Pomacanthidae	*Pomacanthus imperator*	1	
Pomacanthidae	*Pomacanthus maculosus*	18	
Pomacanthidae	*Pygoplites diacanthus*	8	
Pomacentridae	*Abudefduf sexfasciatus*	461	
Pomacentridae	*Abudefduf vaigiensis*	25	
Pomacentridae	*Amblyglyphidodon flavilatus*	360	
Pomacentridae	*Amblyglyphidodon leucogaster*	42	
Pomacentridae	*Amphiprion bicinctus*	23	
Pomacentridae	*Chromis dimidiata*	64	
Pomacentridae	*Chromis flavaxilla*	110	
Pomacentridae	*Chromis pelloura*	37	
Pomacentridae	*Chromis pembae*	2	
Pomacentridae	*Chromis ternatensis*	737	
Pomacentridae	*Chromis trialpha*	55	
Pomacentridae	*Chromis viridis*	3781	
Pomacentridae	*Chromis weberi*	31	
Pomacentridae	*Chrysiptera unimaculata*	384	
Pomacentridae	*Dascyllus aruanus*	26	
Pomacentridae	*Dascyllus marginatus*	647	
Pomacentridae	*Dascyllus trimaculatus*	19	
Pomacentridae	*Neopomacentrus cyanomus*	50	
Pomacentridae	*Neopomacentrus xanthurus*	733	
Pomacentridae	*Paraglyphidodon melas*	118	

Table 2.51 cont.

Family	**Genus/species**	**Number**	**Off Transect**
Pomacentridae	*Plectroglyphidodon lacrymatus*	102	
Pomacentridae	*Pomacentrus aquilus*	23	
Pomacentridae	*Pomacentrus leptus*	862	
Pomacentridae	*Pomacentrus sulfureus*	183	
Pomacentridae	*Pomacentrus trichourus*	922	
Pomacentridae	*Pomacentrus trilineatus*	110	
Pomacentridae	*Stegastes nigricans*	7	
Pseudochromidae	*Pseudochromis flavivertex*	82	
Pseudochromidae	*Pseudochromis fridmani*	12	
Scaridae	*Cetoscarus bicolor*	2	
Scaridae	*Hipposcarus harid*	10	
Scaridae	*Scarus ferrugineus*	119	
Scaridae	*Scarus ghobban*	3	
Scaridae	*Scarus niger*	17	
Scaridae	*Scarus sordidus*	49	
Scombridae	*Rastrelliger kanagurta*	30	
Scombridae	*Thunnus albacares*		X
Scorpaenidae	*Pterois radiata*	3	
Scorpaenidae	*Scorpaenopsis diabolus*	1	
Serranidae	*Aethaloperca rogaa*	1	
Serranidae	*Cephalopholis hemistiktos*	123	
Serranidae	*Cephalopholis miniata*	2	
Serranidae	*Cephalopholis sexmaculata*	3	
Serranidae	*Diploprion drachi*		X
Serranidae	*Epinephelus chlorostigma*	3	
Serranidae	*Epinephelus polyphekadion*	1	
Serranidae	*Epinephelus summana*	18	
Serranidae	*Epinephelus tauvina*	1	
Siganidae	*Signaus argenteus*	8	
Siganidae	*Siganus luridus*	1	
Siganidae	*Siganus rivulatus*		X
Siganidae	*Siganus stellatus*	5	
Sparidae	*Acanthopagrus bifasciatus*		X
Sphyraenidae	*Sphyraena quenie*		X
Synodontidae	*Synodus variegatus*	1	
Tetraodontidae	*Arothron diadematus*	3	
Tetraodontidae	*Arothron stellatus*	1	
Tetraodontidae	*Canthigaster margaritata*	5	
Total Fish Counted		20,491	

2.51 Abu Shuqar Bank and Island

During 4-6 May 2006, fish surveys were conducted in the Abu Shuqar Bank (4 surveys) and Abu Shuqar Island (2 surveys) area, covering a total of 550m^2 of coral reef habitat from 5-11 m depth. These transect contained 5,301 fish representing 71 species and 24 families; off-transect observations added one additional species. The small, generally planktivorous (plankton feeding) damselfishes (Pomacentridae, 16 species) dominated the fish counts (3,491 fish, 66% of the total), and one species of damselfish, *Chromis viridis*, was the most abundant fish (2,463 fish, 46% of the total) recorded in these sites. The planktivorous fusiliers (Caesionidae, 3 species) were the second most abundant group in the fish counts (827 fish, 16% of the total), followed by the omnivorous (generalist feeding) wrasses (Labridae, 12 species; 463 fish, 9% of the total).

Large schools of *C. viridis* (blue green chromis) associated with branching corals were found during both surveys. The second most abundant damselfish, *Dascyllus marginatus* (300 fish), was also closely associated with branching corals where it feeds on plankton, benthic invertebrates, and algae. The fusilier counts were dominated by a large school (700 fish) of *Caesio striata* recorded in a Bank survey. The most common wrasses were the cleaner wrasse *Larabicus quadrilineatus* (117 fish) and the bottom feeding *Oxycheilinus mentalis* (232 fish). These wrasses were found in both surveys, but high counts of *O. mentalis* were mainly in the Island-area transects.

Fig. 2.51a. Blue green chromis (*Chromis viridis*) above a colony of *Stylophora*. Photo by Annelise Hagan

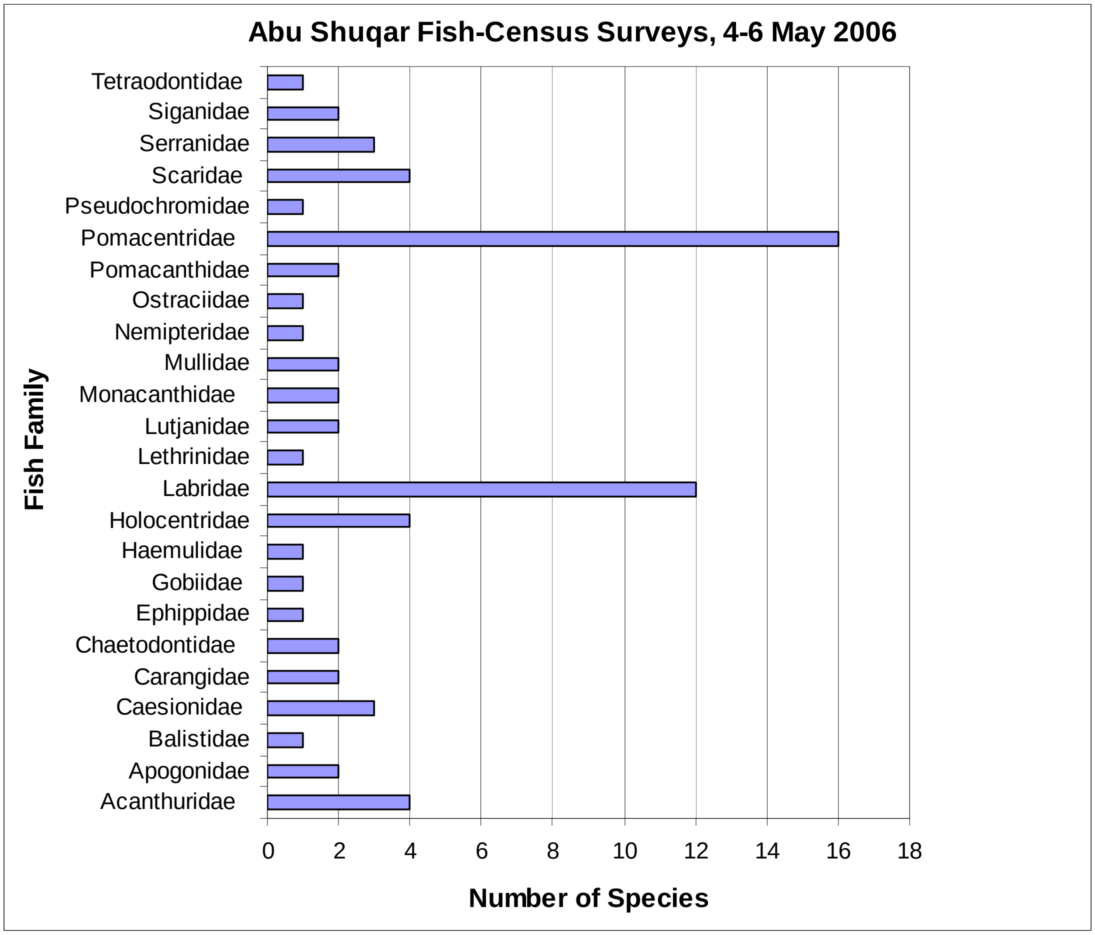


Fig. 2.51b. Numbers of species of fish recorded in surveys off Abu Shuqar Bank and Island.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 73% (3,883) of the 5,301 fish counted in the survey transects. An additional 1,225 fish were recorded in the third size class (11-20cm TL). Overall, 96% of all fish counted were 20 cm total length or less, with damselfishes, fusiliers and wrasses accounting for 92% of all the fish in the first three length intervals. The remaining 8% of the fishes that were up to 20cm TL were represented by 14 families. There were only 38 fish in the 31-40cm TL length interval, and no fish >40cm TL in the surveys. Although transect counts were dominated by fish that were 20 cm TL or smaller, they were present at moderate densities of 9.2 fish/m^2 in the areas surveyed.

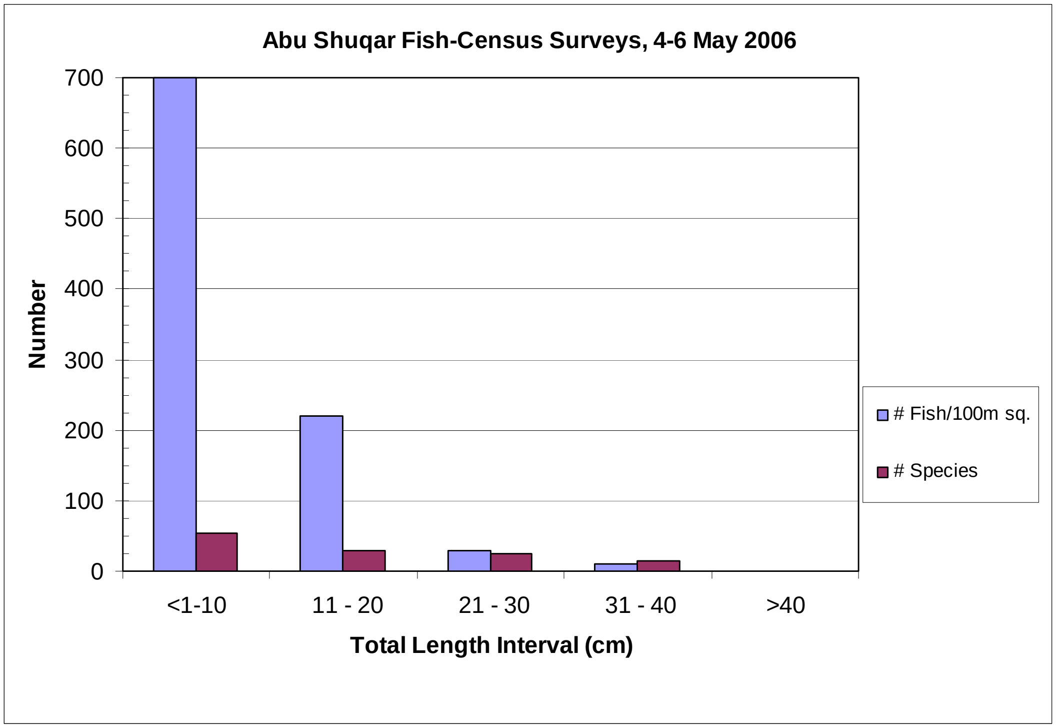


Fig. 2.51c Size classes (total length) distribution of fish recorded in surveys off Abu Shuqar Bank and Island. Data are presented as numbers of fishes (purple) and numbers of species (red).

2.52 Akbayn Island

During 7-8 May 2006, four fish surveys were conducted at Akbayn Island covering a total of 400m^2 of coral reef habitat at 4-16m depth. A total of 3,574 fish, represented by 65 species and 22 families, were recorded in all transects. Six additional species were identified in roving surveys, represented by two additional families and six species, with a total of 71 species and 24 families identified in this area. The planktivorous fusiliers (Caesionidae, 2 species) dominated the fish counts (2,053 fish, 57% of the total), and one species of fusilier, *Caesio striata*, was the most abundant fish (1,610 fish, 45% of the total) recorded. The small planktivorous damselfishes (Pomacentridae, 18 species) were the second most abundant group (866 fish, 24% of the total), followed by the omnivorous wrasses (Labridae, 11 species; 277 fish, 8% of the total).

C. striata is a small species that reaches only 18cm TL as an adult. Large schools of this fusilier were recorded on three of the four surveys. The most common damselfishes were *C. viridis* (220 fish), *Amblyglyphidodon flavilatus* (131 fish), and *Neopomacentrus xanthurus* (165 fish), the latter noted as a southern Red Sea species (Allen 1991;, Field 1998). The most common wrasses were *Halichoeres scapularis* (114 fish), a species that feeds in sand patches between the reef corals, and *Thalassoma lunare* (80 fish) which is usually found singly or in small schools on the reef.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 90% (3,233) of the 3,574 fish counted in this area. The additional 251 fish identified in the third length interval (11-20cm TL) increased the total to 97% of all fish counted. The abundant damselfishes, fusiliers and wrasses accounted for 92% of all the fish in the first three length intervals. The remaining 8% of the fishes that were up to 20cm TL represented 14 families. There were only 28 fish in the 31-40cm TL length interval, and no fish >40cm TL in the surveys. Although the fish up to 20cm TL dominated the transect counts, they were present in only a moderate density of 8.7 fish/m^2 in the areas surveyed.

2.53 Al Baghlan Bank

During 9-11 May 2006, three fish surveys were conducted at Al Baghlan Bank, covering a total of 300m^2 of coral reef habitat at 5-15m depths. These surveys contained 1,348 fish represented by 79 species and 27 families. Three additional species were observed during roving surveys, represented by two additional families, giving a check-list of 82 species and 29 families for the area. The small planktivorous damselfishes (Pomacentridae, 17 species) dominated the fish counts (665 fish, 49% of the total), and one species of damselfish, *Chromis ternatensis*, was the most abundant fish (286 fish, 21% of the total) recorded. The planktivorous fusiliers (Caesionidae, 2 species) was the second most abundant group of fish (185 fish, 14% of the total), followed by the omnivorous wrasses (Labridae, 13 species; 146 fish, 11% of the total). Predatory (fish and invertebrate feeding) snappers (Lutjanidae, 2 species; 136 fish, 10% of the total) were also relatively abundant.

Chromis ternatensis was often associated with the branching coral *Acropora*, occurring primarily on one of the 15m depth transects. The fusiliers were mainly *Caesio lunaris* (110 fish), one of the larger fusiliers found in the Red Sea. The most common wrasses were the cleaner wrasse *Larabicus quadrilineatus* (35 fish) and *Thalassoma lunare* (35 fish). *Lutjanus ehrenbergii* (133 fish) was the dominant snapper, occurring in a single school at 15m depth. Many of these fish had an unusually dark coloration on the head and exhibited aggressive behavior toward the other fish in the school, indicative of a pre-spawning aggregation in lutjanids.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 58% (778) of the 1,348 fish counted in these surveys. An additional 272 fish in the third length interval (11-20cm TL) increased this to 78% of the total fish counted. Damselfishes, fusiliers and wrasses accounted for 82% of all the fish in the first three length intervals. The remaining 18% of the fishes that were up to 20cm TL were represented by 20 families. The 284 fish recorded in the 21-30cm TL interval were primarily *L. ehrenbergii* (47%) and *C. lunaris* (39%). There were only 14 fish recorded in the 31-40cm TL interval, and no fish >40cm TL in the surveys. All fish counted in these surveys occurred at a relatively low density of 4.5 fish/m^2.

2.54 Zufaf Island and Dushuk Island

During 12-14 May 2006, seven fish surveys were conducted on reefs fringing Zufaf Island (5 surveys) and Dushuk Island (2 surveys) covering a total of 700m^2 of coral reef habitat from 3-15m depth. A total of 3,086 fish were counted, representing 83 species and 28 families. Five additional species, which included three additional families, were identified in roving surveys, giving a check-list of 88 species and 31 families for the area. Once again, the small planktivorous damselfishes (Pomacentridae, 16 species) dominated the fish counts (1,369 fish, 45% of the total), and one species of damselfish, *Neopomacentrus xanthurus,* was the most abundant fish (568 fish, 19% of the total) recorded. The omnivorous wrasses (Labridae, 14 species) was the second most abundant group in the fish counts (530 fish, 17% of the total), followed by the carnivorous cardinalfishes (Apogonidae, 3 species; 475 fish, 15% of the total).

N. xanthurus, a southern Red Sea damselfish, was found almost entirely (563 fish) in one transect at Dushuk Island. The other abundant damselfishes, *Pomacentrus trichourus* (219 fish), *Chromis viridis* (149 fish), and *P. leptus* (144 fish), were found off both Zufaf Island and Dushuk Island. The most abundant wrasse, *Paracheilinus octotaenia* (208 fish), was found only on reefs off Zufaf Island, while the second most abundant wrasse, *Thalassoma lunare* (110 fish), was found in both areas. Most cardinalfishes were *Cheilodipterus quinquelineatus* (471 fish), which occurred primarily on reefs off Zufaf Island; these fishes were usually found in association with the black sea urchin *Diadema setosum*, where the juveniles seek shelter among the urchin spines.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 77% (2,359) of the 3,068 fish counted in the survey transects. An additional 430 fish in the third length interval (11-20cm TL) increased this to 91% of the total fish counted. Damselfishes, wrasses, and cardinalfishes accounted for 86% of all the fish in the first three length intervals. The remaining 14% of the fishes that were up to 20cm TL were represented by 20 families. The 248 fish in the 21-30cm TL length interval were primarily (165 fish) the fusilier *Caesio lunaris*. There were only 30 fish in the 31-40cm TL length interval, and only one fish, the moray eel *Gymnothorax javanicus* (Muraenidae), >40cm TL in the surveys. Although the fish up to 20cm TL dominated the transect counts, they were present at a low density of 4.0 fish/m^2 in the areas surveyed.

2.55 Massad Island and Sarad Sarso Island

On 16 and 19 May 2006, four fish surveys were conducted in the Massad Island (1 survey, 16 May) and the Sarad Sarso Island (3 surveys, 16 and 19 May), covering a total of 350m^2 of coral reef habitat from 5-12m depth. These transects contained 3,371 fish represented by 73 species and 24 families. Six additional species were observed during roving surveys, including one additional family, giving a check-list of 79 species and 25 families for the area. The small planktivorous damselfishes (Pomacentridae, 17 species) dominated the fish counts (1,911 fish, 57% of the total), and one species of damselfish, *Pomacentrus trichrourus*, was the most abundant fish (664 fish, 20% of the total) recorded in the transect areas. The planktivorous fusiliers (Caesionidae, 2 species) was the second most abundant group (680 fish, 20% of the total), followed by the omnivorous wrasses (Labridae, 11 species; 269 fish, 8% of the total).

P. trichrourus, and the second most abundant damselfish, *P. leptus* (487 fish, 14% of the total) were found in both the Massad Island and Sarad Sarso Island surveys, and in relatively large numbers compared to the other damselfishes recorded in the transects. This appears to be unusual as *P. trichrourus* is reported to be “usually solitary”, and *P. leptus* as “not very common” in the Red Sea (Field 1998). In comparison, the total count of a damselfish that usually forms large schools, *Chromis viridis*, was only 230 fish. The fusiliers were dominated by a large school (600 fish) of *Caesio striata* recorded in a single Massad Island transect. The most common wrasses were the cleaner wrasse *Larabicus quadrilineatus* (82 fish) and the bottom feeding *Oxycheilinus mentalis* (50 fish). Both of these wrasses were found in the Massad Island and Sarad Sarso Island survey transects.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 87% (2,921) of the 3,371 fish counted in the survey transects. An additional 251 fish in the third length interval (11-20cm TL) increased this to 94% of the total fish counted. The damselfishes, fusiliers and wrasses accounted for 90% of all the fish in the first three length intervals. The remaining 10% of the fishes that were up to 20cm TL were represented by 18 families. Many of the185 fish in the 21-30cm TL length interval were fusiliers (*Caesio lunaris;* 80 fish), and the herbivorous surgeonfish *Ctenochaetus striatus* (Acanthuridae; 44 fish). There were only 13 fish in the 31-40cm TL length interval, and only one fish, the parrotfish *Scarus ferrugineus* (Scaridae), >40cm TL. Although fish up to 20cm TL dominated the transect counts, they were present at a moderate density of 9.0 fish/m^2.

2.56 Dhi Dahaya Island

During 17-18 May 2006, three fish surveys were conducted at Dhi Dahaya Island, covering a total of 300m^2 of coral reef habitat at 4-13m depth. Transects contained 3,167 fish, represented by 77 species and 27 families. One additional species from one additional family was identified in roving surveys, giving a check-list of 78 species and 28 families for the area. The primarily planktivorous damselfishes (Pomacentridae, 15 species) dominated the fish counts (1,317 fish, 42% of the total), followed by the planktivorous fusiliers (Caesionidae, 2 species; 1,270 fish, 40% of the total). Although far less abundant than the damselfishes and fusiliers, the omnivorous wrasses (Labridae, 16 species) was the third most abundant group of fishes (179 fish, 6% of the total). The four most abundant fishes were the fusilier *Caesio striata* (800 fish, 25% of the total), the damselfish *Chromis viridis* (594 fish, 19% of the total), the fusilier *C. lunaris* (470 fish, 15% of the total), and the damselfish *C. ternatensis* (282 fish, 9% of the total).

The fusiliers occurred primarily in large schools. All of *C. striata*, and 400 of *C. lunaris* were recorded in single large schools at 13m depth. The damselfishes *C. viridis* and *C. ternatensis* were recorded at 4m and 5m depths in association with branching corals that they used as refuge habitat. The most abundant wrasses were *Thalassoma lunare* (46 fish), the cleaner wrasse *Larabicus quadrilineatus* (33 fish), and *Gomphosus caeruleus* (30 fish), all recorded at the three depths. Both *T. lunare* and *G. caeruleus* actively moved among the corals where they feed primarily on benthic invertebrates. In the Red Sea, *G. caeruleus* is a distinct subspecies *G. c. klunzingeri* (Debelius 1998).

Fish in the two smallest length intervals (up to 10cm TL) accounted for 46% (1,465) of the 3,167 fish counted in the transects. An additional 1,180 fish in the third length interval (11-20cm TL) increased the total to 83%. The damselfishes, fusiliers, and wrasses accounted for 72% of all the fish in the first three length intervals. The remaining 28% of the fishes that were up to 20cm TL were represented 20 families. The 520 fish recorded in the 21-30cm TL interval were primarily *C. lunaris* (90%). There were two fish recorded in the 31-40cm TL interval, and no fish >40cm TL were observed. Although fish up to 20cm TL dominated the counts, they were present at a moderate density of 9.7 fish/m^2 in the areas surveyed.

2.57 South Kulam Island

On 22 May 2006, one fish survey was conducted at south Kulam Island, covering 100m^2 of coral reef habitat at 7m depth. This transect contained 660 fish represented by 13 species and 27 families. The primarily planktivorous damselfishes (Pomacentridae, 6 species) dominated the fish counts (307 fish, 46% of the total), and one species of damselfish, *Dascyllus marginatus*, was the most abundant fish (190 fish, 29% of the total) recorded. The omnivorous wrasses (Labridae, 9 species) was the second most abundant group in the fish counts (181 fish, 27% of the total), followed by the carnivorous cardinalfishes (Apogonidae, 2 species; 133 fish, 20% of the total).

D. marginatus was associated with branching corals in the survey area. This damselfish feeds on plankton and benthic invertebrates and algae, and uses the coral as a refuge from predators. The most abundant wrasses were *Halichoeres scapularis* (44 fish) and *Coris vareigata* (40 fish), both found mainly in the sand patches between the reef corals where they feed on benthic invertebrates, and the cleaner wrasse, *Larabicus quadrilineatus* (30 fish). The cardinalfishes included *Cheilodipterus quinquelineatus* (80 fish) which were usually found in association with the black sea urchin *Diadema setosum*; and *Archamia fucata* (50 fish), which formed schools along the base of the reef.

Fish in the two smallest length intervals (up to 10cm TL) accounted for 91% (603) of the 660 fish counted in the survey transect. The only other fishes (57) in the survey were in the 11-20cm

TL interval. The damselfishes, wrasses and cardinalfishes accounted for 94% of all the fish counted. The remaining 6% of the fish were represented by 10 families. The fish occurred at a relatively low density of 6.6 fish/m^2.

2.58 Aminah Island

On 22 May 2006, a fish species check-list survey was conducted at Aminah Island on a shallow coral reef. This survey noted 7 species from 5 families that had not been found in previous transect or roving surveys conducted in the other areas.

2.59 Trends in fish population structure

2.591 Statistical Methods

Statistical analysis of the fish survey data was performed using PRIMER v6 (Clarke and Gorley 2006). Data was examined at the species level and was log transformed before analysis in order to prevent data skewing due to high abundances of one or two species. Data from dive sites were grouped together into habitat groupings (Fig).The Bray-Curtis similarity index (Bray and Curtis 1957) was used to determine similarity among sites based on abundance of fish species. Habitat groupings were analyzed to determine if differences in habitat were responsible for variations in the fish community structure. Variation in fish group composition with respect to habitat variables was tested using a 1-way Analysis of Similarity (ANOSIM). Similarity Percentages (SIMPER) analysis was used to determine which fish taxa were most responsible for the variation seen among the habitats. The Shannon-Wiener diversity index (H) (Shannon 1948), Pielou's evenness (J) (Pielou 1966) and species richness (S) were calculated for each site.

Average biomass was calculated for two families of fish species, Acanthuridae and Scaridae. These two families of fish are largely responsible for maintaining a low abundance of macroalgae on reefs Bellwood et al. 2004). The average biomass was calculated by multiplying the average abundance with the average fish length for each family.

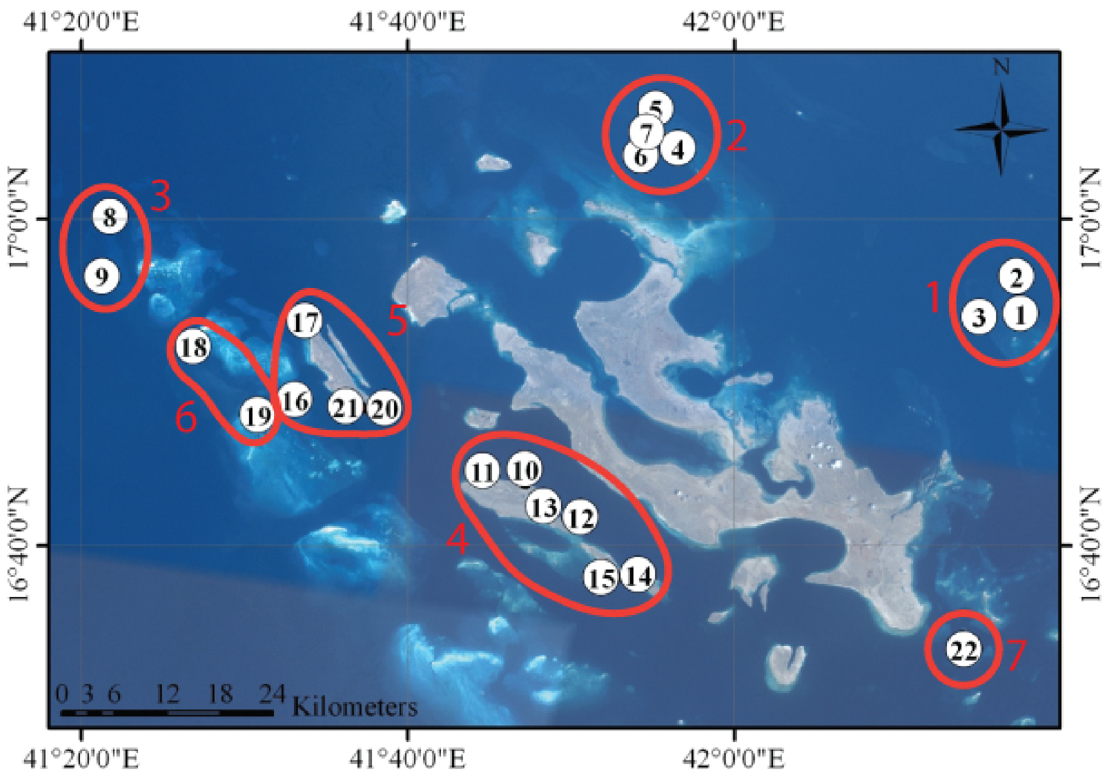


Fig 2.59a. Habitat groupings for the 22 divesites in the Farasan Islands. Red circles and numbers indicate the seven groups.

The fish community composition varied significantly across all habitats (ANOSIM; $p=0.01$, $R=0.963$), the data analyzed had several sites averaged together. This averaging could have potentially inflated the R-value and showed significance where there was none. However, the diversity measures also indicate a difference in community composition between sites (Fig. 2.59b). The back island habitats (1 and 2) have a much lower H and J. However, S remains fairly constant across all habitats, with the exception of 7.

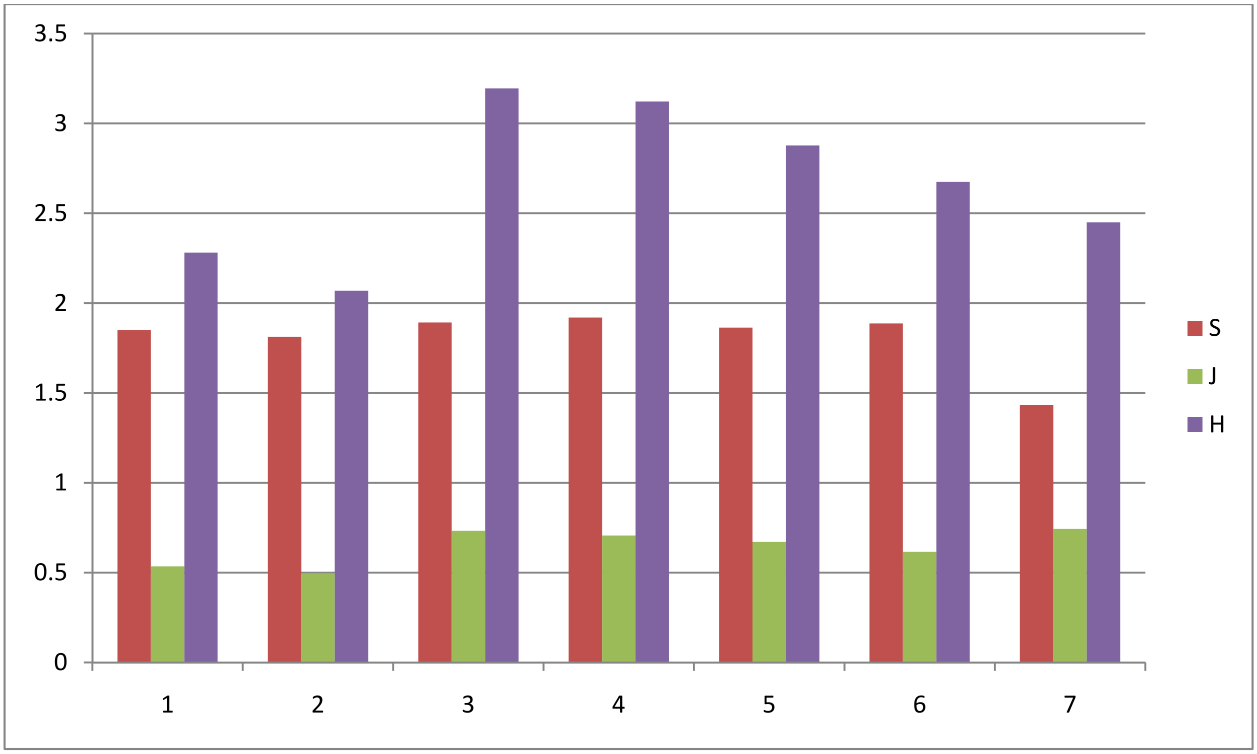


Fig. 2.59b. – Diversity plot for the Farasan Islands. Richness (S)(log transformed to better fit on the axes of the graph), evenness (J), and Shannon-Wiener diversity index (H) are plotted across the 7 sites (Fig) of the Farasan Islands.

The SIMPER results for the habitat groupings help to explain the unevenness. Sites 1 and 2 have high abundances of *Caesio striata* and *Neopomacentrus xanthurus*, and they are so abundant that they are creating the low J and H values (Fig. 2.59b).

	Contrib. %	Cum. %	Av. Abund %
Back Island			
Caesio striata	8.90	8.90	5.91
Chromis viridis	6.43	15.32	5.37
Amblyglyphidodon flavilatus	5.62	20.94	3.60
Thalassoma lunare	4.86	25.80	3.17
Abudefduf sexfasciatus	4.66	30.46	3.48
Scolopsis ghanam	4.43	34.89	3.16
Chrysiptera unimaculata	3.97	38.85	2.50
Larabicus quadrilineatus	3.97	42.82	3.09
Chromis flavaxilla	3.83	46.65	2.79
Pomacentrus leptus	3.75	50.40	2.89
Outer Reef			
Chromis ternatensis	6.31	6.31	4.96
Caesio lunaris	5.12	11.43	4.74
Chromis viridis	4.87	16.30	4.76
Caesio striata	4.65	20.95	4.82
Ctenochaetus striatus	3.93	24.88	3.17
Pomacentrus sulfureus	3.75	28.63	3.06
Chrysiptera unimaculata	3.71	32.34	3.13
Thalassoma lunare	3.71	36.06	3.05
Larabicus quadrilineatus	3.64	39.70	2.89
Plectroglyphidodon lacrymatus	3.36	43.06	2.96
Front Island			
Pomacentrus trichourus	5.83	5.83	4.37
Chromis viridis	5.23	11.05	3.66
Pomacentrus leptus	5.17	16.23	4.01
Caesio lunaris	4.89	21.12	3.20
Abudefduf sexfasciatus	4.32	25.44	2.78
Larabicus quadrilineatus	4.32	29.76	2.88
Thalassoma lunare	3.96	33.72	2.71
Cheilodipterus quinquelineatus	3.70	37.42	3.34
Oxycheilinus mentalis	3.44	40.86	2.37
Ctenochaetus striatus	3.31	44.17	2.37

Table 2.59. Within group similarity SIMPER results examining habitat groupings. Top ten contributing species for each habitat grouping are listed with contributing percentage, cumulative percentage and average abundance. Species are ranked by contribution percentage. South Island is not listed as there was only one dive site at that locality.

When comparing the biomass of Acanthurid with Scarid fish between the Farasan Banks and the Farasan Islands, there is a much lower average biomass seen in the Farasan Islands (Fig. 2.59c). This disparity was due mainly to the lower abundance of these families of fish found in the Farasan Islands. We believe that this lower biomass in the Farasan Islands is due mainly to higher fishing pressure seen in the Farasan Islands. The Farasan Islands have a higher population nearby and more consistent shallow water depths (compared to the Farasan Banks). These two factors combined increase the fishing pressure in the majority of habitats that we surveyed in the Farasan Banks. A consequence of the lower average biomass seen in the Farasan Islands is an increase in the abundance of macroalgae found. If this fishing pressure is maintained or increases, there is a possibility that the abundance of macroalgae will increase, shifting from a coral dominated habitat to a macroalgae dominated one.

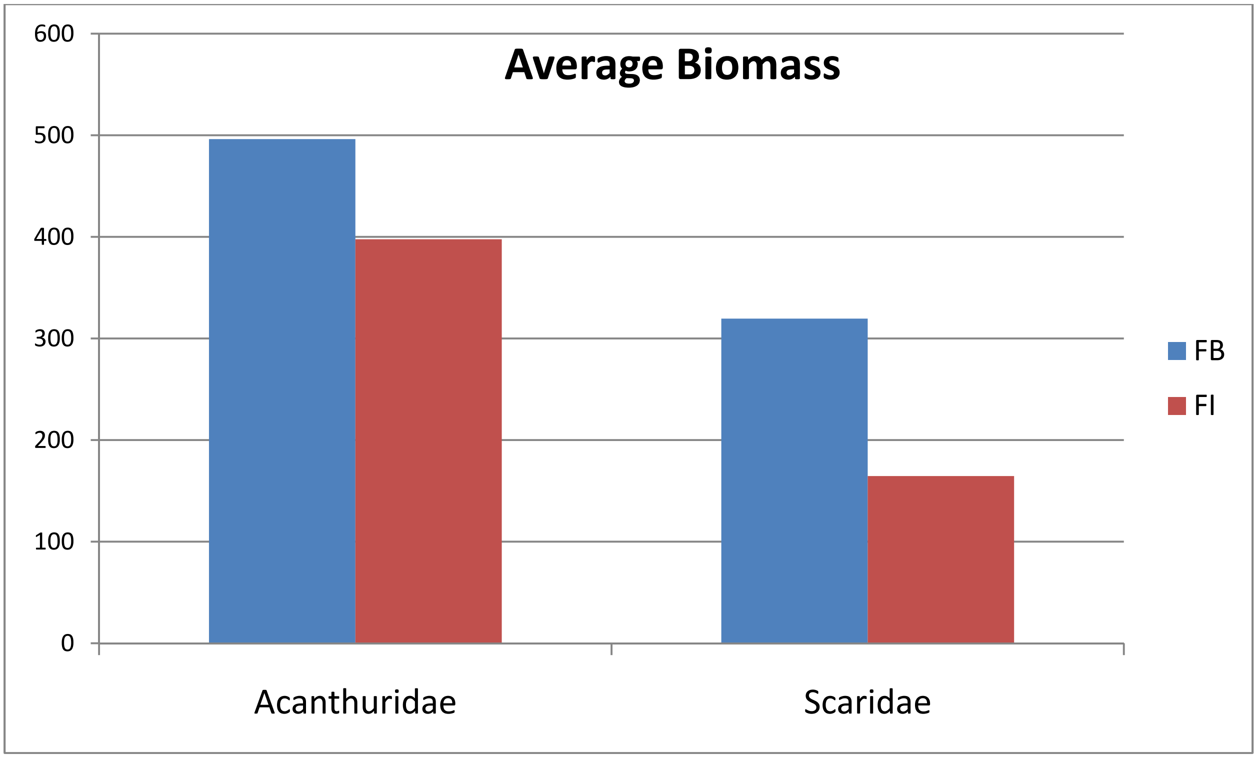


Fig. 2.59c. – The average biomass of Acanthurid and Scarid fish found in the Farasan Banks (FB) and the Farasan Islands (FI)

2.6 Threats and Resilience Indicators

Stressors affecting the reefs included both human impacts and natural factors. The most significant human stressor at the time of the surveys appears to be associated with fishing pressure, as reef fishes identified in belt transect surveys were predominantly small, non-target species with few large groupers, sharks or other commercial and subsistence targets, and less than 1% of fishes above 30 cm total length were recorded. Signs of fishing included traps, presence of fishing boats, fishing gear in reef environments, and fishermen camps on several islands. A minor human impact was pollution, with garbage observed in reef environments and in some coastal areas (Fig. 2.6a).

Natural stressors noted during reef assessments included competition and overgrowth by soft corals and encrusting and bioeroding sponges, coral diseases, coral bleaching and coral predation by *Drupella* snails and *Acanthaster* (COTS) sea stars. Although present, coral mortality from these factors appeared to be minimal, with exception of a single outbreak of COTS. During reef assessments on May 5 2006, on the reefs of Abu Shuqar Island, an outbreak of *Acanthaster planci* (Crown-of-Thorns Starfish; COTS) was observed within an *Acropora* stand. A total of 87 starfish were counted within a 120 m^2 area, giving a density of 0.725 starfish per m^2. The sea stars averaged 24 cm in diameter from arm tip to arm tip. These animals had aggregated on individual colonies and were causing extensive mortality (Fig. 2.6b).

The quality of reef substrates, as measured by the presence of coral rubble, colonization by pest species such as encrusting sponges, and occurrence of macroalgae and cyanobacteria, was highly variable. Macroalgae was most common on nearshore sites off Abu Shuqar Bank and Akbayn Island, while cyanobacteria often carpeted hard substrates in deeper water (15-18 m depth). Hard substrates in many of the reef environments were covered with fine sediment and turf algae that trapped sediments, two features not amenable to coral recruitment. Coral rubble was common in sandy areas and in deeper sites. In some areas this had been stabilized by crustose coralline algae, but more commonly cyanobacterial mats covered rubble and sandy areas.

Fig. 2.6a. Discarded oil can observed on Abu Shuqar Bank on May 6, 2006.

Fig. 2.6b. Aggregation of 7 *Acanthaster* (COTS) on a tabular acroporids on Abu Shuqar reef.

The southern Red Sea, including the Farasan Banks and Farasan Islands also has the highest productivity of fisheries in the entire Red Sea. This rich fishery is a result of the extensive shallow seagrass beds and mangrove habitats that provides refuge, nursery areas and feeding grounds. In addition, the high nutrient content of these waters is known to increase the amount of phytoplankton and zooplankton (secondary productivity) available in the food web, thus supporting larger fish stocks. High nutrients are driven mainly by 1) the broad and relatively shallow shelf which facilities resuspension of nutrient-laden sediment; and 2) the inflow of nutrient rich surface water originating from upwelling areas in the Gulf of Aden. While these factors promote high standing stocks of fishes, they may also degrade resilience. The high nutrients tend to promote rapid growth of macroalgae which compete for space with corals. The combination of high cover of macroalgae and turf algae, many of which trap sediment, along with the higher amount of sediment transport may reduce the potential for recruitment. Further, higher turbidity in the water column may restrict corals to shallower depths, due to reduced penetration of light (necessary for photosynthesis by zooxanthellae), but it may also shelter corals from harmful UV radiation, reducing the likelihood of bleaching during periods of high temperatures.

Overall, the reefs located on the most northwestern submerged bank (Fig. 2.6c, d) appeared to exhibit the greatest health and highest resilience. These were flourishing *Acropora* communities, intermixed with large massive *Porites* colonies and many other plating, branching and massive corals. In addition to the highest cover of live corals, they had low levels of macroalgae and better water clarity, possibly due to their greater distance from island masses.

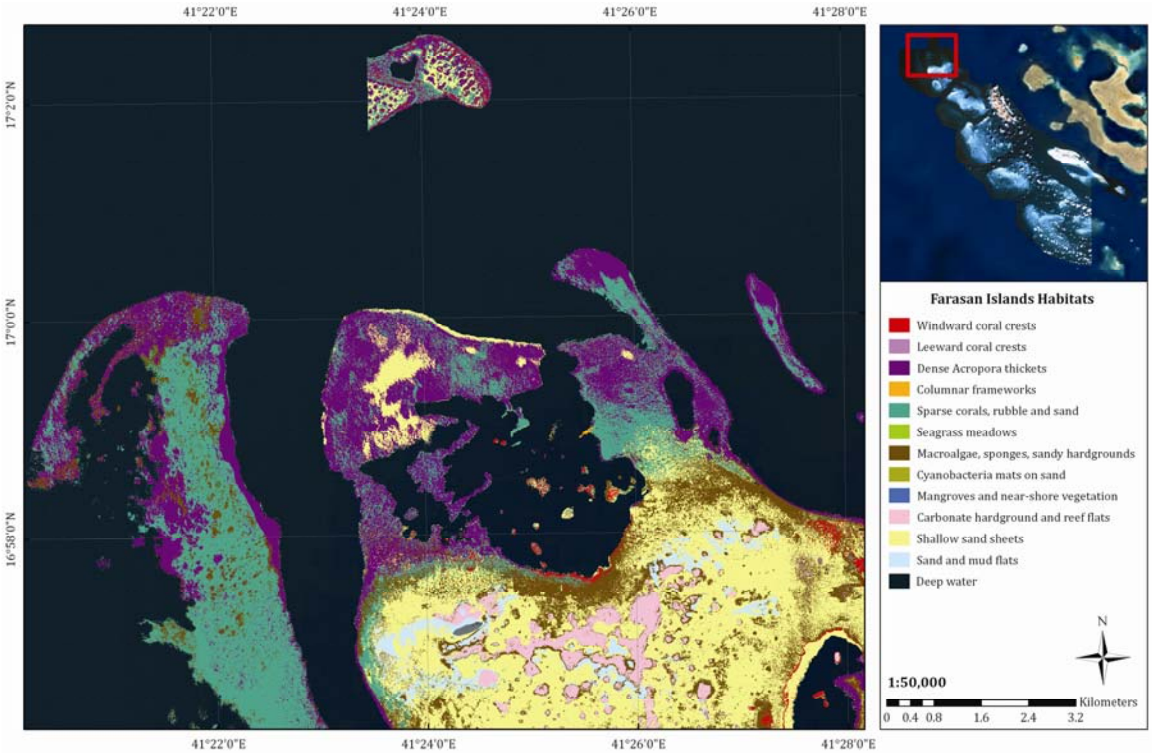


Fig. 2.6c. Habitat map for the northwestern end of the Farasan Islands archipelago, seaward of the main islands. This area is outside the current boundaries of the MPA and contains some of the most valuable high structural relief coral habitats with a dominance by dense stands of *Acropora.*

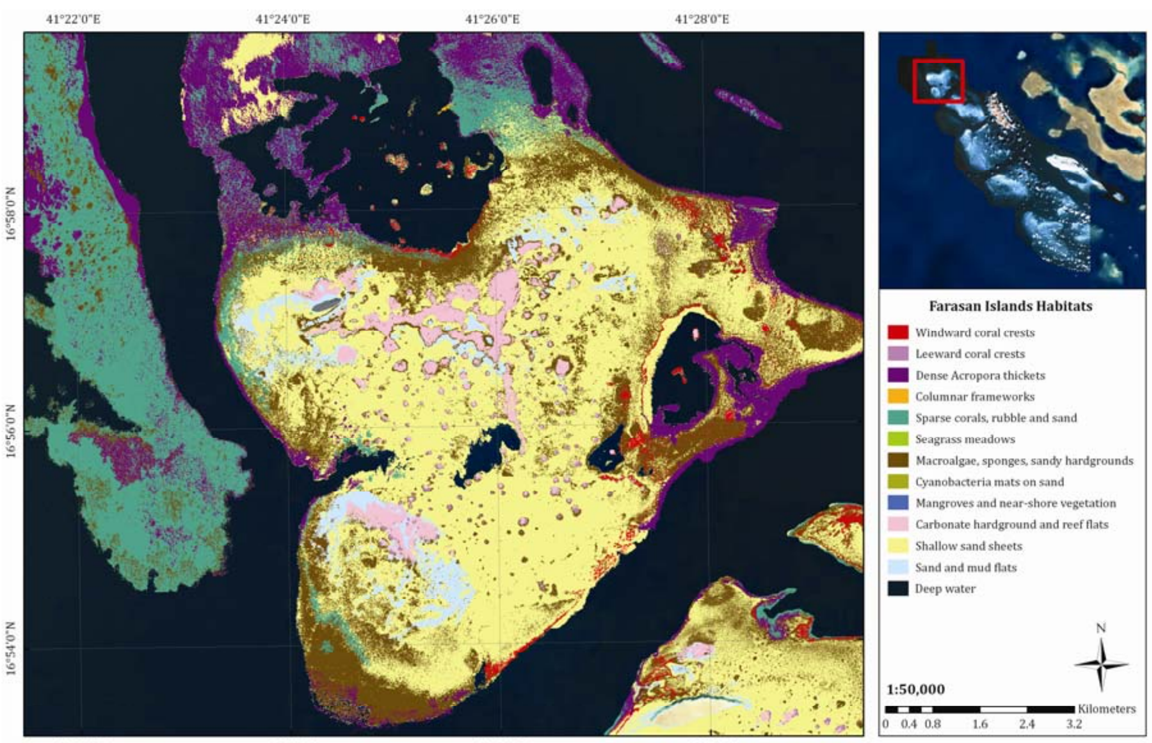


Fig. 2.6d. Habitat map for the lower portion of the platform shown in Fig. 2.6a.

2.7 Seagrass communities in the Farasan Islands

Seagrasses are reported to reach their highest diversity in the central Red Sea, with 12 species reported, and decline to the north and south. In the Farasan Islands Area, five species of seagrass have been recorded (Gladstone, 1994). Four of these, namely *Thalassia hemprichii*, *Halodule uninervis*, *Halophila ovalis* and *Thalassodendron ciliatum*, were identified during ground truthing efforts. The seagrass beds often exhibited a clear zonation pattern in the shallow water, with mixed seagrass beds found slightly deeper. The seagrass beds generally occurred in patches surrounded by sand, mud or other habitats (e.g. edge of lagoonal reefs; adjacent to mangroves).

Four species of seagrass were found west of Sasu al-Kabir Island (41° 34' 04''N 16° 51' 28''E). The sequences of zonation of the species, from shallow to deeper was *Halophila ovalis, Halodule uninervis, Thalassia hemprichii,* and *Thalassodendron ciliatum* respectively. *Thalassia hemprichii* and *Halodule uninervis* where found at Khawr Ma'adi. *Halophila ovalis* and *Halodule uninervis* were found in the northwest of Baghalah Island, while *Halophila ovalis* were found south of the island. In the shallow water off Shumah Island, two species of seagrass were found, *Halophila ovalis* and *Thalassodendron ciliatum.* The seagrass habitats identified in these studies are critical for the survival of herbivorous animals such as green turtle, hawksbill turtle in early stage, and juvenile fishes.

2.8 Mangrove communities

Nearshore islands and coastal areas support extensive stands of mangroves. Two locations of mangrove *Avicennia marina* not previously reported were found in the east of Sasu As-Saghir Island: N 16^{o} 52' 09" E 41^{o} 35' 36" and N 16^{o} 51' 02" E 41^{o} 36' 14".

2.9 Turtles and marine mammal sightings

The Farasan Islands are one of the most important areas of nesting sites for hawksbill turtles. During this expedition, nesting status was evaluated on eleven islands in the Farasan Islands as follows: 1) each island was surveyed for turtle track signs and nesting pits. The number of upward tracks were counted and grouped as fresh and old. 2) The beaches of Kayrah Island and Shawmah Island were patrolled nightly. Nesting behavior of turtles on beaches was documented. 3) The measurements of the Curved carapace length (CCL) and Straight carapace length (CCW) of the turtles were recorded. The encountered female turtles were tagged on the beach using titanium tags. CCL and CCW measurements were made using a flexible fiberglass tape (+/-0.5 cm.). A total of 67 hawksbill tracks were found during the survey (Table 2.9) as follows:

1) Thirteen tracks of hawksbill were observed on the 9th of May at Al-Baghalah Island, the age of the tracks ranging between 3 to 25 days old. It is possible that there were older tracks that disappeared as a result of physical processes. A small hawksbill and adult green turtle were observed in the shallow water north of the island.

2) Fifteen hawksbill tracks were observed on the 12th of May in the southeast of Kayrah Island; those turtles visited the beach during the period of the previous night to a month earlier. Tracks older than that may have existed but disappeared as a result of physical processes. The eastern beach is exposed to high energy caused by wave actions.

3) On the 13th of May, a Hawksbill turtle was tagged - this turtle was the first to be measured in the Farasan Islands Protected Area. The turtle was tagged with the tag number 14002, and its measurements were CCL 74.5 cm, and CCW 67 cm. This turtle is somewhat larger than expected, as Red Sea Hawksbill turtle CCL mean measurements are 71.93 cm in Sudan (*Al-Mansi et al* 2002), 69.4 cm in Yemen (Hirth and Car 1970) and 71.5 cm in Arabian Gulf (*Al-Merghani et al* 2000). 4) On the 18th of May, Al-Ajhan Island (N 16^{o} 53' 28", E 41^{o} 27' 51") was visited. Eleven hawksbill tracks were observed; three tracks were fresh. However, four turtles are believed to have laid their eggs.

5) On the 19th of May, Shumah Island was visited in the evening. Fifteen hawksbill tracks were observed on the island, the tracks were between 5 and 30 days old; one turtle had visited the island to nest the previous night. The most important nesting area occurs in the northwest part of the island. No sign of tracks were observed in the southern side of the island (the lee side). The turtle team monitored the island until 9 pm; no turtles came to the island to nest during the survey.

6) On Zahrat Sumayr al-'Ulya Island **(**16^{o}30'57" N, 42^{o}15'05" E), eight hawksbill tracks were found.

7) On Zahrat Sumayr as-Sufla Island ($16^o 29'14''$ N, $42^o 17'43''$ E), four hawksbill tracks were found. A fisherman's hut is located in the southern end of the Island, and four fisherman's boats were found on the Island.

8) Hawksbill turtles were also observed in the water west of Sasu Al-Kabir Island, two green turtles and a hawksbill turtles at Khawr Ma'adi, two hawksbill turtles and two green turtles were observed in the water north of Baghalah Island, one hawksbill turtle in the water east of Kayrah Island and one north of Kayrah Island.

9) A part of a carapace of green turtle was found in the middle of Baghalah Island. A skull of a whale was found in the western tip of Zahrat Sumayr al-'Ulya Island. Inquiry indicated that the rest of the skeleton (spinal column) was collected by fishermen. Dead common dolphin have been found in the southwest at Dumsuk Island at $14^o 32'55''$ N, $42^o 04'14''$ E. the length of the dead dolphin was 120 cm; a trawling net was thought to be the cause of death.

Table 2.9a Sightings of marine mammals off Farasan Islands.

Site No.	School of Dolphins	No. of Dolphin	Coordinate
A	Common Dolphin	2	N °16 '55 "12 E °42 '17 "36
B	Bottlenose Dolphin	3	N °16 '53 "53 E °42 '17 "38
C	Common Dolphin	12	N °16 '55 "54 E °42 '20 "40
D	Common Dolphin	5	N °16 '54 "42 E °42 '41 "36
E	Common Dolphin	4	N °16 '56 "03 E °42 '22 "13
F	Common Dolphin	15	N °17 '12 "20 E °41 '59 "52
G	Common Dolphin	5	N °17 '10 "46 E °41 '59 "46
H	Common Dolphin	7	N °17 '09 "01 E °41 '59 "16
I	Spinner Dolphin	4	N °17 '08 "38 E °41 '56 "49
J	Common Dolphin	15	N °17 '06 "35 E °41 '57 "19
K	Hump-backed Dolphin	2	N °17 '02 "08 E °41 '50 "24
L	Hump-backed Dolphin	5	N °16 '59 "55 E °41 '49 "21
M	Common Dolphin	9	N °16 '58 "00 E °41 '50 "15
N	Common Dolphin	7	N °16 '53 "12 E °41 '50 "10
O	Hump-backed Dolphin	2	N °16 '49 "59 E °41 '52 "23
P	Common Dolphin	25	N °17 '03 "52 E °41 '23 "46
Q	Common Dolphin	12	N °17 '01 "26 E °41 '25 "29
R	Bottlenose Dolphin	12	N °16 '48 "16 E °41 '43 "33
S	Bottlenose Dolphin	15	N °16 '50 "25 E °41 '34 "15
T	Bottlenose Dolphin	2	N °16 '54 "23 E °41 '30 "58
U	Common Dolphin	5	N °16 '48 "32 E °41 '24 "21
V	Common Dolphin	2	N °16 '46 "34 E °41 '25 "34
W	Common Dolphin	5	N °16 '47 "57 E °41 '34 "10
A	Hump-backed Whale	1	N °16 '52 "15 E °41 '36 "52

3 Ras Qisbah

3.1 Background

The reef system examined in the northern Red Sea during the research mission is located within the Midyan region (Al Farshah), east of the Tiran area and east of Ras Qisbah, in an intermediate area overlapping the Red Sea graben and the Aqaba-Dead Sea-Jordan Shear System (Bayer et al. 1984). The coastline in this area was very intricate, with headlands, wadis and gentle foothills, islands, alluvial sand flats found in narrow belts along the coastline, and numerous small bays with sandy beaches. There were numerous coral reefs identified, including reef-edged sharms at the edge of wadis which flow down from Al Hisa mountains carrying sand and gravel. The littoral zone often contained alluvial sandflats extending along the shoreline in narrow belts up to 1km wide. At the mouths of some wadis, small salt marsh communities, dry sabkhas, and small mangrove stands were observed. Mangroves were found in soft bottom habitats and also, often in a stunted growth form, in rocky areas. Salt marsh vegetation was dominated by *Halocnemum strobilaceum* while mangroves consist primarily of *Avicennia marina.* Extensive *Thalassodendron* seagrass beds were located in deep sandy environments typically at 15-25 m. The abundance of this habitat is of vital importance to a number of species of high conservation concern, for example, Dugongs and turtles. The latter were commonly sighted and evidence of nest building was also noted on the sand islands.

Evaporite and karst features were evident in this region. Ras Qisbah had a similar gross morphology to Al Wajh, with a large lagoon sheltered by a coral rim. Marine habitats present in Ras Qisbah were highly variable, and included coral reef frameworks, seagrass beds, extensive soft coral areas, sand, and algal patches. Much of the reef framework consisted of reticulated or 'honeycomb' reef structures.

3.2 Research completed

Groundtruthing efforts targeted all habitats across the Ras Qisbah region, including grass beds, mangroves, sand flats, coral reefs, algal flats, with representative sampling conducted across the platform. Bathymetry was recorded along a total distance of 186 km with 600,000 soundings. Drop camera assessments were completed at 500 different locations within Ras Qisbah, with a total of four hours of video footage compiled. In addition, detailed measurements of sea floor spectra, emphasizing sand, algal flats dead coral and live coral, to help corroborate satellite imagery (Fig. 3.2b).

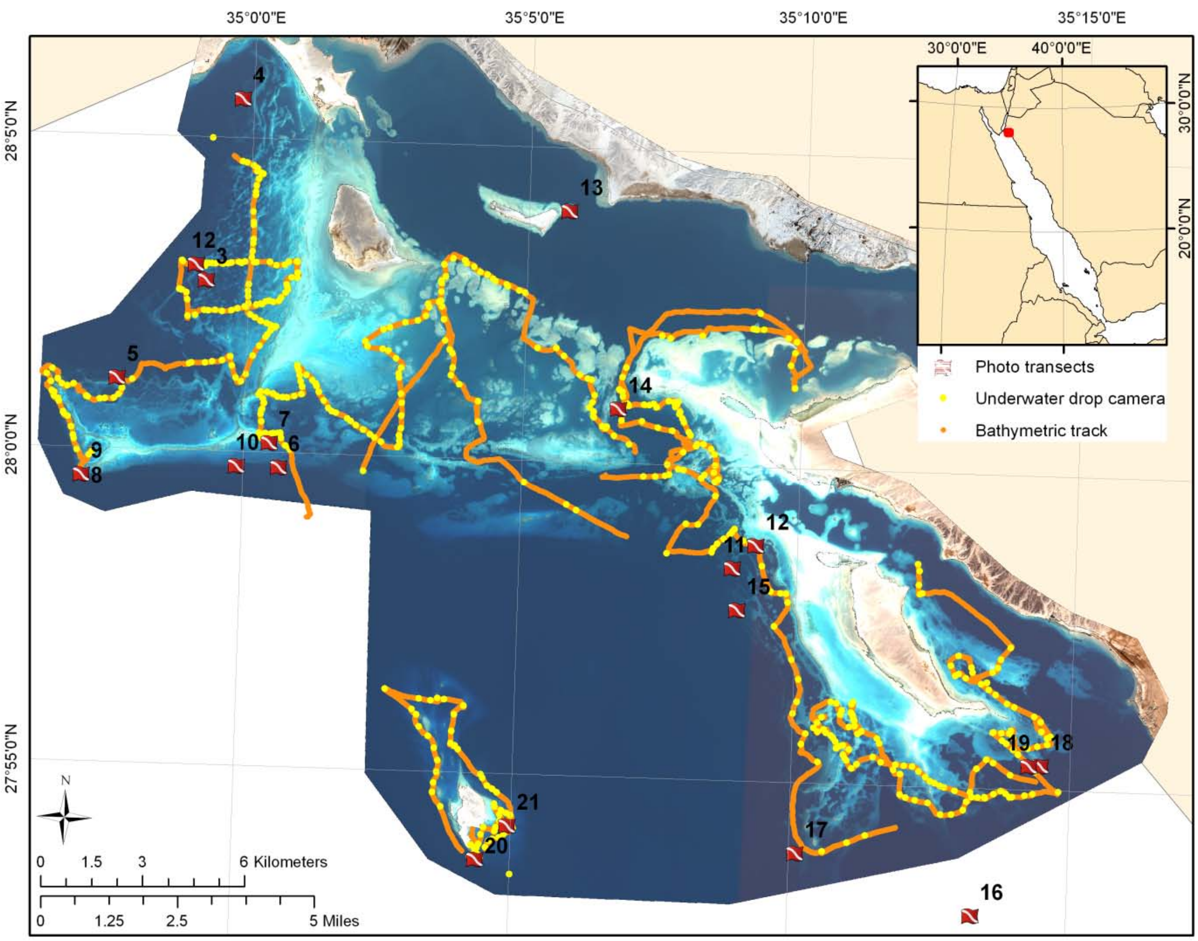


Fig. 3.2a. Satellite image of Ras Qisbah study area depicting the track of the groundtruthing team showing the bathymetric track(orange line) and drop camera locations (yellow circles) and the locations of SCUBA assessments (dive flag).

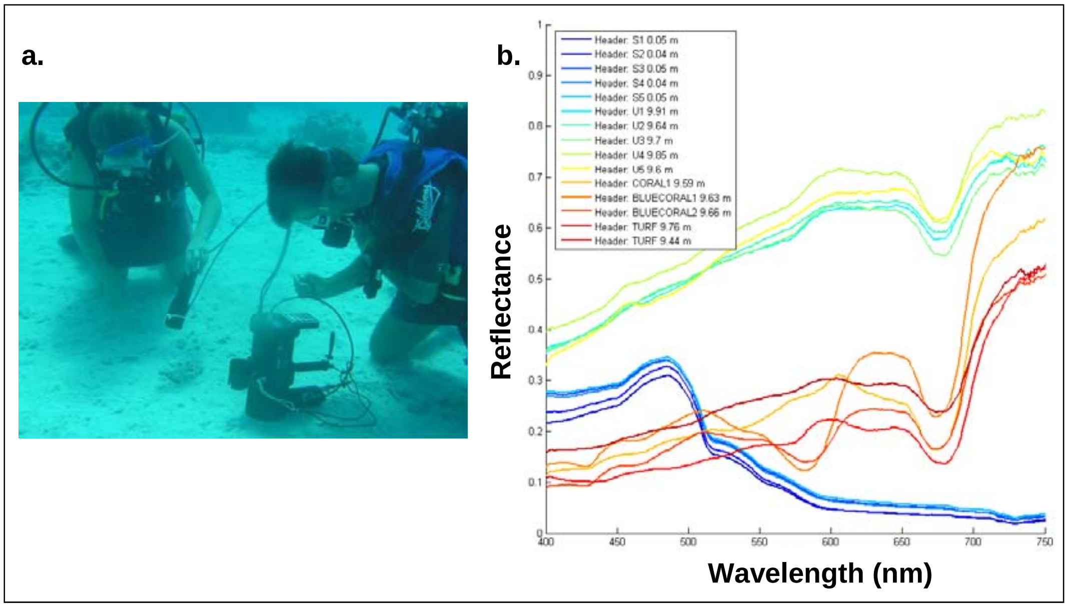


Fig. 3.2b. Spectral analysis of reflectance of the benthos. a) Sarah Hamylton (left) and Sam Purkis (right) collect sea floor spectra using the DiveSpec submersible Spectroradiometer; b) example spectra collected over deep water, underwater sand (blue and purple lines), algae (yellow and green lines), and live and dead coral with turf algae (red and orange lines).

SCUBA surveys of coral reef environments were completed at 19 sites. Photo transects were performed between 3-17 m depth depending on the site. Quantitative and qualitative measurements of coral community structure were also compiled, with emphasis on resilience characteristics; these data were split across the reef types and depths. Most resilience surveys were done at 10 m for consistency; however a smaller number of sites at shallower (5m) and deeper (15m) sites were conducted to compare how bleaching and associated impacts may have changed with depth.

3.3 General habitat attributes

Shallow marine areas surveyed encompassed three major islands, Al Farshah, Umm Qusur and Burqan. These islands and surrounding shallow habitats support a wide range of associated reef types, including mainland and island fringing reefs, platform and reticulate patch reefs, pinnacles and barrier reefs. In addition to prominent coral reef frameworks, seagrass beds, extensive soft coral areas, a large sand-bottom lagoon and algal patches occurred in this area. Much of the reef structure was in the form of reticulated or ‘honeycomb’ structures. These comprise strings approximately 1-10 m across consisting of living coral or a coral reef framework surrounded by fine sand and rubble habitats.

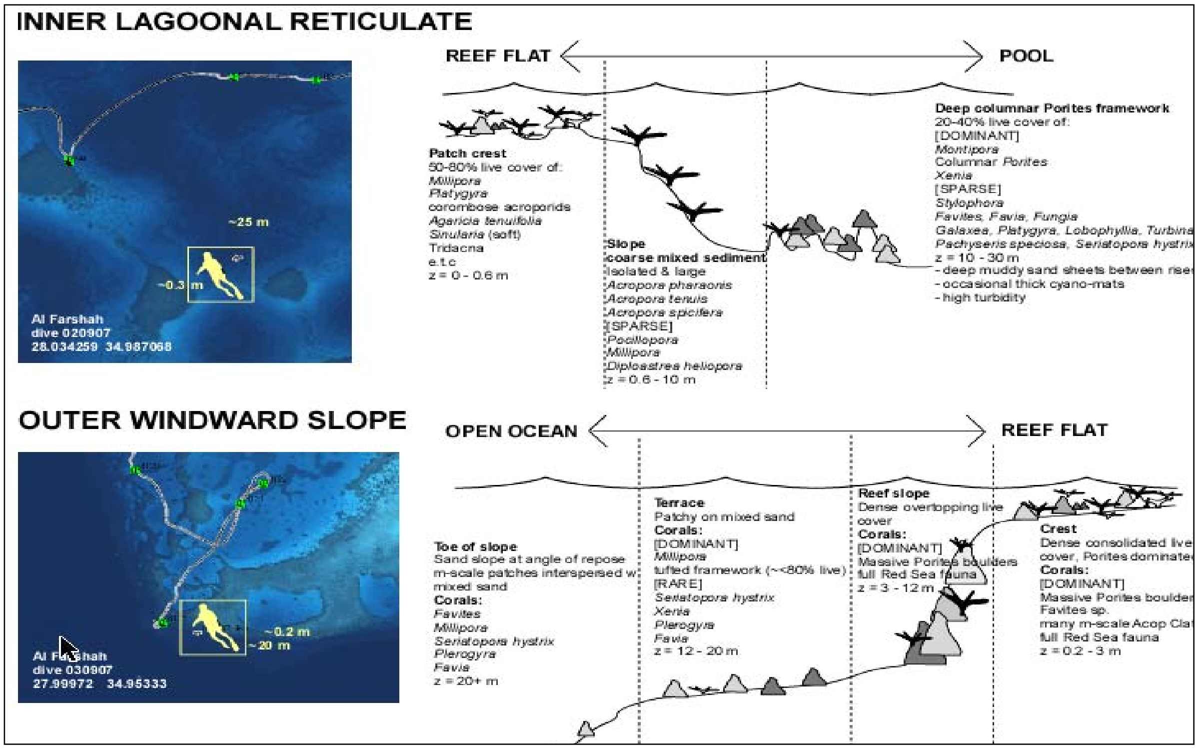


Fig 3.3a. Example of reef profiles generated from broad scale SCUBA assessment for two locations in Ras Qisbah off Al Farshah. The upper profile is for an inner lagoonal reticulate reef and the lower image is the outer reef slope. Site location, depth profile, species composition and relevant geomorphological information are shown.

3.4 Coral community structure

Quantitative coral assessments and phototransects were completed in 19 locations. In general, coral growth in these locations was extremely patchy and most corals were small in size. Overall, live coral cover was estimated to average 10-30% at 3-10 m depth, with some sites having < 5% and others with up to 70% living coral. In general, the highest cover was recorded at the edge of the reef flat, from 3-5 m depth (20-30%), with an abrupt decline in living coral cover below this depth. The major framework builders in the region are of the genus *Porites*, though a diverse array of species had colonized dead colonies of *Porites* and the reef framework.

There is clear evidence of a mass mortality event that affected most of the region. The condition of the reef framework and associated dead corals, as determined from 1) the level of erosion of dead coral skeletons; and 2) patterns of colonization by other organisms on dead coral skeletons suggest that this event occurred 3-9 years ago (depending on the site). For instance, the outer reef platform at Burqan Island showed evidence of high old colony mortality, frequent sediment outflow off the lagoon/platform, and limited recovery of corals through regrowth or recruitment. In many deeper areas the *Porites* based framework was replaced by extensive foliose coral cover, especially plating *Echinopora* sp., and to a lesser degree, *Mycedium*, *Echinophyllia* and *Oxypora*. Interestingly, many of these plating corals had experienced near total mortality and isolated juvenile corals had colonized exposed skeletal surfaces. Fleshy macroalgae and coralline algal cover were minimal throughout the region (average of 0.5-1.5% cover), suggesting a low nutrient environment, in theory conducive to coral growth. Rubble abundance was relatively low at 10%, with a maximum of 50% in the channel between Al Farshah and Umm Qusur (site 12).

Table. 3.41. Location of SCUBA assessments in Ras Qisbah

Site #	Latitude, N	Longitude, E	Date	Location	Depth
1	28.049800	34.984300	9/2/2007	West of Al Farshah	14-16 m
2	28.045600	34.987500	9/2/2007	West of Al Farshah	8-12 m
3	28.094100	34.996800	9/3/2007	Mainland fringing	10 m
4	28.019100	34.961700	9/3/2007	South west of Al Farshah	16-17 m
5	27.996500	35.010900	9/3/2007	South of Al Farshah	11-13 m
6	28.002900	35.007900	9/3/2007	South of Al Farshah	11-13m
7	27.993000	34.951900	9/4/2007		12-13 m
8	27.996500	34.998200	9/4/2007	South of Al Farshah	7-8 m
9	27.973300	35.147500	9/5/2007	NW of Umm Qusur	7 m
10	27.979600	35.154300	9/5/2007	NW of Umm Qusur	4-6 m
11	28.067000	35.095600	9/6/2007		10-11 m
12	28.014900	35.111900	9/6/2007	Usailh Channel	2-3 m
13	27.962300	35.149300	9/6/2007	W of Umm Qusar	12-14 m
14	27.883200	35.221700	9/7/2007		14-16 m
15	27.898400	35.168800	9/7/2007		12 m
16	27.923500	35.241400	9/7/2007	SE of Umm Qusar	10-12 m
17	27.923300	35.238000	9/8/2007	SE of Umm Qusar	12-14 m
18	27.894200	35.073300	9/9/2007	Burqan	8-10 m
19	27.903300	35.082600	9/9/2007	Burqan	6 m

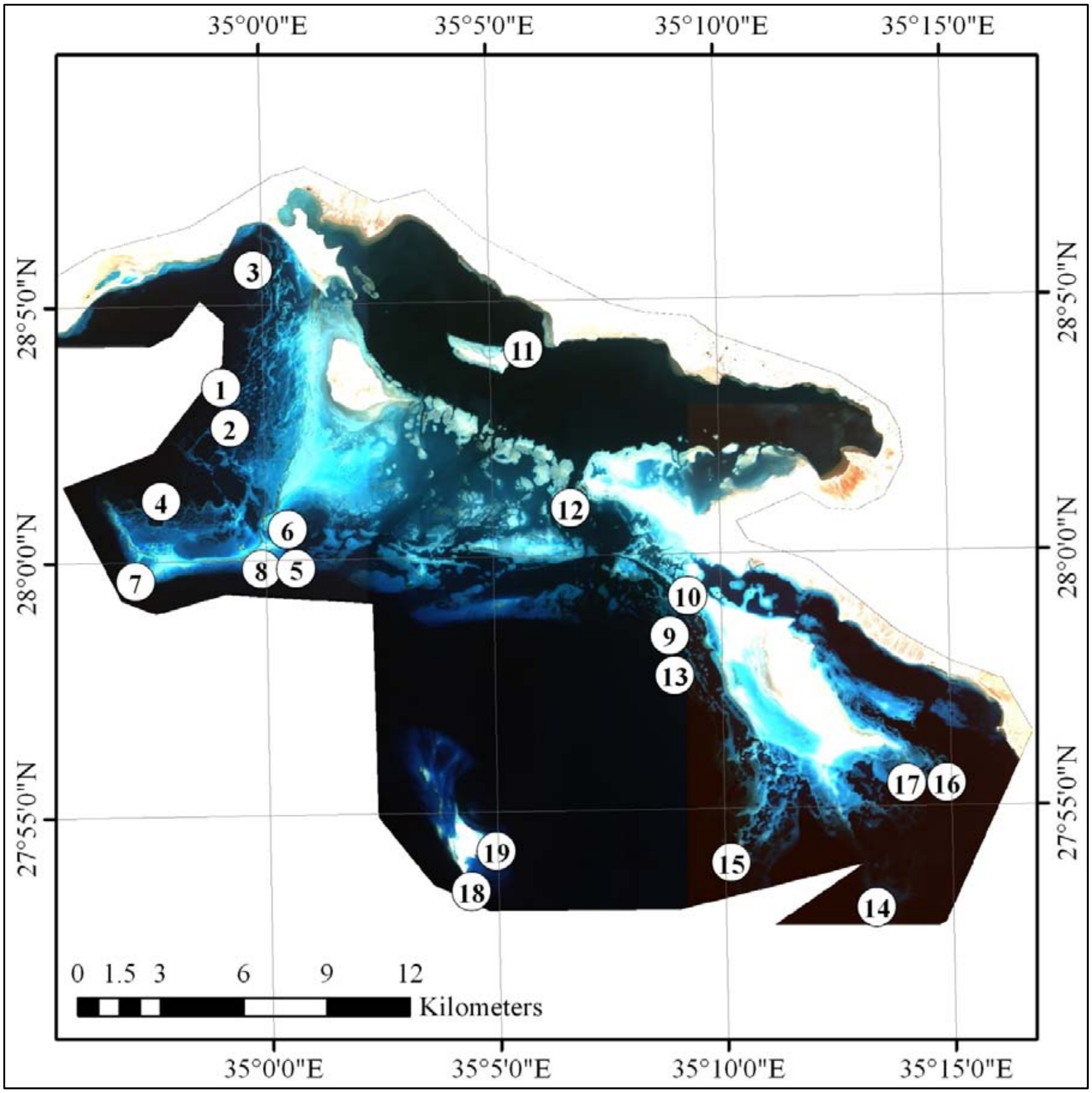


Fig. 3.4a. Location of SCUBA assessments within Ras Qisbah.

Though the overarching impression of the region is one of poor coral growth at the time of the surveys, there remain many healthy reef areas with high live coral cover. The areas with the highest amount of living coral cover were predominantly located in the shallows (less than 4 m depth), and in areas of high current flow. Such habitats were species rich, but dominated by *Millepora*, *Acropora*, *Seriatopora,* and *Stylophora* species. Sites with the smallest colony sizes (less than 30 cm diameter) tended to be back reef and island sites most strongly impacted by past mortality, with reef systems dominated by highly fragmented remnants of the large colonies that originally made up the reefs. At several locations in the survey area, particularly on the exposed seaward fringe of the barrier reef and reefs off the outlying island (Burqan), massive colonies measuring over two meters in height and diameter were recorded. The largest corals (4-5 m across) were generally observed on outer reef slopes. Individual massive colonies, particularly *Lobophyllia corymbosa* and *Porites lutea*, occurred within the reticulate reef system of Al Farshah. Colonies of such large size indicate continuous and stable coral growth conditions in the region for at least several hundred years, yet many of these had experienced partial mortality within the last decade or so which suggests conditions may be changing and recent global perturbations (e.g. temperature anomalies) are affecting the survival of the reefs.

Coral community structure was assessed in two manners. Resilience assessments conducted by Dr. Obura involved an assessment of coral community at 10 m depth, with recorded observations on the numbers of genera of corals noted at each site (Fig. 3.4a) and their size, pooled into five size classes (Fig. 3.4b). These assessments also included a ranking of a series of resilience indicators, based on a visual estimate (see resilience analysis below). The total coral cover reported by Obura was much higher than that observed within photo-transects, possibly because this was based on a visual assessment and the photo-transects were quantitatively assessed. The other main difference between the two methods is that Obura examined a large swath of reef habitat, while photo-transects were limited to smaller 10 meter X 0.5 m long belts.

Coral reefs in Ras Qisbah area contained 44 genera of reef building corals, with 15 genera recorded at every site (Fig. 3.4a). Nearly 50% of the sites (8 out of 19) were dominated by corals in the smallest size classes (1,11-20 cm) while only five sites had at least one colony in the 4th (160 cm) and 5th (320 cm) size classes (Fig. 3.4b). Detail on specific sites is provided below.

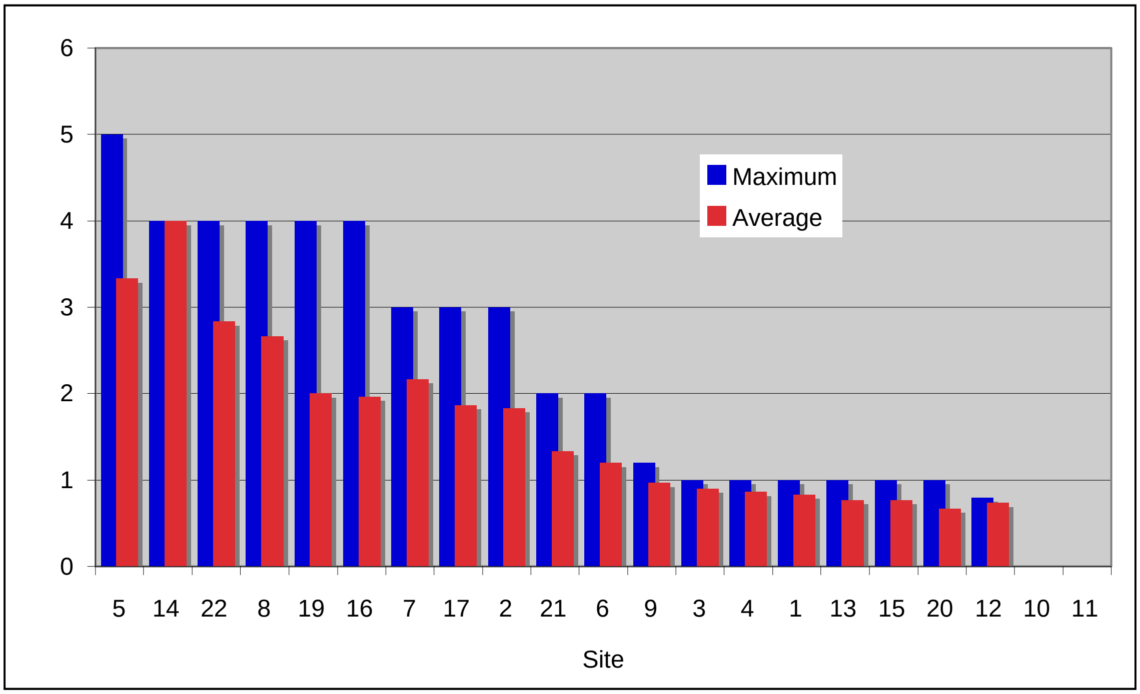


Fig. 3.4b. Average and maximum size of coral colonies at each site.

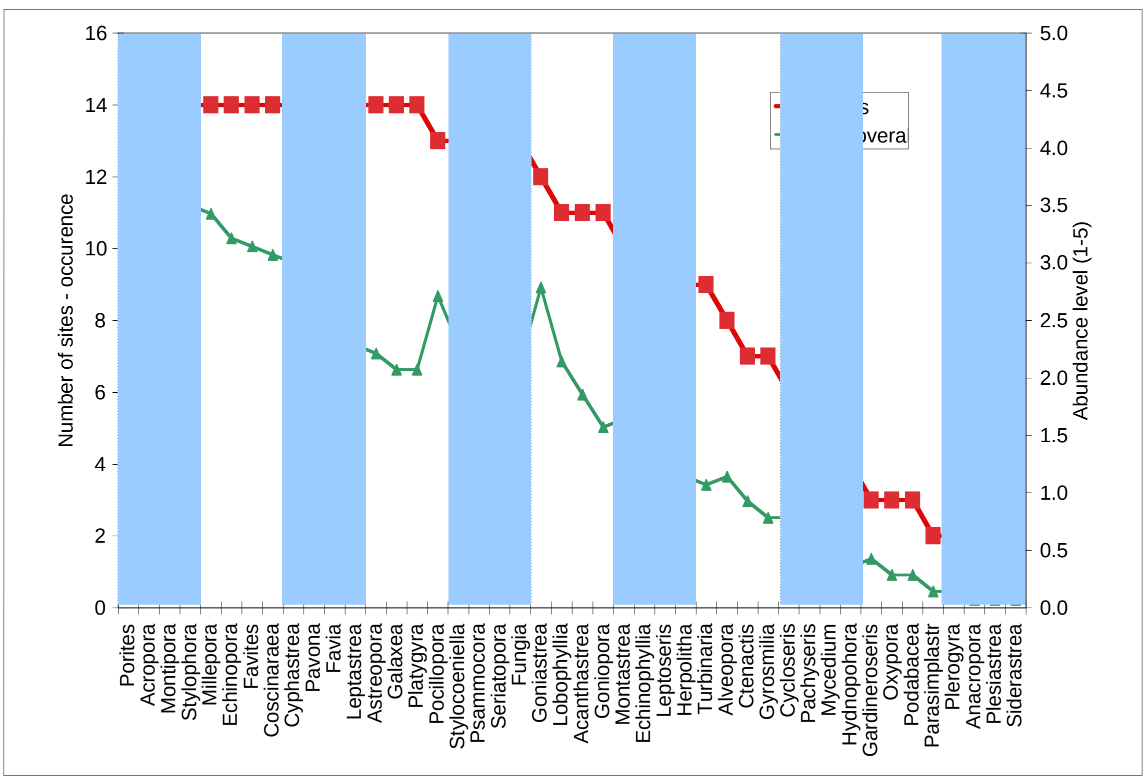


Fig. 3.4c. Coral genus abundance at survey sites, showing the number of sites (red squares) at which each genera was observed, and its average abundance across all sites (green triangles).

3.41 Site 1 and 2, West of Al Farshah

Surveys were performed from 14-16 m depth (site 1) and in a nearby location at 8.8 and 11.6 m on the outer edge of the reticulated reef framework. Both sites had a columnar framework composed of *Porites* colonies and a total live cover estimated at 10-15%. Most of the *Porites* colonies were dead, or reduced to tiny tissue remnants (50-70% mortality) at site 1, compared to 30-50% mortality at site 2. There were also large patches of this framework that had been colonized by foliose *Echinopora* colonies, most of which had also died. Some colonization of the dead coral skeletons had occurred. The dominant colonies, mostly 5-15 cm diameter, included *Echinopora, Goniastrea, Platygyra, Stylophora* and small to medium sized *Acropora* (10-20 cm) colonies. Many of the larger colonies of other species, especially *Echinopora, Goniastrea* and *Lobophyllia* had experienced partial colony mortality and skeletal surfaces had small live tissue remnants. Algal colonization of the reef substrate and dead corals was minimal, with a notable absence of both macroalgae and crustose coralline algae. Soft corals (*Xenia*) were present at low abundances in both sites, although site 2 had some large colonies of *Lithophyton*.

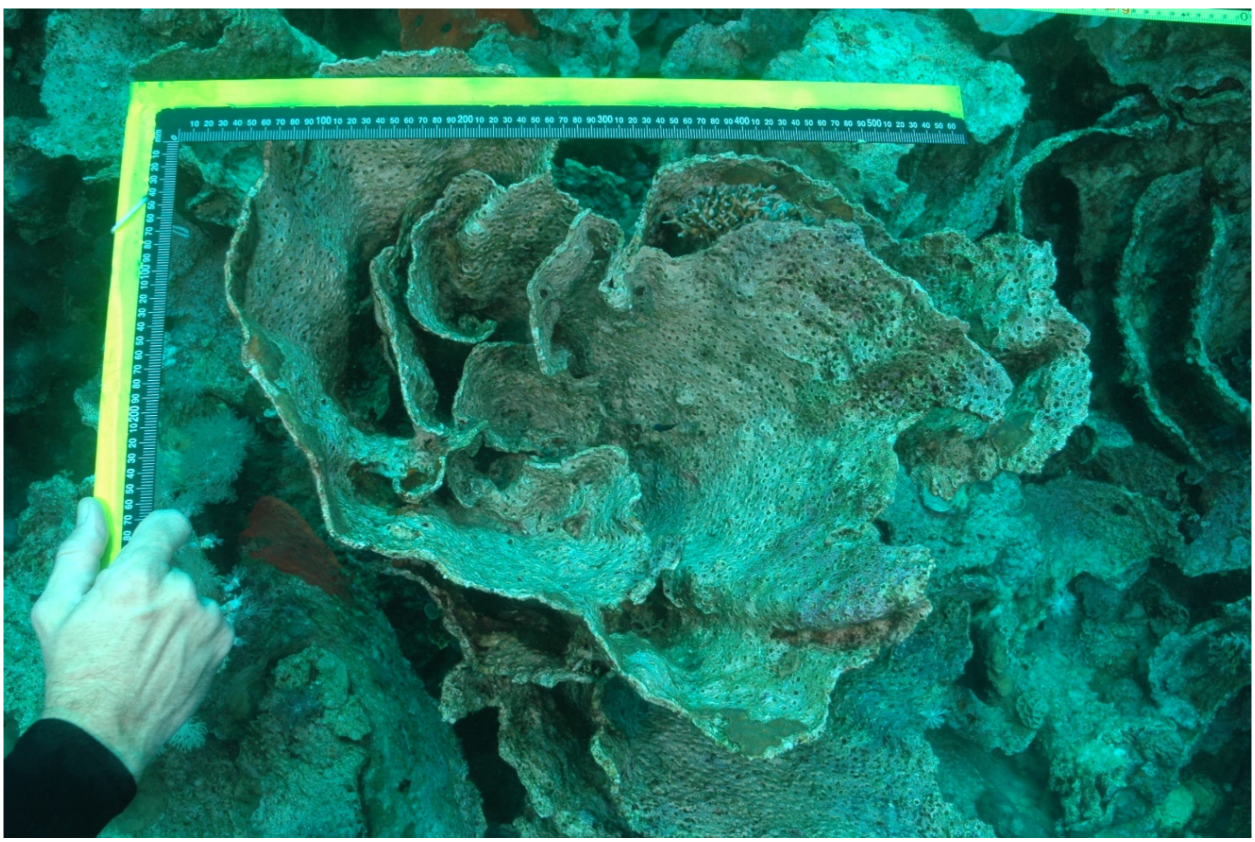


Fig. 3.41. Foliose colony of *Echinopora* that is 99% dead. Large areas of the *Porites* framework were colonized by this species, and most subsequently died or contained small tissue remnants.

3.42 Site 3

A single fringing reef located close to the mainland, west of a small peninsula that extends seaward toward Al Farshah. At 10 m depth, the community had a sand bottom with isolated coral heads constructed by *Porite*s, most of which had died. Cover was estimated at about 5%. In addition to the columnar *Porites* colonies, *Goniastrea* colonies also exhibited columnar growth form; living tissue on these corals was restricted to small nubbins and lobes 5-10 cm in diameter, located at the tops of the columns. Large colonies of *Lobophyllia* (20-50 cm diameter) occurred throughout the site, but these were typically 50-75% dead, and partially smothered with sediment. The largest living corals at the site were isolated *Astreopora* colonies (20-30 cm diameter) and *Echinopora forskaliana* (20-40 cm diameter), but these also contained dead patches, denuded several years ago. Soft coral cover was fairly low, with exception of a few large *Lithophyton* colonies.

3.43 Site 4

The reticulated reef framework extends seaward and to the southwest of Al Farshah Island forming a j-hook shape. Site 4 was located on the inner site, facing towards land and southwest of site 1 and 2. Coral cover at 16.5 m depth was estimated at 20-25%. This site was also dominated by columnar *Porites*, with colonies having live tissue on 50-60% of their skeletal surfaces, although a number of colonies exhibited recent and transitional mortality and skeletal surfaces were colonized by cyanobacteria. This site also had a number of large dead *Lobophyllia* colonies, considerable *Lobophyllia* rubble and large patches of *Xenia*.

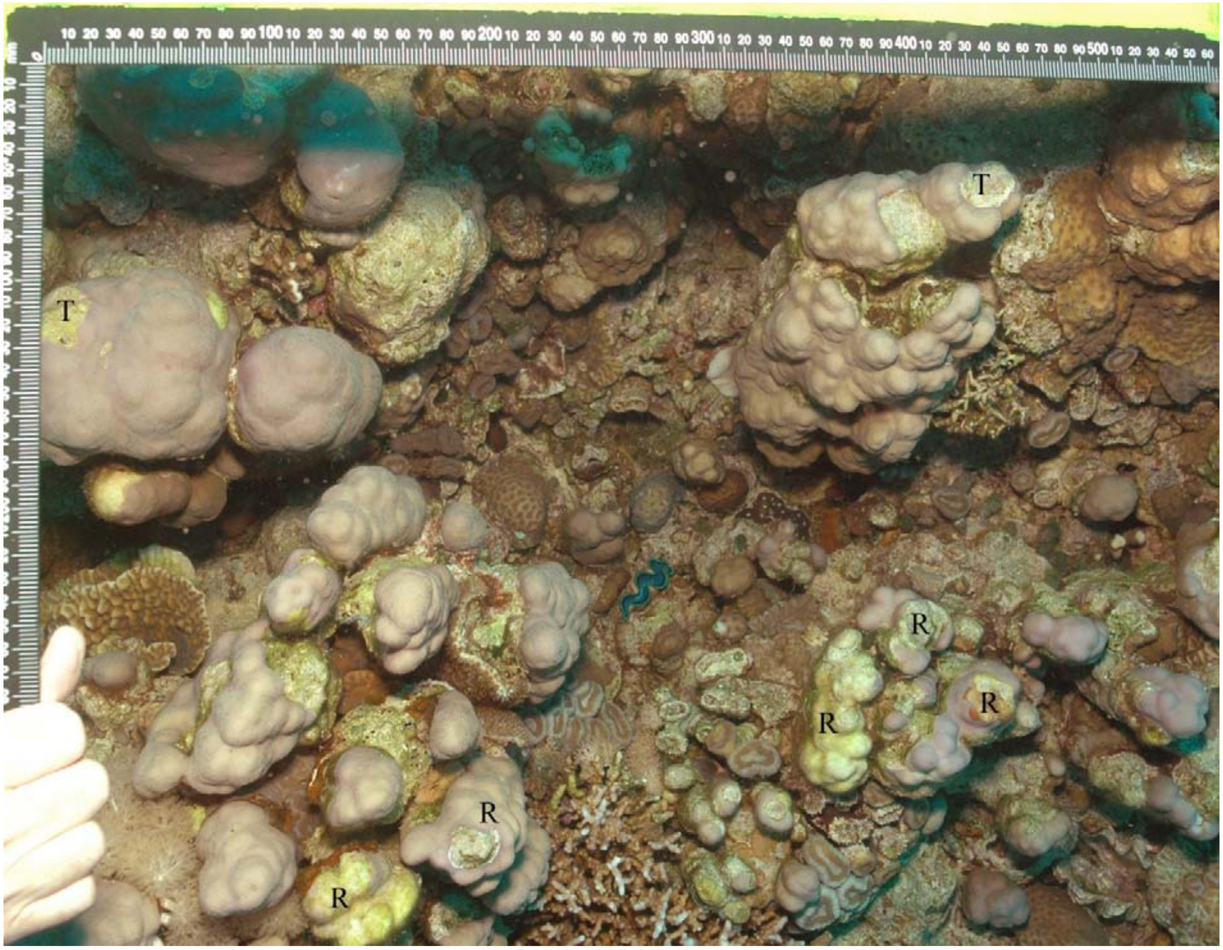


Fig. 3.43. ***Porites* colonies with recent (R) and transitional (T) mortality.**

3.44. Site 5 and 6

These sites were located from 11-13 m depth due south of Al Farshah, near the edge of the reef platform within the reticulated *Porites* framework. As other sites in the region, much of the *Porites* (60-70%) was dead, with small tissue remnants and some colonization by other corals, especially *Goniastrea*. Site 5, located at the seaward end of the reef system, had moderately high relief consisting of coral heads separated by small sandy patches. Site 6 had much less relief and most of (90%) the *Porites* was dead. Site 5 also had higher cover (15-20%) consisting predominantly of *Goniastrea, Porites, Platygyra, Echinopora, Lobophyllia, Stylophora* and *Astreopora* (respectively), and a relatively high number of *Seriatopora* colonies. Site 6 had very low cover of stony corals (5%) consisting of isolated colonies of *Acropora, Stylophora, Goniastrea* and a few other species, and a much higher cover of soft corals (mostly *Xenia*, isolated *Sarcophyton* and *Sinularia*) and large, bushy horny corals (*Clathraria* spp.).

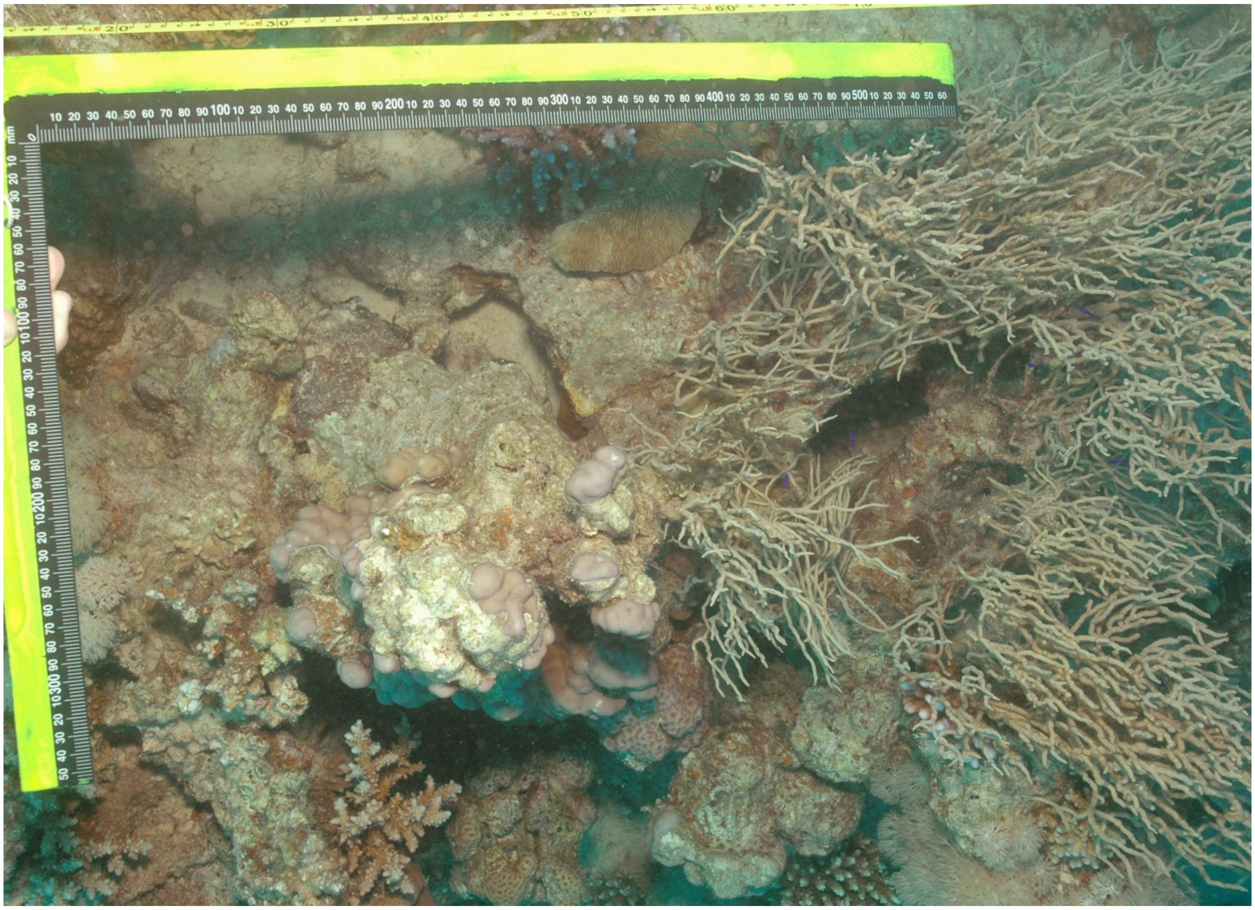


Fig. 3.44. Typical photoquadrats at Site 6, 14 m depth. A large horny coral (*Clathraria*) is visible on the right side of the image.

3.45 Site 7

This was located at the seaward end of the Al Farshah reef system at 12-13 m depth. It had a moderately high relief *Porites* framework with small patches of living coral and a total live coral cover of 15-20%. Many of the *Porites* skeletons had been colonized by *Xenia*, which was often encircling a small nubbins of live coral. This site had a high abundance of *Millepora* fire coral and also a relatively high number of small to medium-sized (20-30 cm) *Acropora* colonies.

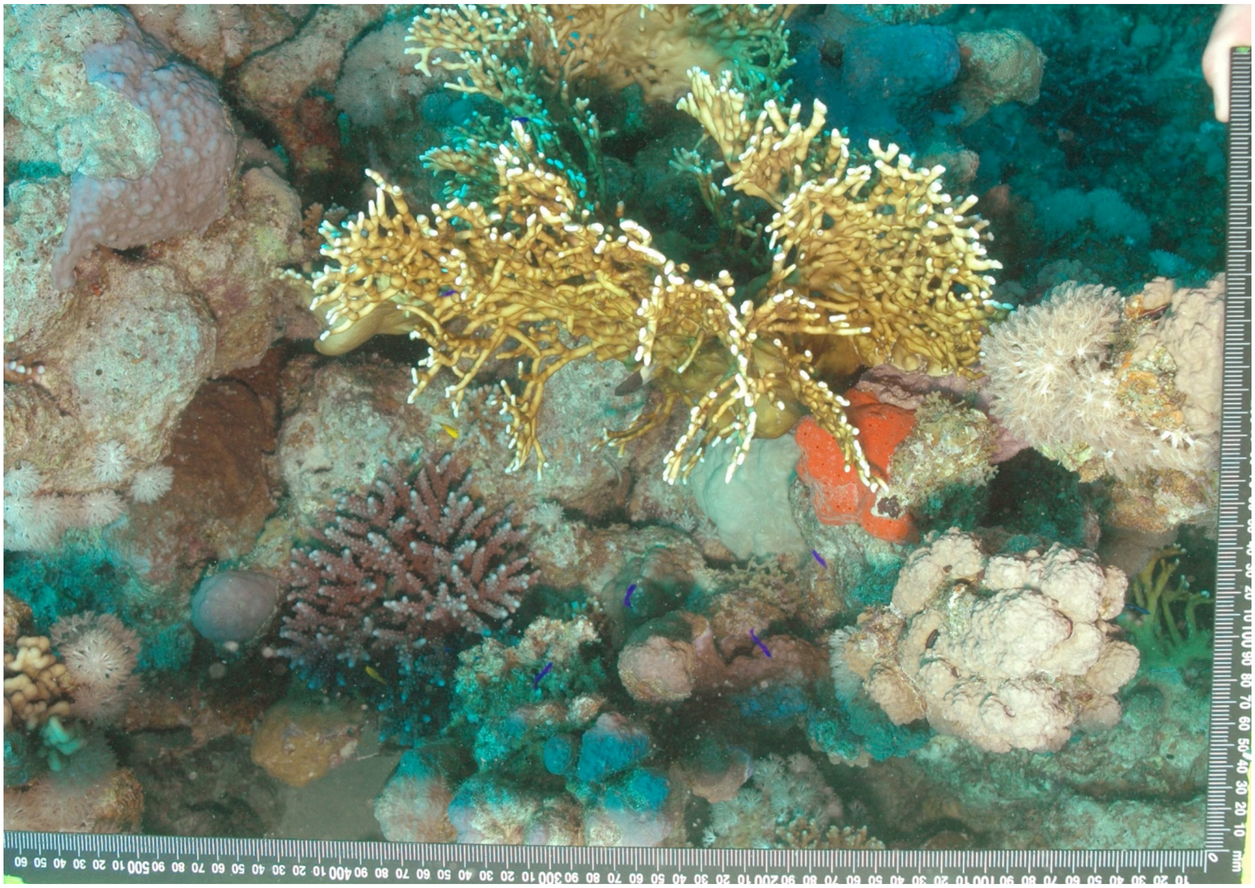


Fig. 3.45. Photoquad at 13 m depth with *Millepora, Acropora* and small tissue remnants of *Porites*.

3.46. Site 8

Site 8 was located due south of Al Farshah Island, on the seaward edge of the reef system, from 7-8 m depth. This site had one of the healthiest remaining populations of columnar *Porites* colonies. Live coral cover ranged from 20-25% with a dominance by *Porites* and *Acropora*. Reef substrates and dead lobes of *Porites* were frequently colonized by *Xenia*. As observed in other sites in this area, macroalgae was virtually absent and crustose coralline algal cover was very low.

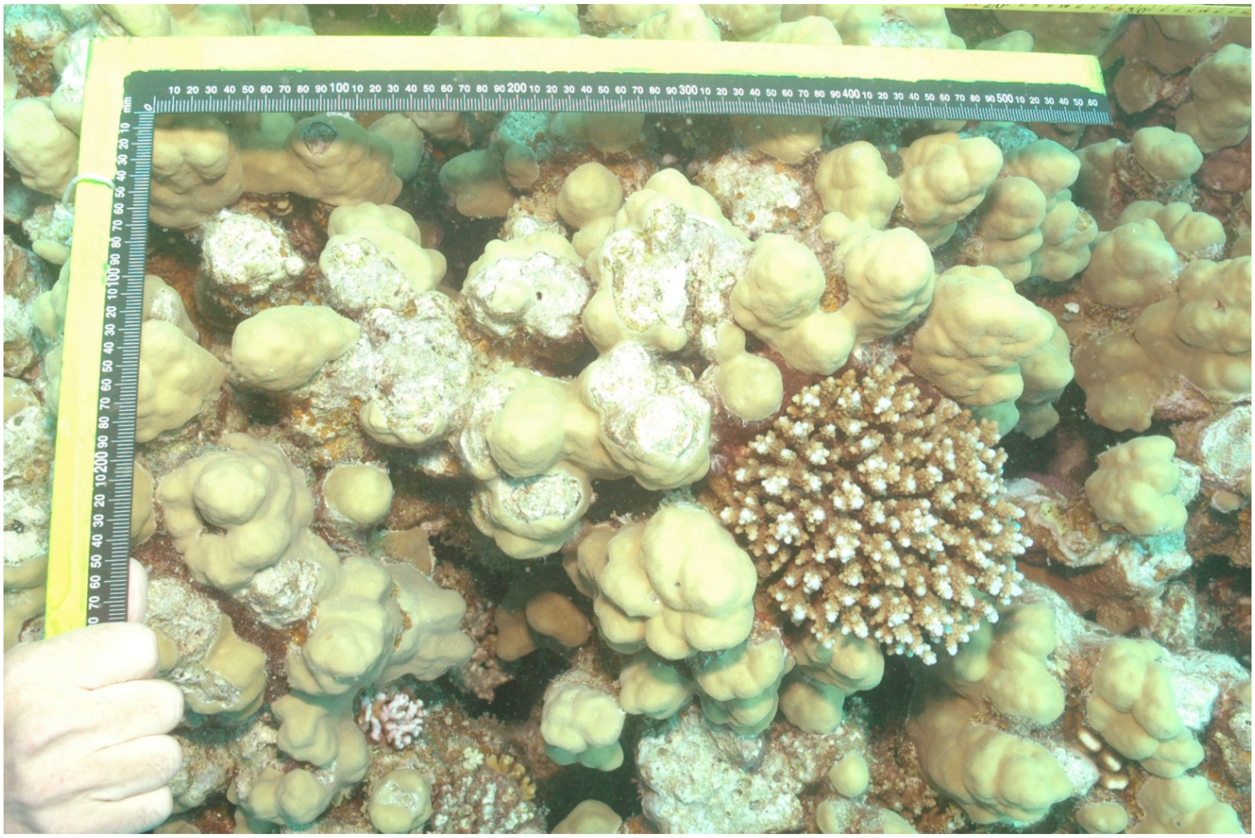


Fig. 3.46. Columnar *Porites* framework with a high proportion of living coral and colonization of dead areas by *Acropora*.

3.47. Site 9, 10 and 13

Three sites were examined on the reef system located east of Umm Qusur at the edge of the drop-off. Site 9 (7 m depth) was a low relief hardground with small patches of rubble and about 5-10% living coral cover. Most corals were small (5-10 cm diameter) and included *Acropora*, *Montipora*, *Goniastrea*, *Pavona*, *Favia* and isolated *Porites* colonies. Site 10 (4-6 m depth) consisted of a *Porites* dominated framework with 20-40% live coral cover. The substrate consisted predominantly of medium to large sized (30-80 cm diameter) rounded boulders of *Porites*, roughly 40-50% dead, although there were extensive areas where 60-80% of the *Porites* colonies were surviving. Skeletons of *Porites* and surrounding areas were colonized by numerous massive *Goniastrea* colonies, often with 20-30% old mortality, small –medium sized branching acroporids (20-40 cm) that were mostly alive, large brain corals (20-60 cm diameter) also with numerous dead patches on their skeletons, other small massive corals such as *Echinopora*, *Montipora*, *Lobophyllia* and *Favites*, and branching *Seriatopora* colonies. *Xenia* soft corals occurred in large patches, and there were a large number of small tridacnid clams. Site 13, at 12 m depth, had about 10% living cover dominated by small colonies (5-20 cm) of *Goniastrea, Acropora, Montipora, Echinopora, Stylophora* and *Platygyra*. Larger, completely dead colonies of branching *Acropora,* massive and lobate *Porites* and other species were found throughout the area. There also were several recently killed corals, especially *Stylophora,* that appeared to have been eaten by crown of thorns sea stars. This site appears to have a relatively good recent recruitment event, as many 2-5 cm diameter *Acropora* colonies were present.

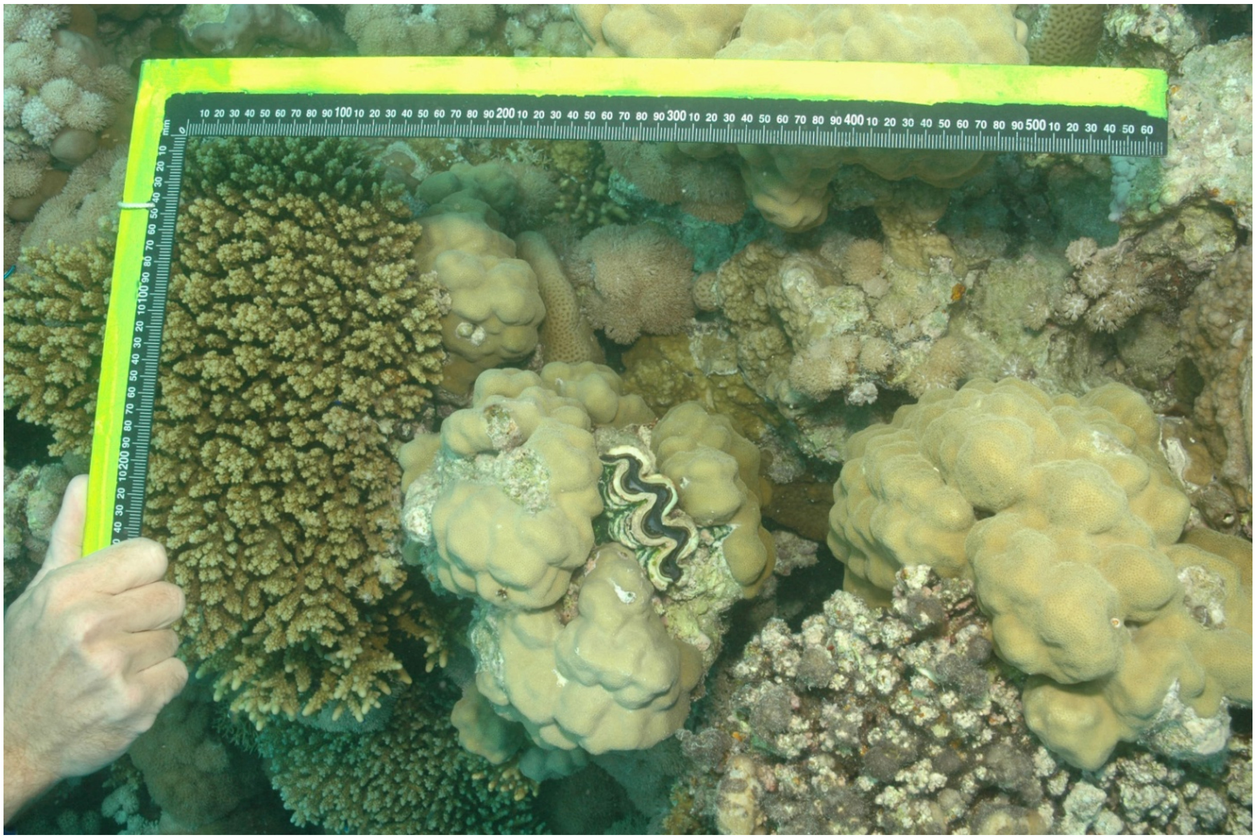


Fig. 3.47. Photoquadrat at 4.3 m depth at site 10. Many of the *Porites* colonies in shallow water had survived and there were numerous small to medium sized *Acropora* colonies.

3.48 Site 11

The reef habitat at10-11 m was unusually murky. Large areas of soft bottom, consisting of fine silts and muds, and rubble patches were located between isolated coral heads. Among the unique aspects of this reef, it had a much higher cover of red crustose coralline algae (Fig. 3.48a) than seen in other locations (3-10%), there were a high number of herbivorous *Diadema* sea urchins, and large tube sponges were common. The coral community was also different from other sites, with moderately high cover (20-40%) on boulders consisting predominantly of small polyp species (SPS) that formed extensive encrusting plates, small foliose corals and species with short branches (*Montipora*, *Pavona*, and *Echinopora;* Fig. 3.48b), along with large numbers of *Fungia* in adjacent soft bottom areas. Other less common corals included *Platygyra*, *Galaxea*, *Stylophora*, and massive colonies of *Echinopora*.

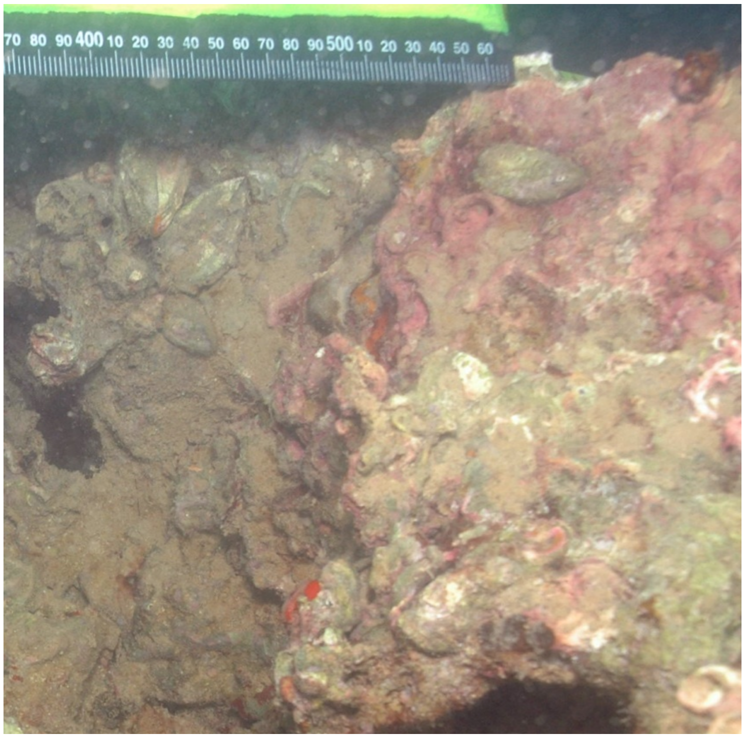


Fig. 3.48a. A piece of reef rock with fine sediments and a high cover of red crustose coralline algae (CCA).

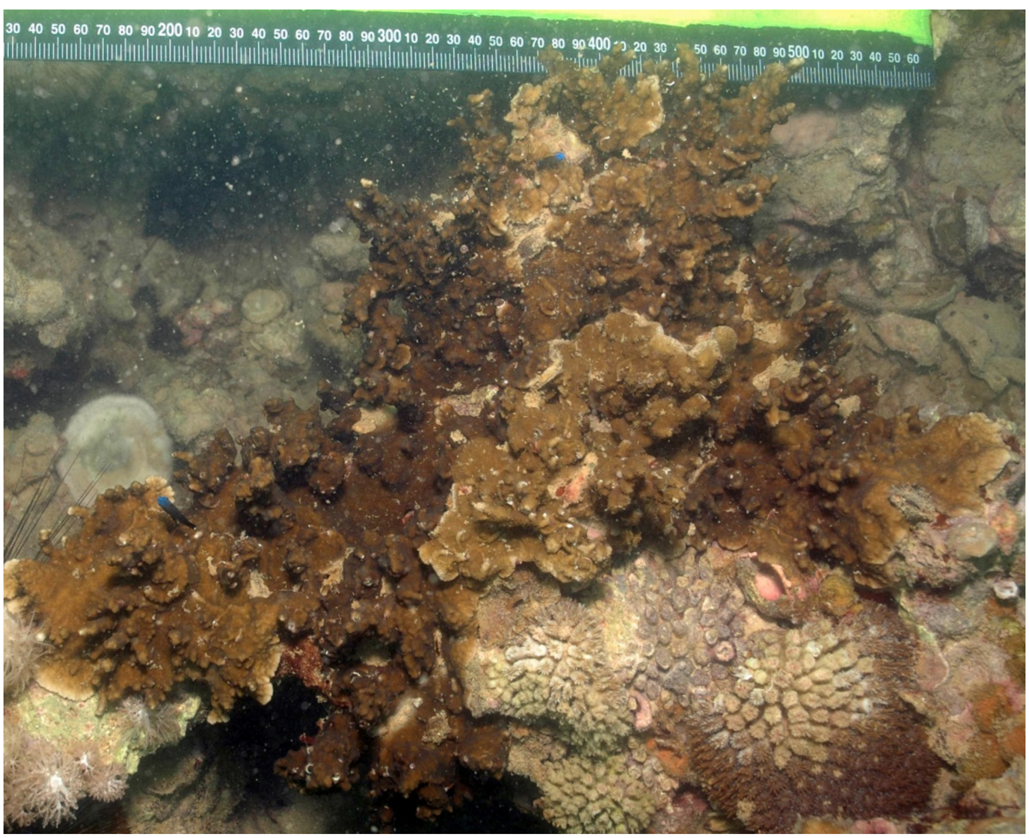


Fig. 3.48b. Colony of *Montipora* spp. forming a crust with small branches. The colony of *Galaxea* in the lower portion of the coral has a white syndrome and has lost about half its tissue

3.49 Site 12

Site 12 was located in the channel between the Al Farshah reef system and the Umm Qusur reef system. This was the primary channel that empties the large sandy lagoon. The site had high turbidity with the coral community occurring primarily in shallow water (2-3 m depth). Coral heads were separated by large patches of sand and rubble fields. The reef had 20-30% live coral cover dominated by branching corals in the genera *Acropora*, *Seriatopora* and *Stylophora*. Hard substrates also had extensive colonization of the colonial anemone, *Palythoa*.

Fig. 3.49. Reef community at site 12, 3 m depth. Small branching corals were intermixed with soft corals, colonial anemones and leather corals.

3.410 Site 14

This site was located at 14-18 m depth, seaward of the major Ras Qisbah reef system. It was constructed of columnar *Porites*, most of which was dead. Live coral cover was estimated at about 5%, consisting predominantly of small tissue remnants of *Porites* and *Goniastrea*. The reef substrate had a layer of green turf algae and also large clumps of cyanobacteria (Fig. 3.50).

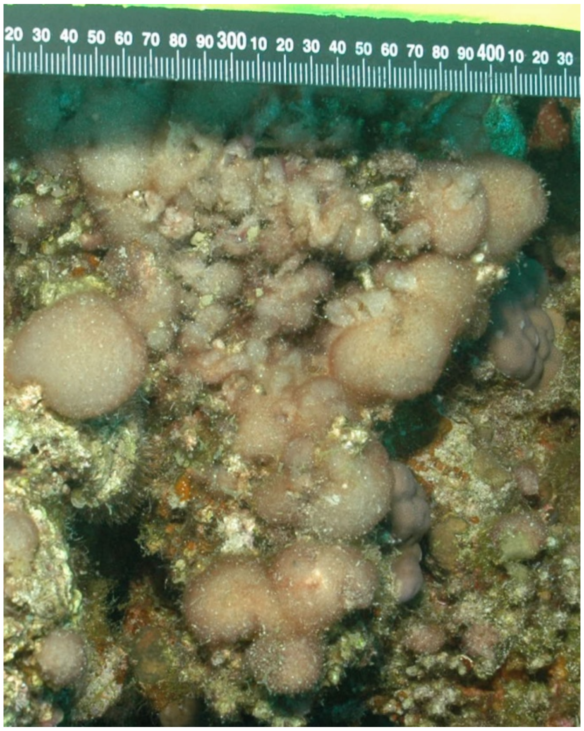


Fig. 3.410. The reef system at site 14 had little living coral, and most of the reef substrate was covered by turf algae and cyanobacteria, as seen in the image.

3.411 Site 15, 16, and 17

These sites were located at the seaward edge of the reticulate reef system located off Umm Qusur. Site 15, at 12 m depth, consisted of a *Porites* framework with dead fused branches of Acropora. Living coral cover was less than 5%, consisting of small (<10 cm) tissue remnants of *Goniastrea*, isolated branching *Acropora* and small massive *Echinopora* and *Porites* colonies. Up to 20% of the bottom was colonized by *Xenia* and *Lithophyton* soft corals. Site 16 (10-12 m) also had a Porites framework, with coral heads interspersed among sand patches and patches of rubble. Coral cover was about 5%, consisting of remnants of *Porites* and *Goniastrea*, and small colonies of *Acropora, Stylophora, Platygyra,* and *Lobophyllia.* Site 17 (12-14 m depth) was similar, with a Porites framework, and extensive patches of dead coral skeletons and colonies with tiny tissue remnants. Cover was about 5%.

3.412 Burqan Island Sites

Site 18, at 8 m depth, had a similar *Porites* framework with very little living coral. The site had moderately low relief, with extensive flat hard-bottom areas, a thin veneer of sediment over rocky areas, and large patches of fine sediments. Live coral cover (<3%) was limited to a few

Porites tissue remnants, *Millepora*, isolated *Acropora* colonies and a few other corals. Xenia formed large patches in places, ranging in cover from 5-20%. The structure was similar at 6 m depth (site 19), although there was a bit more live coral (5-10% cover). The living corals were dominated by *Porites* and branching *Acropora*, with numerous *Millepora* colonies and areas dominated by *Xenia*. Soft bottom areas between coral heads had accumulations of coral rubble.

3.5 Fish and fisheries

Fish diversity was highest (over 30 species recorded) at Umm Qusur and Burqan Island. Herbivory and percent herbivorous fish species was highest at sites 9 (25%), 11 (24%), and site 18. Fish diversity was highest (over 30 species recorded) in Umm Qusur sites 11 and 19 and Burqan Island sites 20 and 22. 30%) at Burqan Island (Fig. 3.5a). The area shows clear signs of overfishing, as individuals were predominantly of small size and of low abundance. Evidence of fishing (fishing lines and pots) was especially evident in the Umm Qusur area.

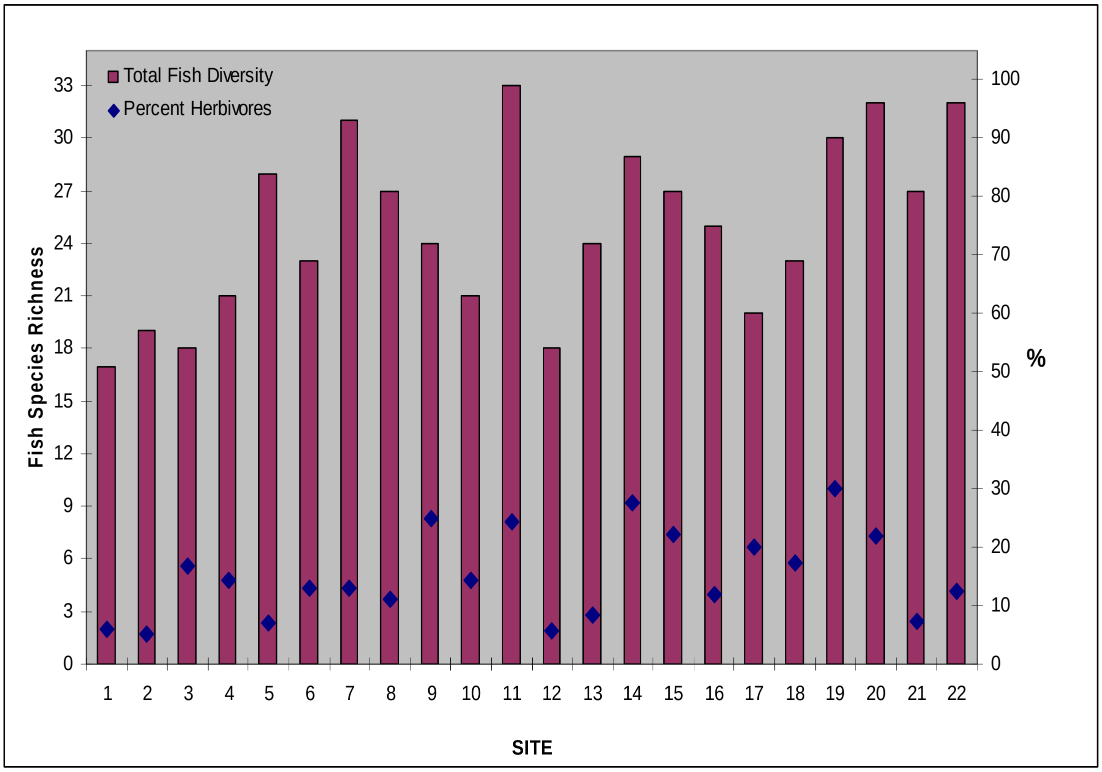


Fig.3. 5a. Species richness and percentage of herbivores for all sites.

3.6 Threats and resilience indicators

Natural stressors observed at low levels included coral diseases, bleaching and predation by crown of thorns starfish. Recent mortality throughout the site was low, suggesting these were having a minimal impact at the time of the surveys. In contrast, there is evidence of past disturbance events, as much of the framework was dead and most larger colonies had prominent areas of old partial mortality. Many species of soft coral were recorded, particularly *Xenia* sp. and *Lithophyton* which on occasion formed dense mats covering large areas of the substrate and dead corals. Nuisance species included mats of the colonial anemone *Palythoa,* cyanobacteria, and boring sponges, although these were present in high abundances each at only single sites.

Fig. 3.6a. Overgrowth of a *Porites lutea* colony by a red boring sponge

3.61 Resilience analysis

Twenty two sites were surveyed for resilience characteristics, split across the reef types and depths. Most surveys were done at 10 m for consistency, however a smaller number of shallower (5m) and deeper (15m) sites were conducted to compare how bleaching and associated impacts may have changed with depth. Resilience characteristics are summarized in Table 3.61, showing range over all sites combined. Overall, coral cover was estimated to average 30%, ranging from 5% to 70%. Maximum coral cover was on the outer fore reef slope at Al Farshah, where large coral colonies showed evidence of survival. Minimum coral cover was on the outer reef platform at Burqan Island which showed evidence of high mortality, frequent sediment outflow off the lagoon/platform and nil recovery of corals. Fleshy and corralling algal cover were minimal throughout average 0.5-1.5%, and rubble cover was relatively low at 10%, with a maximum of 50% at Site 13, in the channel at Usailh between Al Farshah and Umm Qusur.

Though no reefs surveyed were shallow enough to suffer aerial exposure at low tide, the extensive bank and reticulate reef systems at Al Farshah and Umm Qusur could be affected by pooling of water over the shallow reefs, which heats up during daylight and flows across the reef flat and down the reef slope stressing organisms in its path. This phenomena was thought to affect many of the platform-edge sites, and potentially the highly-impacted outer site at Burqan Island, where outflow of high-sediment and super-heated water may have caused high mortality in the past, and inhibited recent recovery since then. Further support of this occurring is based on the presence of numerous live corals that only occurred on stalks, being raised above the bottom layer that would be heavily impacted by sediment outflow.

Temperature averaged 27.4^{o}C across all sites, but with a clear bimodal pattern. Temperatures of 28-29^{o}C were recorded in the shallow and fore reef sites at Al Farshah and Um Qusur and the sheltered sites of Usailh, up to 6 September. However from the afternoon of 6 September to the end of surveys, temperatures of 25-26^{o}C were recorded on more exposed sites of Umm Qusur and Burqan I. This probably reflects both greater exposure to open water/upwelling conditions at the latter sites, but also stormy activity on 5 September that caused greater water mixing and thus cooling of surface waters.

Current and past bleaching and mortality patterns (variables 24-27) showed interesting patterns. Current bleaching was minimal, at background levels expected for the end of the summer season, with highest levels at site 16 on the outer platforms at Umm Qusur, but still at less than 5% of coral cover affected. Recent mortality was negligible (level 1). However mortality from a past major event was high throughout the area, on average at level 4, some sites level 5 and minimal impacts at level 3. It is likely that old mortality was from a past bleaching event, as it appeared highly uniform across the whole area. It is most likely that widespread bleaching reported from

1998, and/or from the subsequent hotspot in 1999 (Devantier 2001), resulted in widespread mortality, here estimated as ranging between 50-75% for most sites, > 75% for some sites, and least at the Al Farshah reef edge (see coral cover results above) at < 50%. While *Acanthaster planci* seastars were present in low numbers and could potentially have had outbreaks in the past, greater patchiness in the appearance of old mortality would be expected.

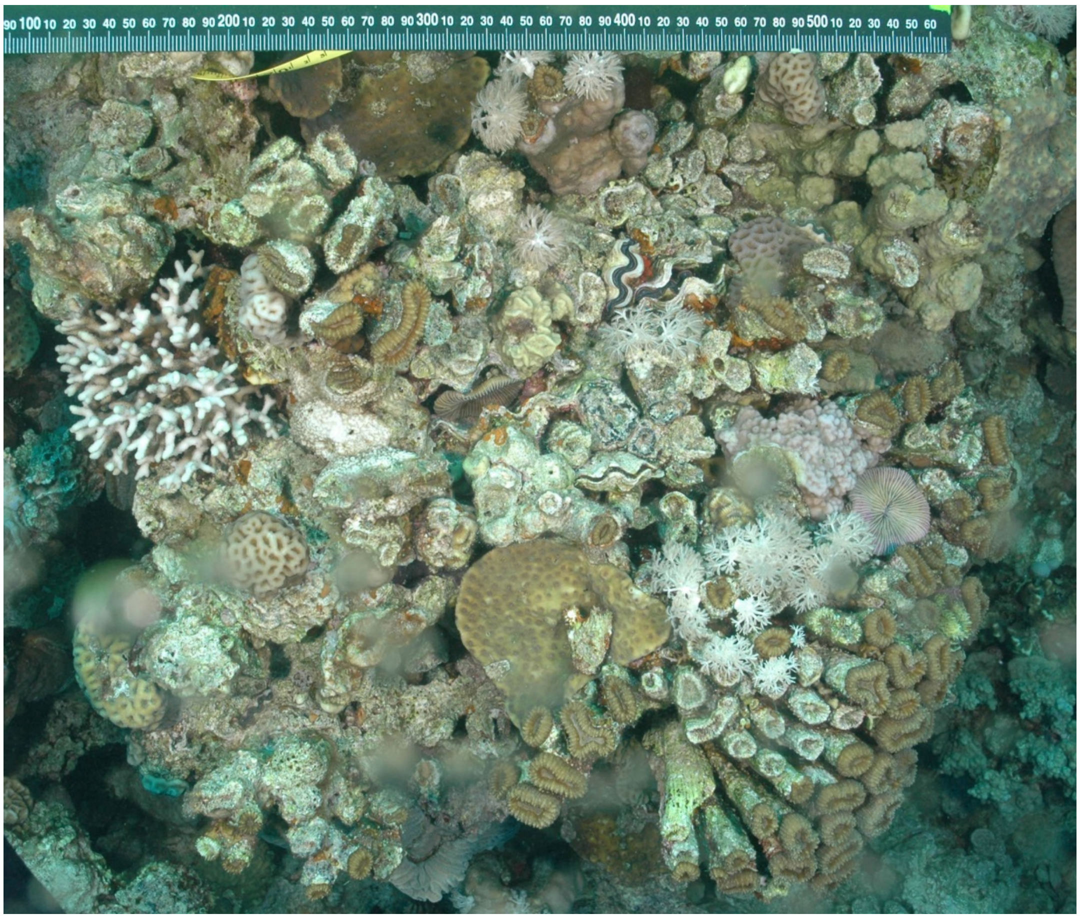


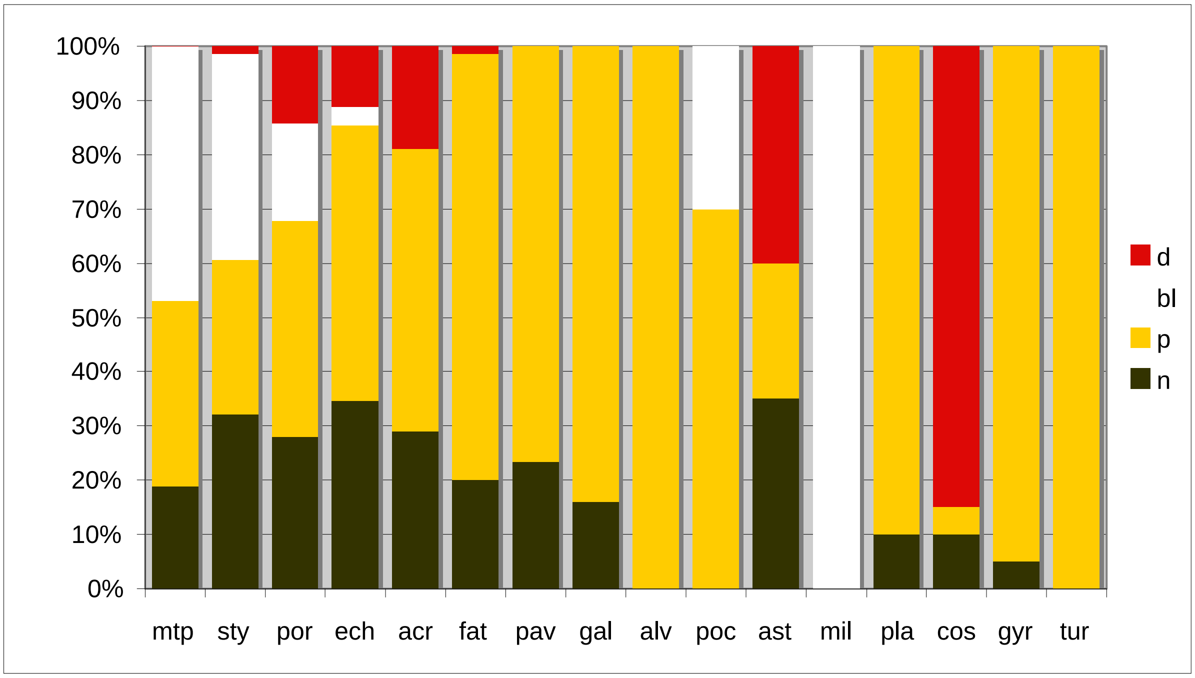
Fig. 3.6b. Partial survival of colonies, such as the Lobophyllia, and subsequent settlement and colonization of skeletal surfaces by massive and branching corals were apparent in some but not all sites at Ras Qisbah.

Other variables of interest were those related to acclimatization (variables 22 & 23). Though no reefs surveyed were shallow enough to suffer aerial exposure at low tide, the extensive bank and reticulate reef systems at Al Farshah and Umm Qusur was affected by ponding/pooling of water over the shallow reefs, resulting in enhanced heating of waters. This may have affected the platform-edge sites, and the highly-impacted outer site at Burqan Island, site 22, where outflow of high-sediment and super-heated water may have caused high mortality in the past, and inhibited recent recovery since then. This was evidenced by many live corals only occurring on stalks, being raised above the bottom layer that would be heavily impacted by sediment outflow.

The largest corals (variables 29-31) were generally observed on outer reef slopes, of 4-5 m across, however within the reticulate reef system of Al Farshah, individual massive colonies, particularly of *Lobophyllia corymbosa*, could be found. Sites with the smallest colony sizes, of < 1m tended to be back reef and island sites most strongly impacted by past mortality with highly fragmented remnants of the large colonies that originally made up the reefs. Fish diversity was highest (>30 species) in Umm Qusur sites 11 and 19 and Burqan Island sites 20 and 22. Another important indicator of resilience is herbivory (variables 38-41) and percent herbivorous fish species was highest at sites 9 (25%), 11 (24%), and site 18 (30%) at Buraqan Island. Evidence of fishing (variables 47-49; fishing lines and pots) was recorded in sites 11, 12, and 16 all in the Umm Qusur area.

Fig. 3.6c. An unusually large colony of *Platygyra daedalea* on an outer reef.

A.



B.

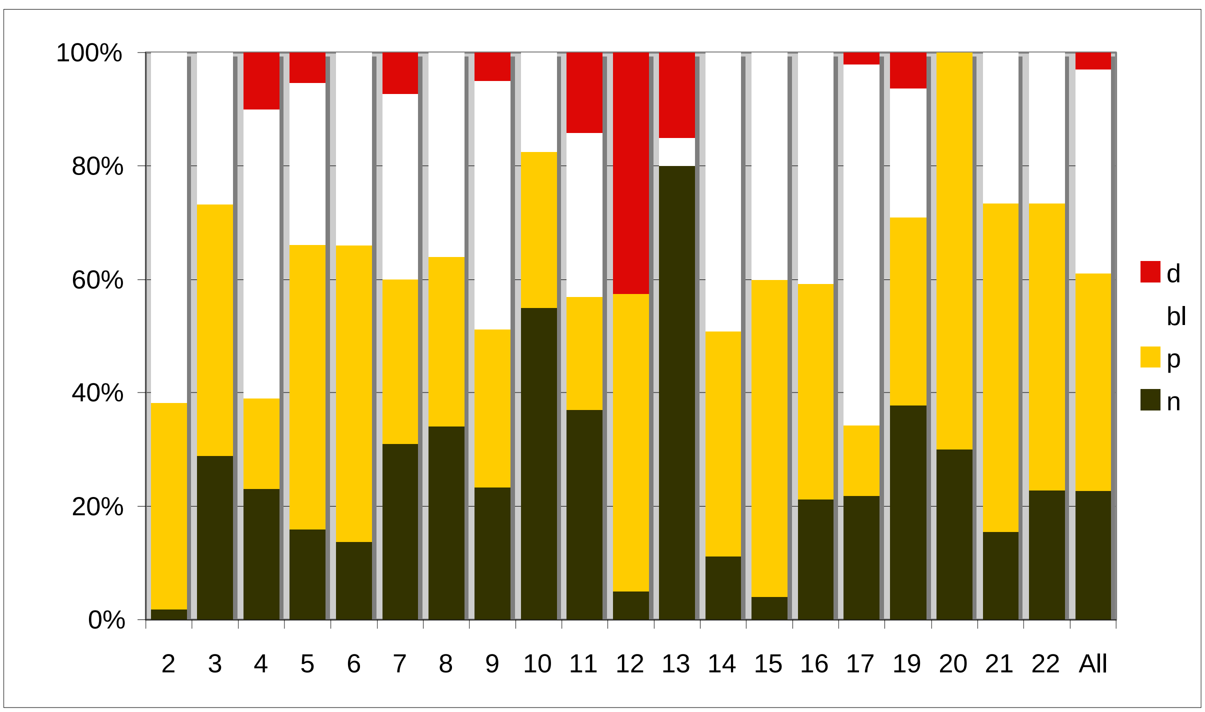


Fig. 3.6d. Levels of bleaching and mortality recorded in belt transects, by a) genus and b) site. Genera are ordered from highest to lowest prevalence of bleaching and mortality observed. Maximum numbers were 185 colonies for *Montipora* (mtp), 9 colonies for *Acropora* (acr) and <5 colonies from *Alveopora* (alv) for all sites combined.

Table 3.61. Summary of site resilience factors.

Group	#	Factor	Variable	m	sd	min	max
2-Cover	1	Coral	Coral cover	29.8	14.8	5	70
	2	Algae	Fleshy Algae	0.5	1.1	0	5
	3	Algae	CCA	1.7	1.9	0	5
	4	Substrate	Rubble	10.6	10.6	1	50
3-Physical	6	Thermal	Temperature	27.4	1.7	24	30
	7	Substrate	Topographic complexity - micro	3.6	1.0	2	5
	8		Topographic complexity - macro	3.0	0.7	2	4
	9		Sediment texture	2.0	1.2	1	4
	10		Sediment layer	2.0	1.2	1	5
	11	Cooling &flushing	water movement	2.8	1.0	1	5
	12		deep water (30-50m)	4.1	0.9	2	5
	13		upwelling (micro)	3.0	1.1	1	5
	14		wave energy	2.6	1.2	1	5
	15		exposure	2.8	1.2	1	5
	16	Shade & screen	depth (m)	10.8	2.9	5	16
	17		aspect	3.5	1.2	1	5
	18		slope (degrees)	16.9	16.7	0	45
	19		phys. shading	1.4	0.6	1	3
	20		canopy corals	1.4	0.7	1	3
	21		Visibility (m)	18.6	7.3	5	30
	22	Acclimatization	Exposed low tide	1.0	0.0	1	1
	23		Ponding/pooling	1.6	0.7	1	4
4-Coral	24	Health	Bleaching	2.0	0.4	1	3
	25		Mortality-recent	1.0	0.0	1	1
	26		Mortality-old	4.0	0.5	3	5
	27		Recovery	3.2	0.8	2	5
	28		Disease	1.2	0.7	1	4
	29		Largest corals	2.4	1.4	1	5
	30		Largest corals	1.5	1.0	1	4
	31		Largest corals	1.1	0.9	1	4
	32	Positive	Obligate feeders	1.2	0.4	1	2
	33		Branching residents	1.4	0.7	1	3
	34	Negative	Competitors	2.1	0.8	1	3
	35		Bioeroders (urchins)	1.0	0.2	1	2
	36		Bioeroders (sponges)	1.1	0.5	1	3
	37		Corallivores (negative)	1.2	0.4	1	2
5-Herbivory	38		Abund/diversity Herbivores	1.2	0.4	1	2
	39		Eroders	1.2	0.5	1	3
	40		Scrapers	1.2	0.4	1	2
	41		Grazing	1.2	0.4	1	2
6-Human	42	Water	Nutrient input	1.2	0.4	1	2
	43		Pollution (chemical)	1.2	0.4	1	2
	44	Substrate	Pollution (solid)	1.3	0.5	1	2
	45		Turbidity/Sedimentation	1.2	0.4	1	2
	46		Physical damage	1.1	0.4	1	2
	47	Fishing	Destructive fishing	1.1	0.4	1	2
	48		Pressure on carnivores	4.1	1.0	1	5
	49		Pressure on herbivores	4.1	1.0	1	5

4 Al Wajh

4.1. Background

Al Wajh Bank (25°35'N, 36°45'E) is located in the northeast part of the Red Sea, in Tabuk, Saudi Arabia, between the towns of Al Wajh in the north and Umluj in the south. It encompasses an area of approximately 2,880 sq km. Al Wajh extends 26-50 km offshore from the mainland, running parallel to the shoreline for about 50 km before changing course landward at its northern and southern ends.

Al Wajh Bank is comprised of mainland coastal habitats, a central lagoon with shallow grassbed, algal and mangrove communities, complex reef systems, and a plethora of islands. The seaward (western) side of the bank is enclosed by an extensive barrier reef, which drops abruptly to depths of 500 m or more on its seaward edge. Numerous islands and associated reef formations are supported on the shelf inside the barrier reef; several islands are also located offshore between Al Wajh and Umm Lajh, and others form a major component of the barrier reef system. The mainland coast is characterized by alluvial sand flats with several salt marsh communities found on the saline sandy flats near the shoreline, and a number of wide wadi drainage systems. The central lagoon covers an area of about 1400 sq km, with a maximum depth of 30-40 m and becoming progressively shallower toward land. The southern part of the bank is shallower than the northern part, and contains extensive seagrass beds and tidal flats. The lagoon is flushed by several narrow (< 200 m wide) channels that connect the inside and outside of the bank. Although tidal amplitude is usually minimal (< 1m), the narrowness of the openings between the bank and the open ocean generates strong currents.

The archipelago contains six main islands and over 40 smaller islands, ranging in size from 0.01 sq km to 11 sq km. Most islands are sandy and flat, whereas others are rocky with low cliffs, usually of less than 5 m height. The protected sides of the islands often have mangrove communities, grassbeds, and shallow subtidal and intertidal sand and mud flats. The three main islands located on the outer barrier reef are Jazirat Umm Rumah, Jazirat Birrim and Jazirat Shaybarah. Qummaan, the largest island within the lagoon, is a relatively flat, sandy island surrounded by a shallow fringing reef. South of Qummaan, and closer to shore, are numerous other large sandy islands including Shurayrah, Suwayhil and Abu Lahio. Islands within the lagoon to the north of Qummaan are small and low lying. Ash Shaykh Marbat is a steep rocky island that bounds the northern end of the bank.

Some islands in the region support vegetation, consisting predominantly of mangroves and salt-tolerant bushes, but elsewhere they are barren. *Avicennia marina* mangrove thickets occur along the coastline, and both *A. marina* and *Rhizophora mucronata* are found on islands on the outer barrier reef. Relatively dense mangrove stands are found at Hanak and nearby islands between latitudes 25° and 26° N, while the largest stands of *R. mucronata* stands occur around Umm Ruma Island and on the mainland shore at Dugm Sabq. The mainland coast adjacent to the bank consists predominantly of an alluvial sand plain interspersed with small wadis. At the northern and southern end of the bank the wadis extend into coastal sharms with extensive reef development on their outer margins.

The reef systems rest upon ancient alluvial plains (Sheppard et al. 1992). Horst-and-graben faulting was an important structuring process for the region (Hotzl 1984). The quaternary coastal plain abutting the reef areas is wider than elsewhere along the north central coast. Al Wajh is separated from the Yanbu little barrier reef system by a horst structure at Um-Lajh. Um-Lajh also represents a significant change in the course of the coastline. North of Um-Lajh the coastline is predominantly straight. South of this point however a more sigmoidal coast, typical of the central and southern Red Sea is evident.

4.2. Research completed

The research team was divided into three teams. One team focused on groundtruthing needed to classify marine habitats, a second team collected data needed to classify the hyperspectral datasets obtained from the coastal areas, and a third team conducted SCUBA assessments to collect coral, fish and resilience data from coral reef habitats. Locations of the dives made by the three teams are illustrated in Fig. 4.2a.

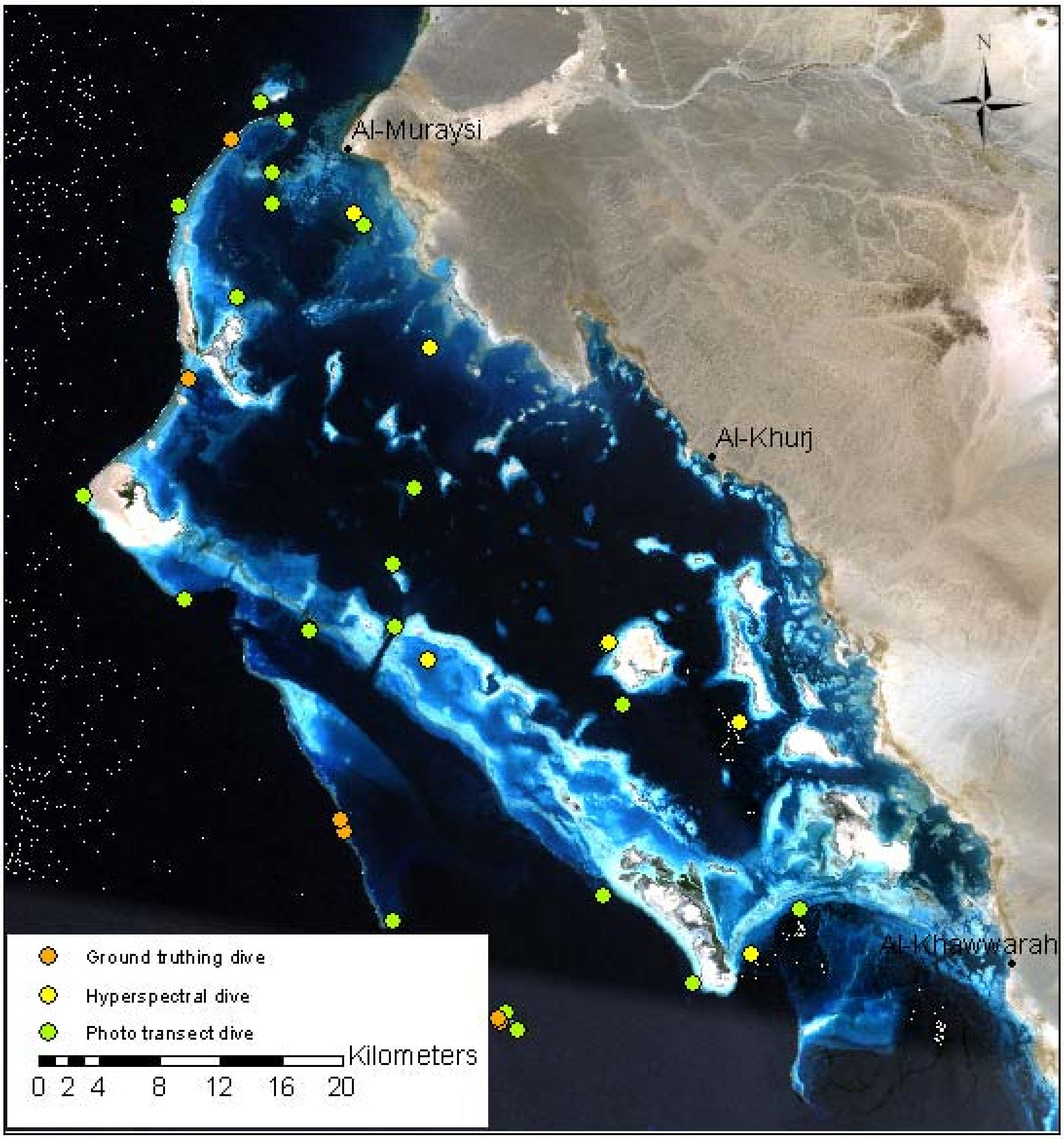


Fig 4.2a. Location of dive sites by survey team at Al Wajh.

4.21 Mapping

Utilizing a spectral remote sensing approach, habitats within Al Wajh Bank were classified from the high spatial resolution (2.4 m pixel) ‘QuickBird’ multispectral satellite imagery. Much of the field effort centered on collecting the necessary data for correcting the effects associated with the attenuation of both the incident and reflected light as it passes through the atmosphere and water column prior to satellite detection, as well as training the algorithms needed to classify the different habitats; namely bathymetric, in-situ spectral, and ground truth data (Fig. 4.3a). A total of 2147 sq km of shallow marine habitat was surveyed in the Al Wajh study areas. This included 417 km of bathymetric data (145,087 soundings) and 410 video drops (3.4 hours of video footage).

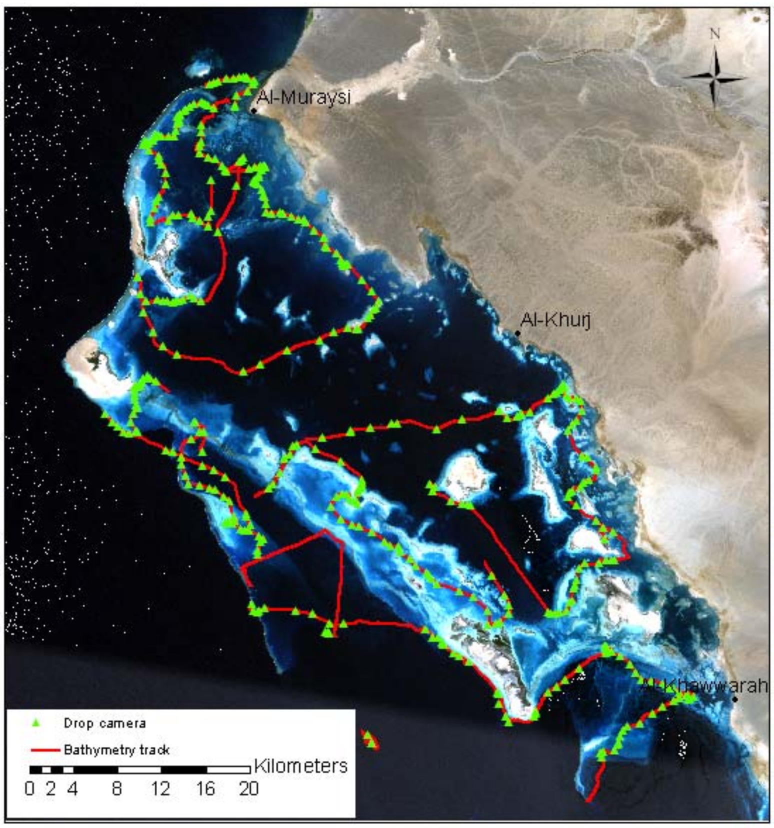


Fig 4.21. Drop camera positions (green triangles) and bathymetry track (red line) followed by the groundtruthing team at Al Wajh.

4.22 Hyperspectral surveys

Fieldwork was undertaken at Al Wajh from the 13th-23rd May 2008 to support classification of hyperspectral imagery of the area, which was acquired from simultaneous airborne surveys conducted during this period. Information was collected on parameters necessary for atmospheric and water column correction of the hyperspectral imagery. Terrestrial and underwater ground referencing information was collected for supervision and accuracy assessment of the final image classification. Spectral signatures were collected with a field spectrometer to parameterize light reflectance from key benthic assemblages, such as sand, coral, algae and seagrass. Fieldwork took place across six days beneath the area covered by the airborne surveys (Fig. 4.1a).

In addition to this, information was collected on potential biophysical drivers of the community features apparent on the Al Wajh bank, including depth, water movement (surface wave activity and subsurface currents), water turbidity, and sediment characteristics. Table 4.221 summarizes the field data collected during this period.

Fieldwork	**Number of measurements**
Phototransects	**13**
Benthic spectra	**112**
Suspended sediment readings	**29**
Water samples	**25**
Bed sediment samples	**23**
Depth measurements	**50**

Table 4.221. A summary of the field data collected during the Red Sea expedition

Post-field data analysis can be broadly divided into processing of the hyperspectral imagery to develop a habitat map; quantification of potential biophysical drivers underpinning community structure, such as suspended sediment concentration, water depth and wave exposure and the development of ecological models to investigate interactions between these drivers and community characteristics, as represented in the habitat map.

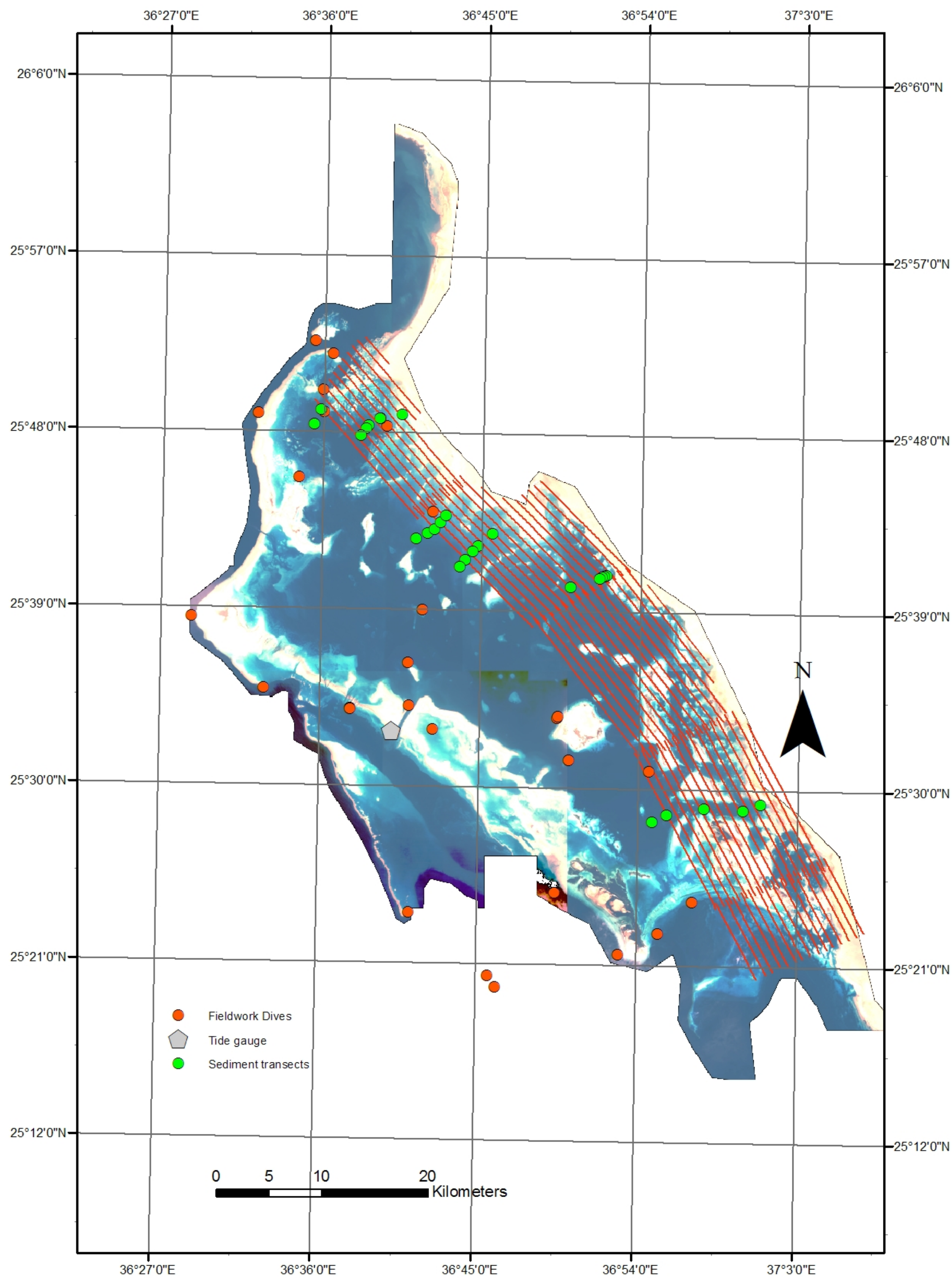


Fig. 4.22a. Locations of the airborne survey flight lines, fieldwork dives and suspended sediment readings carried out at Al Wajh from June 13th-23rd

The imagery delivered by SpecTIR went through a series of pre-processing steps prior to generation of the habitat map (Fig. 4.22b). Applications were developed for correction of influences from the atmosphere and water column. This will bring spectral signatures collected in the field into a common frame of reference with the airborne imagery, facilitating image classification. The image will then be classified using standard hyperspectral supervised classification algorithms and validated using field data. The resulting habitat map was then be used as a basis for ecological model development, as described below.

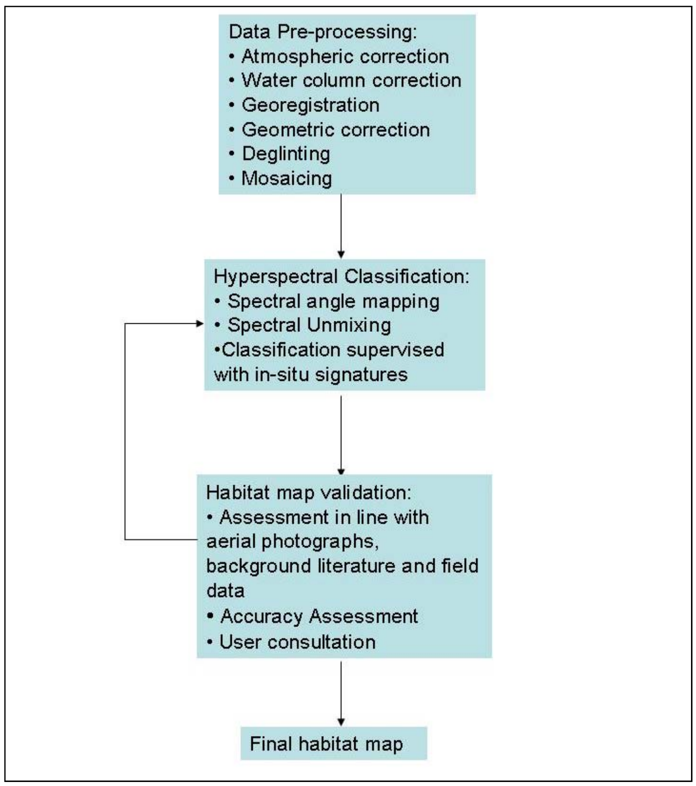


Fig.4.22b. Habitat map production steps for the AISA Eagle dataset

The concentration of suspended sediments was investigated along transects that spanned a depth range from 25m-1m. These were established along lines running perpendicular with the coast, crossing the coastal shelf. At 5m depth intervals, secchi disk readings were taken and a water sample was extracted from a depth of 1.5m below the surface. This was achieved by mounting a 250ml sample bottle onto a 1.5m length of piping. The suspended sediment concentration was determined by filtering water samples through a pre-weighed filter of pore size 0.5 micrometers, and measuring the change of mass. Inorganic and organic components were separated out through combustion. Output results were used to train the output parameters of the optimization model, which yielded synoptic estimations of suspended sediment across the coastline. Bed sediment samples were collected from a depth of 10m at all dive locations. These were analyzed for particle size distribution using a laser Malvern mastersizer.

Once the habitat map was produced, it was used as a basis for developing ecological models to investigate biophysical drivers of community structure at Al Wajh. The geomorphological character of the reef systems at Al Wajh was variable; structures included reticulated networks of reef matrix, pinnacles, submerged reef ridges, cay reefs and platform or patch reefs. It has been suggested that coral communities on these different systems have distinctive characteristics depending on their depth, exposure to incident wave power and water turbidity (De Vantier, 2000). A combination of a landscape ecology and a geomorphological image interpretation framework was used to develop models that empirically assess regional drivers of community structure.

A two stage approach to model development was adopted. An initial exploratory phase will use a combination of data collected in the field and broad scales statistics drawn from the habitat maps to quantify landscape patterns using a series of "descriptive" geostatistical techniques. The aim of this step is to expose individual functions that summaries the influence of independent functional drivers on community structure empirically. The second phase of the model development process is to use inferential geostatistics to extend statements made on the basis of the first stage across the habitat map. The aim of this phase is to test the combined explanatory power of the range of different functional drivers under investigation. One key link between these two phases is the mapping of residuals from phase one as a key activity in the exploration of additional model covariates. This is a unique feature of geostatistics that facilitates the approach to model development described here.

In the case of water turbidity as an example of a biophysical driver of community structure, initial investigation comprised an examination of data collected in the field. Indicators of suspended sediment content will be derived from the imagery using optimization techniques. The relationship between depth and turbidity observed informed initial hypothesis formulation on sediment entrainment processes underpinning the spatial distribution of turbidity observed in the imagery.

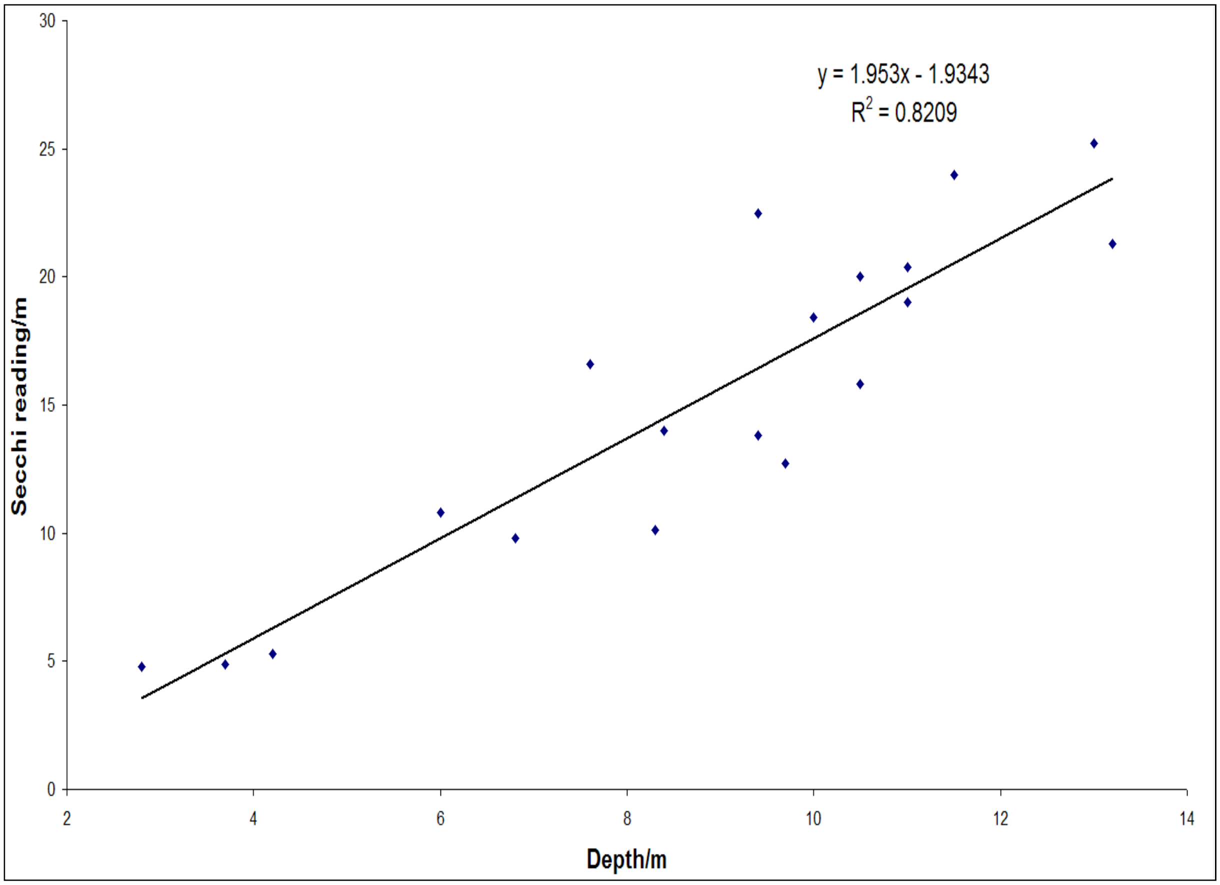


Fig. 4.22c. Relationship between depth and turbidity (secchi disc measurement) in Al Wajh

In addition to depth, an exploration of particle size informed this initial descriptive phase. A number of substrate samples were extracted from Wajh and the spatial distribution of particle sizes was mapped to suggest the potential sources of sediment in different areas of the lagoon (Fig. 4.22d). Investigations carried out at this level facilitated model development and interpretation, yet it is the turbidity values derived from the imagery that offer comprehensive coverage of the study area that will be fed into the inferential geostatistics that comprise the crux of this phase.

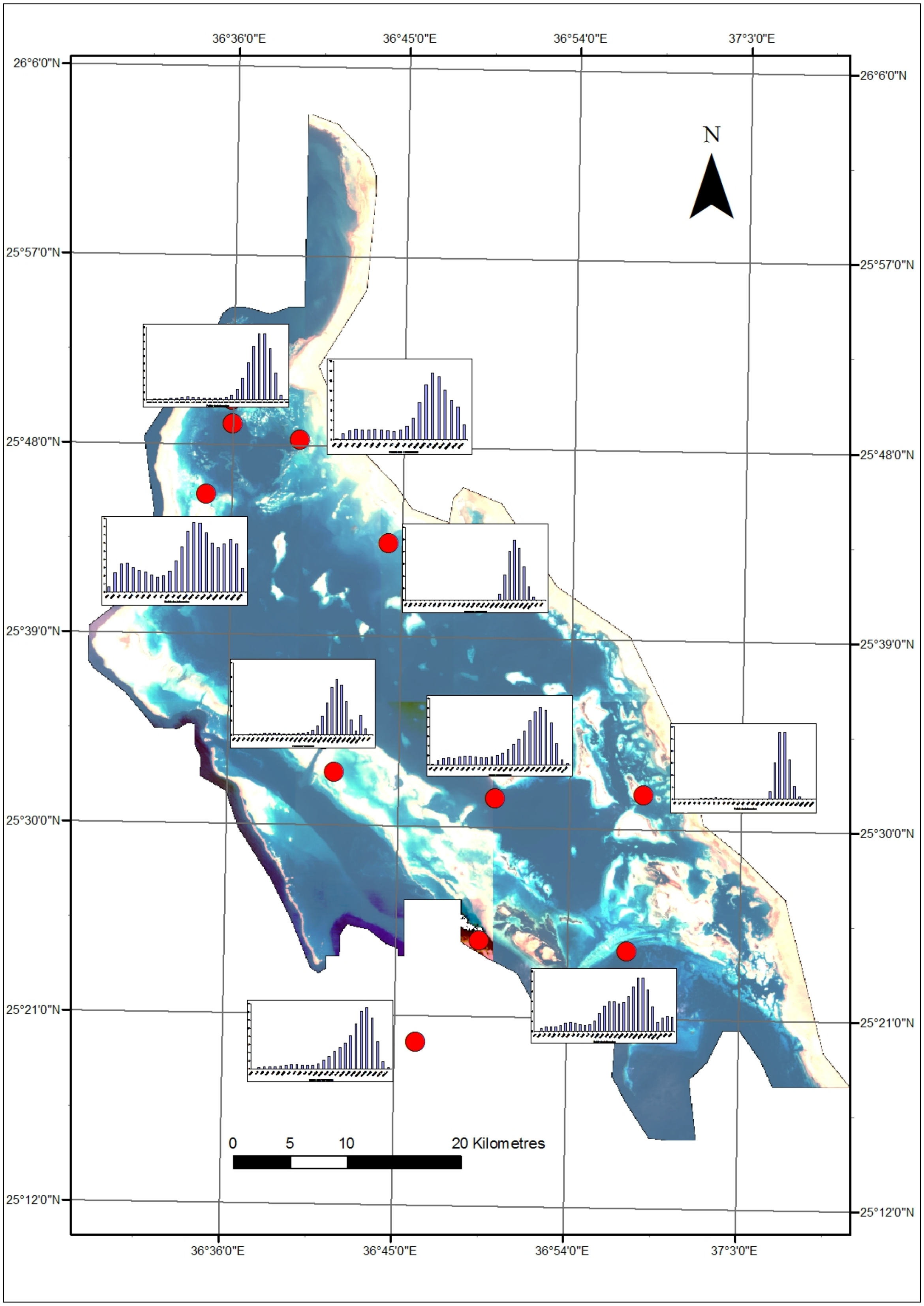


Fig. 4.22d. Spatial distribution of particle sizes in bed sediment samples taken from Al Wajh

4.3 General habitat attributes

Al Wajh represents the most extensive coral reef ecosystem of the Red Sea, containing mainland coast and offshore islands, and numerous shallow marine habitats including mangrove communities, seagrass beds, algal flats, subtidal sandy and mud-bottom habitats, and coral reefs. Overall, this region contained the most extensive continuous coral reef system found off the Saudi Arabian Red Sea coastline. The bank and adjacent coastline to the north and south support the greatest range of reef types in the northern Red Sea, including reefs developed in open and closed sharms, mainland and island fringing reefs, platform reefs, reticulate reef systems, submerged patch reefs, cay reefs, lagoon pinnacles, a well developed barrier reef and an offshore horst. Two deeper submerged ribbon reef systems also lie outside the bank, due south. The outer edge of the barrier reef was located about 26 km offshore. In several locations, the barrier reef system contains an exceptionally wide reef flat, exceeding 50 m in width in many places.

The barrier reef surrounds a very large (>2500 km^2) deep water lagoon which contains islands, shallow banks, patch reefs, and fringing coral reefs, as well as numerous other associated shallow marine habitats. The barrier reef was also perforated by several narrow channels, which were critical in flushing the bank, and in mitigating temperature stress, thereby enhancing the resilience of reefs located near the channel and within the channels. Typically, coral growth was sparse at the base of the channels, possibly due to considerable transport of sediments, while proliferant coral growth occurred at the edges of the channel. The southern part of the lagoon was shallower than the northern part. At the southern end of the bank, much of the habitat consisted of a reticulated reef structure formed by columnar *Porites* colonies. While much of the underlying framework corals were dead, numerous species had colonized the substrate. A large platform between 10-15 m deep in the northern lagoon supported extensive sea grass beds, tidal flats and mangroves. Thickets of *Acropora* spp. were identified on this platform in several nearshore locations, while reef communities also existed on banks located further from shore. Shallow habitats (1-2 m depth) around lagoonal islands included sandy areas and hardbottom substrates with isolated corals. Closer to shore, nearshore habitats were silty, muddy or fine sands, often with a colonization by sea grasses, algae or cyanobacteria. Mangroves were found on the leeward side of several islands and also close to shore.

4.4 Coral community structure

A total of 20 locations were examined using SCUBA (Fig. 4.4a) and one additional location was examined through snorkeling (Table 4.41). These encompass outer barrier reef locations, reef channels, reticulated reef systems in the south, coral banks, offshore horst structures, and lagoonal patch reefs (Table 4.41).

Site #	Latitude, N	Longitude, E	Date	Location	Depth
1	25.410930	36.823370	5/13/2008	Wajh S	14 m
2	25.359050	36.883830	5/13/2008	Wajh S	12 m
3	25.404270	36.952460	5/13/2008	Wajh S	14 m
4	25.641990	36.479300	5/14/2008	Wajh S	17 m
5	25.581810	36.547780	5/14/2008	Wajh S	13 m
6	25.568170	36.684450	5/14/2008	Wajh S	9 m
7	25.559070	36.824010	5/15/2008	Wajh S	16 m
8	25.523890	36.835330	5/15/2008	Wajh S	15 m
9	25.565400	36.629300	5/15/2008	Wajh S	17 m
10	25.649640	36.695530	5/16/2008	Wajh S	20 m
11	25.604590	36.683010	5/16/2008	Wajh S	5 m
12	25.761020	36.577790	5/17/2008	Wajh N	4 m
13	25.835790	36.599550	5/17/2008	Wajh N	12 m
14	25.815220	36.538970	5/18/2008	Wajh N	20 m
15	25.877004	36.591466	5/18/2008	Wajh N	12 m
16	25.866670	36.608060	5/18/2008	Wajh N	15 m
17	25.805480	36.659600	5/19/2008	Wajh N	5 m
18	25.817110	36.600350	5/19/2008	Wajh N	10 m
19	25.392830	36.687410	5/20/2008	Wajh S	15 m
20	25.330060	36.768950	5/22/2008	Wajh S	27 m
21	35.339888	36.762017	5/22/2008	Wajh S	31 m

Table 4.41. Coordinates of the reefs surveyed using SCUBA.

Reef communities were highly variable in species composition and condition, with some reefs exhibiting near total mortality from the water's surface to the base of the reef, and others with virtually no mortality. In general, the highest cover of living corals was observed on the reef crest and shallow forereef (1-5 m depth), with low cover (1-10%) of hardy, temperature tolerant corals on the reef flat. On the reef slope, moderate cover was recorded at mid depths (6-8 m depth; 20-30%). Cover was reduced at the base of the reef slope (9-12 m depth; approx. 5-20%),

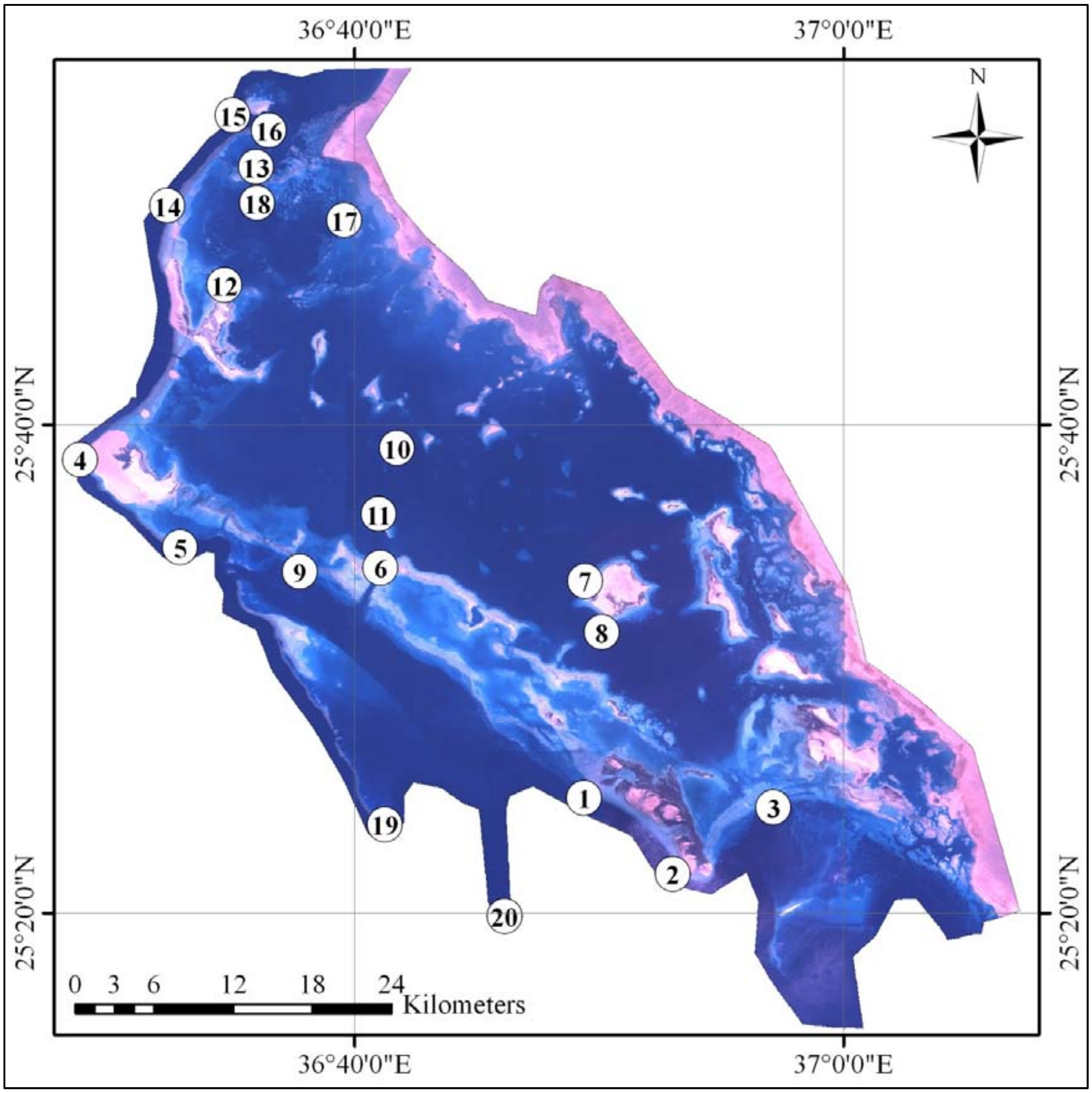


Fig 4.4a. Satellite imagery for Al Wajh showing the locations of SCUBA assessments. Site 20 and 21 are on opposite sides of an offshore horst and are only labeled as "20".

with 0-10% cover in deeper water (13-20 m depth). The base of the reef often consisted of a dead *Synarea* (*Porites*) carpet with sporadic colonization by soft corals, small branching corals, and small massive corals. There were exceptions, however, especially on outer barrier reef sites where high cover extended from the reef crest (3-5 m depth) to 25-30 m depth. On inner reefs in Al Wajh, much of the underlying framework consisted of columnar *Porites*, most of which was dead or had extensive patches of old mortality affecting 60-99% of their surface. Dense *Acropora* thickets were found at several nearshore sites within Al Wajh lagoon, in areas of high turbidity, although these were generally confined to depths of less than 5 m.

A higher diversity of corals was recorded on southern reefs (52 genera), with 44 genera seen on northern reefs (Fig. 4.4c). Between 8-12 m depth, *Porites* was the dominant coral on southern reefs, followed by *Acropora* and *Millepora* in roughly equal proportions, while northern reefs had more *Acropora*, followed by *Porites* and *Millepora*. Other dominant corals included *Pocillopora*, *Montipora*, *Echinopora*, *Favia*, *Goniastrea*, *Stylophora*, and *Pavona*. In general, most corals were small (1-20 cm diameter), while most of the live coral cover consisted of colonies that were 11-80 cm diameter (Fig. 4.4d). There were minor differences in size structure of corals between northern and southern reefs (pooled sites). When examining individual reefs, however, composition, cover, size structure and health varied considerably.. Moderate levels of recruitment were apparent in many areas, including sites that had experienced large die-offs of corals. Most recruits and juveniles consisted of species other than *Porites, e*specially branching corals in the genus *Acropora* and *Pocillopora.* Other species of massive, plating and submassive corals had also experienced extensive amounts of partial mortality, but small tissue remnants often had survived, and these were slowly resheeting over exposed skeletal surfaces.

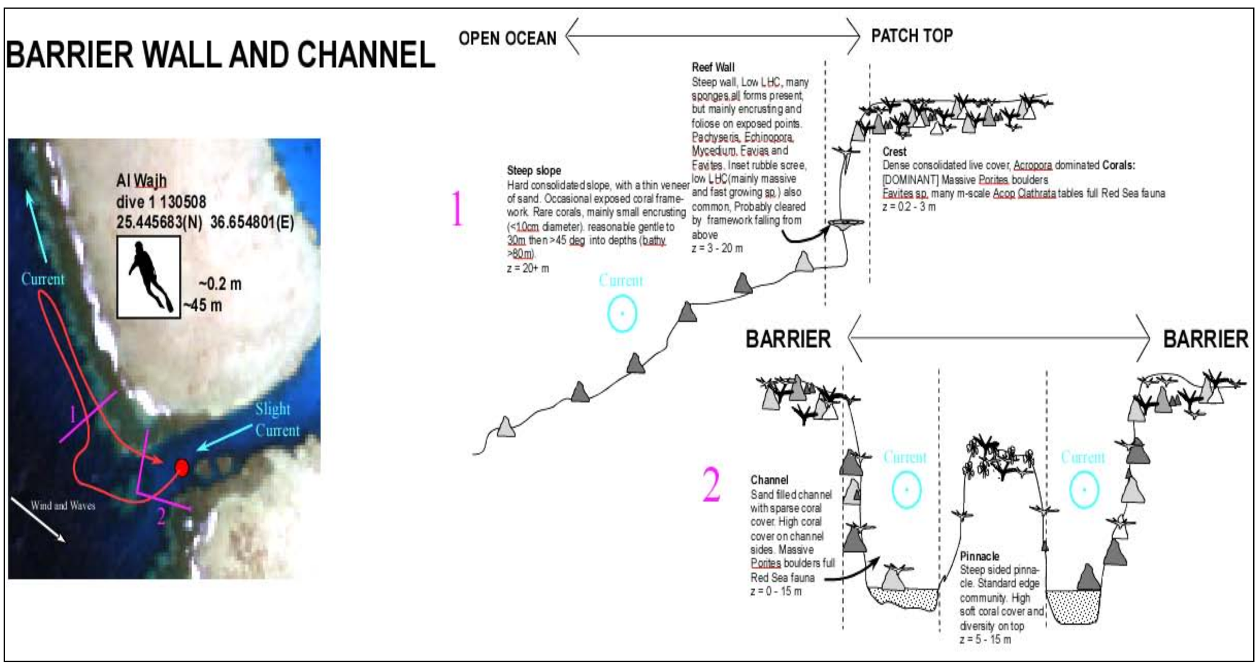


Fig 4.4b. Example of reef profiles from Al Wajh generated from broad scale SCUBA assessment; site location, depth profile, species composition and relevant geomorphological information shown.

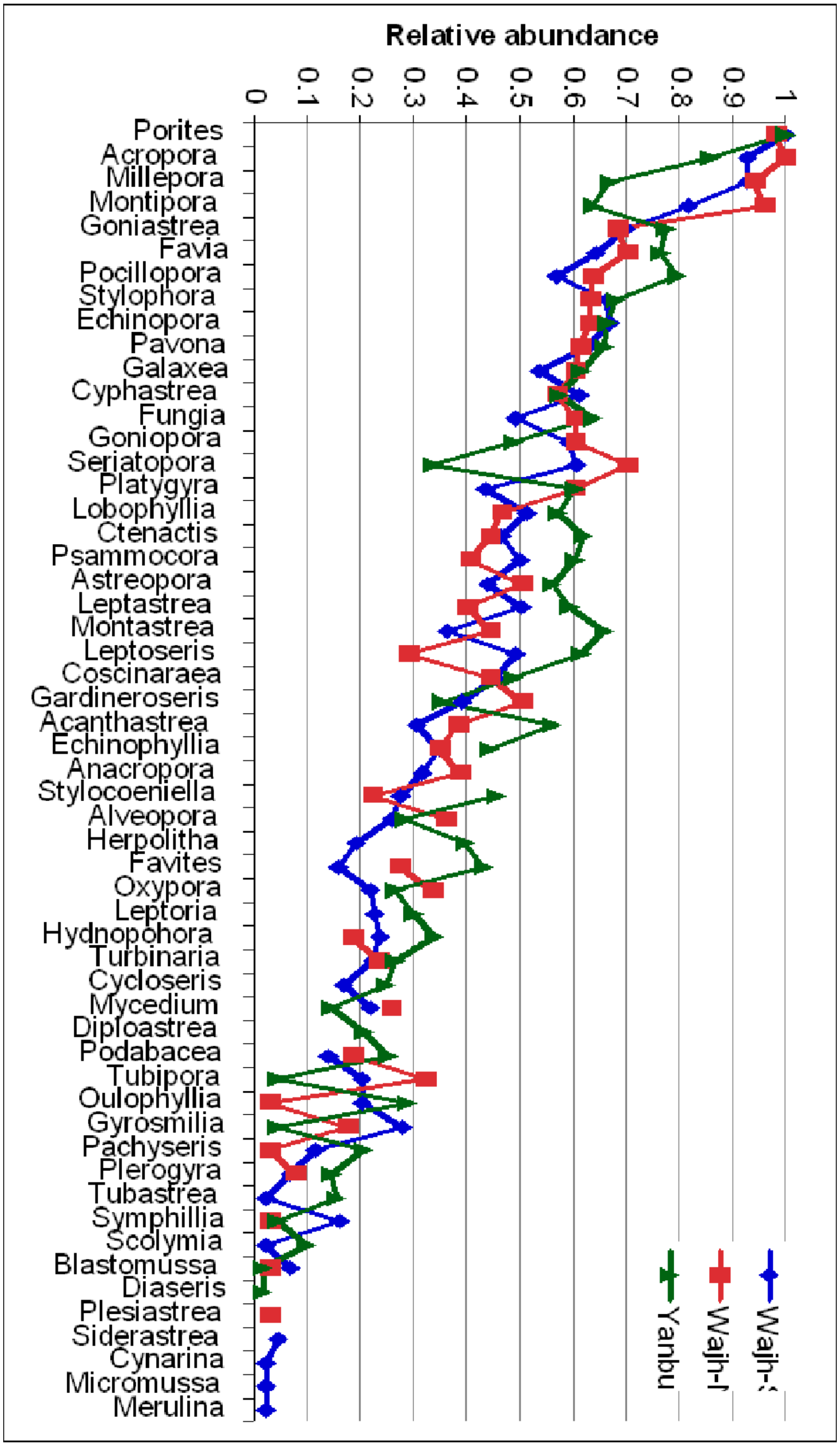
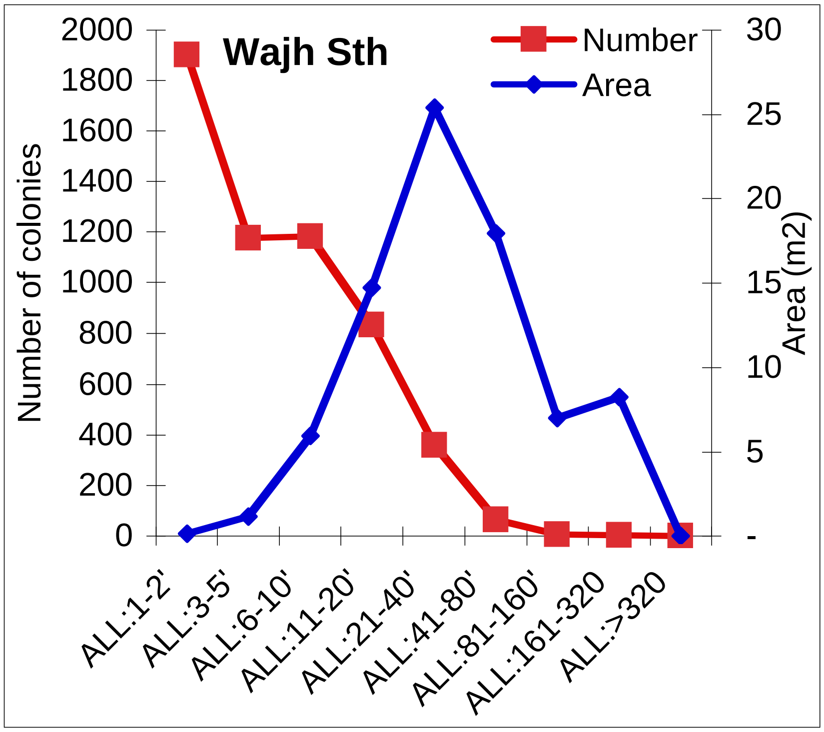


Fig. 4.4c. Relative abundance of the dominant genera of corals recorded along transects on Al Wajh south (blue), Al Wajh north (red) and Yanbu (green).



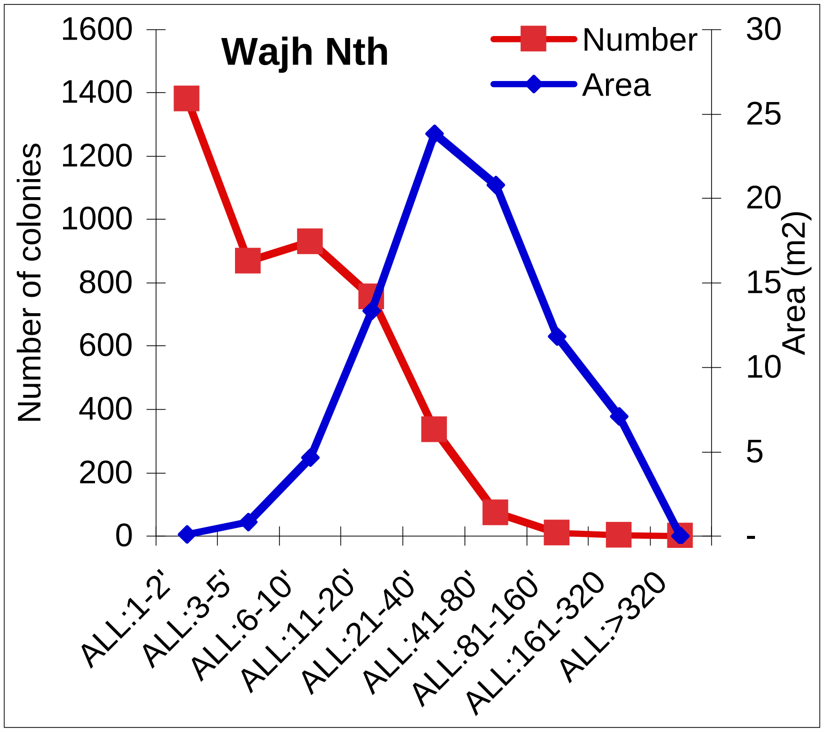


Fig. 4.4d. Size structure of corals assessed on Al Wajh Bank reefs. The number of colonies and the total area (sq m) of the reef occupied by corals within nine size classes are shown for southern (Sth) and northern (Nth) reefs. The size classes represent the maximum diameter in cm.

4.41 Southern reefs (site 1 and 2)

Reef system from 10-13 m consisted of a dead *Synaraea* carpet, with a narrow reef system that slopes upward to the reef crest at about 5 m. Deep areas had < 5% live cover consisting of dead framework with isolated remnant of *Porites* and small juvenile *Acropora* and *Pocillopora* colonies. Site 2 had more live *Porites*, consisting of both *P. lutea* and *P. rus*, at 10 m depth and total cover of 10-15%. The reef slope began at about 8 m depth with 5-10% cover, increasing to 20-30% near the crest. Large sections of the reef at 5 m depth were completely live with a dominance by *Porites lutea* and *Favia stelligera*.

4.42 Southern reticulated reef system (site 3)

Reefs in this area consisted of a reticulated Porites framework with coral constructions separated by intricate narrow channels and patches of sand. Relief of colonies at the base of the reef was fairly low (up to 1 m height from sand to tops of corals) with greater relief near the reef slope. At 10 m depth, the site had a high diversity of corals, with 36 genera recorded, including a high abundance of *Echinopora, Seriatopora, Stylophora, Goniastrea, Galaxea, Lobophyllia, Favia* and large plates of *Mycedium*. Live coral cover was about 20%, with large patches of *Xenia* soft corals in areas lacking live coral.

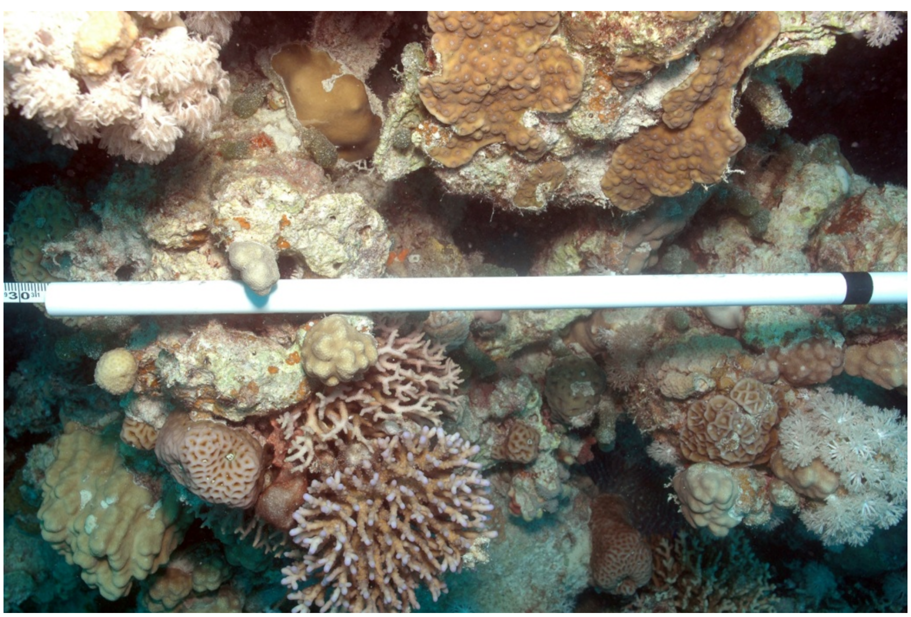


Fig. 4.42. Typical photoquadrats within the southern reticulated reef system in Al Wajh, 10 m depth. A high diversity of corals had colonized the Porites framework.

4.43 Birrim Island barrier reef system (site 4 and 5)

The outer (seaward) reef of Birrim Island represented a typical windward, semi-exposed red Sea reef community. The northwest corner had well developed spur and grove structure that extended from the surface of the water to the base of the reef. The reef slope was very steep (60-90° slope) from 2-3 m depth to about 15 m, interspersed with small ledges and caves. Below this, the slope continued at a 45° angle, ending in sand at about 20 m depth. The reef slope was covered with live stony corals with no apparent signs of mortality. In several locations, dense assemblages of *Acropora austera* cascaded down the reef slope from 1-10 m depth, interspersed with large (2-3 m diameter) *Porites lutea* colonies. In other areas several species of tabular and bushy Acropora were found on the outer side, with Millepora colonies in channels and cuts in the reef. The reef system at the southern end of the Birrim island reef forms a long spur that extends to the south. It had a narrower slope then the northwest corner (30-40°) that dropped to about 13m, where it abruptly breaks to a near vertical slope to 16 -17m depth, followed by a wide gently sloping forereef. The upper reef slope and edge of the drop-off was colonized by large *Favia stelligera* and *Porites lutea*, with bushy *Acropora* and *Pocillopora* in deeper areas. Live coral cover ranged from 30-100%.

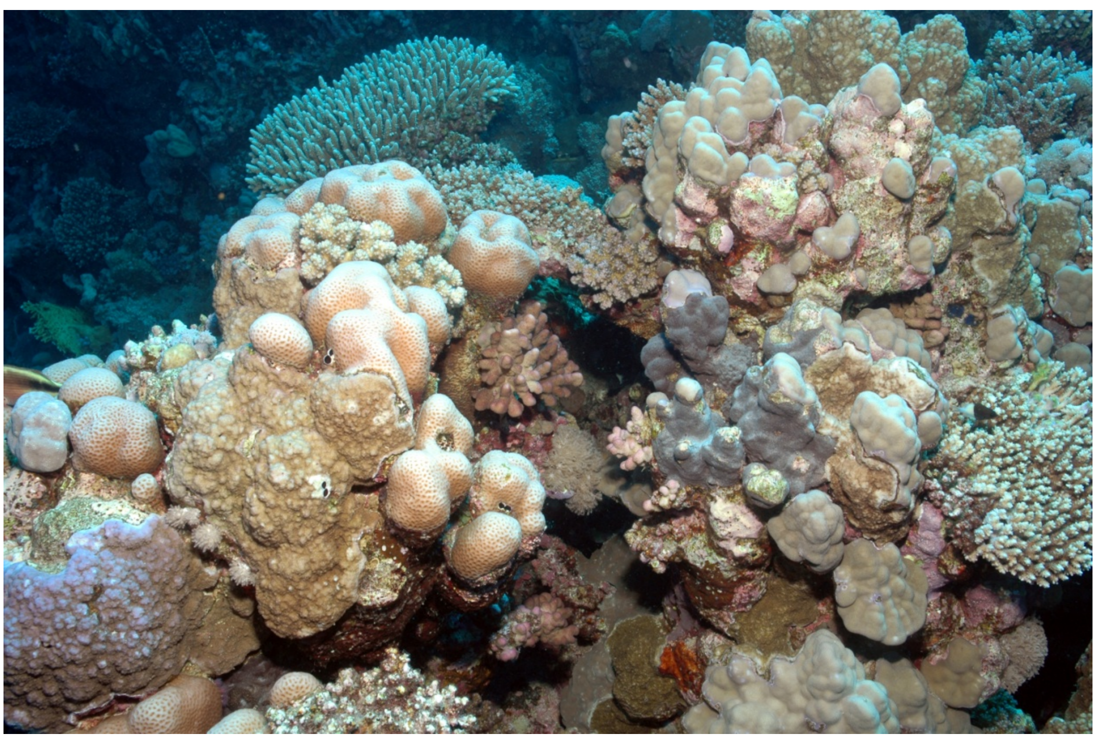


Fig. 4.43. Barrier reef off Birram Island at 6 m depth.

4.44. Channel (site 6)

The reef system located in the channel between Shummazah and Ummahat Shaykh was relatively shallow (5-10 m depth) and very turbid. It had the typical *Porites* framework with large patches of fine silt between coral boulders. Few live Porites colonies existed, but the skeletons had been colonized by a diverse assemblage of corals. The reef was dominated by branching acroporids including large *Acropora formosa* and *Acropora pharaonis* colonies. There were also numerous large Stylophora colonies and small massive corals (*Echinopora, Galaxea, Goniastrea, Favia* spp.). In areas without stony corals, large soft corals were present, especially *Sinularia* and *Sarcophyton* and mats of *Xenia*. The orange boring clionid (*Pione* spp.) was relatively common at this site. Live coral cover was 20-40%.

4.45. Qummaan island lagoonal reefs (site 7 and 8)

The island of Qummaan is surrounded by a wide bank with a coral fringe on its edge. Shallow areas on the top of the shelf are sand and hardground, with isolated live corals extending all the way to land. The coral fringe was originally a typical *Porites columnaris* or *Synaraea* carpet which has mostly died. Coral skeletons are well preserved, and occasionally small remnants of live *Porites* tissue remain. The live cover of Porites is <5% at 10 m depth and slightly higher in deeper water (15 m depth; 5-10%) with some larger living colonies. Other massive corals that colonized the *Porites* framework, especially *Echinopora*, *Goniastrea*, *Favia* and *Lobophyllia*, also appear to have been affected by past mortality events. Most surviving colonies had large patches of old mortality and live tissue consists of small remnants. Coral recovery seems to be low, with few recruits and a predominance of mainly of surviving tissue remnants. Living corals were mostly 10-20 cm diameter and were dominated by *Echinopora, Acropora* and *Stylophora*, although most of these had patches of dead skeleton on their surfaces. At the southwest end of the island, many of the surviving colonies of Echinopora had large patches of recently exposed (white) skeleton. A moderate abundance of COTs sea stars were observed on this reef, and several were actively feeding on *Echinopora*. Live cover ranged from <5%-10%.

4.46. Shummazah (site 9)

Extensive coral reef habitat and small emergent islands exist along the barrier reef from Birrim Island to Shaybarah in the south. These often form series of reef spurs separated by channels.

Shummazah reef system is sheltered from the Red Sea by Shib al Judyar, which extends parallel to the barrier and is separated from the main barrier reef system by a deep channel. The Shummazah reef system was very turbid and the bottom covered in fine, easily suspended silt. The reef consists of a long, wide (>200 m) spur at 5-7 m depth, with a steep slope on the seaward side that drops to 10 m depth, ending in sand. The top of the spur had large branching acroporid colonies, interspersed with many live *Porites*, *Millepora* and massive corals including large (30-60 cm) colonies of *Echinopora* and *Lobophyllia.* Cover ranged from 20-35%. The reef slope has lower cover (10-20%), but a high diversity of plating corals, along with small massive *Goniastrea, Echinopora, Porites, Galaxea* and other species. .

4.47. Lagoonal reefs (sites 10 and 11)

Two banks located in the central part of the lagoon associated with small islands were examined. The top of the banks, at 5 m depth contain coral patches separated by sand patches, with a dense fringe of Porites carpeting the edge. At the inner site (Al ISHSH, site 10) both the top and fringes were mostly dead, and remaining corals exhibited a high amount of recent mortality and active diseases. The second site, similar in morphology, was flourishing. It had dense patches of living columnar *Porites* colonies and large colonies of *Acropora pharaonis* and other acroporids. The site had 20-40% cover, although extensive patches of recent mortality were noted. This site was being impacted by an outbreak of COTs sea stars.

4.48 Northern lagoonal reefs (site 12, 13 and 18)

Site 12 was located near Al Rumah Island, on the inside of the bank within a protected embayment. The bank has a narrow coral fringe primarily of *Porites*, with most colonies displaying extensive patches of tissue denuded skeleton. Other dominant corals included *Pavona* and *Millepora*. The lagoon floor is deep mud (>1m sediment depth), and visibility was poor; a dense turf covered much of the hard substrate and dead areas on corals and this trapped considerable sediment.

Site 13 was located on the inside margin of a bank near Ghawar. The base of the bank, at 10 m depth, was covered by *Millepora,* small acroporids, and isolated massive corals. There was a considerable amount of coral rubble. The substrate and rubble was pink due to incrustaceans of coralline algae. Shallower areas had sparse cover of live corals, with a dominance of

Pocillopora, small acroporids, *Seriatopora*, and *Millepora*. Live coral cover ranged from <5% at the base of the reef to 15-20% in the shallows.

Site 18 is another bank inside the lagoon with steep sides and a well-developed reef fringing the slopes. The reef was dominated by large Poritids, with *Millepora* on the upper fringe. At 10 m depth, there were numerous large (30-50 cm) *Stylophora* and *Diploastrea* colonies along with smaller acroporids, *Goniastrea* and *Echinopora*. Much of the *Porites* framework was dead and dead lobes were often colonized by *Xenia*. Living corals had extensive old partial mortality.

4.49 Umm Rumah barrier reef (Site 14)

Site 14 was a well-developed groove-and-spur reef. located on the barrier reef off Umm Rumah. Coral cover was very high in patches, often exceeding 50-60%, and rather sparse in others. Uncolonized patches of reef substrate had moderately high amounts of coral rubble. At 12 m and 15 m depth the framework was colonized primarily by acroporids, interspersed with small to medium (20-30 cm) diameter colonies of *Porites, Favia, Echinopora* and other massive corals. *Millepora, Pocillopora* and *Acropora* covered much of the substrate in the shallower regions.

4 .410 Umm Uruma (site 15 and 16)

Two sites were examined at the northern end of the barrier reef, southwest of Ash Shaykh Marbat Island. The bank had a dense coral fringe at 5 m depth on both the seaward side and landward side (20-30% cover) which declined precipitously with depth. The base of the reef, (10-15 m) consisted of fine sediment with isolated coral outcrops and live cover of 2-10%. On the seaward side, shallow areas had many large, completely live *Porites lutea* colonies. Interspersed between the *Porites* colonies were numerous small to medium-sized *Pocillopora, Acropora, Acanthastrea, Favia* and *Echinopora* colonies, along with larger encrusting *Pavona* and *Montipora* colonies. The leeward side had many large *Porites* colonies as well as massive *Echinopora* colonies, large colonies of *Millepora*, an abundance of *Seriatopora*, and other species. Considerable coral rubble accumulated in sediment patches between coral at 7 m depth.

4.411 Nearshore *Acropora* mounds (Site 17)

A number of shallow bank were identified close to shore within Al Wajh Lagoon. These extended from 1-2 m depth to 5-6 m depth, terminating in low-relief sand bottom seafloor with sparse cover of *Halophila* seagrass. The tops of the banks had dense *Acropora* growth, with a large number of species and also many *Anacropora* forming very large colonies. Cover within these patches ranged from 60-100%.

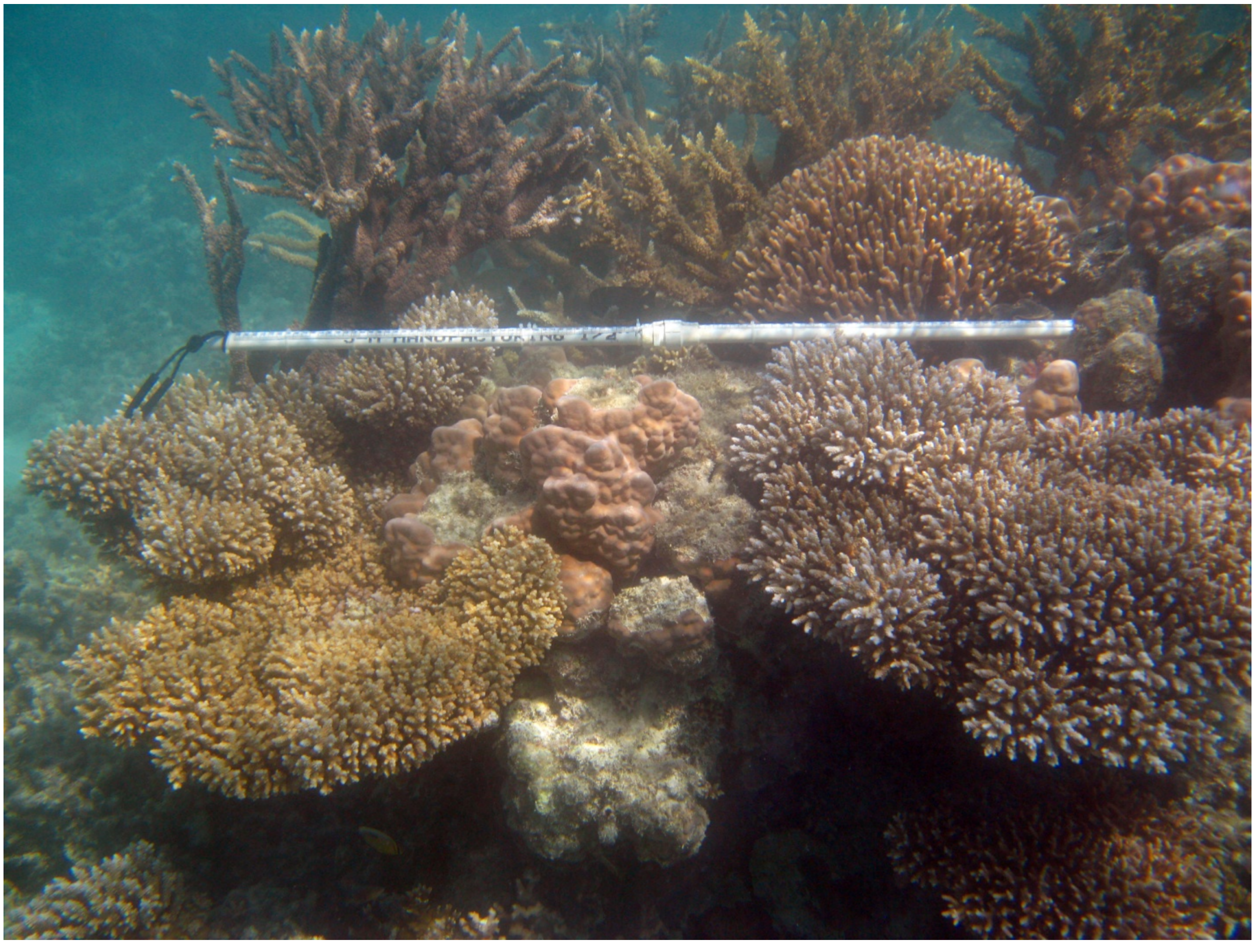


Fig. 4.411. Dramatic shallow *Acropora*-dominated reefs occur in the northern portion of the lagoon in Al Wajh Bank, relatively close to shore. These extensive habitats are found in 1-5 m depth, and are surrounded by sand and *Halophila* seagrass beds.

4.412 Site 19

Reefs located off Shib Al Judayr consist of a series of mushroom-shaped patch reefs that extend from the substrate at 15-20 m depth to 4-5 m depth, with wide channels between each patch reef. The reefs have a Porites community on their sides, consisting of large (2-5 m diameter) lobate colonies that were often largely living. These were interspersed with large plates of *Montipora*, branching acroporids and other corals. The upper edges of the reef had a dense growth of *Millepora* with occasional large patches of *Acropora*. Live coral cover ranged from 20-60%, although lower in some sites. In a few areas, the reef was carpeted in a dense growth of green macroalgae and there was evidence of damage from dynamite fishing.

4.413 Site 20 and 21

Site 20 and 21 were located furthest from shore off the southern end of the Al Wajh system. This submerged structure, called a horst, is a raised block fault which has been uplifted, while surrounding seafloor has dropped (graben). It had a relatively flat-topped reef flat with a low cover of live coral and vertical walls that drop to about 15-20 m. Below this, the slope continues at an angle of 45°, with a second vertical dropoff at about 30 m depth. A well developed coral community, with 30-60% live cover occurs at the edge of the drop off (3-5 m depth), adjacent to the reef flat. The reef edge has many big *Favia stelligera* and in some places nice tabular *Acropora* (*A. hyacinthus*) and numerous large *Porites* colonies that extend from the top down the reef slope. Small ledges and crevices along the wall also support proliferant stony coral growth, including small *Goniastrea, Seriatopora, Favia, Echinopora, Acropora, Montipora, Platygyra* and *Pocillopora* colonies.

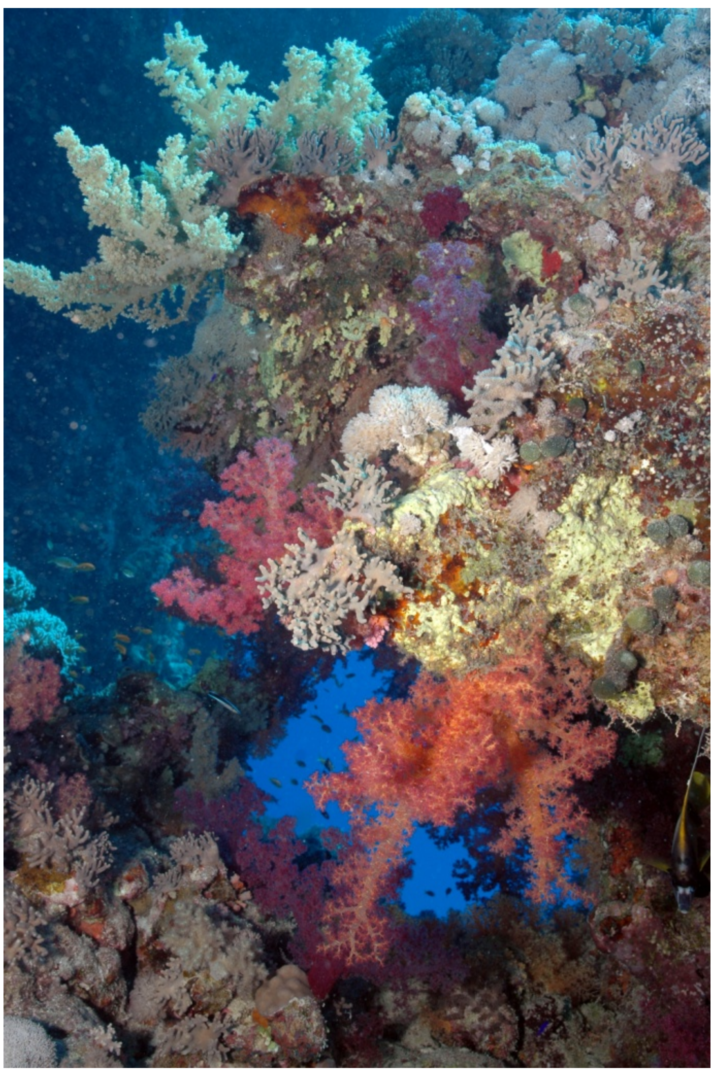


Fig. 4.413. Ledges located on the wall surrounding the offshore horst structure had extensive colonization by soft corals including *Dendronepthya.*

Much of the vertical slope is colonized by soft corals and isolated plating corals such as *Pachyseris, Echinopora, Montipora*, and *Mycedium*. Coral cover ranges from about 5% on vertical surfaces, 20-40% on ledges and in crevices, and 30-60% at the reef edge (3-5 m depth).

4.6 Fish community structure

Reef fish communities in Al Wajh were diverse, with representatives of most functional groups present in low numbers. In most locations, a low abundance and diversity of fishes was recorded, and most fish were less than 30 cm total length. The lowest diversity and abundance, and the smallest fish overall were recorded within lagoonal habitats of Al Wajh, especially in sites with low cover of live corals. Offshore sites tended to have a more diverse fish community, including groupers, snappers, jacks and large wrasses and occasional predatory sharks. However, many of the top predators and second level predators were juveniles or subadults. . Of note was the large number of juvenile and sub adult humphead wrasse recorded in Al Wajh. This is a species that has been assigned an endangered status in the IUCN Red List and is now protected through CITES due to heavy fishing pressure in support of the live reef food fish trade. Giant clams also appeared to be very abundant, although the largest individuals were generally less than 20 cm. Many small groupers and snappers were identified, but these were usually less than 30 cm in length.

Fig. 4.6a. Juvenile humphead wrasse (*Cheilinus undulatus*) at Al Wajh.

4.7 Threats and resilience indicators

Al Wajh is generally under low levels of threat from human impacts, with exception of some of the nearshore areas located off small towns and fishing villages. The main human impacts to the reef system were fishing pressure on the barrier reef, offshore sites and in the lagoon. In addition to a large number of fishing boats, fish traps were widespread within lagoonal sites, and fishing line was frequently found on barrier reef sites. At least two sites had evidence of dynamite use. Although turbidity in the lagoon and in other sites near islands was often high, this appears to be due to resuspension of fine silts and not due to run-off from land.

Fig. 4.7a. Two fishermen in Al Wajh lagoon using handlines.

Fig. 4.7b. Artisanal fishermen were often seen fishing in offshore lagoonal areas in large groups, such as the six fishing vessels seen here.

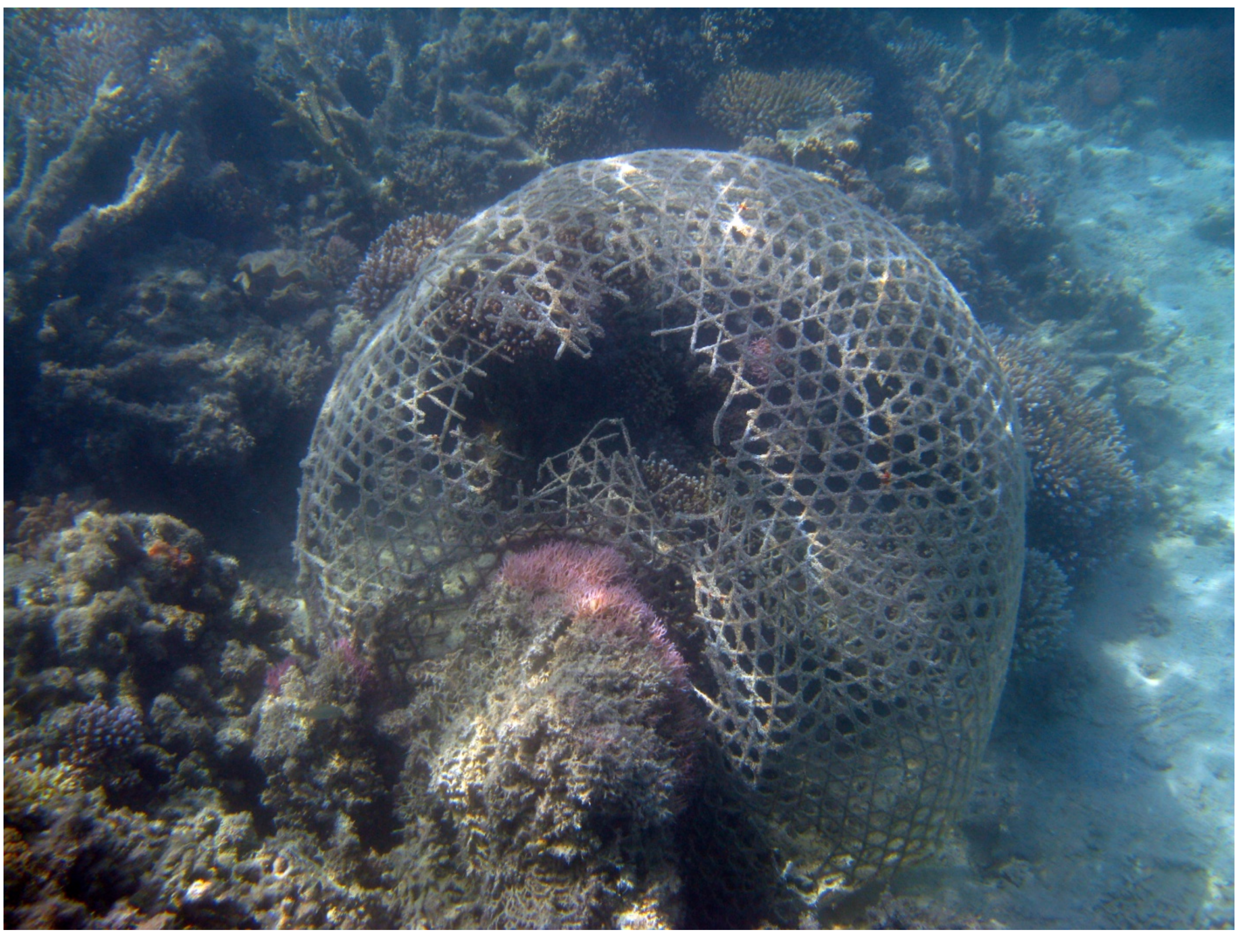


Fig. 4.8c. Numerous abandoned fish traps were identified in lagoonal reefs. While some continued to capture fish, the wire on others, such as the trap above, had degraded, allowing fish to escape. These traps still cause habitat impacts when in contact with corals.

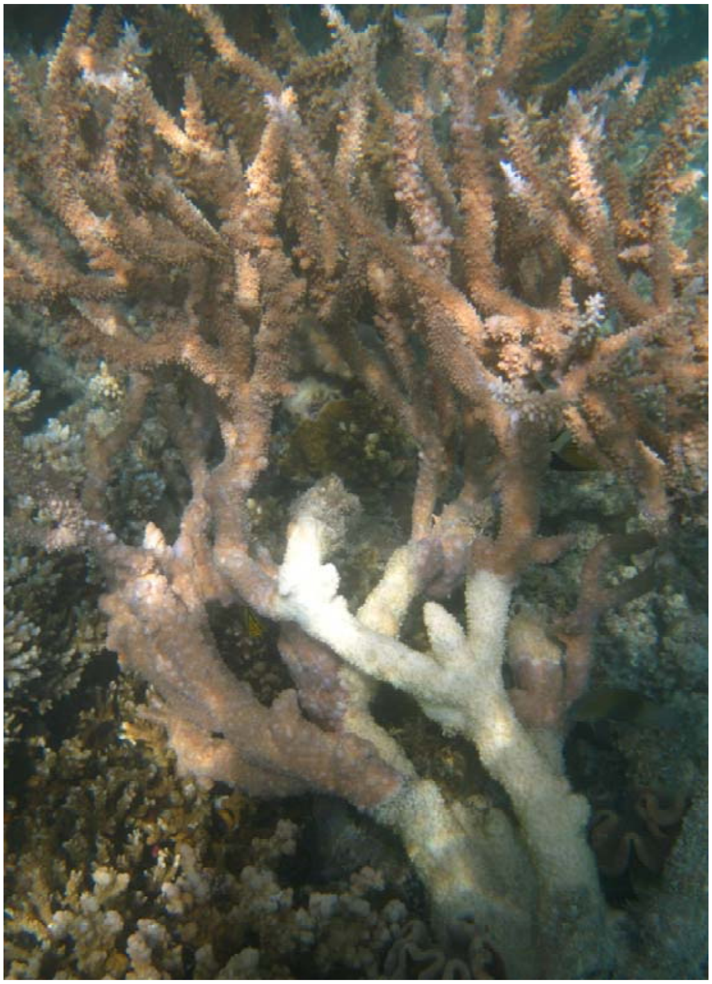


Fig. 4.7d. A white syndrome affecting *Acropora* spp. The disease is spreading from the base of the branches upward.

Biotic stressors included coral disease, coral predators, and competitive interactions with algae, cyanobacteria and invertebrates. All of the common diseases, including various white syndromes, black band disease, brown band disease, dark spots disease, pink line disease on *Porites* and growth anomalies were identified on these reefs at low levels. For instance BBD was observed at a single offshore location, where it affected *Pachyseris*. Growth anomalies were largely restricted to *Acropora* and *Pocillopora*, while white syndrome was noted on multiple taxa. White syndrome was the disease of most concern, as it was causing extensive mortality to colonies of *Pocillopora, Acropora* and *Echinopora*. In particular, an outbreak of this disease was recorded on 7% of the *Echinopora* colonies examined within lagoonal reefs of Al Wajh. *Drupella* snails were most common on *Pocillopora*, but were also recorded on branching and plating *Acropora* colonies. While isolated colonies had lost relatively large patches of tissue from these snails, they were generally fairly uncommon. COTS predation was recorded on about 30% of the reefs, although typically only one or two starfish were identified on any particular reef. The only exception was in Al Wajh lagoon. At one site, 73 crown of thorns seastars were counted within a 100 sq meter area. These were primarily consuming acroporids, but other species (except for *Porite*s, which was the dominant coral at this site) were also targets. At a second site off Qummaan Island, 21 COTs were counted and many *Echinopora* colonies had white patches associated with sea star predation affecting 10-40% of their surface.

4.71 Resilience

The initial examination of resilience indicators involved a comparison among pooled sites for Al Wajh north, Al Wajh south and Yanbu. This is presented after the summary of research findings for Yanbu. Shown below are pooled means and standard error for 1) benthic cover of hard corals, soft corals, macroalgae, turf algae, crustose coralline algae, rubble and reef slope; 2) physical parameters; 3) substrate composition; 4) cooling, shading and acclimation; 5) coral health; and 6) positive and negative coral associates. Pooled data showed only minor differences between northern and southern reefs (Fig. 4.71a).

Group	Factor	Variable	Group	Factor	Variable
Cover	Coral	Hard coral	Physical	Substrate	Topographic complexity - micro
	Coral	Soft coral			Topographic complexity - macro
	Algae	Fleshy Algae			Sediment texture
	Algae	Turf Algae			Sediment layer
	Algae	CCA		Physical	Temperature
	Substrate	Rubble			Visibility (m)
Coral population	Health	Bleaching			depth (m)
	Health	Mortality-recent		Cooling &flushing	water movement
	Health	Mortality-old			deep water (30-50m)
	Health	Recovery			reefbase depth
	Health	Disease			exposure
Coral Associates	Positive	Obligate feeders		Shade & screen	aspect
	Positive	Branching residents			slope (degrees)
	Negative	Competitors			phys. shading
	Negative	Bioeroders (urchins, nonfish)			canopy corals
	Negative	Bioeroders (internal, sponges)		Acclimatization	Exposed low tide
	Negative	Corallivores (negative impact)			Ponding/pooling

Table 4.71. Resilience indicators recorded during May 2008 reef surveys. All indicators were recorded on a scale of 1 (poor condition) to 5 (good condition).

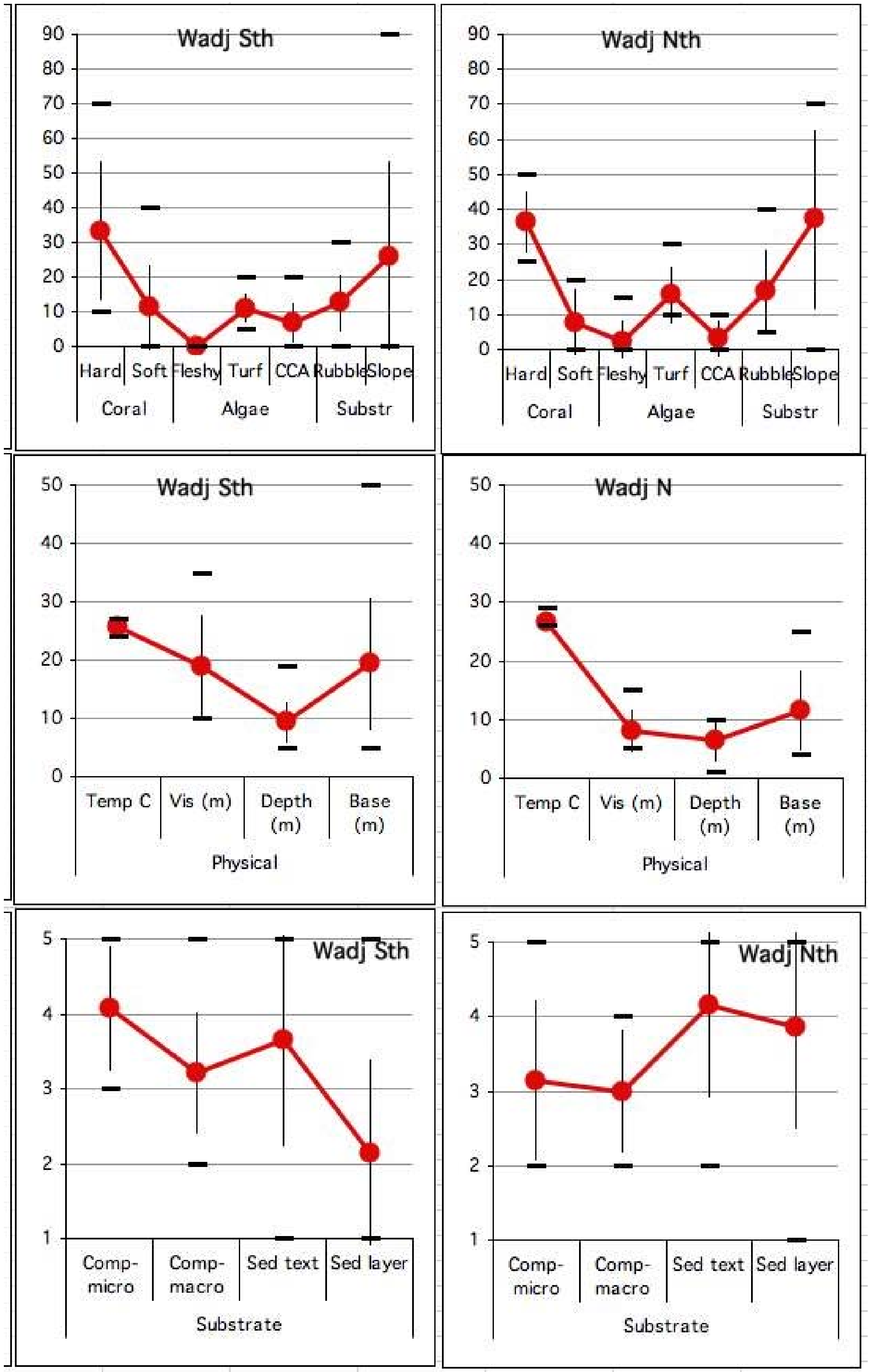


Fig. 4.71a. Comparison of resilience indicators between northern and southern sites (pooled for all sites in each region).

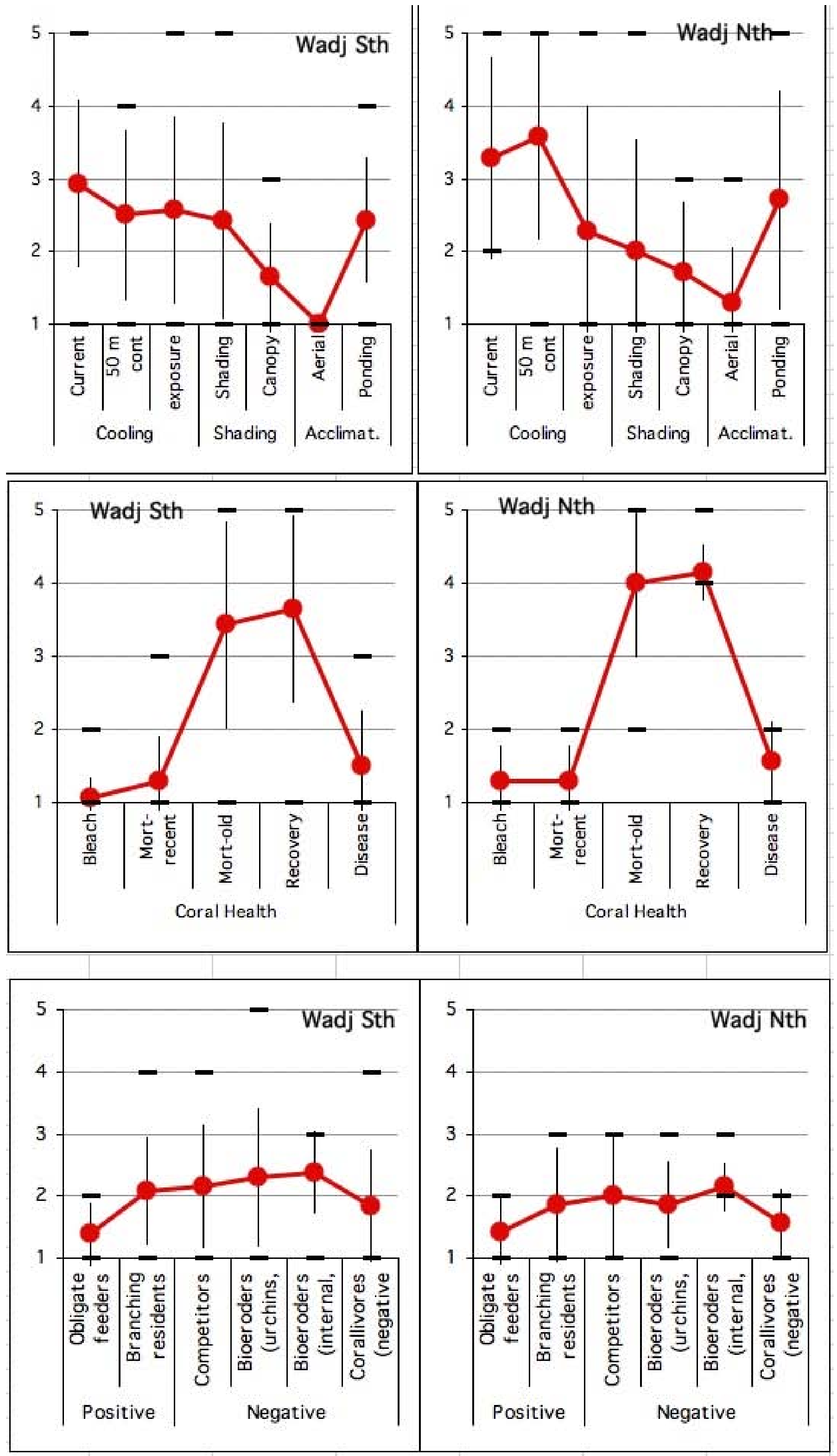


Fig. 4.71b. Comparison of resilience indicators between northern and southern sites (pooled for all sites in each region). All data are calculated from a rank of 1-5 for each site.

5 Yanbu

5.1 Background

The Yanbu region, extending from Sharm al Khawr near Ras Jarbu in the north to Masturah in the south, covers a linear distance of about 160 km. The region contains extensive shallow coastal marine habitats and a complex offshore barrier reef system. The coastline consists of alluvial sand flats and low-lying hills that extend inland for more than 10 km, with salt marshes found in several locations in the intertidal zone. Yanbu's industrial city covers approximately 15 km of the coastline, occupying an area of 158 sq km. The city contains the largest oil shipping complex in the Red Sea as well as more than 20 hydrocarbon, petrochemical and mineral facilities. Along much of the shore, to the north and south of Yanbu, are dense mangrove assemblages closest to shore, with some sand, mud and seagrass habitats. There is also a fringing reef slightly seaward of these habitats, north of the industrial area. These nearshore reef system mostly contain low densities of corals, occupying an area of approximately 5.3 sq km and dense coral assemblages over an area of about 3.3 sq km. Offshore, immediately south of Al Wajh and Umlaj, is an extensive series of submerged limestone platforms. These form a chain of small islands and reefs termed the "Little Barrier Reef". This barrier reef system begins about 2-4 km off the coastline and is separated from the mainland by a major shipping channel.

5.2 Research completed

5.21 Habitat mapping

Utilizing a spectral remote sensing approach, habitats within the Yanbu Barrier Reef System were classified from the high spatial resolution (2.4 m pixel) 'QuickBird' multispectral satellite imagery. Field effort centered on collecting the necessary data for correcting the effects associated with the attenuation of both the incident and reflected light as it passes through the atmosphere and water column prior to satellite detection, as well as training the algorithms needed to classify the different habitats; namely bathymetric, in-situ spectral, and ground truth data (Fig. 5.21a). A total of 2187 sq km of shallow marine habitat was surveyed in the Yanbu study areas. This included 204 km of bathymetric data (84,314 soundings) and 252 video drops (2.1 hours of video footage).

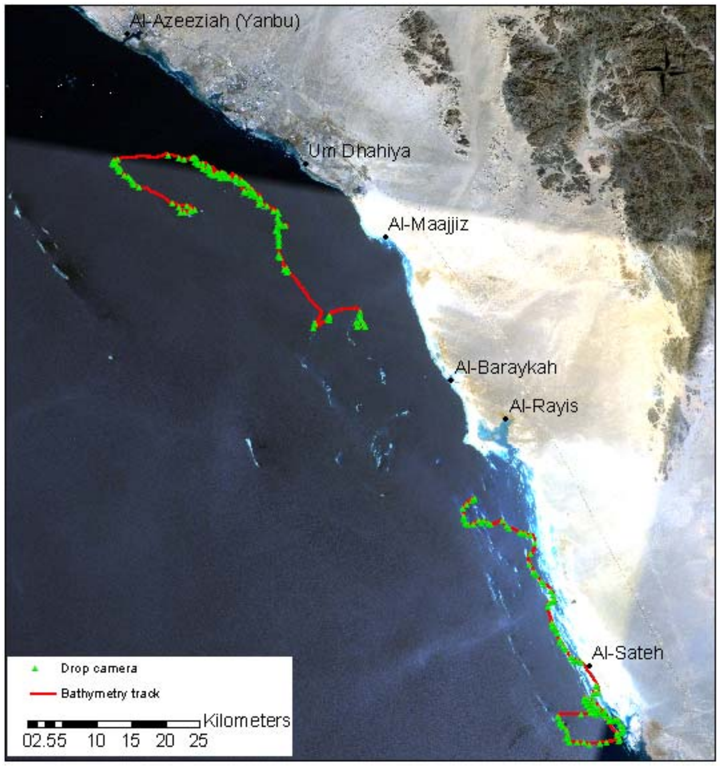


Fig. 5.21a. Drop camera positions (green triangles) and bathymetry track (red line) followed by the groundtruthing team at Yanbu.

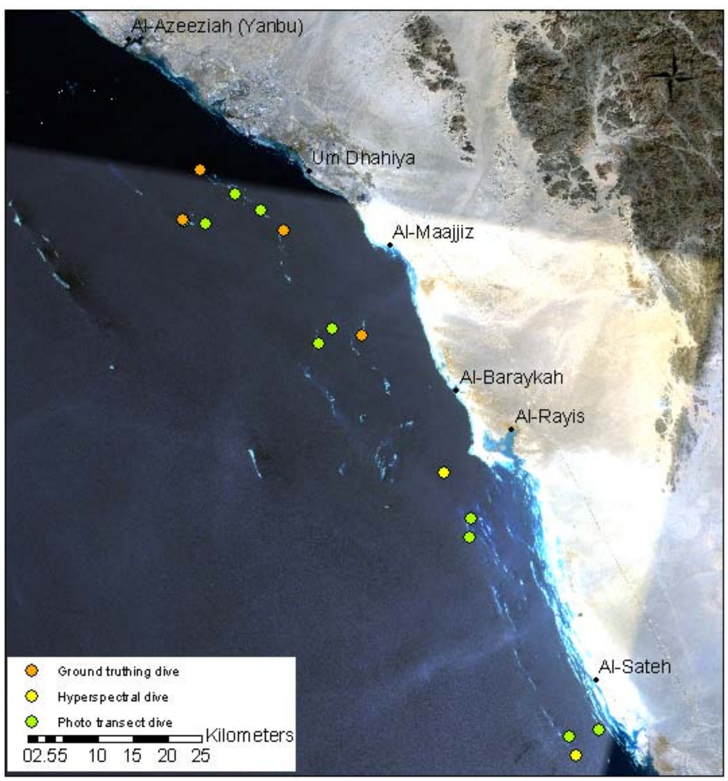


Fig 5.21b. Location of dive sites examined by the survey team at Yanbu.

5.3 General habitat attributes

A vertical profile extending from the shore to deep water at Yanbu includes extensive shallow sand sheets, carbonate hardgrounds and reef fl at close to shore, a leeward reef crest, and a columnar framework which drops into a deep channel separating nearshore habitats from the barrier reef system. The barrier reef consists of a series of discontinuous columnar reef frameworks, shallow hardground and reef flat communities, windward reef crest, dense *Acropora* thickets, and a *Porites*-dominated reef slope. In some areas the reef community surrounds emergent land.

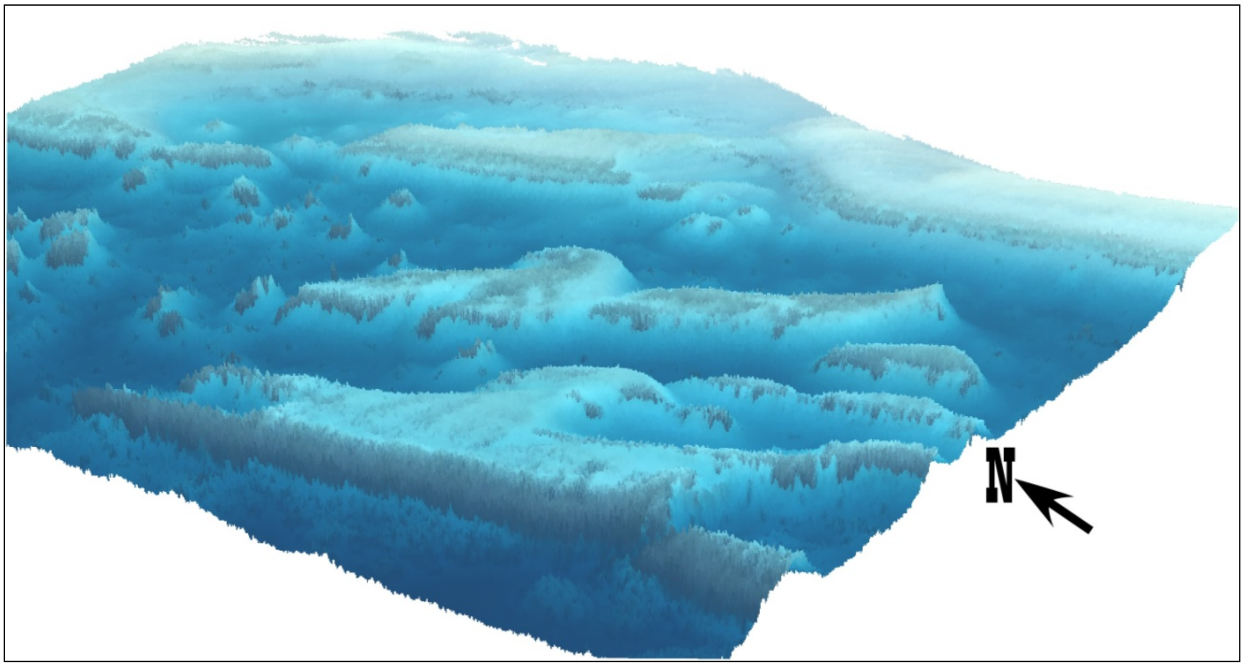


Fig 5.3a. Example of bathymetric model generated for the southern region of the Yanbu study area with QuickBird satellite imagery overlaid.

5.4 Coral community structure

The team completed a five day examination of coral reefs found off Yanbu, focusing on the reef habitats located seaward of the major shipping channel within the “Little Barrier Reef” system. A total of 11 locations were examined using SCUBA (Fig. 5.4a, Table 5.4). The main objectives of this work were to map and characterize the marine habitats, and assess the structure, composition and health of associated coral reefs.

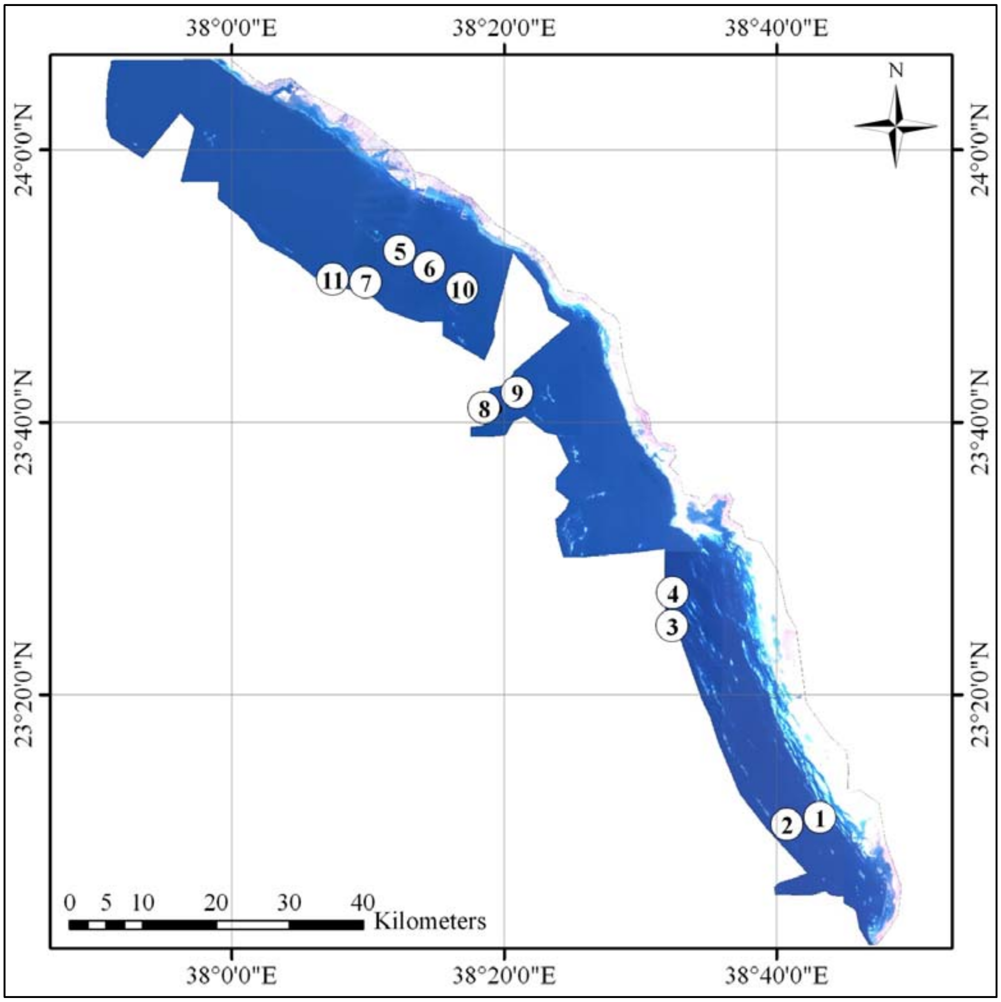


Fig. 5.4a. Locations of SCUBA assessments to characterize corals, fish and resilience.

Site #	Latitude, N	Longitude, E	Date	Location
1	23.181700	38.720340	5/7/2008	Yanbu
2	23.173280	38.679780	5/7/2008	Yanbu
3	23.431130	38.539210	5/8/2008	Yanbu
4	23.454900	38.539890	5/8/2008	Yanbu
5	23.875423	38.205989	5/9/2008	Yanbu
6	23.855330	38.241910	5/9/2008	Yanbu
7	23.836960	38.164420	5/9/2008	Yanbu
8	23.682880	38.324170	5/10/2008	Yanbu
9	23.701890	38.344370	5/10/2008	Yanbu
10	23.829240	38.274140	5/10/2008	Yanbu
11	23.840210	38.132580	5/11/2008	Yanbu

Table 5.4. Coordinates of SCUBA assessments on Yanbu Barrier Reef.

5.41. Coral assessments

In most locations examined during the study, the distribution of corals was extremely patchy and most colonies were of a small colony size (20 cm or less in diameter), while corals from 11-80 cm made up most of the benthic coverage. There was also an almost negligible contribution of the largest corals (>3.2 m), and only approx. 5% contribution by area of 0.8-1.6 and 1.6-3.2 m corals. The presence of a large number of small corals, as well as high levels of old mortality on many of the larger framework corals suggests there has been one or more major regional disturbances that has affected these sites. The largest corals identified at the site included tabular acroporids (e.g., *A. cytherea* and *A. clathrata*) found on some offshore, exposed reefs off Yanbu; large colonies of *Porites lutea* occurred in exposed areas, especially around channels, *Lobophyllia hemprichii*, and *Favia stelligera*.

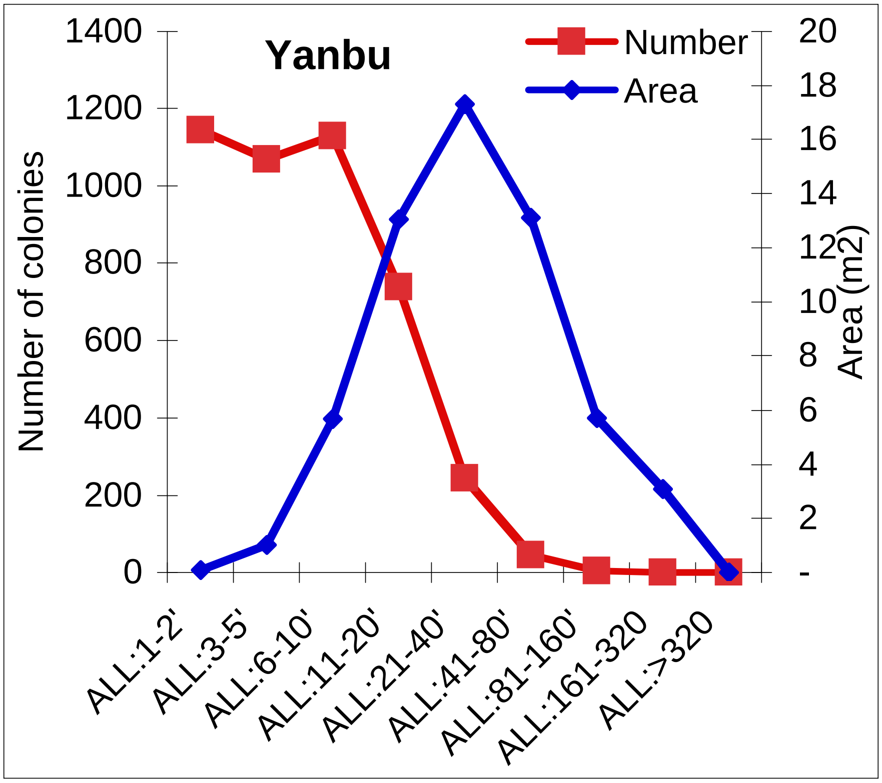


Fig. 5.41. Size structure of corals assessed on Yanbu reefs. The number of colonies and the total area (sq m) of the reef occupied by corals within nine size classes are shown for pooled coral species on all reefs examined. The size classes represent the maximum diameter in cm.

5.42 Southern reefs (site 1 and 2)

The southern reefs are typical large patch reef communities with a framework slope ending at about 12m. The reef slope has moderately high cover (20-40%) with a dominance of large massive corals (30-80 cm) such as *Favia stelligera, Platygyra, Echinopora* and *Goniastrea*, large crustose *Montipora* colonies, and medium-sized (20-40 cm) tabular and digitate acroporids. From 12 m to 20 m depth, the reef consists of a low relief (20-40 cm height) dead *Synaraea* framework separated by large sand patches. Small corals in the genus *Goniastrea, Acropora, Galaxea, Stylophora, Echinopora, Favia, Astreopora* and other species have colonized the framework. Cover is approximately 10% on the framework. Soft bottom areas are fine sands and occasional rubble patches.

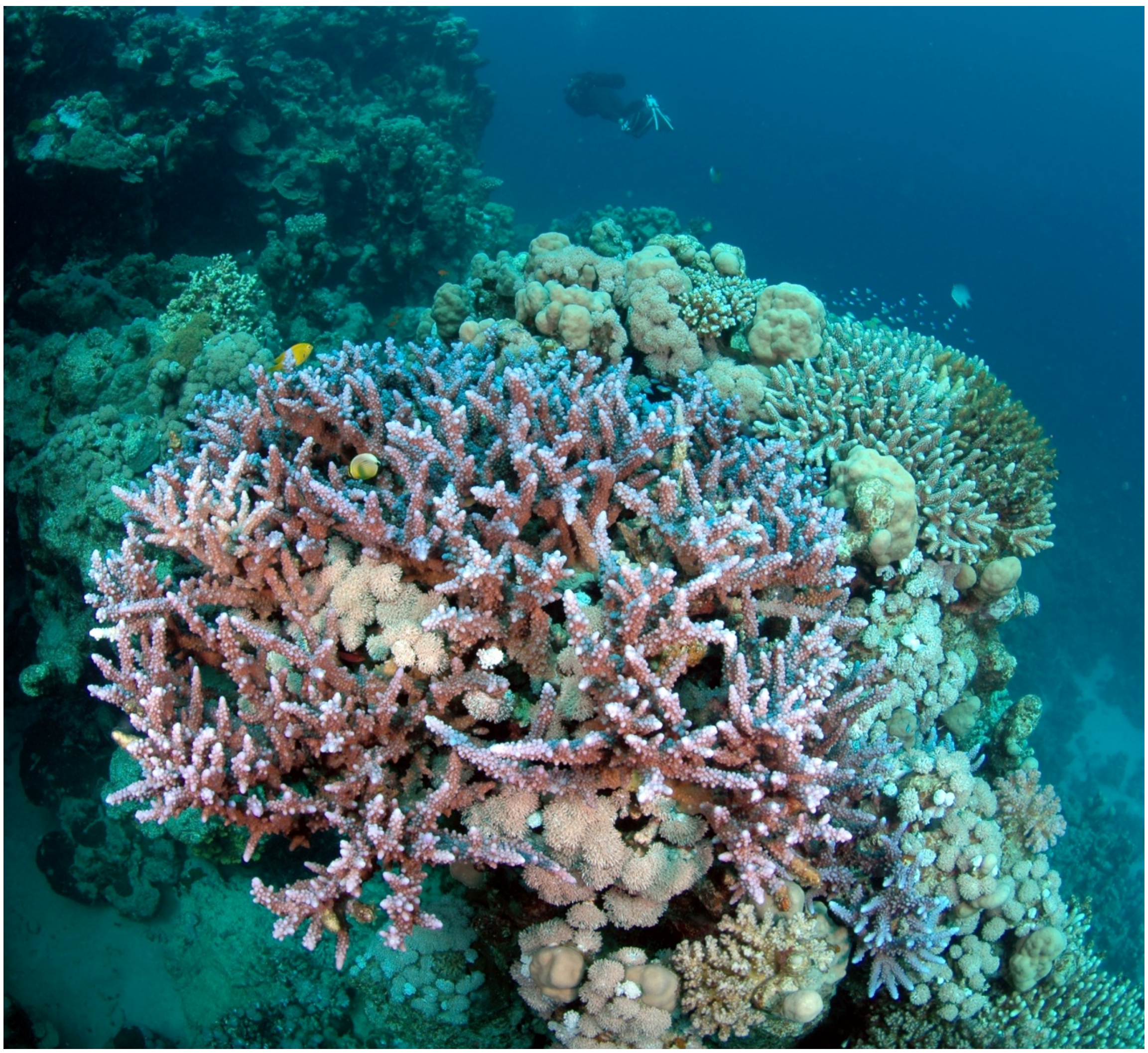


Fig. 5.42. *Acropora*-dominated community on the reef slope of a southern reef.

5.43 Central reefs (site 3 and 4)

Site 3 was a diverse reef community located on the outer, northern corner of an extensive dune field (=erg). The reef had a steeply sloping forereef that met, at about 15m a steep reef-slope. The reef slope was constructed by tall turrets, several formed as patch reefs in front of the reef slope. The slope had very high coral cover, often exceeding 60-80%. Throughout the slope were numerous surviving large (1-3 m diameter) massive *Porites lutea* colonies, dense thickets of *Acropora* with a branching and tabular growth form, and massive (1-2 m) *Echinopora* and *Diploastrea* colonies. At 20 m depth, coral still flourished (cover >30%), with a diverse assemblage of genera, including large *Montipora* colonies, *Pocillopora, Goniastrea, Echinopora, Pavona, Stylophora, Favia, Favites* and large (> 1m diameter) *Acropora* colonies.

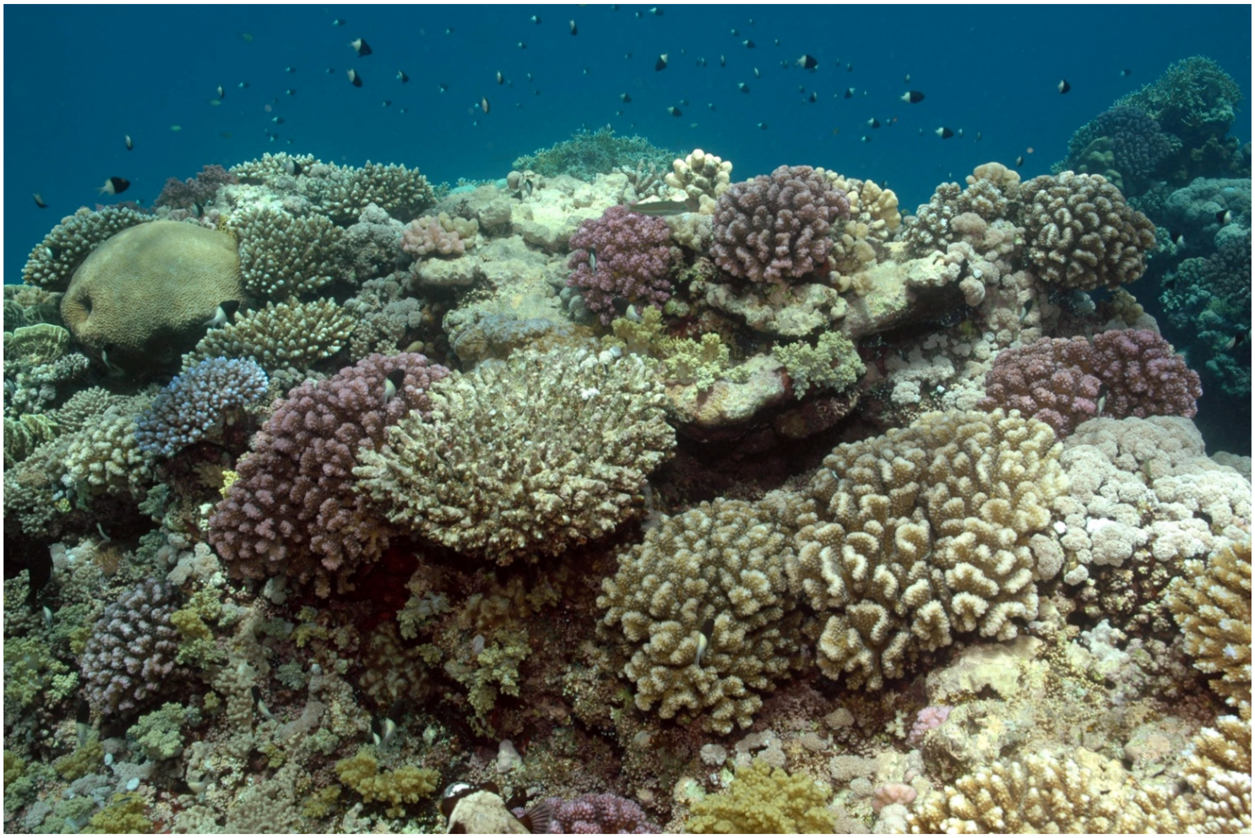


Fig. 5.43. In central reefs, shallow reef areas that experienced past mortality events were often colonized extensively by *Pocillopora* and small acroporids.

Site 4 appears to have been impacted by a past mortality event, as the dead framework was colonized by many species of massive, plating and branching corals that had subsequently died. While many smaller corals existed (10-20 cm), much of the hard substrate was colonized by *Xenia*. Live coral cover was 5-10%.

5.44 North central reefs (site 8 and 9)

Site 8 was another offshore Erg, located on the more landward, moderately protected side of the reef structure. It had a fairly steep reef slope of about 45°. At ~20m depth, the base of the reef slope had broken off and slid onto the steeply sloping forereef below. A deep cleft existed between the reef and the broken piece of the reef slope. Numerous unusually large *Acropora pharaonis* colonies had colonized the reef slope. In the shallows, at the reef edge and upper slope, large (2-3 m diameter) completely live *Porites lutea* colonies were dominant. On the reef edge proper, a former *A. hyacinthus* zone was completely dead and not yet replaced. Strong *Pocillopora* recruitment was seen on the upper slope in areas where *Porites* colonies had died.

Fig. 5.44. A shallow reef community at site 8 with a large *Porites lutea* in the background.

Site 9 was located in the lee of an Erg adjacent to a large lagoon. The upper reef slope was colonized by large branching *Millepora* colonies and some tabular *Acropora*. The reef sloped to about 5 m depth, ending in a sandy area with large live *Porites* colonies that often exceeded 3-4 m diameter. Beyond the sandy area, the reef sloped gradually to deep water into a former *Porites* carpet with high relief, but mostly dead. The reef appears to be regenerating but many diseases were observed, including white syndrome and black band disease.

5.45. Northern inner reefs (site 5, 6 and 10)

Site 5 was an outer (seaward) slope of an Erg that had low cover in the deeper areas (5-10% cover) but with a rich Pocillopora zone (50-100% cover). Site 6 was a deeper bommie that began 5m below the water's surface. It was surrounded by a *Porites* carpet with several very large (~5m diameter) living *Porites lutea* colonies. Numerous remnants of *Porites* were present throughout the area, and a high number of recruits and juveniles were present. Site 10 was located on the leeward side of a small Gota. The reef consisted of a former *Synaraea* carpet that was mostly dead. In the shallow areas, from 1-5 m depth, a very dense *Pocillopora* community and numerous bushy *Acropora* colonies occurred.

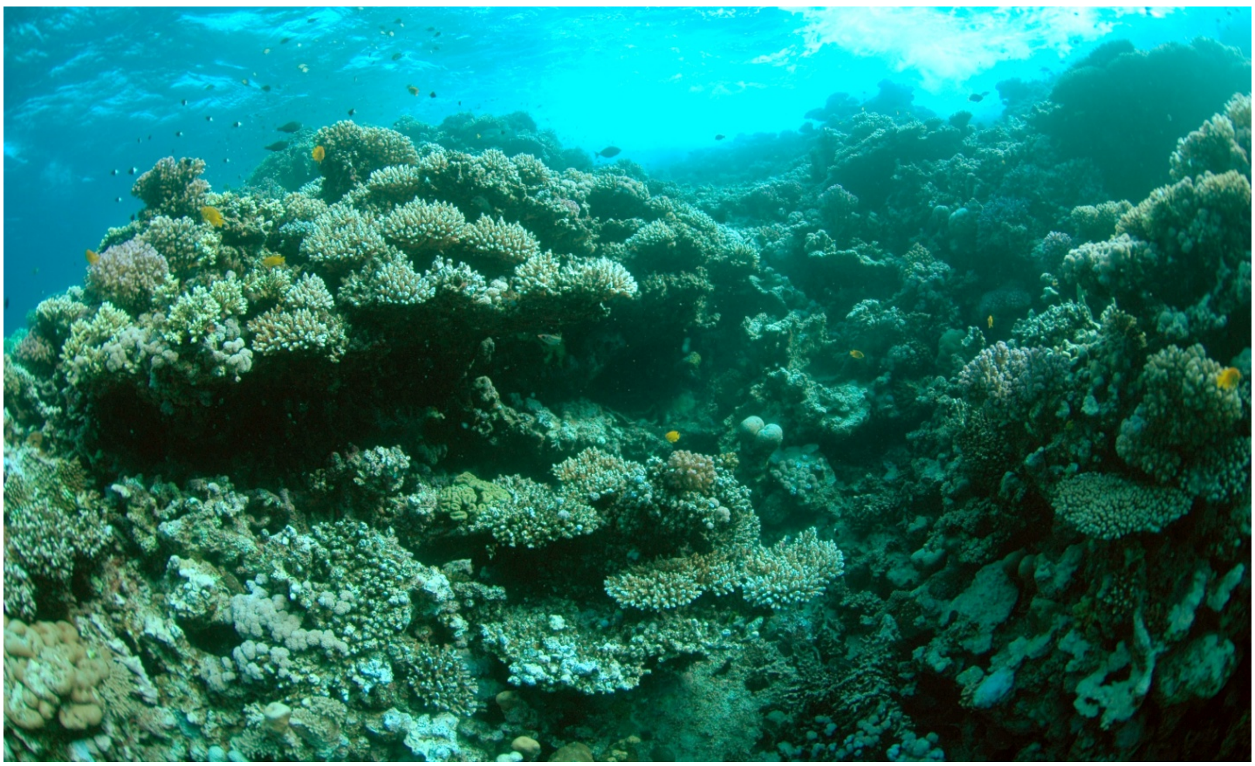


Fig. 5.45. While deeper areas of site 10 were largely dead, the reef structure from 1-5 m depth had high cover consisting predominantly of small *Pocillopora* and *Acropora* colonies.

5.46 Northern outer reefs (site 7 and 11)

Site 7 was a small, offshore patch reef with high relief and high live coral cover. Throughout the reef were large (4-5 m diameter, maximum 15 m diameter) *Porites* colonies, mostly live, particularly in shallow water. There was also a tabular *Acropora* zone with many large, fully live colonies. The deeper community was in poor condition, consisting of a *Porites* carpet with few live tissue remnants and minimal regeneration.

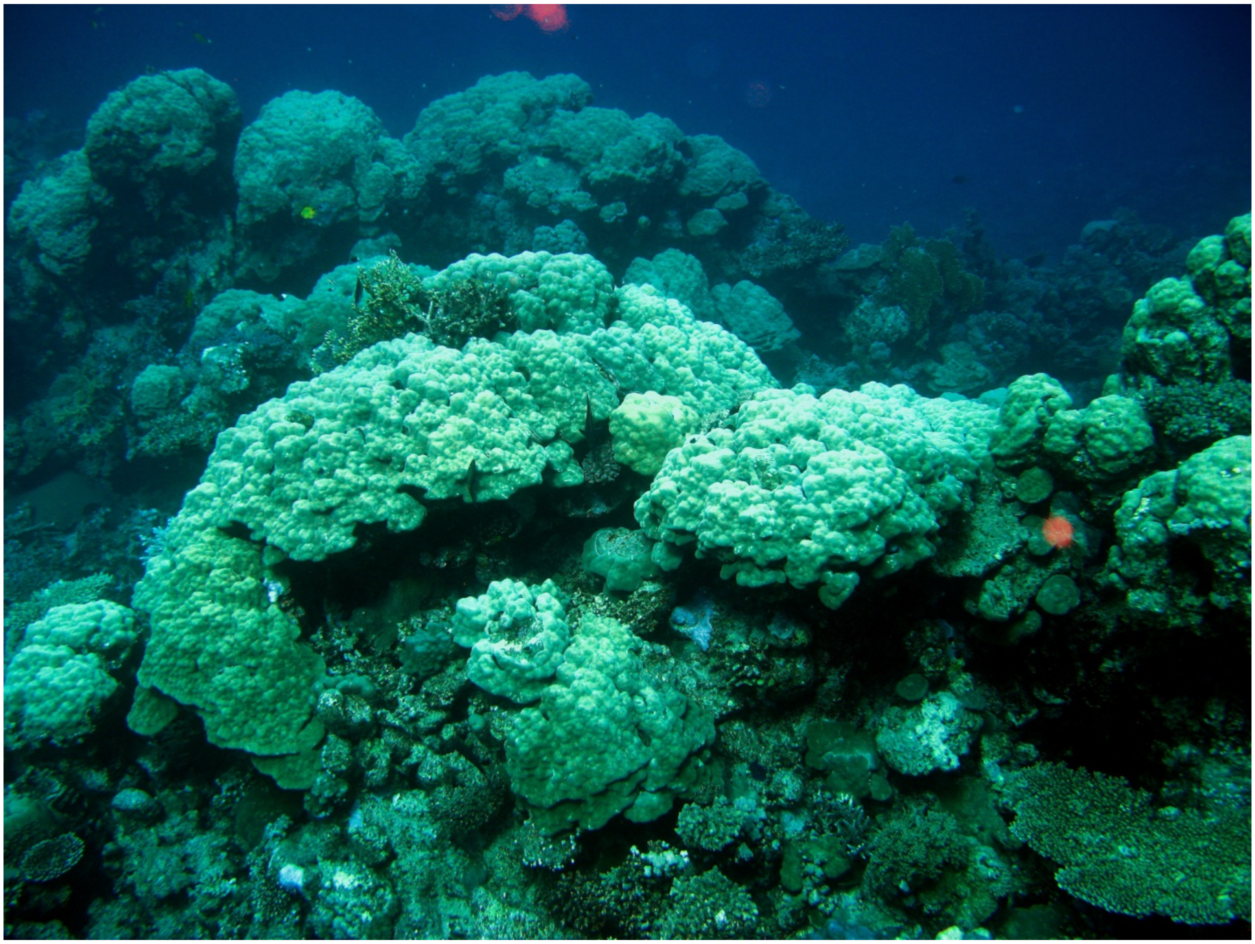


Fig 5.46a. Unusually large, mostly live *Porites lutea* colonies occurred on the offshore northern reefs.

Site 11 was far offshore, adjacent to the beacon located in the reef crest. This is an offshore Gota with very gently sloping reef slope and a diverse coral community. The reef exhibited high rugosity, built largely by Porites colonies. Most shallow-water *Porites* were completely live. Through shallow water (3-6 m depth) were large stands of *A. hyacinthus, A. clathrata*, and *A. austere*, many of over 10 m diameter. These were intermixed with many other species of *Acropora*. While most corals were in excellent condition, signs of disease were noted among the *Pocillopora* colonies and *Acropora* colonies, with several cases of white syndrome and brown band disease.

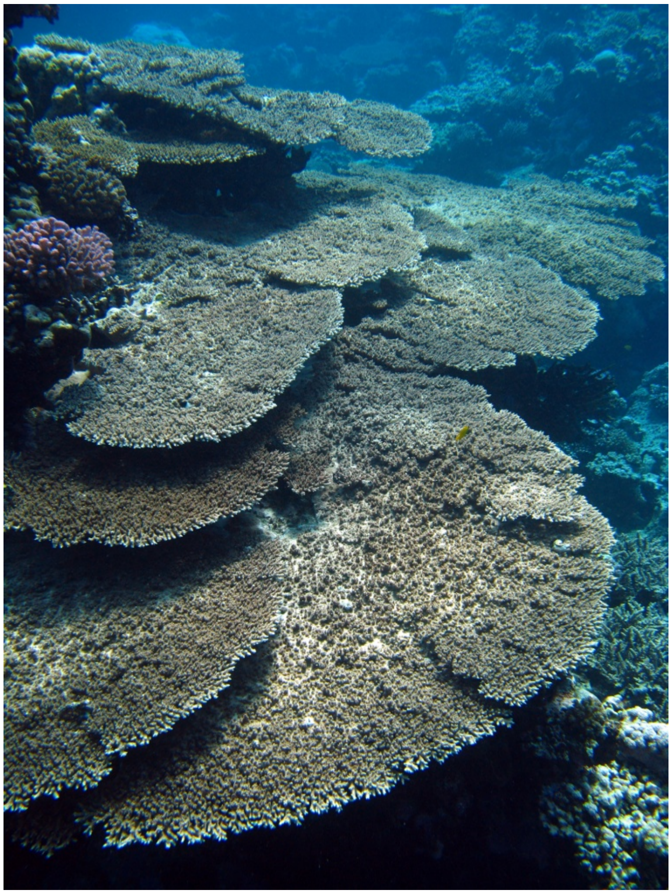


Fig. 5.46b. Dramatic stands of table and branching growth forms of *Acropora* occurred on offshore reefs in northern Yanbu.

5.5 Fish

Reef fish communities were diverse and most functional groups were represented. Slightly larger populations of grouper and snapper were noted, as compared to Al Wajh. Sharks were rare. Fishing pressure appears to be greatly reduced, possibly due to a prohibition of fishing near the major shipping channel.

5.6 Threats and resilience indicators

Anthropogenic stressors affecting Yanbu's shallow marine habitats are likely to be greatest for the nearshore sites, due to the presence of a large industrial city, the power, seawater and freshwater facilities associated with the desalinization plant, and the petrochemical companies. Perhaps the greatest threat to offshore reefs are from large vessels, including the potential for oil and chemical spills, anchor damage, and ship groundings, as the reef system is located adjacent to a major shipping channel. Fishing pressure appears to be minimal throughout the barrier reef system. Minor impacts may also be associated with recreational SCUBA diving operations, including anchoring and discharge of polluted water from a live-aboard dive vessel that operates on these reefs.

There were few natural stressors observed during these surveys. While several different coral diseases were recorded and predation by *Drupella* (gastropods) was relatively common among acroporids and pocilloporids, the total amount of mortality from these factors was minimal in 2008. Recent mortality from disease was observed on four genera, *Porites, Pocillopora, Acropora* and *Echinopora*, but <1% of the colonies were affected. COTs sea stars were identified in low numbers on two reefs. Boring sponges were not recorded and competitive interactions among algae, cyanobacteria and other invertebrates were rare.

5.61 Resilience assessment

Natural stressors have caused mass mortalities to coral communities in the past. These reefs have been affected in the past by thermal stress during past El Niño events and climate perturbations, especially during 1998-1999 and 2005. Many locations show signs of extensive die-offs of corals, including the *Porites* framework and corals that subsequently settled on the dead *Porites* skeletons. While bleaching-associated mortality is reported to be have killed a lot of coral in 1998-1999, other factors may have played a role in more recent disturbances. The variation in size structure of live corals between reefs and the patchy distribution of intact dead corals suggest that these reefs may have been affected by diseases, predator outbreaks and other factors as well. Many offshore reefs are dominated by unusually large colonies of *Porite*s and *Acropora*. In contrast, inner reefs tend to have fewer large corals, most of which are found in very shallow water. Inner reefs also have a high abundance of small faviids and small colonies of other species on inner reefs. These differences suggest that mortality events were not associated with bleaching, but rather may be due to outbreaks of crown of thorns (COTs) sea stars.

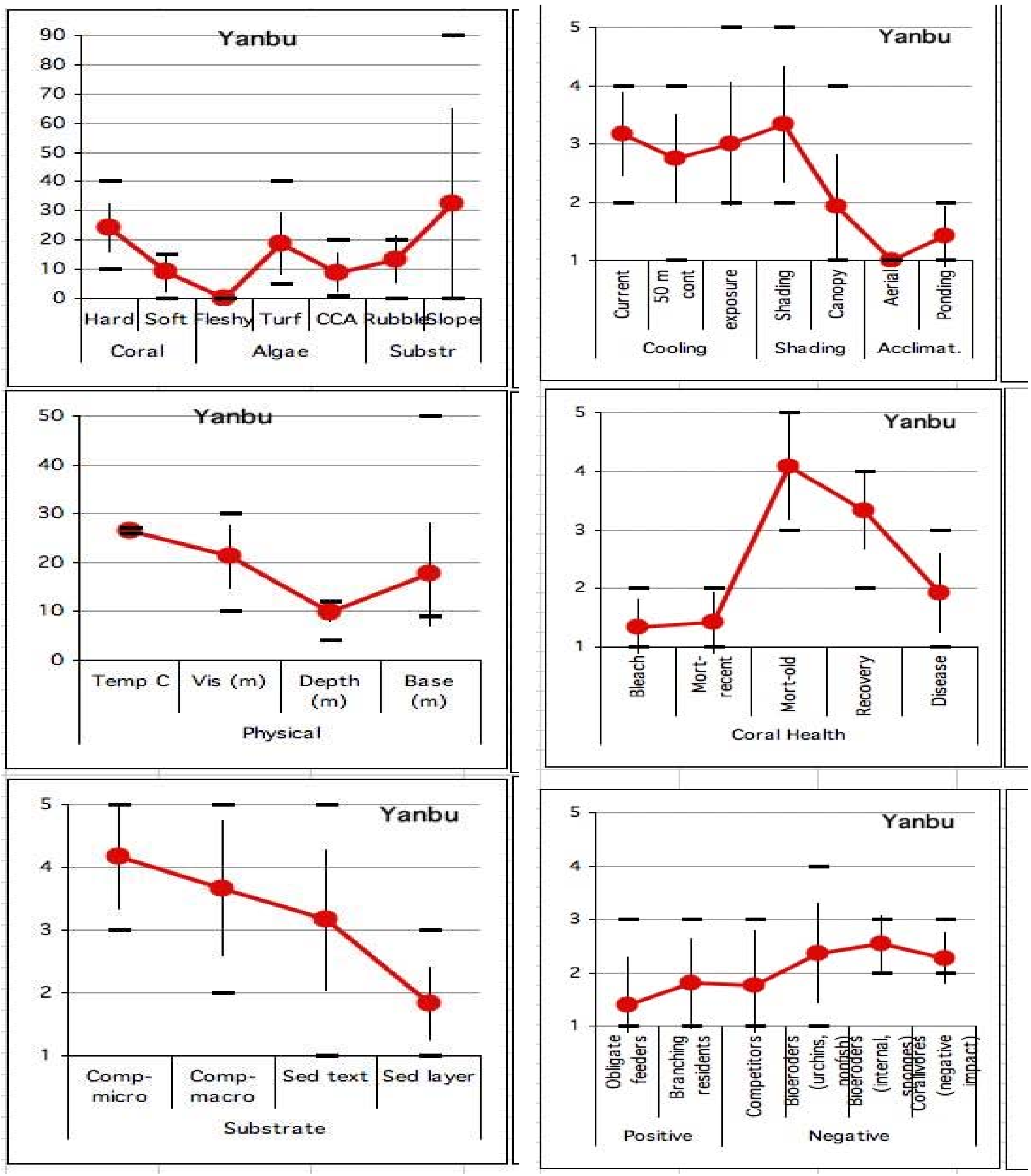


Fig. 5.6a. Mean values and standard error for resilience indicators (pooled for all sites in Yanbu). Estimates of percent cover of coral, algae and substrate type and ranked data for physical parameter, coral health, substrate condition, and indicator organisms are shown.

6. Comparison of coral structure among Yanbu and Al Wajh reef systems

6.1 Coral composition

Using IUCN data collected by David Obura, comparisons of size structure of corals were made between Yanbu and two regions of Al Wajh. Twenty coral genera were included in the size class surveys, including *Acropora*, *Acanthastrea*, *Astreopora*, *Coscinaraea*, *Echinopora*, *Favia*, *Favites*, *Fungia*, *Galaxea*, *Goniastrea*, *Hydnophora*, *Leptastrea*, *Lobophyllia*, *Montipora*, *Pavona*, *Platygyra*, *Pocillopora*, *Porites* (split among massive and branching forms), *Seriatopora* and *Stylophora*. Among these genera, the number of colonies and area covered by each genus confirmed the high dominance by *Porites*, particularly in number of colonies, due to the abundance of small colonies of *P. columnaris* and *P. rus*. Next in abundance by area was *Acropora* then *Montipora*, but in number of colonies was *Montipora* then *Goniastrea*.

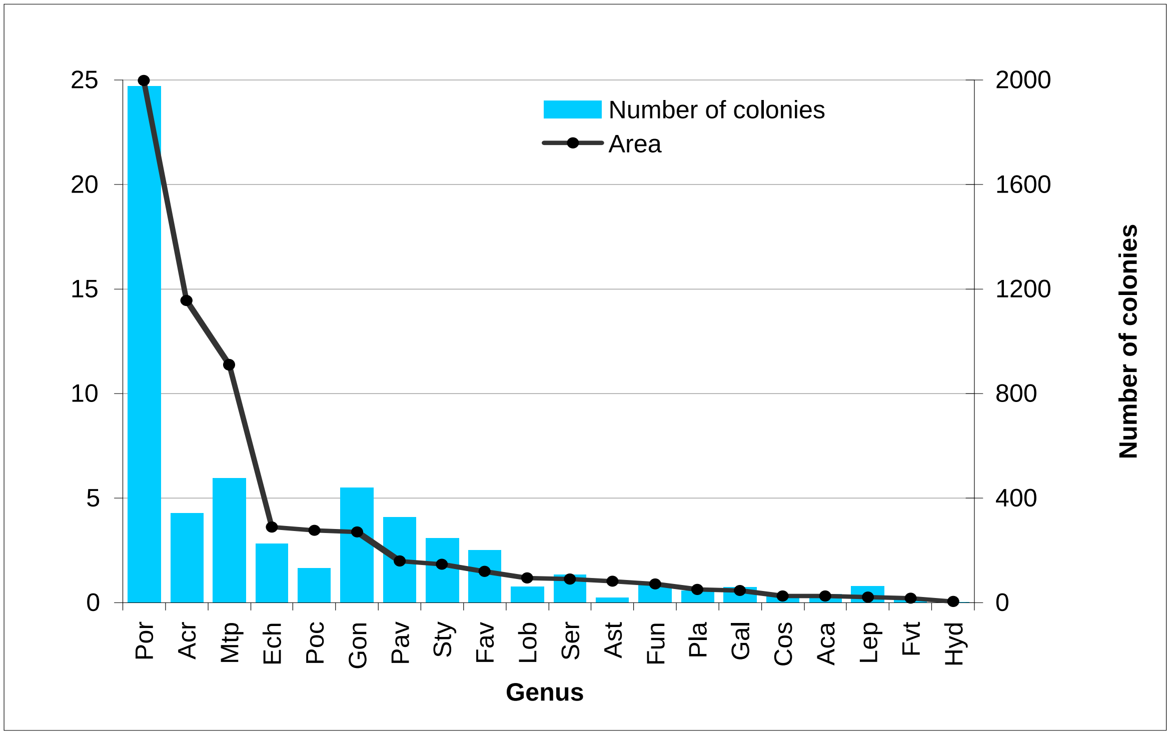


Fig. 6a Total number of colonies (blue bars) and area occupied by the 20 genera examined. Size class distributions of coral colonies for all genera at all sites, by number (left axis, blue line) and area (right axis, red line) of colonies per 100m^2.

The coral community was dominated by *Porites* at Yanbu and Al Wajh, followed by *Acropora* in second place. At this point the coral communities differed in relative abundance, with *Millepora* and *Montipora* next most abundant at Al Wajh, but *Goniastrea*, *Favia* and *Pocillopora* next most abundant at Yanbu. Overall however, there was a great deal of similarity between the two regions.

6.2. Size structure of corals

The region was overwhelmingly dominated by 21-40 cm corals, with almost negligible contribution of the largest corals (>3.2 m), and only approx. 5% contribution by area of 0.8-1.6 and 1.6-3.2 m corals. Comparing the regions, Yanbu had the lowest number of colonies across size classes, and particularly in large sizes, while Al Wajh had a larger area contributed by large colonies > 80 cm. Within the Wajh region, the southern area showed larger numbers of small colonies and medium size colonies, but both areas had similar populations of large colonies.

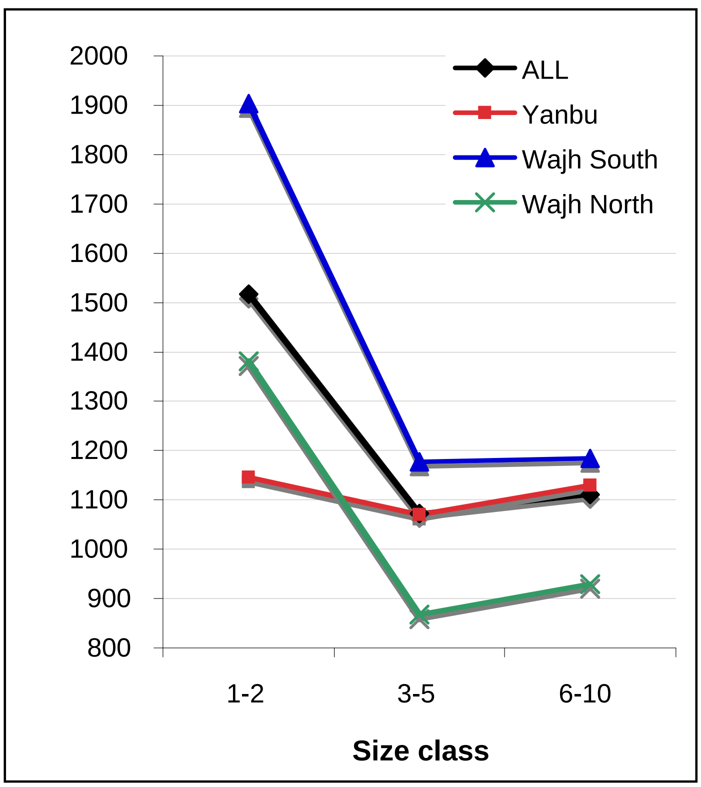


Fig. 6.2a. Abundance of corals (pooled species) in the three smallest size classes for Al wajh south (blue) Al Wajh north (green), Yanbu (red) and all sites pooled (black).

Looking more closely at small colonies (total number within 1-2, 3-5 and 6-10 cm size classes per 100 m^2 area of reef) abundances were highest in the south Wajh bank, with highest number of colonies in all small size classes. The consistent number of colonies in 3-5 and 6-10 cm sizes may be related to partial mortality from larger sizes into the 6-10 cm class, and/or the predominance of coral species that seem to stay in the small size classes – including *Porites columnaris, P. rus, Stylophora wellsi, S. mamillata* and various *Montipora spp*.

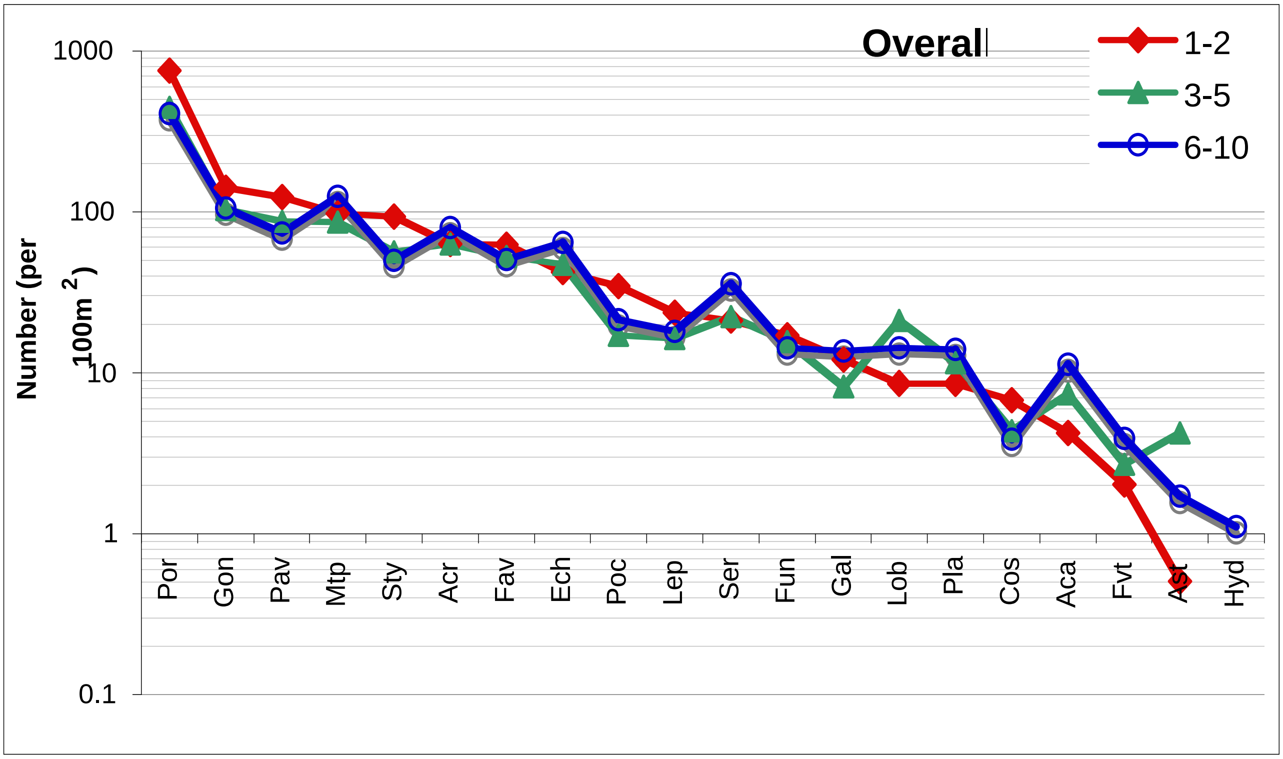


Fig. 6.2b. Abundance (numbers per 100 sq m) of corals in each of the three smallest size classes for each of the dominant 20 genera. Among small corals, the region was strongly dominated by *Porites*, followed by *Goniastrea* and *Pavona*.

Only 3 genera, *Porites* and *Acropora* and had significant area of colonies > 40 cm, while *Montipora* also had a reasonable area of colonies in the 21-40 cm size class. Even so, the size class distribution for all corals essentially reflects that for *Porites*. The abundance of small colonies was very high, particularly for *Porites*, *Goniastrea* and the stress-susceptible but rapid colonizers in the top graphs – *Acropora*, *Pocillopora*, *Stylophora*, *Seriatopora* and *Montipora*. The high abundance of small colonies of Porites probably reflects survival of tissue remnants from larger colonies, and not newly recruiting corals. On the contrary, high numbers of small *Acropora*, *Pocillopora*, *Stylophora*, *Seriatopora* and *Montipora* reflect juveniles that survived recent recruitment events.

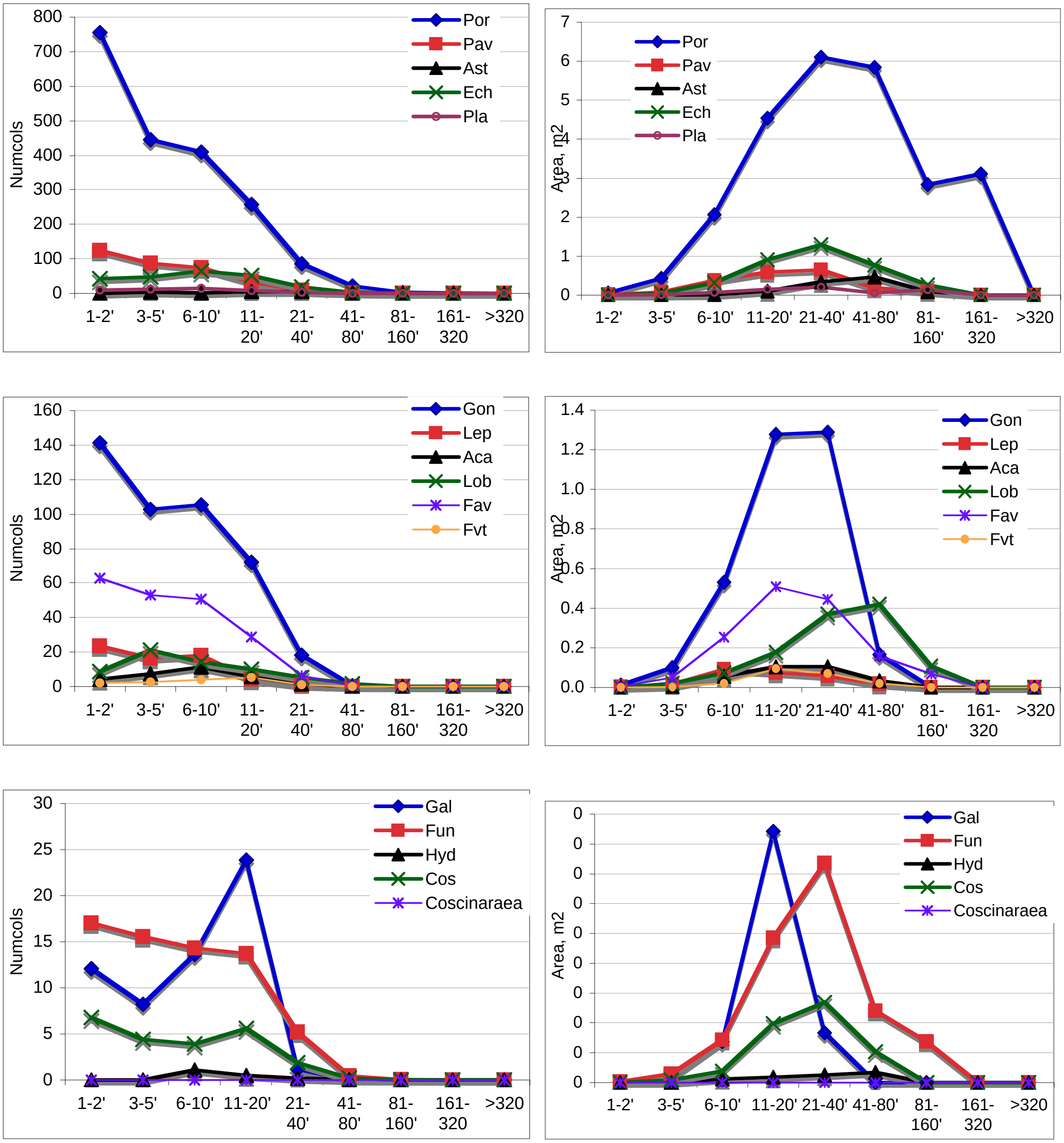


Fig. 6.2d. Comparison of the abundance of the 20 dominant genera for each of the 9 size classes. Figures on the left are for Yanbu and the right are Al Wajh. All corals are pooled from all sites in each region.

Coral reefs within both Yanbu and Al Wajh reef systems showed signs of high resilience at regional scales, although differences occurred among sites. In both regions a large scale die-off of corals, estimated to have occurred 10 years prior to these surveys, was apparent at many but not all sites. In most locations, especially deeper frameworks, the dominant framebuilder had died, or experienced partial mortality. New corals had colonized *Porites* skeletons in the intervening period, but many of these had also died in some locations. These mortality events could be attributed to temperature stress and bleaching-related mortality in some but not all cases. In particular, when mortality was prominent in shallow water or throughout all depths, and bleaching susceptible species were most affected, temperature is the likely culprit. However, there were reefs, especially in Yanbu, where mortality of the large, older Porites and Acropora colonies occurred predominantly on inshore reefs in deeper areas, while the large colonies of these species in shallow water had survived. Furthermore, in the clear, offshore locations no mortality was apparent. This is the opposite of what would be expected from bleaching, and is hypothesized to be the result of COTs outbreaks.

At the opposite end of the spectrum, some lagoonal reefs in Al Wajh suffered extensive mortality through all depths, while nearby reefs experienced little mortality. Several of the reefs in the best shape are located near a channel connecting the lagoon to the Red Sea. It is likely that these reefs receive more flushing, which help maintain cooler temperatures. These locations are likely to be the more resilient to temperature stress than other sites within the lagoon.

At a regional level, coral cover was higher in Al Wajh bank than at Yanbu, and algal turf higher at Yanbu and Wajh north. In both locations, macroalgae was generally low, while crustose coralline algae were much more abundant on offshore reefs in both Yanbu and Wajh, and little CCA was apparent within Al Wajh Lagoon. In both locations, moderate levels of regeneration were occurring, as evidenced by high numbers of recruits, although many of the smallest corals (1-2 cm) do not appear to be surviving to a larger size class. The southern reefs in Al Wajh had substantially more recruitment and survival of corals to juvenile stages. Yanbu had the lowest numbers of settler, while northern Al Wajh reefs had lowest numbers of juveniles.

Twelve physical factors were compared between Al Wajh and Yanbu:

1) Temperature variability was higher at both Wajh sites due to the larger bank system, with higher values than at Yanbu.

2) Visibility was lower on the northern Wajh sites, but this was likely due to strong winds during the surveys at the sites. The depth of the reef base was lowest on the north Wajh, as many sites were surveyed within the shallow bank system.

3) Topographic complexity at the scale of coral recruits was lowest on the north Wajh sites while large scale topography was most complex on the Yanbu linear reef system.

4) Sediment texture was finer, and sediment layers deeper on the Wajh bank, particularly in the north.

5) Exposure to currents was similar at the three regions, though more variable in the Wajh banks, due to variation among inner sheltered sites, channels and reef edges.

6) Exposure to wave energy was higher at Yanbu, as the extensive bank and reef systems of the Wajh resulted in many sheltered locations.

7) Shading by reef structure was most pronounced in Yanbu, as the linear reef system runs north/south, with a high degree of shading on vertical faces and slopes, particularly for the steeper west-facing slopes in the morning.

8) Aerial exposure for study sites was generally minimal due to the depths being surveyed, however in the inner reaches of the Wajh bank, very shallow reefs were sampled.

9) Ponding and pooling of water was minimal in the linear reef systems of Yanbu, but higher on the extensive Wajh bank.

10) Current bleaching, disease and recent mortality were low at all sites.

11) Old mortality and recovery from it were deemed to be high at all sites, with better recovery on the Wajh banks than at Yanbu.

12) Indicators of positive and negative associates of corals were judged relatively low throughout the survey sites, though at individual sites some associates such as crown of thorns, or sea urchins, were abundant.

7 Farasan Banks

7.1 Background

The Farasan Banks is an extensive area of small islands, shoals and reef platforms in the southern Red Sea, occupying a total area of approximately 30,000 km^2. The Farasan Banks begin approximately 230 km south of Jeddah (in the vicinity of Al Lith) and extend nearly 250 km to the Farasan Islands, with most of the reef structures located from 7 to 100 km offshore. The Farasan Banks sit atop the same flat carbonate shelf (located at 600m depth) as the Farasan Islands, and are contiguous with the southerly Farasan Islands. The area contains a significant number of island, atoll, and fringing reef systems. Flat shelf areas appear between these atolls at 30-60 m, which may represent an ancient Pleistocene high. Like the Farasan Islands, evaporite and conventional tectonic influences are also seen in the geomorphology of the region.

As in other locations in the Red Sea, this area is exposed to relatively harsh environmental conditions. Salinities can be quite high, up to 41 parts per thousand in some areas, largely due to the hot climate and absence of river discharge. Unlike much of the Red Sea characterized by well established fringing reefs, the Farasan banks is characterized by a shallow platform that extends from the coast as far as 100 km offshore, forming complex archipelagos and islands perforated by deep water channels. In addition to the seaward extension of the continental shelf, there are extensive groups of isolated reefs, pinnacles and atoll-like formations separated by deep (500m +) channels and extending near vertically to a few meters from the surface. Many reefs have complex, deep-water lagoonal environments with seagrass beds, algal flats and protected (leeward) coral reef environments. Inshore, mangroves and grassbeds fringe the coastline.

Because of the remote nature of the Farasan Banks and the extensive shallow habitat, including reef platforms that are geologically different from other areas examined along the Saudi Arabian Red Sea coast, these areas are well suited to support healthy and resilient coral reefs. Baseline data on the habitat types, their spatial distribution and the complexity of these areas was collected to: 1) fill major gaps in coverage of our previous Red Sea Expeditions, 2) characterize the status of reef communities and major threats, 3) understand factors and processes that promote the resilience of these coral reefs, and 4) identify spatially-based conservation targets.

7.2 Research completed

Surveys occurred over a 2º latitudinal gradient from 20º N to 18º N, and included representative sites on the leeward and windward sides of reef systems, as well as sites extending across gradients of exposure (nearshore/offshore) and human pressure. Field work involved detailed groundtruthing efforts to characterize habitat features and the geomorphic structure of the area. Additional SCUBA assessments were undertaken to determine the reef structure, composition and health across gradients of exposure. Because of the large area occupied by the Farasan Banks, representative sites were selected in nearshore (1-10 km from the mainland), mid shelf (11-30 km offshore) and outer reef systems (31-70 km offshore). Sites examined using SCUBA were located within a 10-20 km radius of each anchorage point of the Golden Shadow, while groundtruthing surveys were conducted up to 40 km from the Golden Shadow. Sites included northern, central and southern Farasan banks, nearshore, midshelf and offshore. When possible the leeward and windward side of each reef complex was examined. A total of 55 SCUBA assessments and 3 snorkel assessments were undertaken. One site was also visited three times, including at night, to better characterize impacts from COTs sea star predation.

Fig. 7.2. One of the KSLOF researchers, Bernhard Riegl, assessing coral community structure.

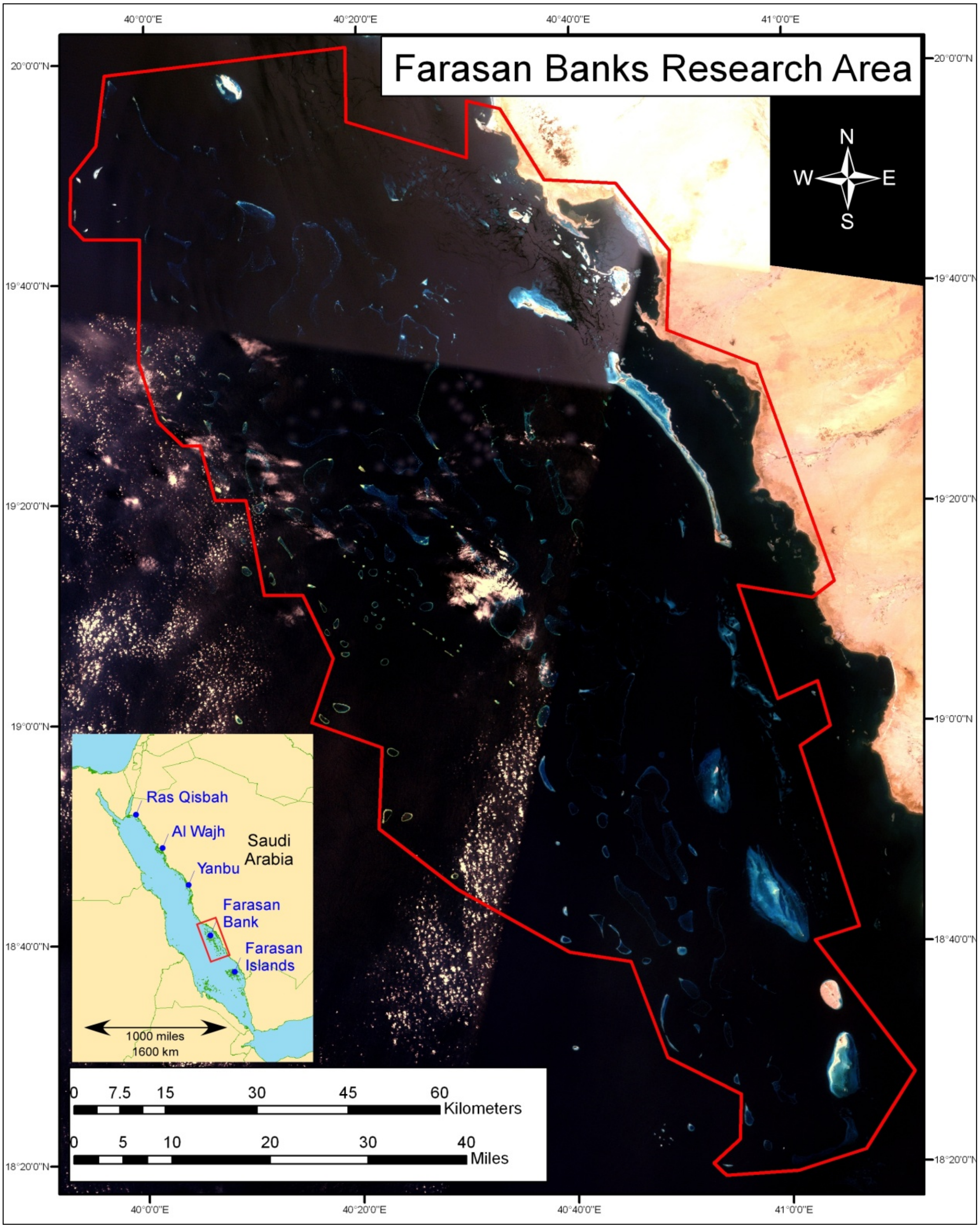


Fig 7.2a. Farasan Bank research area. QuickBird Satellite imagery and habitat maps cover the area within the red outline. Area is 12,000 km^2. SCUBA surveys were completed in representative reef habitats in nearshore, midshelf and offshore locations.

7.21 Habitat mapping

As mentioned in earlier sections, one of the greatest challenges to resolving sea floor habitats through satellite remote sensing lies in accounting for the disproportionate attenuation of both the incident and reflected light as it passes through the atmosphere and water column prior to satellite detection (Purkis & Pasterkamp 2004, Purkis 2005. The successful scientific protocol developed during previous Red Sea expeditions was applied to the Farasan Banks. Much of the field effort of the ground-truthing team centered on collecting the necessary data for correcting the effects described above, as well as training the algorithms needed to classify the different habitats; namely bathymetric, in-situ spectral, and ground truth data. The ground-truthing team completed 402 km of acoustic bathymetric surveys, 100 km of acoustic sub-bottom stratigraphy surveys and 605 drop cameras assessments to support the development of high resolution habitat maps covering a total area of about 12,000 km^2. The locations of drop camera, bathymetry and SCUBA assessments are shown in Figures 7.21a,b.

	Statistic	Value
General		
	QuickBird Imagery	12,000 sq km, 5,630 sq miles
Bathymetry		
	Total track distance	402 km, 250 miles
	Total soundings	2,189,605
Ground truthing		
	Total video drops	605
	Total video footage	5.1 hrs
Stratigraphy		
	Total transects	52
	Total transect distance	99.9 km, 62.1miles

Table 7.21. Summary of the imagery and field data collected by the groundtruthing team and used in the production of habitat maps for the Farasan Banks.

Contrasting previous expeditions, the Farasan Banks expedition saw the increased use of acoustic remote sensing tools. In addition to the general acoustic survey of bathymetry, an acoustic sub-bottom stratigraphy survey system was employed in certain lagoonal environments in the Farasan Banks. This instrument emits a low-frequency acoustic wave that propagates through the seafloor and down into the underlying rocks and sediments. This pulse of sound reflects off layers beneath the seabed caused by the juxtaposition of different sediment types.

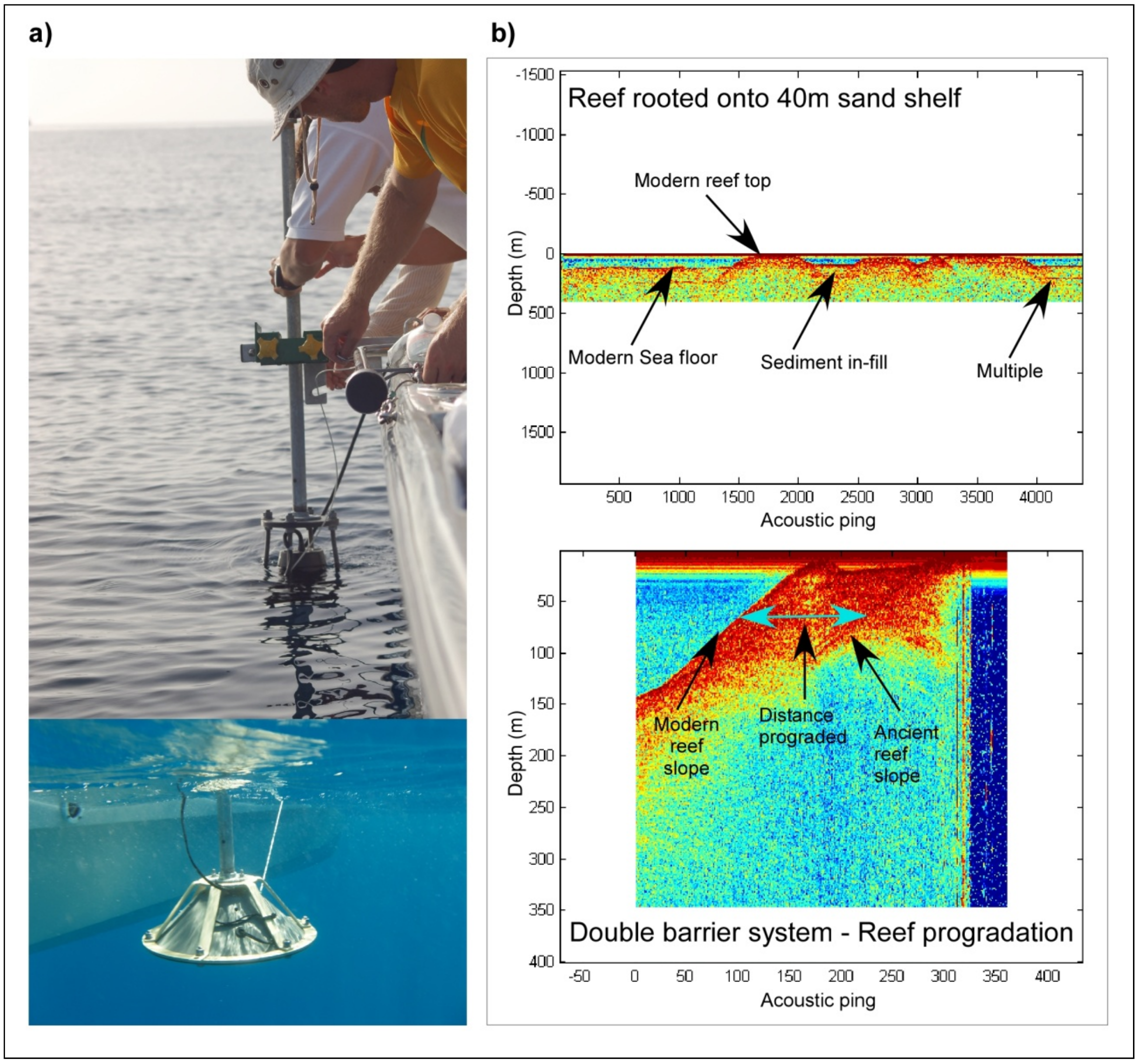


Fig 7.21b. Stratigraphic survey; a) Deployment of 3.5 kHz transducer, 10 kHz transducer shown underneath; b) Examples of raw data files from two transects in the Farasan Banks with geomorphological features of interest highlighted.

By measuring the time taken between the instrument emitting a pulse and receiving the various echoes back, a two-dimensional digital representation of the structure beneath the seabed is generated. In essence, this tool allowed us to look back in time to a period when the buried reefs were thriving on the seafloor. The deeper they lay buried, the longer ago that they lived. The instrument allowed identification of structures that now lie up to one hundred meters below the seabed and would have died and been buried shortly after the last ice age (12,000 years ago).

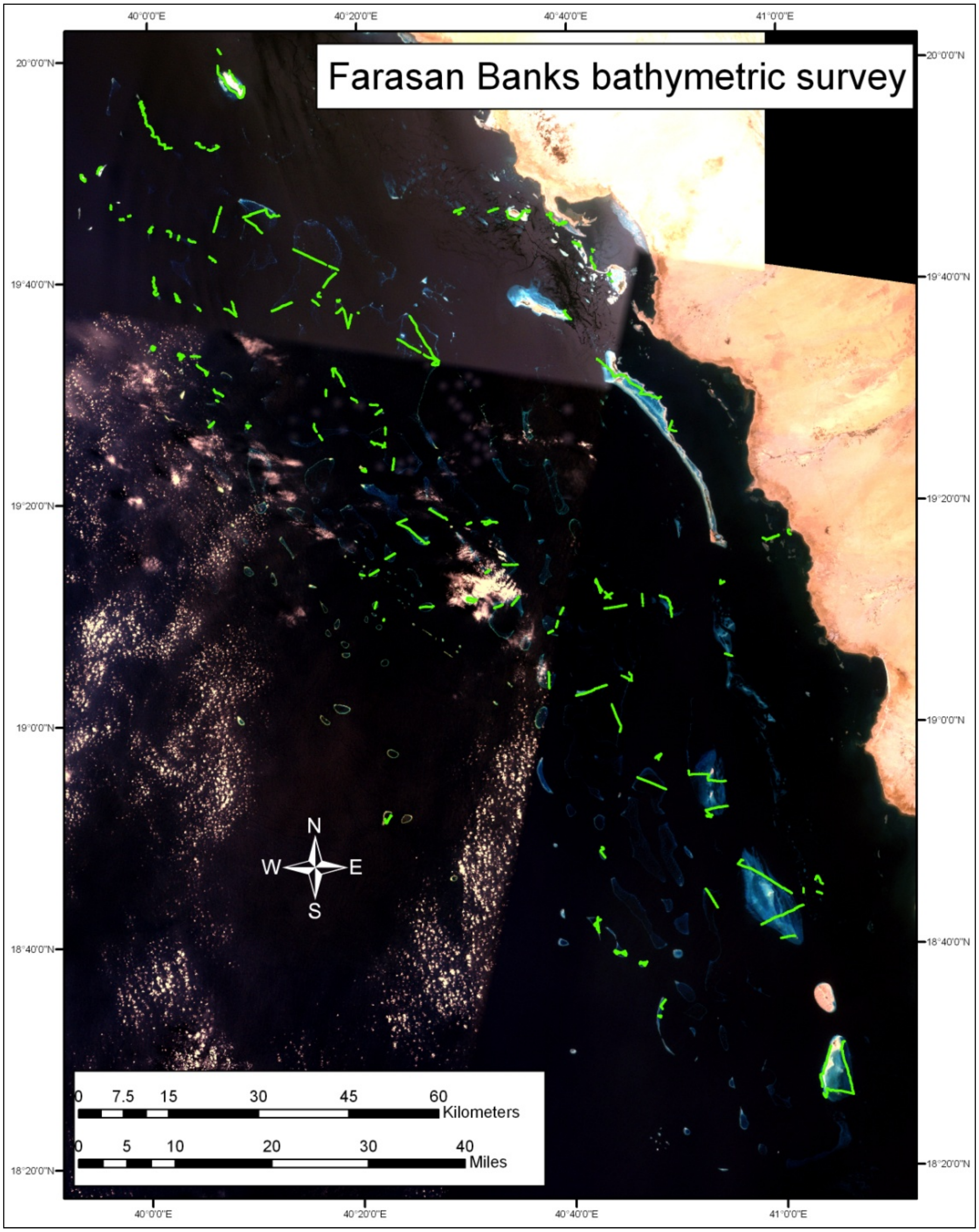


Fig 7.21c. Bathymetry track (green lines) across the Farasan Banks research area.

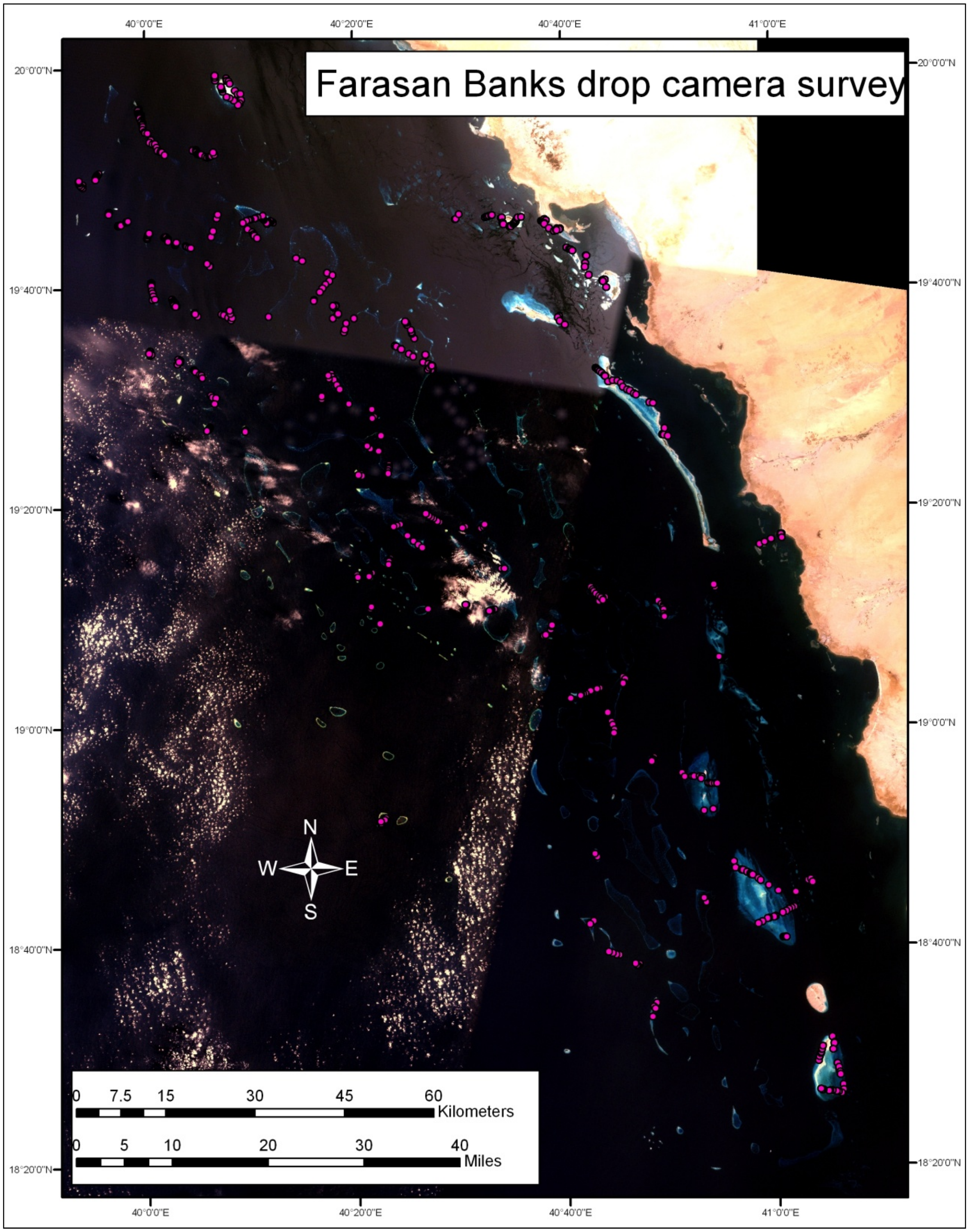


Fig. 7.21d. Position of the 605 video camera drops (purple points) across the Farasan Banks research area.

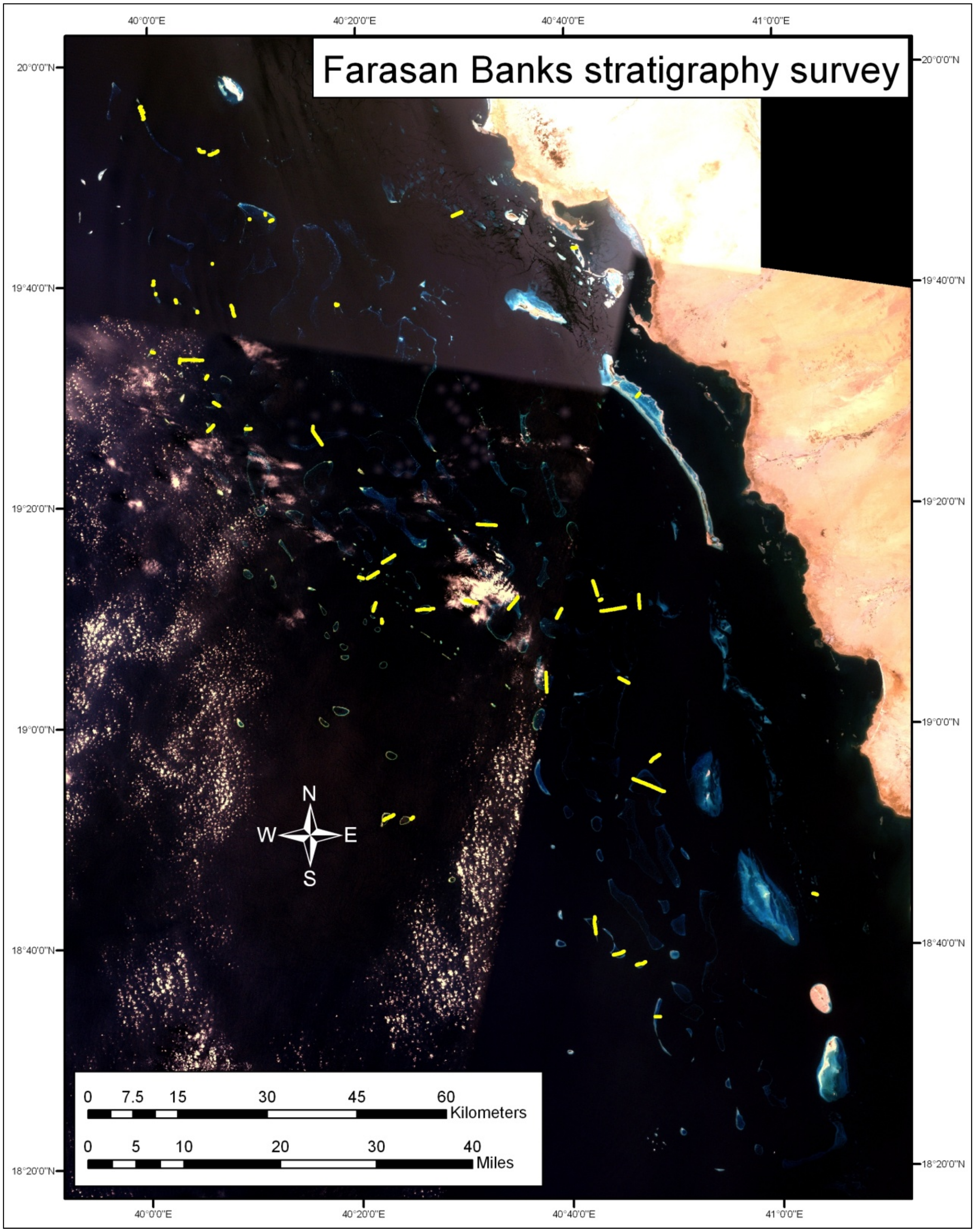


Fig 7.21e. Stratigraphic survey transects (yellow line) in the Farasan Banks research area.

Approximately 100 km of stratigraphic survey were completed (Fig. 7.21d). Transects were routed perpendicular to slopes, bisecting lagoonal systems and other geomorphological features of interest. Either a 10 kHz or 3.5 kHz transducer was used depending on depth and substrate hardness. The transducers are easily deployed at points of interest through the use of a side clamp system (Fig. 7.21b). The flexibility of this system allows stratigraphic survey to be carried out concurrently with standard bathymetric and sea-floor ground truthing survey. In figure 7.21b, two example profiles are shown through a reef system on a 40 m sand shelf, and at the entrance to an offshore atoll with a double barrier. In the latter example it can clearly be seen how the reef has grown (prograded) from its historical extent. Processing of multiple stratigraphic lines will lead to an understanding of regional patterns in reef growth and development.

7.22 SCUBA assessments

SCUBA assessments were completed in 55 locations within representative nearshore, midshelf and offshore coral reefs (Fig. 7.22a, Table 7.22a), with an additional assessment of three sites using snorkeling. SCUBA assessments typically involved paired dives conducted on the leeward and windward sides of representative emergent islands and shallow, submerged reef platforms. These were undertaken predominantly at 8-12 m depth, with additional photo-transects completed at 15 m and 5 m depth, and supplementary observations and photographs taken at 20 m and 1-3 m depth. Most sites were examined during a single dive, however, a few sites were surveyed on multiple days and at night to better understand and characterize impacts from an *Acanthaster planci* (Crown of Thorns) Sea Star outbreak.

Photo-transects were used to estimate benthic coverage of corals, algal functional groups, other benthic invertebrates and substrate type. These transects were each 10 m in length, with replicate surveys conducted at three depths (indicated above) by three researchers. Photoquadrats were imported into NCRI’s Coral Point Count software (CPCE) and 30-60 points were overlayed and examined for each photograph.

Adult colonies: Surveys recorded the genus and longest diametric axis (cm) of all hard corals >10 cm lying within a randomly placed 10 m x 1 m belt at 10 m depth. Only colonies lying with more than 50% surface area within 10 m^2 belt transect were measured. Up to 6 replicate transects were sampled per site. In addition to size measures, estimates of mortality were made for those corals exhibiting recent tissue loss.

Analyses of trends in both the generic composition and size frequency distribution of coral communities across all sites were carried out using non-metric Multi-Dimensional Scaling (MDS) ordinations based on Bray-Curtis dissimilarities of root transformed multivariate sample data. Transformation was used as a means of down-weighting the importance of highly abundant taxa (such as *Porites*), so that community similarities depended not only on their values but also those of less common (‘mid-range’) categories. For analysis of trends in taxonomic composition across samples (reef sites), variables used were the mean number of colonies per genus per unit area per site. For analysis of trends in size distribution of corals across the samples (reef sites), variables used were the mean number of corals per colony size class (cm) per unit area per site. In both cases these analyses were repeated using average total colony surface area data for each sample (per genus or per size category) as well as average colony density data (number of colonies per unit area) for each sample. ANOSIM was used to identify significant differences between groups of samples defined by factors *a priori*. Factors tested including distance of survey sites from shore, latitude of site, orientation of site to prevailing swell (seaward/leeward), and location of the site within the Farasan Banks (following classification of the overall Banks into 9 delineated subregions.

Juvenile colonies: Surveys recorded the genus and longest diametric axis (cm) of all hard corals <10 cm. Up to 10 replicate 0.11 m^2 quadrats were sampled per site within the same reef area covered by the belt transects, again at 10 m depth. For the purposes of this study the term ‘adult’ coral refers to colonies greater than 10 cm maximum diameter, whereas the term ‘juvenile’ coral refers to colonies less than or equal to 10 cm maximum diameter. This categorization is entirely arbitrary, based on the need to differentiate colonies based on size between the two sampling techniques used (belt transect and quadrat). This terminology refers purely to the size of the corals in question and should not be interpreted as inferring any aspect of the sexual maturity of corals surveyed: it is of course accepted that post-pubescent colonies of many taxa may be considerably smaller than 10 cm.

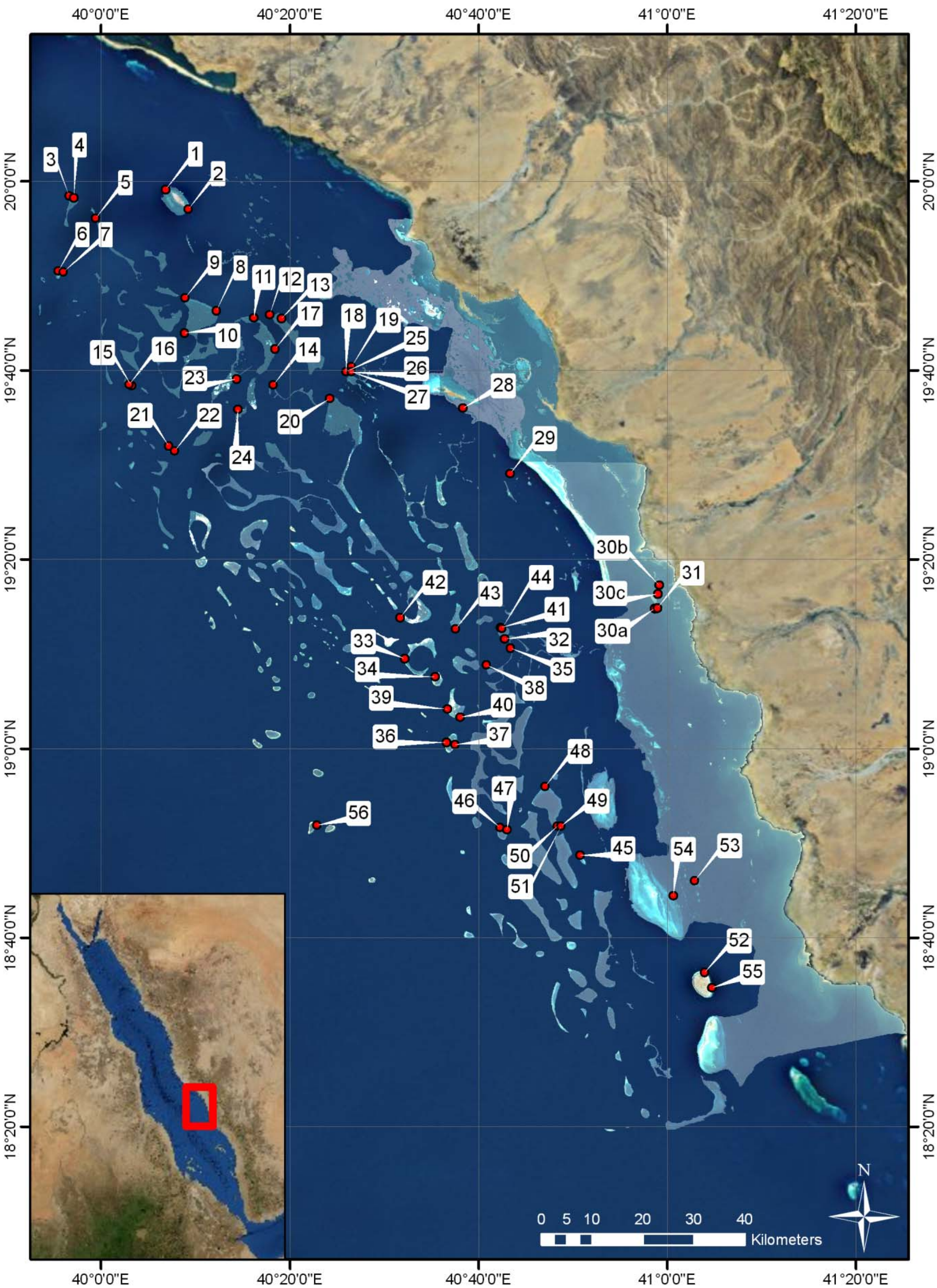


Fig. 7.22a. Locations of SCUBA assessments of coral, fish and resilience indicators.

#	Latitude, N	Longitude, E	Date
1	19.98585	40.11390	4/5/2009
2	19.95083	40.15405	4/5/2009
3	19.97410	39.94327	4/6/2009
4	19.97135	39.95163	4/6/2009
5	19.93499	39.99026	4/6/2009
6	19.84162	39.92428	4/7/2009
7	19.84000	39.93333	4/7/2009
8	19.77177	40.20365	4/7/2009
9	19.79441	40.14799	4/8/2009
10	19.73251	40.14767	4/8/2009
11	19.75891	40.26950	4/8/2009
12	19.76498	40.29776	4/9/2009
13	19.75843	40.31802	4/9/2009
14	19.64091	40.30381	4/9/2009
15	19.63983	40.05317	4/10/2009
16	19.64205	40.04946	4/10/2009
17	19.70419	40.30751	4/10/2009
18	19.66434	40.43226	4/11/2009
19	19.67330	40.44167	4/11/2009
20	19.61684	40.40340	4/11/2009
21	19.53389	40.11900	4/12/2009
22	19.52500	40.12940	4/12/2009
23	19.65140	40.23876	4/13/2009
24	19.59761	40.24142	4/13/2009
25	19.66434	40.43226	4/14/2009
26	19.66420	40.44222	4/14/2009
27	19.60009	40.63850	4/15/2009
28	19.48476	40.72180	4/15/2009
29	19.24685	40.97718	4/15/2009
30a	19.24748	40.98206	4/16/2009
30b	19.28833	40.98666	4/16/2009
30c	19.24833	40.98166	4/16/2009
31	19.19353	40.71233	4/17/2009
32	19.15886	40.53606	4/18/2009
33	19.12629	40.58944	4/18/2009
34	19.17681	40.72295	4/18/2009
35	19.01122	40.60947	4/19/2009
36	19.00666	40.62473	4/19/2009
37	19.14720	40.68010	4/19/2009
38	19.06971	40.61148	4/20/2009
39	19.05488	40.63392	4/20/2009
40	19.21296	40.70494	4/20/2009
41	19.23090	40.52824	4/21/2009
42	19.21110	40.62551	4/21/2009
43	19.21129	40.70736	4/21/2009
44	18.81185	40.84597	4/22/2009
45	18.86103	40.70445	4/23/2009
46	18.85695	40.71630	4/23/2009
47	18.93308	40.78437	4/24/2009
48	18.86361	40.81184	4/24/2009
49	18.86317	40.80553	4/24/2009
50	18.86361	40.81184	4/25/2009
51	18.60553	41.06599	4/25/2009
52	18.76667	41.04833	4/26/2009
53	18.74029	41.01057	4/26/2009
54	18.57837	41.07859	4/26/2009
55	18.86454	40.38068	4/27/2009

Table 7.22a. Coordinates of 55 locations examined using SCUBA

Recruits: A 0.25 m^2 quadrat was deployed along each transect at 2, 4, 6, 8, and 10 m to assess abundance of coral recruits (0-2 cm diameter). These were identified to genus and counted. An additional novel technique was employed for surveying juvenile corals at all survey sites. The method involved using an ultra violet lamp to highlight the location of small and cryptic colonies that might otherwise remain undetected using conventional visual surveying. After using the conventional quadrat sampling methodology (described above), each quadrat was subsequently resurveyed with a UV lamp. This repeated method resulted in two data sets for each replicate quadrat, in order to enable comparison of the resolution of the two methods. This was carried out in order to assess the value of UV underwater surveying in discriminating cryptic juvenile coral colonies that might otherwise be overlooked in
conventional visual light surveying.

Colony surface area: For all corals (adults and juveniles) colony surface area was modeled as approximately equivalent to πr^2, where r equals half the maximum diametric axis of each colony.

7.23 Fish and fisheries

Fish species were counted and identified to species level and included herbivores, predators, and indicator species. Six herbivore functional groups were identified following Green et al. (2009): large excavators, small excavators, scrapers, grazers, browsers and grazers / detritivores. These groups play an important ecological role in coral reef resilience (Obura & Grimsditch 2009) and include the Scarids (parrotfishes), Acanthurids (surgeonfishes); Kyphosids (chubs), Ephippids (batfishes), and Siganids (rabbitfish). We also included predators such as Caracharhinids (sharks), Lutjanids (snappers), Serranids (groupers), and Letherinids (emperors) and certain indicator families such as the Chaetodontids (butterflyfish) and Caesonids (fusiliers) that are corallivores and planktivores respectively.

7.24 Resilience assessment methodology

Surveys characterized the population dynamics (species composition, abundance, cover and size structure) and health of corals, cover of major functional groups of algae, size and abundance of over 100 species of reef fishes, and severity of biotic and abiotic stressors. An additional 63 ecological, physical and environmental factors that control ecosystem function and health were assessed and ranked by site. These measures are particularly relevant to examine because 1) climate change and anthropogenic stressors are driving shifts in coral assemblages worldwide; 2) changes in the structure and composition of coral reefs in response to these disturbances have profound impacts on the ecological functions of coral reefs as well as the architecture and habitat complexity and the potential for continued reef growth; and 3) few quantitative studies have been undertaken to describe the composition and condition of corals and other organisms found on coral reef communities in the Farasan Banks. These indicators provide relevant information that can be used to predict the ability of these systems to cope with disturbance and continue maintaining a high degree of structural and functional integrity.

A total of 57 nearshore and offshore reefs in the Farasan Banks were haphazardly selected for sampling. Two sites were normally sampled per reef; a site each on the windward and leeward side according to the prevailing winds at time of sampling. At each site, two researchers undertook a survey of both coral and fish species. The percentage cover of corals and other sessile organisms were estimated in two 20 m length belt transects placed on the seafloor at 10 m. Fish species were surveyed using two 50 m length belt transects at 10 m depth and corresponded to the coral transects. Two replicate transects were surveyed per site and only at a depth of 10 m because of time constraints. Benthic lifeforms included: living hard coral, recent dead coral, old dead coral, soft coral, turf algae, macroalgae, crustose coralline algae, rubble and other. In the same transects, the abundance of hard coral genera were ranked on a semi-quantitative (Likart) scale of 1 to 5. These scores equated to: 1 = <2 colonies; 2 = <10 colonies seen; 3 =>1% of population or >20 colonies; 4 =10-30% of population or>100 colonies; 5 = > 30% cover or most dominate genera at site. Corals were not identified to species because accurate identification requires observation of skeletal material (Veron 1993). Hard coral genera identification followed Veron (1993), Veron & Stafford Smith (2000) and Sheppard & Sheppard (1991).

Biological patterns were compared with the following variables:

Latitude: The variable latitude pertained to four relatively discrete clusters of reefs along a north - south gradient. Thus latitude was a categorical variable and coded as: North Reef Group (N);

North Central Reefs (NC); South Central Reefs (SC) and South Reefs (S). Note that genera level data were not taken in the most northerly reef group (i.e. reef group N).

Distance from the mainland: Distance from land was measured as a straight line between the site and the mainland immediately due east. Distances were than coded into categories: <1-20 km; 21-40 km and so on until 81-100 km.

Exposure: This factor was coded as exposed (to the northerly prevailing winds), semi-exposed and sheltered (facing south). Note that in this region of the Red Sea there is a seasonal change in wind direction with the prevailing winds blowing from south to north in the winter and north to south in summer (Edwards & Head 1987).

Reef size: Maximum reef width was used as a proxy for reef size.

Distance from closest reef: Connectivity between reefs was a factor of interest and this was measured as a linear point to the reef closest to the survey reef. Adjacent reefs were predicted to share similar genera composition because exchange of larvae should be higher than more distant reefs (Ayre & Hughes 2004).

Data analysis was performed with non-parametric multivariate techniques using the PRIMER software (Clarke & Gorley 2006). For the benthic lifeform analysis, samples similarity was calculated using the Bray-Curtis coefficient, subsequent to square-root data transformation while for the fish analysis we used a log transformation. Both transformations were used to reduce the influence of taxa characterized by relatively large abundances that could easily mask important patterns in the data. The genera data (based on a categorical scale 1- 5) was not transformed prior to analysis. Non-metric multidimensional scaling (nMDS) was used to produce two-dimensional ordination plots. One-way Analysis of Similarity (ANOSIM; Clarke & Gorley 2006) was used to provide formal tests of our null hypotheses. ANOSIM test produces a statistic (R-statistic) that lies in the range (-1 to 1). R is a very useful statistic for interpretation because it is not unduly influenced by sample size. R will equal 1 only if all replicated within sites are more similar to each other than any replicates from different sites. R is approximately zero if the null hypothesis is true, so that similarities between and within sites will be the same on average (Clarke & Gorley 2006). The Similarity Percentages (SIMPER) function in PRIMER was used to highlight species contributing the greatest quantity of dissimilarity between two observed sample clusters.

7.3 General habitat attributes

The Farasan Banks contain a range of marine habitats that differ depending on the oceanographic regime, degree of exposure, and topographic features (including the distribution of suitable antecedent topography for development of coral reefs and presence of mangrove stands and seagrass beds). The predominant reef types include fringing reefs along the mainland coast (often extending across or into coastal bays and around islands), algal reefs in certain nearshore areas, circular or elongated patch and platform reefs and barrier reefs in mid shelf areas, coral pinnacles, and emergent or submerged atoll-like structures situated further offshore. Overall, the reefs and associated ecosystems were divided into ten biotic and sedimentary classes, including coral crests and patch reef habitats, algal flats, seagrass beds, sand, and rubble.

In addition to critical information on the location and spatial extent of various habitat types, a detailed examination of the factors and processes that control the abundance, size, shape, and distribution of various habitat patches across the eastern Red Sea is being undertaken. Through acoustic sediment profiling, the substrate beneath sandy lagoons within the Farasan Banks system was examined to identify buried reef structures. The instrument permitted the team to look back in time to a period when the buried reefs were thriving on the seafloor under the premise that the deeper they lay buried, the longer ago they lived. In the Farasan Banks, structures that lie as much as one hundred meters below the seabed were identified. The coral reefs which created these buried structures were drowned and subsequently buried by sediments shortly after the last ice age (~12,000 years ago) (Braithwaite 1987, Behairy et al. 1992).

The benthic community at most sites throughout the Farasan Banks was dominated by stony corals, either living or dead standing, with low cover of other sessile invertebrates and algae. Reefs had steep, often vertical walls descending to depths of more than 60 m from the reef crest (3-5 m depth) at midshelf and offshore sites, while inshore areas had a more gradual slope, with reef growth terminating in a sand flat at 15-30 m depth. An overhang in the reef wall was often present at approximately 15 m depth, with a recessed cave penetrating 2-4 m into the reef platform. A shallow reef flat was generally found above the reef wall, between 3-5 m depth. This area had variable coral cover, depending on exposure and other factors. Like the reef slope, the shallow-water zone above the reef crest was generally dominated by a *Porites* framework, although some sites showed abundance of other taxa in this higher-energy environment, notably survey sites 18, 27, 28 and 51, which exhibited almost complete coverage of diverse *Acropora* spp..

The inshore reef sites were generally an exception to this typified geomorphology; their gradient was generally shallower, with the reef slope terminating at a sandy seafloor at between 15 and 35 m depth. High turbidity prevailed at all inshore reef sites surveyed, with corals more commonly growing in plating growth forms beneath 10-15 m in these localities, particularly *Echinopora*, *Mycedium, Acropora* and *Montipora* spp.

Almost all sites showed very high structural complexity, with reef architecture overwhelmingly dominated by massive *Porites* colonies. Coral cover was lowest on reefs with the highest relief, which in many cases was vertical from a shallow reef crest to depths exceeding 60m. At sites where coral cover was low, remaining reef space was generally occupied by sand or bare coral rock. A pronounced *Echinopora* spp zone was a common feature of many reef slopes, generally occurring as a band of foliose colonies at a variable depth of 15-25 m.

Notwithstanding the high structural complexity of the reefs surveyed, 20 of the 54 sites visited showed distinct evidence of recent widespread coral mortality, with several sites having shown almost complete mortality of all adult corals. The causes of past mortality were not clear, however coral death was typically estimated as having taken place 1-3 years prior to surveying. These estimates were based on the low degree of erosion of the remaining standing coral framework (which could often be identified to species level), as well as the size structure of living juvenile corals colonizing the available substrate.

Most notably, at survey sites 8, 17, 41, 45 and 42, almost all adult colonies were dead at the survey depth, with mortality in some cases extending from the surface to a depth of at least 55m. At all sites affected in this way the dead colony structures remained intact, with skeletons generally identifiable to genus or species level, little turf algal overgrowth and negligible macroalgae coverage. Importantly, juvenile corals were present in extremely high abundance at all sites that had experienced mortality.

In several cases where mortality was most pronounced on the reef slope (i.e. at sites where live adult corals were effectively locally absent in the vicinity of the survey depth of 10m) live adult colonies were abundant in shallow water above the reef crest. Predation of colonies by *Acanthaster planci* was observed at many sites, with widespread evidence of recent predation and regular sightings of actively feeding individuals; over 500 feeding starfish were recorded within ~100m along the outer reef slope during one survey dive alone.

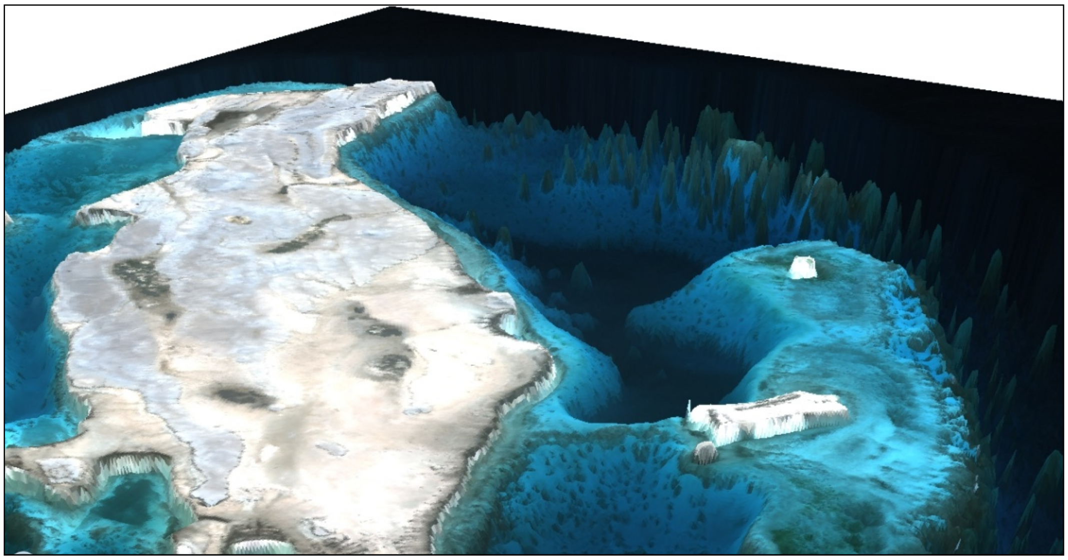


Fig.7.3a Bathymetric model looking south along Al Latt Island in the north of the Farasan Banks research area. QuickBird satellite imagery is overlaid (vertical exaggeration = ×40, land shown with false height of 2 m) onto bathymetric data. This models illustrates the steeply sloping reef and deepwater between islands and reef structures.

7.4 Coral community structure

Coral reef habitats throughout the Farasan Banks were constructed on a framework of massive *Porites* colonies. In many locations, shallow and deeper reef habitats were dominated by a high cover of living *Porites* (50-70% of the living coral cover in some areas), but there were also large areas of dead Porites framework as well as signs of recent mortality from disease and predation. Massive colonies of *Porites* taxa were numerically dominant and often the largest corals in the population, except for four sites that exhibited close to 100% cover of multiple species of branching and table *Acropora* colonies.

Most of the reefs had a shallow reef flat community with low cover of living corals. Nearshore sites often had a high abundance of macroalgae including *Sargassum*, while substrates on offshore reef flats was generally barren, hard bottom or covered predominantly by turf algae.

Most corals on the reef flats were small, often with a high amount of partial mortality associated with aerial exposure during low tides. The reef crest, from the seaward edge of the reef flat (0.5 m depth) to about 3-5 m depth on the reef slope was the most diverse area, exhibiting a high cover of branching, massive and plating corals, including dense assemblages of *Acropora, Porites, Pocillopora, Montipora, Goniastrea, Pavona, Echinopora, Favia* and other species. Distinct differences were noted between zones and degree of exposure. For instance, plating corals such as *Montipora, Echinopora, Echinophyllia, Mycedium* were common on vertical slopes in offshore sites, but rare on inner sites. *Pocillopora* was overall less common in the Farasan Banks than observed in northern sites (e.g. Al Wajh, Yanbu and Ras Qisbah). In the most disturbed sites where coral diversity and live coral cover was extremely low, *Diploastrea* was often the dominant surviving coral. Inshore sites were very different from offshore locations, with a narrower reef flat and more gradual reef slope that terminated in sand at 15-35 m depth. These sites were considerably more turbid and included shallow reefs with the highest abundance of tabular acroporids seen in the region. One new species of coral (*Seriatopora*) was found on nearshore reefs.

Colony density: The density, size and total surface area of corals varied considerably between sites and depths. The lowest mean density of corals (> 10 cm diameter) was 5 colonies per 10 square meters, while the highest density was 195 colonies per 10 m^2 (mean density of 85 colonies per 10 m^2). Colonies that were 21-40 cm diameter occupied most of the available reef substrate, while juvenile colonies (<10 cm diameter) were most abundant numerically. Massive and submassive colonies of *Porites* spp. accounted for 59% of the total live surface area of corals and 38% of the total number of colonies above 10 cm diameter.

Colony size frequency distributions: For corals >10 cm maximum diameter, colony size frequency decreased with an approximate power relationship with increasing colony maximum diameter. This trend was true across all sites surveyed. Total colony area increased with maximum diameter following an approximately 2nd order polynomial relationship. Across all genera the frequency of juvenile hard corals increased up to 3cm maximum diameter, then decreased with increasing colony size. The shape and nature of this decrease varied widely between different genera and between groups of genera. The shape of this juvenile coral size frequency distribution is broadly similar to coral community structure data from other Indian

Ocean sites, however the density and total surface area of colonies within each juvenile size class on Farasan Banks reefs dramatically higher than at any other site recorded in the Indian Ocean to date.

Across all sites juvenile corals (<10 cm maximum diameter) accounted for, on average, 99.0% of the total number of hard coral colonies, but only 21.1% of the total hard coral surface area. These colony size frequency statistics illustrate the non-linear relationship between colony diameter and surface area, by showing the disproportionately large contribution of a small number of large colonies to the total surface area of corals within the reef community. These data also emphasize important life history processes within the coral community, such as the extent to which coral survivorship increases with colony size (as mortality rates decrease).

Taxonomic composition: *Porites* dominated the scleractinian community on all reefs surveyed. Across all reefs surveyed, *Porites* accounted for over half of the total surface area (59%), and 38% of the total number of colonies greater than 10 cm maximum diameter. This dominance is also apparent within the juvenile coral community, with *Porites* accounting for 27% of the total surface area, and 30% of the total number of colonies 10cm maximum diameter, across all sites surveyed.

Across all survey sites, the maximum total live colony surface area (hard corals >10 cm maximum diameter) was 107.36 m^2 per 10m^2, of which only 6.97 m^2 of total coral area was attributed to non-*Porites* taxa (survey site 12). This extremely high surface area of coral cover (over 10X the 2 dimensional surface area of the transect for colonies greater than 10 cm maximum diameter alone) gives an indication of the considerable 3-dimensional structural complexity created by the dominant *Porites* framework. In addition to the high abundance and surface area dominance of Poritidae in absolute terms, Poritids are also relatively much more dominant within the coral community in the Farasan Banks than in other sites that have been previously surveyed using directly comparable Methodologies.

7.41 Site 1

This site was characterized by a forereef with well-developed coral spurs consisting primarily of *Porites* framework and a well-developed and rich shallow slope with high (>50%) coral cover dominated by *Millepora* and *Acropora*. Coral cover in deeper areas was low (<10%), but coral diversity was high. Several colonies exhibited signs of coral disease. Active overgrowth by boring clionid sponges was observed on *Goniastrea* and *Diploastrea*.

Fig. 7.41. *Porites lutea* at site 1 with red line disease. The center of the colony has died and affected tissue forms a narrow line or band separating live tissue from exposed skeleton.

7.42 Site 2

Site 2 had a well-developed columnar framework constructed by *P. columnaris* or columnar *P. lutea* colonies. The coral framework, up to 10 m thick in places surrounded deep depressions filled with muddy sand. There were numerous dead corals; most large *Acropora* tables were dead and broken down while live colonies were up 1.5m diameter. Recovery from a past disturbance was underway. Coral cover low (5-10%). Shallow areas had a maximum of 20% live coral cover, with a dominance of *Millepora*, but no clear *Acropora* zone.

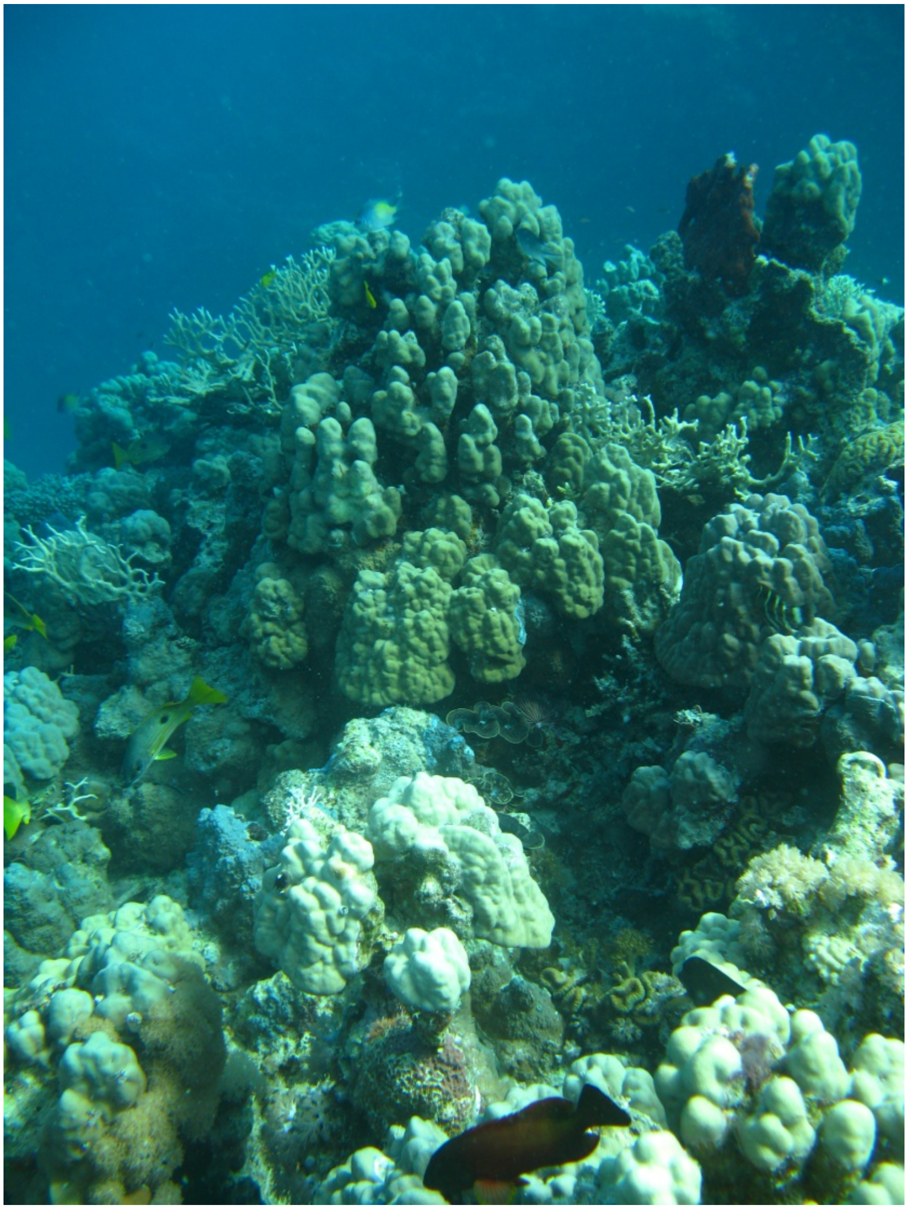


Fig 7.42. Site 2 was characterized by a well developed *Porites* framework with abundant live *P. lutea* colonies at 10 m depth.

7.43 Site 3

Site 3 was on the outside of the outermost Erg at the northern end of the Farasan Banks, facing the Red Sea trough. The reef consisted of two sets of constructional groove-and-spur structures. The shallower one extended from the surface to about 20 m, where a narrow platform, about 100 m wide, was possibly formed by the former reef-flat of the deeper groove-and-spurs. The two structures look identical: grooves are deep, and the spurs are essentially discontinuous frameworks. Cover of living coral on the reef slope at 10 m depth ranged from 40 to 45%. Colonies were mostly small (<20 cm across) to medium sized colonies, with a few moderately-large ones. Dominant hard corals, in terms of their percentage cover included *Porites*, *Pocillopora*, *Favia*, *Favites* and the fire coral *Millepora*. The reef crest was dominated by *Millepora* and *Acropora* with plate-like growth forms. The reef flat (water depth ≈ 1.5 m) had low (<5%) cover dominated by al *Stylophora*.

Fig. 7.43. Large colonies of *Millepora* were found in the reef crest and top of the reef slope at site 3.

7.44 Site 4

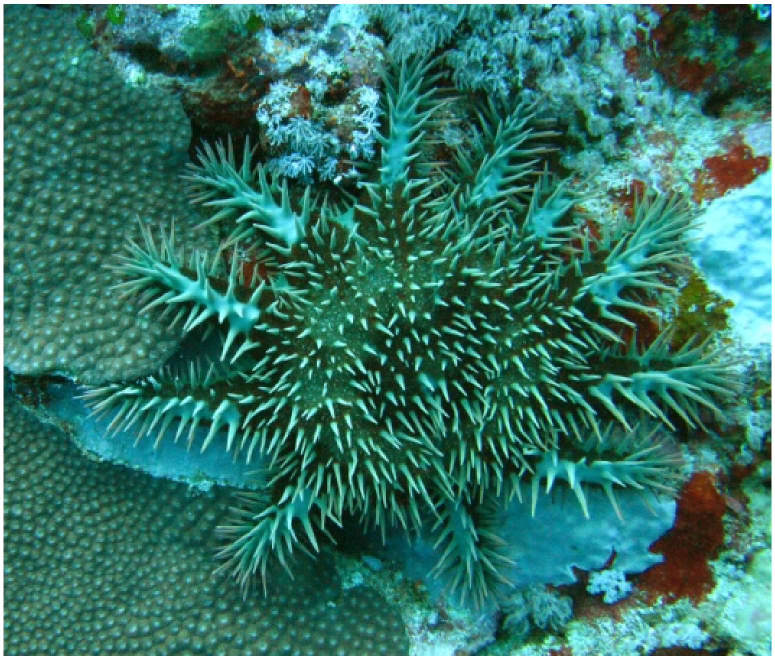
The dive site was around the northern tip of the Erg at the transition zone between slope and lagoonal platform. Numerous patch reefs, constructed of *Porites lutea*, rise from about 15m at the base of the reef until almost the surface. This bommie-and-carpet morphology becomes more accentuated further into the landward sections of the Erg. Other dominant corals were faviids (*Favia* and *Favites*), *Pocillopora*, and *Gardineroseris*. Cover of living hard corals was close to 50%; Dead standing coral was low (<5%).

7.45 Site 5

Site 5 was another offshore tower reef in the northern Farasan Islands. Coral cover was close to 40% from about 4-10 m depth. Approximately 30% of the substrate at 10 m was colonized by soft corals, while soft corals were rare at 4 m depth (<5% cover) and turf algae was more abundant (40% cover). The fore reef was dominated by medium to large sized colonies of *Porites*, *Goniastrea* and *Pocillopora*, with isolated patches of *Acropora* and large colonies of *Diploastrea*. Live plating colonies of *Echinophyllia*, *Oxypora* and *Podabacia* were attached to vertical reef surfaces. Many of the branching corals were 40-70% dead and active diseases were seen on the acroporids.

7.46 Site 6 and 7

Two sites were examined on an isolated tower reef consisting of a horst structure with an emergent island. The structure looks very much like a cork, with a low relief flat top (reef flat), well developed coral community at the edge which formed an overhang, extending out toward the Red Sea and a near vertical reef slope extending to depths of 300 m or more. Coral growth on the reef slope was richer than the three other offshore tower reefs examined in the northern Farasan Banks, but cover of stony corals was still relatively sparse (<20%) when compared to other steep slopes. There were, however, ledges and areas with less slope that had 30-40% cover Most colonies attached to the near-vertical reef slope were small, usually <30 cm in diameter. Live coral on the reef flat and reef crest consisted predominantly of *Stylophora danae* and *S. mordax*. Dominant taxa at the edge of the drop-off, in terms of percentage cover, included *Porites*, *Pocillopora*, *Montipora* and the fire coral *Millepora*. There were also large areas dominated by Sinularia near the edge. In deep water (>30m), antipatharians, gorgonians and organ pipe coral (Tubipora spp.) were the dominant cnidarians; the overhang at about 12 m depth also supported colonies of the nodded-horny coral (*Acabaria delicatula*) and the giant-sea fan (*Annella mollis*). Recent mortality associated with *Drupella* (gastropod) predation on Pocilloporids and *Acanthaster* (COTs) predation on massive corals was common. Several COTs were also seen actively feeding.



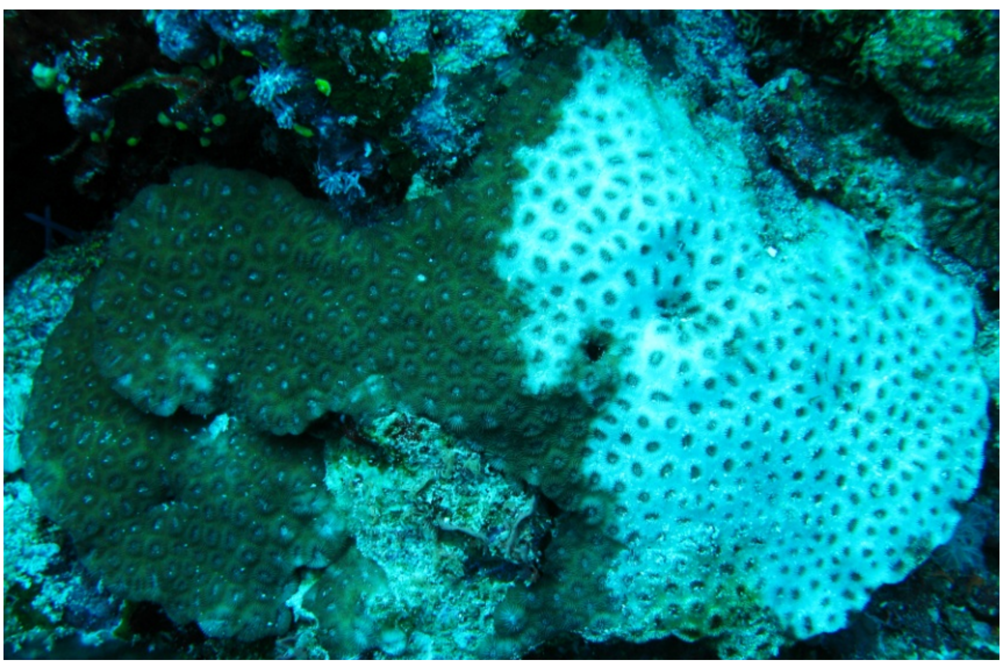


Fig 7.47. Recent mortality to *Favia favus* (left) from crown-of-thorns (COTs) seastars (above).

7.48 Site 8

Site 8 was a completely dead reef that appears to have been affected by an outbreak of *Acanthaster* (COTs) about 3 years ago. All *Acropora* tables were denuded of tissue, but still in growth position. Other medium and large-sized corals were dead and largely uncolonized by other epibionts. Mortality extended to at least 30m. The reef has begun to regenerate, with high levels of recruitment and isolated juvenile and adult colonies, up to 20 cm diameter. *Pocillopora* was one of the dominant colonizers. Cover of living hard coral was low (<10 %), whereas soft coral (cf. *Xenia*) was abundant (30 to 50% coverage).

7.49 Site 9 and 10

These sites were both small platform reefs that sloped steeply on their deeper sides (about 45 degrees). The deeper areas were largely dead: dead standing coral covered 40 to 45% of the hard substratum. Most of the surviving corals consisted of small patches of surviving tissue surrounded by large tissue-denuded patches. The largest corals on these reefs, most of which were completely intact and some that were several meters in diameter, were colonies of *Diploastrea*. In contrast, small patch reefs on the tops of these platforms were mostly live. On dive 1, an entire bommie was largely made up of a monospecific stand of *Galaxea fascicularis*, but these colonies were affected by focused biting by parrotfish. *Porites* colonies (several meters in diameter), fire coral (*Millepora*) and *Pocillopora* were also abundant in shallow water.

7.411 Site 11, 12, 13 and 17

Four reefs were examined on a bank located approx. 30 miles offshore in the northern Farasan Banks. These are submarine humps that peak at about 10 m, and from there, coral pinnacles grow towards the surface. However, the pinnacles have not yet amalgamated to form a continuous rim, so it is not yet a platform reef. On the front side, living hard coral ranged from 25 to 35%, while soft coral ranged from 30 to 40%. The corals are mostly completely live, with good *Acropora* growth and large (5m diameter) *Porites lutea* in the shallows. In the deep (15-20 m), a typical faviid carpet, also mostly live.

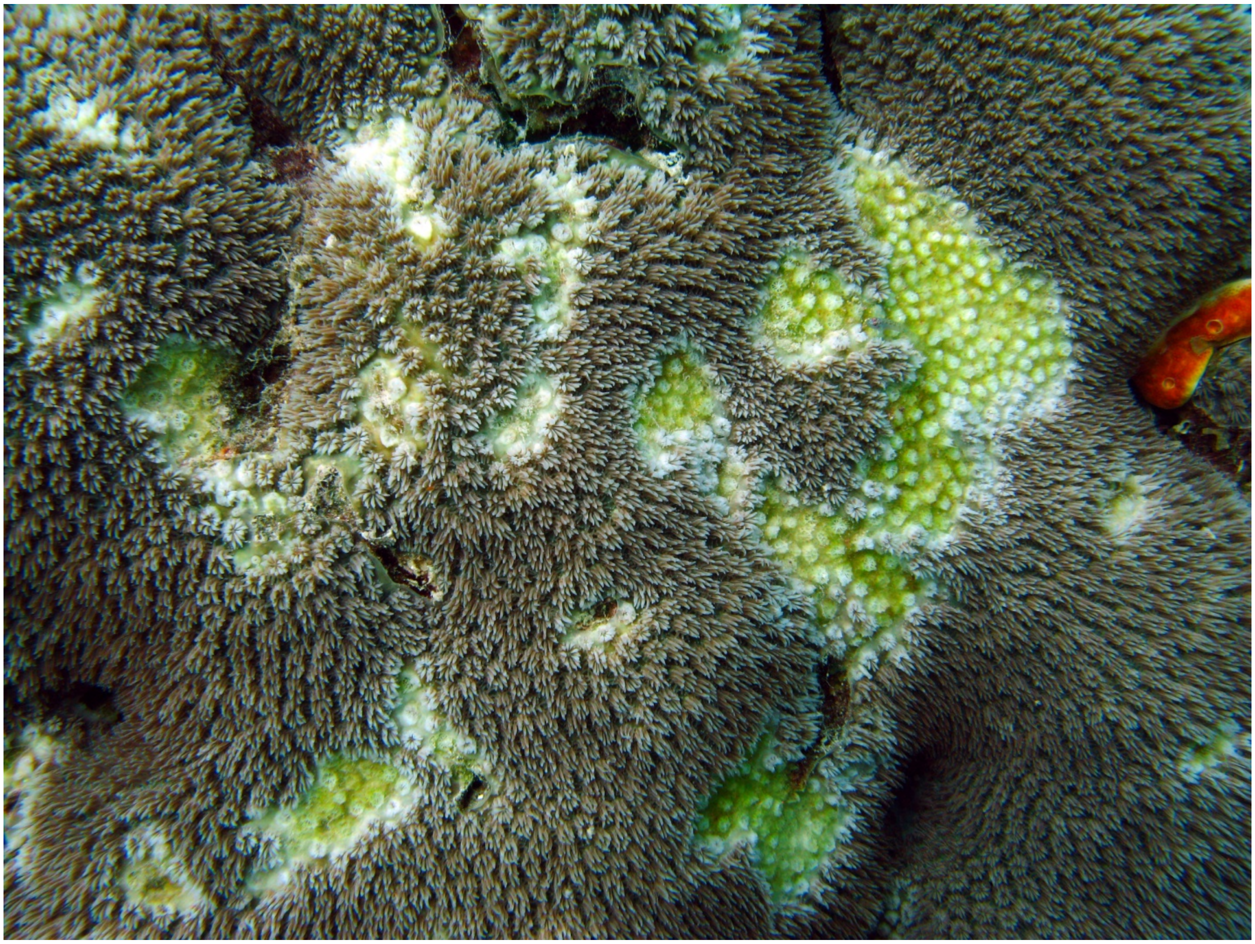


Fig. 7.410. *Galaxea fascicularis* with extensive lesions caused by parrotfish predation.

On the backside of the same bank the reef has the same structure, with the bank top at about 10m, then coral pinnacles that are mostly live. Large, several meter diameter *Porites lutea* and *P. solida* colonies on bank top, patch reefs all alive. Most table *Acropora* are dead, and are completely covered by Xeniid soft corals. This site was also characterized by moderate abundances of macroalgae.

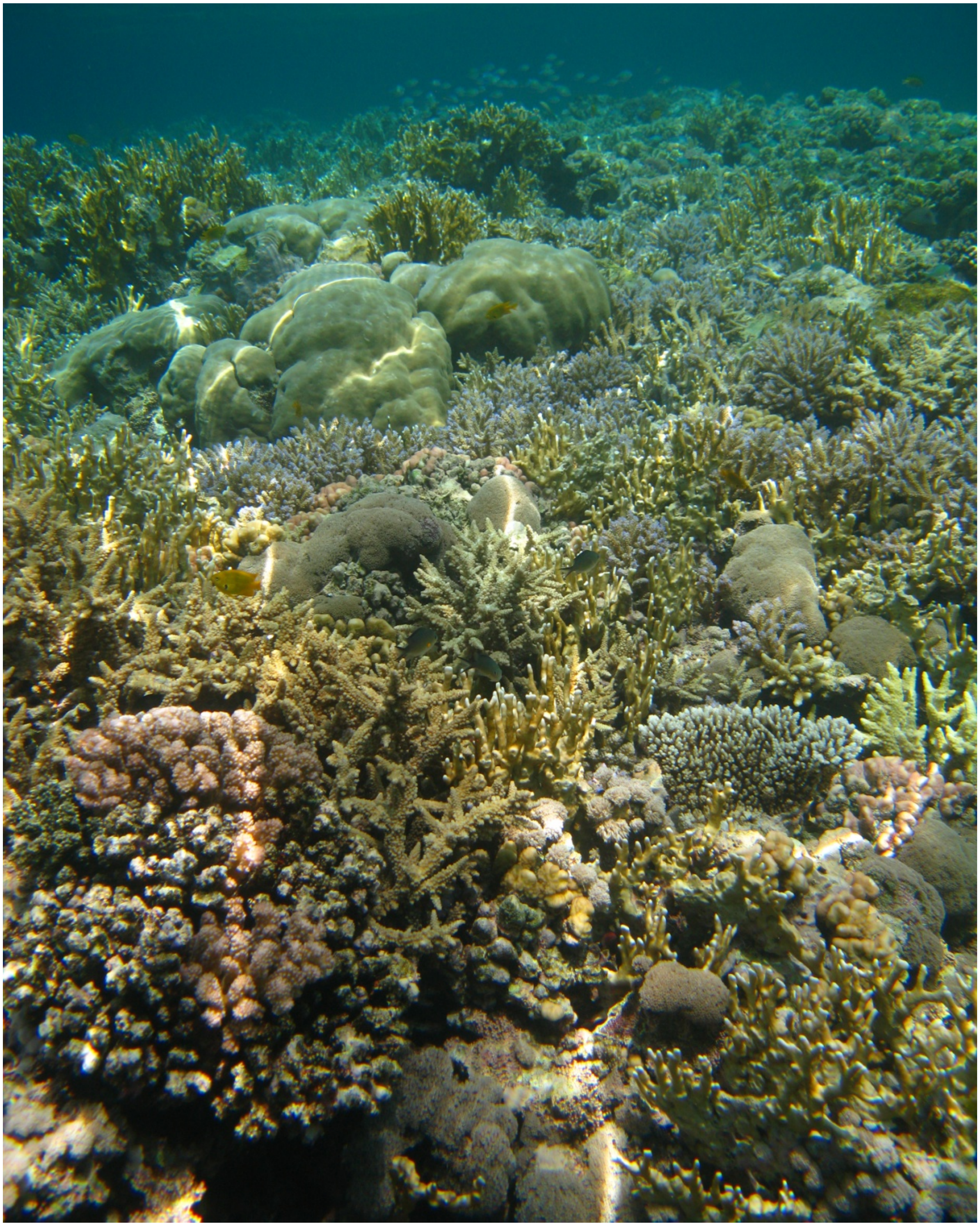


Fig. 7.411. Flourishing reef community at 10 m depth. A high cover of living stony corals, including *Acropora, Porites, Pocillopora* and many faviid species carpeted the bottom.

The southern end had low relief with cover of hard substratum and sand. Cover of living coral ranged from 5 to 10%, while cover of dead standing coral ranged from 10 to 15%. The base of the reef formerly had a faviid carpet, most of which is dead now. The fragile *Seriatopora* was the numerical most abundant coral at the site, followed by *Pocillopora.* High levels of recruitment were recorded, even in the presence of thick algal turf which covered much of the bottom.

7.412 Site 14

Located approx 28 miles offshore, this reef structure had a steep sloping reef face and reef top at about 10 m depth, a second terrace at about 20 m, and a steep drop-off. The reef crest was dominated by *Pocillopora* and *Acropora*. The reef slope was built by numerous massive coral taxa, and has an unusually high diversity of corals including faviids, poritids, *Acropora* tables and patches of leather corals (*Synaraea*). Several unusual corals were identified including an undescribed species of *Acropora* that is tabular and has naked, twisted axial corallites, and a submeandroid hard coral in the genus *Oulophyllia*. Large areas were dominated by *Acropor*a, with table acroporids interspersed among smaller corymbose and arborescent colonies.

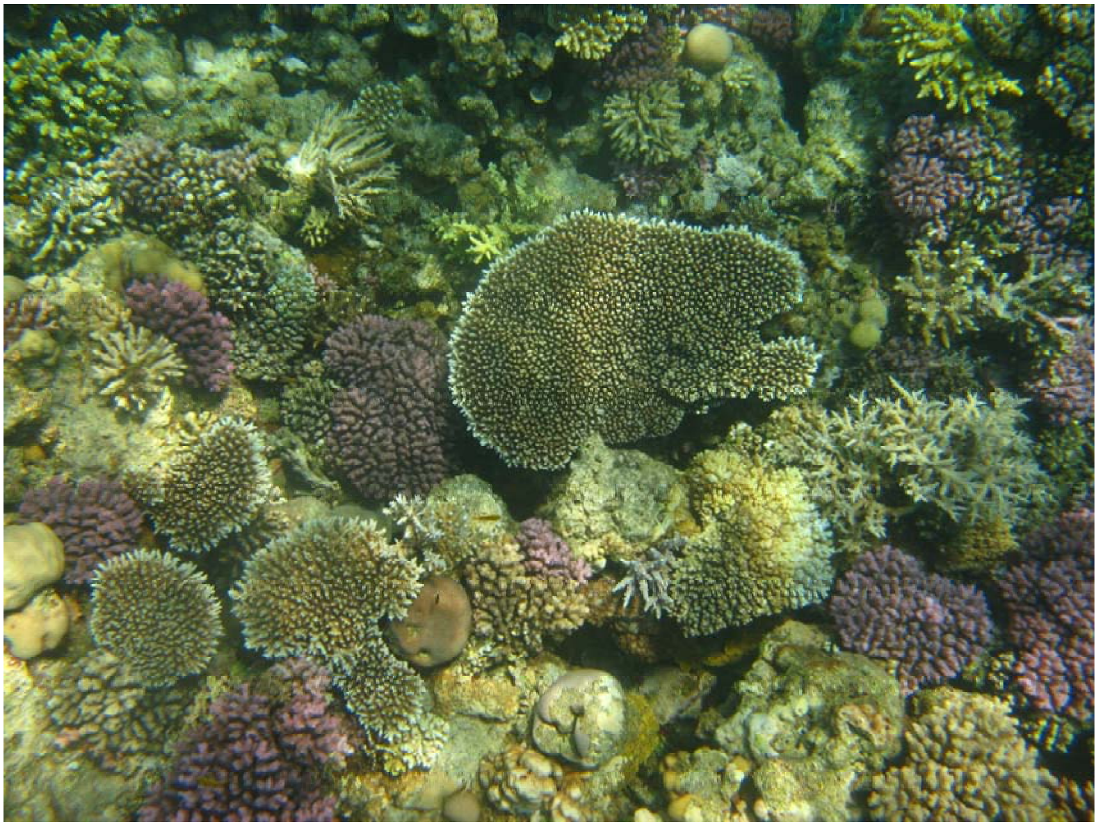


Fig. 7.412. Shallow reef crest community with numerous small branching and table *Acropora* colonies, *Pocillopora*, and small massive colonies.

7.413 Site 15 and 16

Two dives were conducted on an offshore shoal, the first on the outside at the SE corner and the second inside the lagoon. The outer reef had a steep reef slope coming up from the abyss to -20m, then a 2 m wide moat and a second steep slope from 20m to the surface. Coral cover was high (40-50%) throughout the site, including both deep and shallow areas.

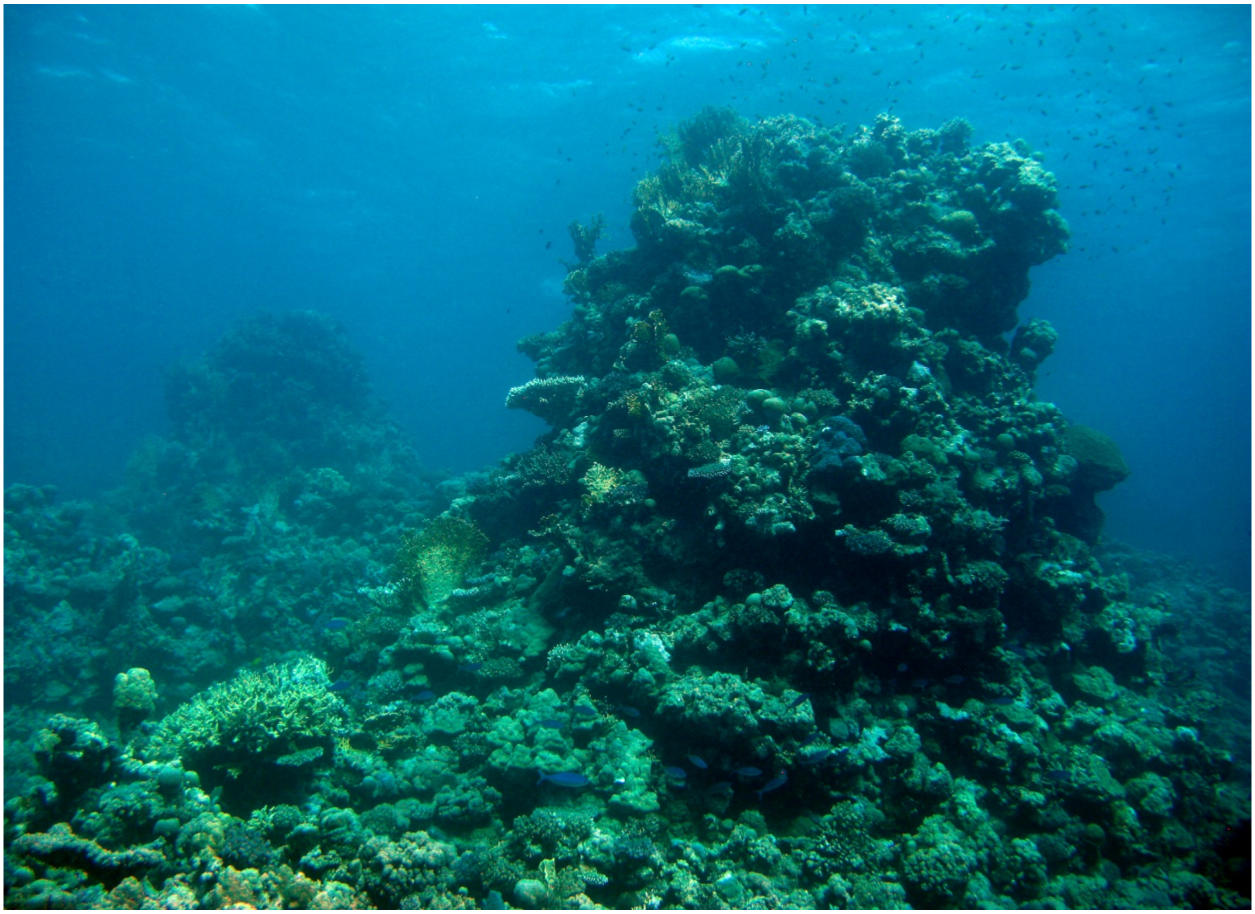


Fig. 7.413. Dramatic pinnacles, covered with living corals, formed on top of the reef platform on the outside of the reef.

The lagoon was fairly deep (>20 m) and turbid, with well-developed faviid carpets at the base and a gentle slope with small massive, branching and plating corals around the rim. Cover of living coral was 15% and dead standing coral 10%. Cover of soft coral was high (50 to 60%). The dominant hard corals were *Echinopora*, *Favites* and *Seriatopora*. This site also had several unusually large (>15 m diameter) colonies of *Lobophyllia*.

7.414 Site 18 and 19, 26, 27

Four locations were examined along an elongate reef system, which extended north to south and curved east at the lower portion. At the southern end, where the reef bends around to the east, a submerged reef systems that lacks a reef crest but has a well-developed shallow terrace (5 m depth) with 80-100% cover of branching *Acropora* and other small massive and branching corals. This terrace slopes gently to 10-15 m to a second terrace with a faviid/poritiid carpet and scattered, large *Acropora* tables. At the edge of the second terrace the reef drops off sharply to the depths. The largest *Acropora* plate measured over 3 m in width (Figure 8). Cover of living coral was 50 to 60%, while dead standing coral was 5 to 10%. The site had many standing table acroporids in growth position, but completely dead for several months, as well as many recently killed (white) corals. Many of the surviving table acroporids also had recent tissue mortality affecting 5-90% of their surface which was attributed to white syndrome and COTs predation. White syndrome was also observed on a large *Diploastrea* colony and several *Goniastrea* colonies. Extensive recent mortality was also observed within the shallow *Acropora* terrace. A night dive verified that the mortality was due to an outbreak of COTs, with several hundred seastars observed within a 300 m^2 area.

The second dive was located to the north, on the exposed western side, where there is a sheer drop-off, with a crest at about 8m. The reef crest forms a 100 m wide, gradually sloping plateau that extends from the shallows (1 m depth) to the drop-off (5 m depth). Living coral cover on the aslope ranged from 15 to 20%. Cover of macroalgae was 25-30%, while cover of crustose coralline algae ranged from 25- 30%. At about 4 m, the 'reef crest' is dominated by small branching *Acropora* (nearly 100% cover of the substratum). Between 4 m and 10 m coral cover was 35-40 %, with a dominance of *Porites*, *Echinopora* and *Galaxea*.

The third dive was on the eastern side, in a relatively protected environment. The shallow terrace (5-10 m depth) had fairly good cover of small branching corals. The reef slope, which was vertical in places, was dominated by unusually large colonies of plating *Montipora*, with 20-60% live coral cover.

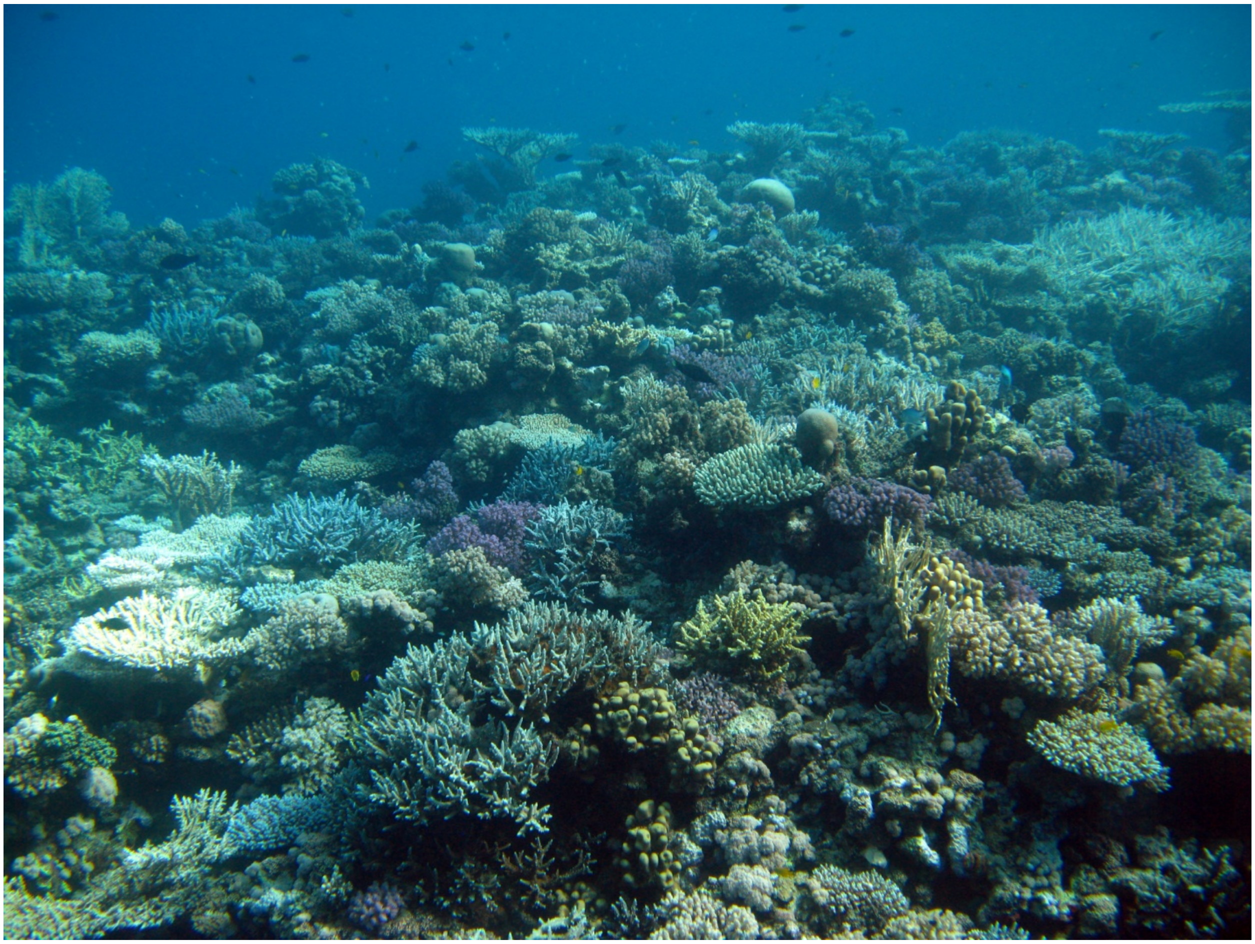


Fig. 7.414. Shallow forereef with a high cover of branching acroporids, pocilloporids and other species. The site is being affected by an outbreak of COTs seastars.

7.415 Site 20

This site was characterized by a very steep reef slope with low cover of living hard coral (≈15%) Dead corals appeared to have died 3-5 years ago, and their skeletons were readily recognizable. Much of the bottom was covered with xeniid soft corals

7.416 Site 21 and 22

Both sites were on an outer atoll-like tower reefs. The first, on the outer windward margin at the northeastern end had steep drop-off, with high cover of living coral (35 to 40%) and moderately high cover of crustose coralline algae at the edge of the slope. The most abundant coral genera, in terms of percentage cover, were *Pocillopora*, *Gardineroseris*, *Favia* and *Diploastrea*. The second site, on the leeward margin consisted of isolated patch reefs in a channel between two reefs. Patch reefs dominated in shallow water by big, live Porites, with a faviid framework, about 1m thick, above the sand, in deep water. Cover of living coral was low (20%), but soft coral ranged in cover from 30 to 40%.

7.417 Site 23 and 24

These sites were located on a small offshore bank reef. At the first site, the entire top of the reef is covered by an open branching *Acropora*, with large *A. hyacinthus* colonies on the reef slope. In the deep, there are well-developed faviid carpets. *Porites*, *Echinopora* and *Millepora* were also very abundant. At the second site, *Pocillopora* was the most abundant coral in terms of percentage cover and number of colonies followed by *Porites* and *Favites.* An unusual massive growth form of *Pavona* was also common. This site was characterized by moderate level of living hard coral (20-30 % and high cover of soft coral (20 to 40%). Abundance of dead standing coral was low.

7.418 Site 27 and 28

Site 27 is a submerged platform located seaward of a nearshore island. The reef has a moderately steep reef slope, (45 degrees) built primarily by *Porites rus*, most of which was alive. Live cover of *P. rus* was 50-80%, with only tiny patches of old mortality. Other dominant coral taxa included *Montipora*, *Echinopora* and *Pocillopora*. In the shallows, (2- 10 m depth), Acropora tables of several species were common.

The second site is another nearshore bank reef, slightly further from the island. It has a similar, moderately deep slope, built primarily by *Synaraea*, with large *Montipora* colonies, especially in the deeper areas and large *Porites* colonies (1 -2 m diameter) at 8 to 12 m. *Echinopora* and *Seriatopora* were also abundant. The shallow 10m were dominated by large *Acropora parapharaonis* and *A. forskali* colonies. Fleshy macroalgae (green and brown algae), especially *Halimeda*, were abundant, covering 20 % of the hard substratum. Sea urchins (*Diadema*) were also common. Both reefs have not been disturbed in the recent past, and no obvious signs of *Acanthaster* predation were seen**.** Coral recruits were about 75% fewer than that seen on offshore reefs.

7.419 Site 29

Site 29 is a shallow fringing reef around a sandy island near the mainland shoreline (within sight of mainland, one could see houses very clearly). The structure appears to be diapiric in origin based on its shape. Coral cover was unusually high from about 2-5 m (80%), corals continued deeper but with strongly decreasing cover. Water was unusually warm, which may have explained the large number of dead corals in very shallow water (<2 m depth). . The corals in the shallow region are dominated by *Acropora*, *Montipora* and *Anacropora* including *A. robusta* which has not been observed on other reefs. *Pavona cactus* and other species of *Pavona* were also common. In deeper water *Cyphastrea* and *Coscinarea* begin to dominate, and free-living fungiids are abundant.

Gentle reef slope dominated by large colonies of *Porites* and *Lobophyllia*. Other corals included *Galaxea*, *Hydnophora* and *Platygyra*. Cover averaged at about 40 percent of the hard substratum. Colonies were healthy, with little evidence of recent mortality or mechanical damage associated with storms events or anchors. Soft corals were extremely abundant, representing about 35% of the hard substratum. COTs, up to 15 cm in diameter, were abundant and feeding during the day. Despite the availability of large *Acropora* plates, these COTs were feeding on *Porites* and *Echinopora*.

7.4120 Site 30a, b, c

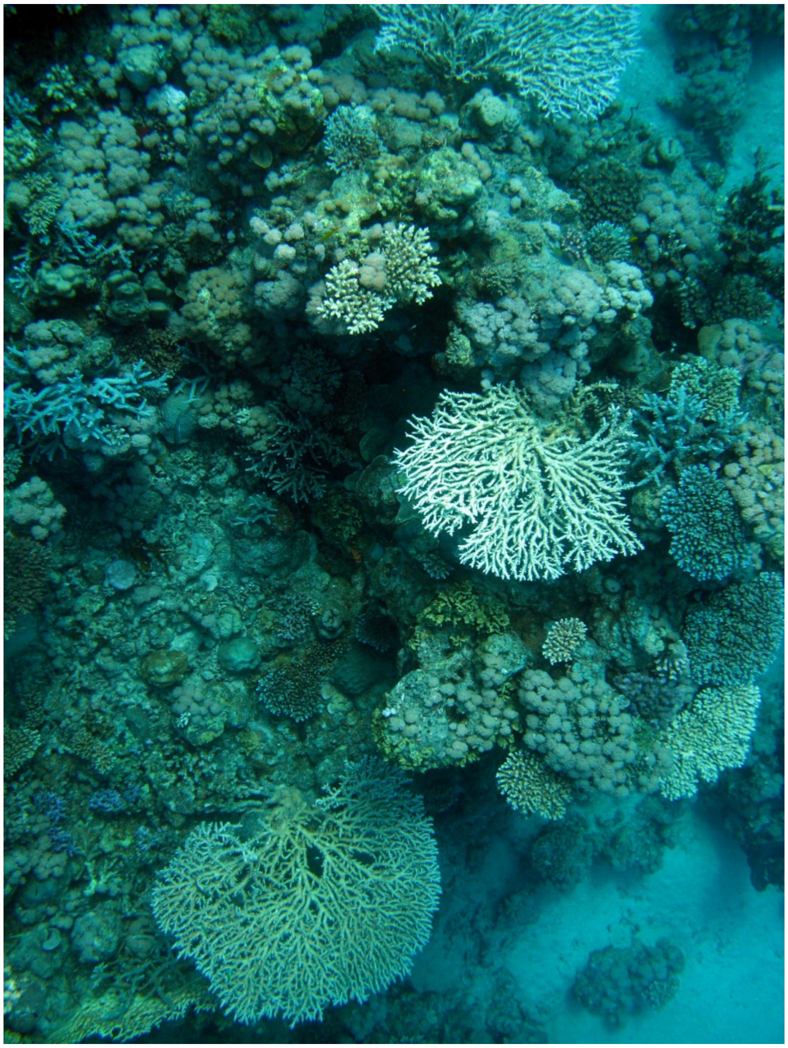
Three inshore reefs near Al Qunfudah were examined on SCUBA and snorkeling. In all locations the water was turbid, seafloors sandy and coral cover drops off quickly with high cover to about 3 m depth and isolated massive corals deeper. The first site, 15 km from the mainland is situated on a shallow shelf (<20 m). Despite high turbidity and sedimentation rates, the reef supported high abundances of living coral. The most dominant taxa in terms of percent coverage were *Porites*, large *Acropora* plate growth forms and *Montipora*. *Millepora* and *Pocillpora*, hard coral genera common at offshore sites were not observed. There was a notable absence of *Pocillopora* and the fire coral *Millepora*.

The second site is an offshore bank with a small sand-island in the middle. The reef fringes the bank for a few meters. Mainly *Porites* colonies are around the sides and on the top. The top of the reef is densely populated by large macroalgae (*Turbinaria* sp. and *Sargassum*) with isolated small colonies of hard corals (*Porites* and *Favites)* and large numbers of urchins (*Diadema* and *Echinometra*). The seagrasses *Halophila ovalis* and *Thalassia hemprichii* were common in protected lagoons in the reef flat. The third site had large *Porites* colonies in the reef crest and upper reef slope *with isolated Echinopora* and *Montipora* colonies.

Fig. 7.4120. Corals compete with macroalgae on the reef flat and reef crest on inshore reefs. Shown here is a dense mat of *Dictyota, Caulerpa* and other species of brown algae atop crustose coralline algae on a reef flat at site 30b.

7.4121 Site 31, 34, 40 and 43

Four sites were examined along a bank reef. The reef system forms the fringe around a large, shallow lagoon. The outer slope is steep, around 60 degrees, and has coral growth to 30-40m. Coral cover is very high (>50%) and diversity is also high. The upper reef slope is marked by



numerous caves or overhangs that support many specimens of cup corals (*Tubastrea*) and wire corals (*Cirripathes*). At 10 m, hard coral was abundant (50% of the hard substratum), being dominated by *Porites* and *Montipora*. Many large *Acropora* tables also occur on the upper slope. There was evidence of mechanical damage (e.g. broken branches of some colonies of *Acropora*) but overall, the community appeared healthy with no sign of major impact.

Figure 7.4121a. Table acroporids are intermixed with a diverse assemblage of hard corals in the upper reef crest at site 31.

Site 34 was on the sheltered edge of the reef. Cover of living hard coral at 10 m was high (40-45%), with a dominance of *Porites* followed by *Favia*, *Favites* and *Lobophyllia*. The soft coral *Tubipora musica* (organ pipe coral) was also abundant at this spot.

Site 40 was mostly dead reef. The break to the drop-off occurred at 10m. The entire drop-off and shallow area was dead. Within the *Pocillopora* zone, no regeneration was observed.

Site 43 had a well-developed framework reef slope to about 20m, beneath that a gently sloping seafloor with even more framework. This was a site of an ongoing *Acanthaster* outbreak, with 496 COTs occurring within a 100 m^2 area of reef. Mortality at the eastern end of the reef was characterized by partial colony mortality rather than whole colony mortality. Much of the mortality was recent and consisted of 1) fresh feeding scares (exposed clean skeleton) on some colonies, and 2) dead coral covered in fine algae. In the area of the outbreak, every single adult coral colony was partially eaten. The recruits had not been eaten (at least in the deeper area. But in the shallow, there is less recruitment, therefore losing the adults is more serious and sets back the population for a longer time.). Looked just like a bleaching event, because the corals were fresh dead. All genera appeared to be attached by COTS. *Porites*, *Echinopora*, *Galaxea* and *Stylophora* were the abundant coral genera, but most were represented by small colonies. A few large plates of *Acropora* survived in the area. Of those colonies that exhibited partial mortality, living tissue seemed to have survived best in crevices or locations not easily accessible to COTS.

7.4122 Site 32 and 33

These sites were located on the same reef, on opposite sides of the outside of the big sinkhole. In the first position, the reef was alive and had dense coral cover, in the second it was mostly dead and covered by recruits (virtually no coral bigger than 5cm). The reefs begin at sea-level and drops steeply about 10 m, to a wide (10-20 m) plateau which is sandy with a faviid carpet. At the edge of the plateau, at 15 m depth is a second drop off. This is near vertical, ending at a second narrow (1-5 m) plateau, at 25-30 m. Coral cover moderately high (30%) on the vertical slope, but much lower at the lip of the drop-off and on the plateau.

The second site has a steep reef slope, from 30 m- 12 m, and a wide sandy plateau at 10 m depth that abuts the modern reef edifice. Very few surviving medium or large corals were seen on the plateau (with exception of *Diploastrea*). There were also few colonies > 5cm, and corals present belong to commonly recruiting taxa such as *Porites*, *Pavona*, *Psammocora*, and *Leptastrea*. The plateau appears to be a major passage through the reef, where heated lagoonal waters could have emptied causing colony bleaching and mortality at frequent intervals. Thick mats and long fronds of red algae covered the substratum and sand.

7.4123 Site 35 and 36

The windward and leeward site of the reef was examined. Both sites had steep, vertical, almost overhanging drop-off extending from 10m depth down. The drop-off had very good coral cover, however, above 10 m there was very little coral growth. At 10 m, there is a 90 degree bend from a vertical cliff to a horizontal reef crest. On the windward side coral cover was high in the deep, but the shallow, at around 10m was largely barren community dominated by soft corals. Many of the large surviving *Porites* colonies were pock-marked with large patches of denuded skeleton. Much of the mortality was recent, and several COTS were seen. An unusually large colony of Goniopora was seen in the lagoon. On the leeward side coral cover was low throughout all depths examined and 90% of the colonies were <20 cm. The largest common hard coral colonies were *Diploastrea* and *Acropora*. Some of the large *Diploastrea* had suffered considerable partial mortality (up to 80% of the entire colony). The site had a high cover of crustose coralline algae (20-30%) and patches of cyanobacteria on the reef, sediment and in among colonies of Xenia. Red algae and cyanobacteria also were competing with recruits for space and many recruits (massive and branching) were being encroached by red algae.

7.4124 Site 37

This site was on the inside slope of a bank reef, facing the lagoon. The reef begins at about 10 m depth, with a very rugose surface, and a steep (45 °) slope that extends to 30m in a sandy lagoon floor. At 10 m, cover of living coral ranged from 20 to 35%. The hard coral *Diploastrea* represented the largest colonies. *Montipora*, *Porites* and *Acropora* colonies were common on outer exposed surfaces and *Leptoseris* was abundant in shaded areas. The site had high cover of crustose coralline alga (CCA; 10 to 20%) and few soft corals.

Figure 7.4124. Filamentous cyanobacteria and *Xenia* covered much of the bottom at site 37.

7.4125 Site 38 and 39

Site 38 was located at the edge of a drop-off with a 45 degree slope. The reef experienced a past disturbance, but was regenerating. Coral populations consisted mainly of small massive faviids, isolated large plating corals and a few *Acropora* colonies. The only large colonies belonged to the genus *Diploastrea*. Most living hard coral colonies were smaller than 30 cm, and were dominated by the genera *Goniopora*, *Pocillopora* and *Porites*. Numerous *Acropora* tables were completely dead, but in growth position. Cover of living coral at 10 m was approximately 10% ; dead standing coral was higher (≈ 20%) and included a large number of small coral colonies. Small brown zoanthids had colonized extensive portions of the reef.

Site 39 was very similar with a lot of dead coral (30-40% cover) and little live coral (10%). The cause of mortality is not clear. Below 3 m, cover of living coral was higher. At 10 m, the only large coral colonies belonged to the genus *Diploastrea*. Other corals included *Astreopora*, *Goniopora*, *Gyrosmilia*, *Pocillopora* and *Porites*. Soft coral (cf. *Xenia*) was common at 10 m. *Xenia* soft corals look like the hard coral *Goniopora*, but the former (like all the Octocorallia) has eight tentacles (versus 24) and the tentacles are fringed by rows of pinnules.

7.4126 Site 41

Site 41 is a beautiful and alive reef. The lagoon had moderate coral cover, consisting mostly of round and elliptical massive and branching colonies of 30-40cm diameter. The shallow reef crest was mostly devoid of corals, while the reef slope, initially a gentle 10° gradient to 10m depth, at the drop-off. The edge of the drop-off had high coral cover (>50%), few dead corals and high numbers of new recruits. No *Pocillopora* zone, neither in the shallowest areas, nor on the edge of the drop-off. The coral assemblage included a full range of colony size classes. The dominant genera were *Echinopora*, *Pocillopora*, *Montipor*a and *Porites*, along with *v*ery large colonies of the hard coral *Hydnophora*.

7.4127 Site 42

This dive was on a small offshore bank reef that is completely submerged. The top of the structure is about 10 m depth, with a relatively gently fore reef slope. Shallow furrows that resemble a spur and groove structure, with considerable sediment in the groove, ran down the slope. Set back from the edge are individual patch reefs that grow to within 1 m of the surface. Cover of living hard coral on the slope was low (≈10 %) and most colonies were small (<20 cm). Soft coral and crustose coralline algae were abundant, covering about 35 and 20% of the hard substratum, respectively.

7.4128 Site 44, 47, 48, 49 and 50

Five locations on adjacent midshelf bank reefs were examined. Dramatic differences in live cover of corals were seen on these reefs. The fore reef slope at sites 48 and 49 was mostly alive, consisting of large massive *Porites* colonies, patches of branching and table acroporids, and a diverse assemblage of large plating corals, while the fore reef of site 50 was mostly dead. The *Porites* framework at this site consisted of small living tissue remnants with isolated small massive corals. In the reef crest, cover was very low (<10%) The *Pocillopora* zone is devastated and shows only very weak regeneration. *Acanthaster* was present and some large colonies were eaten, including about 50% of all *Acropora* tables were eaten. Cover of dead standing coral was high (35-40%). The area was characterized by major overhangs, that supported many colonies of whip corals (cf. *Junceela* or *Viminella*)..

7.4129 Site 45 46

Two dives were completed on another cork-shaped reef. The reef had a shallow crest (7m depth) adjacent to a vertical drop-off. The drop-off had high cover of corals (30 to 35%), mostly live, many of which were large in size. Cover of crustose coralline algae was also high (30%). Consistent with almost all other sites, the genera composition was dominated by *Porites*, *Montipora* and *Favia*. However, some of the largest hard coral colonies included *Diploastrea*. The second dive was in a more sheltered position. The typical 10m platform was sandy, with some early diagenetically cemented hardgrounds, unlike most other areas that are solely hardground. The drop-off, also vertical, had good coral growth with very little free space and numerous large *Porites* (45 to 50% cover). An unusually large plating *Hydnophora exaesa*, several m diameter was observed at 12 m depth. The site also had many other plating corals, including many *Montipora*.

7.4130 Site 51 and 54

Two fringing reefs very close to shore, located near a big island in the southern Farasan Banks were examined. Despite the high turbidity, the coral community was both structurally complex (many different growth forms and size classes) and covered a large area of the hard substratum (50 to 60% coverage). The dominant genera were large plate *Acropora*, massive *Porites* and *Montipora* (encrusting and foliose growth forms). The hard coral genus *Gyrosmilia*, which was normally only observed in shaded areas on the offshore reefs, were found in the open at this site. An undescribed species of *Seriatopora* was also common. Colonies were also larger, on average, than specimens found on the offshore reefs. All hard coral size classes were evident, and there was little old mortality. There was some recent mortality due to COTs predation. Five COTs (average size 15 cm) were observed, two of which were feeding on *Porites* and *Echinopora*, respectively.

7.4131 Site 52-53

Two dives were conducted on nearshore patch reefs located 8-10 miles from shore. These reefs have a much more gentle slope than the offshore structures and much higher coral cover. Water is fairly turbid. In general, from0-7m table acroporids dominated. Between 7-15m isolated table acroporids and abundant soft corals and massive species. Between 15-30m plating corals and flattened colonies of *Porites* dominated. The first reef had very high structural complexity, largely due to *Acropora* tables and *Montipora* plates to about 10 m depth and a moderate cover of living coral (20 to 30%), dominated by *Echinopora*, *Platygyra* and *Porites*, below this. Corals colonies of size classes equal or <10cm were not abundant (average 6 per 1 m^2). A fan-weed macroalgae (*Lobophora* sp.) was abundant at this site. Large areas of the reef framework located at or the reef crest had collapsed and slide down the reef slope. These resulted in furrows of rubble and sand.

Site 53 was on the leeward side of a small linear shaped reef, further seaward than site 52, in turbid water. The reef top (2-3 m depth) was dominated by large *Acropora* plates, while the reef slope, at 10 m, supported many genera of equal abundance. Most colonies at this site were small to medium in size (<40 cm). Common taxa included *Lobophyllia*, *Pavona* and *Seriatopora*.

Pavona was well represented by different growth forms and or species. This was the first site in which the hard coral genus *Merulina* was abundant in terms of number of colonies.

At site 54, cover of living coral ranged from 30 to 40%, with the dominant genera being *Acropora*, *Echinopora*, *Lobophyllia*, *Montipora* and *Porites*. Some of the *Montipora* formed very large colonies with plating and foliose growth forms. Many corals exhibited recent feeding scars associated with COTS. Many corals showed old partial mortality consistent with patterns produced by COTS predation.

7.4132 Site 55

This was an offshore tower reef located at the southwestern end of the Farasan Banks. A survey was completed on the leeward (eastern side, adjacent to a narrow passage leading to the lagoon. The reef had a steep, near vertical drop from ~10 m to 18-20 m where there was a narrow ledge, and overhang and small caves, followed by a vertical drop to the depths. There were very few corals on the top, and sparse coral growth along the vertical surfaces. The best coral development occurred on the top of the ledge.

7.5 Fish assemblages

In analyzing the fish data, variations in fish assemblage structure and relative abundance with the environmental factors described earlier were evaluated. Additional effort was devoted to determining the taxonomic resolution needed for our monitoring protocol to detect differences in fish communities between sites. Species assemblages were significantly different between all latitudinal categories (N, CN, CS, S) with the exception of the comparison between CN and CS (Table 7.51; Figure 7.5g). A loss of discriminatory power occurred when aggregating the data to higher taxonomic levels (i.e. genus, family, and functional group). For instance, when aggregating the data by genera, reefs N compared to S ($R = 0.394$, $p = 0.04$; Table 7.51; Figure 7.5h) and CS compared to S ($R = 0.199$, $p = 0.12$; Table 7.52; Figure 7.5a) were significantly different. By aggregating further to the family level, only N reefs were significantly different from S reefs ($R = 0.445$ $p = 0.03$; Table 7.52; Figure 7.5i). However one pattern was consistent in all of these analyses, fish assemblages differed statistically between N and S reefs. These results question the utility of taxonomic aggregation for purposes of small scale monitoring of fish diversity in the Farasan Banks. When comparing functional groups (planktivore, grazer, etc.) across latitude, reefs N and S (0.221, $p = 0.2$; Table 7.53; Figure 7.5j) and N and CS ($R = 0.23$, $p = 0.33$; Table 7.53; Figure 7.5j) differed statistically. Functional group comparisons between N and S reefs show that planktivores, grazers, grazers / detritivores, and browsers explain approximately 52% of the total variation between the N and S reefs (Table 7.54). Planktivores and browsers were more abundant in the S reefs than N reefs while grazers were more abundant in the N reefs than the S reefs (Table 7.55).

Visual examination of a graphical nMDS plot presenting fish species composition in relation to distance from the mainland, shows distinct clustering of reef fish assemblages on 1-20 and 21-40km reefs as compared to the other categories (41-60km, 61-80, and 81-100km; Figure 16.83k1). In statistically examining reef fish assemblages with increasing distance from mainland, significant differences were noted between most distance categories (Table 7.56). However, fish assemblages on 41-60 km reefs did not statistically differ from those on 81-100km reefs and 61-80km reef fish assemblages were not different to 81-100km fish assemblages (Table 7.57). The results suggest that there is a detectable influence of distance from mainland on fish assemblages. Finally, there was no difference in fish assemblages between exposed (defined as facing north), semi-exposed and sheltered reefs.

Previous work in the Red Sea suggests that fish assemblage structure will vary with latitude (Ormond et al. 1984, Roberts 1986; Roberts & Ormond 1987; Sheppard et al. 1992). These studies reported that in the northern and Central Red Sea, fish diversity typically increased from north to south. Using a cluster analysis to examine species composition and relative abundance of four families (Butterflyfish, Damselfish, Parrotfish, and Surgeonfish) on the Saudi Arabian coast, Roberts (1986) concluded that there were two main and distinct regions of fish species diversity and relative abundance in the Red Sea. The two regions are the North and Central Red Sea and the Southern Red Sea with a distinct boundary at 20 ´N. This is the northern boundary of the Farasan Banks, suggesting that fish assemblages in the Farasan Banks and south are unique and distinct from those north of 20´N. In Roberts´(1986) study, this distinction was most apparent in the surgeonfish, followed by the damselfish and butterflyfish, and finally by the parrotfish. These distinct fish regions are thought to be a consequence of habitat type /structural complexity and water quality effects such as turbidity and nutrient concentration (Edwards & Head 1987; Roberts & Ormond 1987; Sheppard et al 1992).

The extrusion of the broad (130km) and shallow continental shelf starts at the northern boundary of the Farasan Banks (20´N) continuing south to the Strait of Bab el Mandeb, and allows for higher resuspension of sediment and nutrients than in the north. Fringing reefs in the south are therefore shallower, more turbid, less developed and inshore reefs are dominated by macroalgae (Sheppard et al 1992). As fish species richness in the Red Sea is strongly correlated with biological diversity of the substratum (Roberts & Ormond 1987), fish species diversity in the Farasan Banks is expected to be lower than on northern reefs. Furthermore, the proximity of the Farasan Banks to the Strait of Bab el Mandeb, allows for inflow of high nutrient rich waters yielding high primary productivity (plankton) in the water column. This is supported by our observations that planktivores in the S reefs were higher in abundance than those in N reefs (Table 7.57). Similarly, distribution of other species, such as *Pomacanthus asfur* an angelfish that is more abundant on inshore as compared to outer reefs may be due to relatively higher abundance of its preferable prey, sponges, on inner, more turbid reefs (Table 7.58). The herbivorous surgeonfish *C. striatus* and *N. elagans*, and the parrotfish *C. sordidus* were dominate on less turbid outer shelf reefs, suggesting a more plentiful source of food and higher algal cover (Table 7.59).

Consistent with our earlier analyses of benthic lifeforms, we observed no difference in fish communities between exposed, semi-exposed and sheltered reefs. This is to be expected as Red Sea fish communities are strongly correlated with benthic biodiversity and habitat complexity (Roberts 1986; Roberts & Ormond 1987). Reefs that were sampled are probably exposed to both northerly and southerly wind / current action (Edwards & Head 1987) and therefore have not developed biological communities characteristic of windward / leeward conditions. Even pelagic (or water column) species such as *C. lunaris and C. striatus*, that may associate more closely with prevailing winds and the associated currents did not show strong differences in abundance or diversity. Finally most of the reefs sampled were small in size and therefore did not have truly sheltered benthic habitats (lagoonal habitats, etc.) that could support truly distinct associated fish communities associated with these features.

Latitude	*R statistic*	*Significance Level %*	*Permutations*	*Permutations*
N, CN	**0.291**	**1.1**	**1184040**	**999**
N, CS	**0.304**	**1.5**	**1161280**	**999**
N, S	**0.584**	**0.1**	**11440**	**999**
CN.CS	0.036	**19.6**	**Very large**	**999**
CN, S	**0.161**	**3.3**	**14307150**	**999**
CS, S	**0.189**	**2.8**	**817190**	**999**

Table 7.51 Pairwise comparison of fish species on the different reef groups. Statistically significant differences are in bold. Reef groups are classified as N = North, CN = Central North; CS = Central South and S = South.

Latitude	*R statistic*	*Significance Level %*	*Permutations*	*Permutations*
N, CN	0.13	11.4	1184040	999
N, CS	0.156	9.3	1161280	999
N, S	**0.394**	**0.4**	**11440**	**999**
CN.CS	-0.003	46.7	Very large	999
CN, S	0.146	5.9	14307150	999
CS, S	**0.199**	**1.2**	**817190**	**999**

Table 7.52. Pairwise comparison of fish genera on the different reef groups. Statistically significant differences are in bold. Reef groups are classified as N = North; CN = Central North; CS = Central South; and S = South.

Latitude	*R statistic*	*Significance Level %*	*Permutations*	*Permutations*
N, CN	0.08	18.7	1184040	999
N, CS	0.101	14.1	1161280	999
N, S	**0.445**	**0.3**	**11440**	**999**
CN.CS	-0.018	55.7	Very large	999
CN, S	0.093	15	14307150	999
CS, S	0.126	7.8	817190	999

Table 7.53. Pairwise comparison of fish families on the different reef groups. Statistically significant differences are in bold. Reef groups are classified as N = North, CN = Central North; CS = Central South and S = South.

Latitude	*R statistic*	*Significance Level %*	*Permutations*	*Permutations*
N, CN	0.148	9.7	1184040	999
N, CS	**0.23**	**3.3**	**1161280**	**999**
N, S	**0.221**	**2**	**11440**	**999**
CN.CS	0.003	43.6	Very large	999
CN, S	-0.049	66.1	14307150	999

Table 7.54. Pairwise comparison of fish functional groups on the different reef groups. Statistically significant differences are in bold. Reef groups are classified as N = North, CN = Central North; CS = Central South and S = South.

	Group N	Group S				
Functional Group	*Av.Abund*	*Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Planktivore	**2.4**	**4.11**	**4.7**	**1.25**	**23.23**	**23.23**
Grazer	**1.81**	**1.14**	**2.11**	**1.48**	**10.45**	**33.69**
Grazer / Detritivore	**1.01**	**1.1**	**1.98**	**1.35**	**9.8**	**43.49**
Browsers	**0.35**	**0.87**	**1.62**	**1.2**	**8.02**	**51.5**
Excavator	1.43	1.17	1.58	1.55	7.8	59.31
Generalist/Corallivore	1.48	1.11	1.55	1.27	7.67	66.98
Omnivores	1.85	2.42	1.53	1.47	7.57	74.55
Predator	2.85	3.25	1.45	1.43	7.17	81.71
Scraper	2.83	2.82	1.39	0.97	6.89	88.6
Corallivore	1.91	1.98	1.28	1.53	6.31	94.91

Table 7.55. Individual functional group pairway comparisons between N and S reefs. Planktivores, grazers, grazers / detritivores, and browsers are in bold as they explain the majority of total variation (52%) between these reefs.

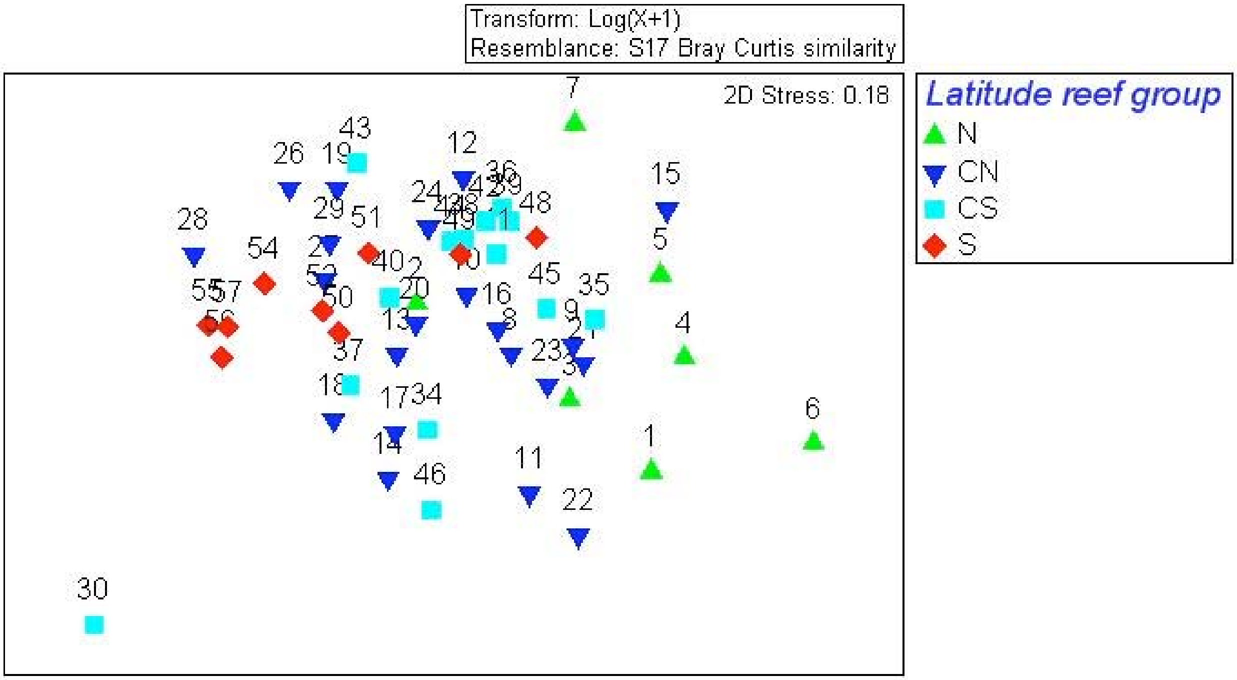


Fig. 7.5a. nMDS plot showing relationship between fish species on reef groups with distance from north to south of the study area (CN or Central North Reef Group, CS or Central South Reef Group and S or South Reef Group (Log transformation with Bray Curtis Similarity).

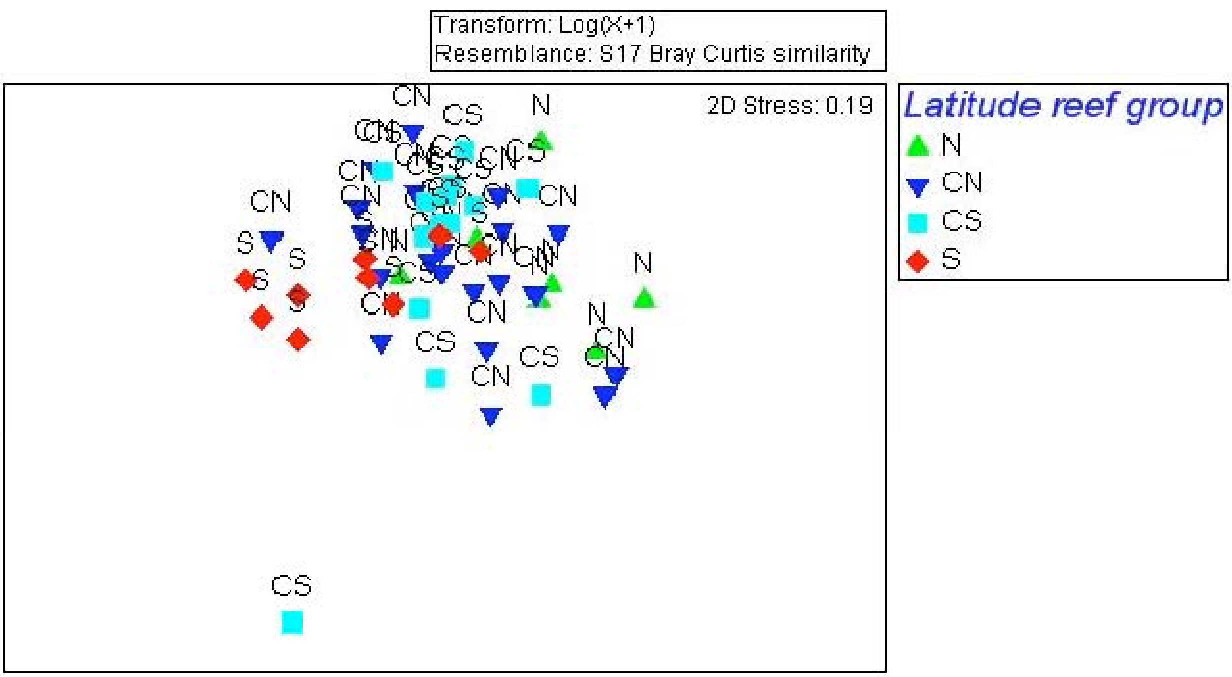


Fig. 7.5b. nMDS plot showing relationship between fish genera on reef groups with distance from north to south of the study area (CN or Central North Reef Group, CS or Central South Reef Group and S or South Reef Group (Log transformation with Bray Curtis Similarity).

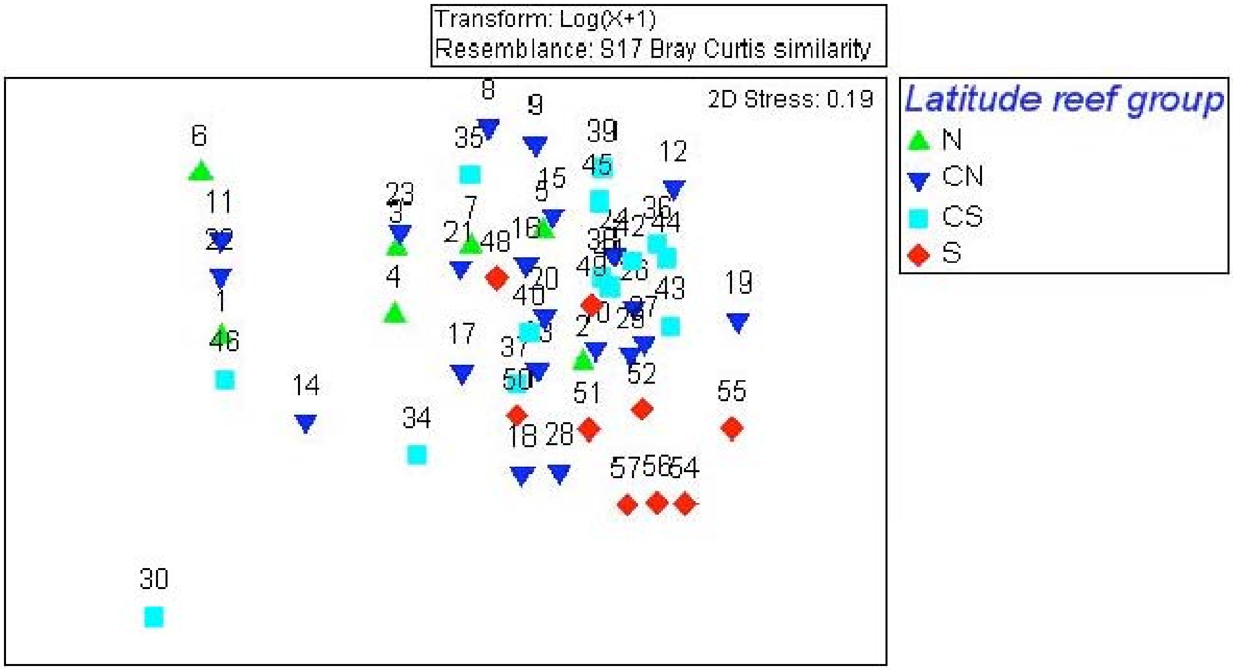


Fig. 7.5c. nMDS plot showing relationship between fish families on reef groups with distance from north to south of the study area (CN or Central North Reef Group, CS or Central South Reef Group and S or South Reef Group (Log transformation with Bray Curtis Similarity).

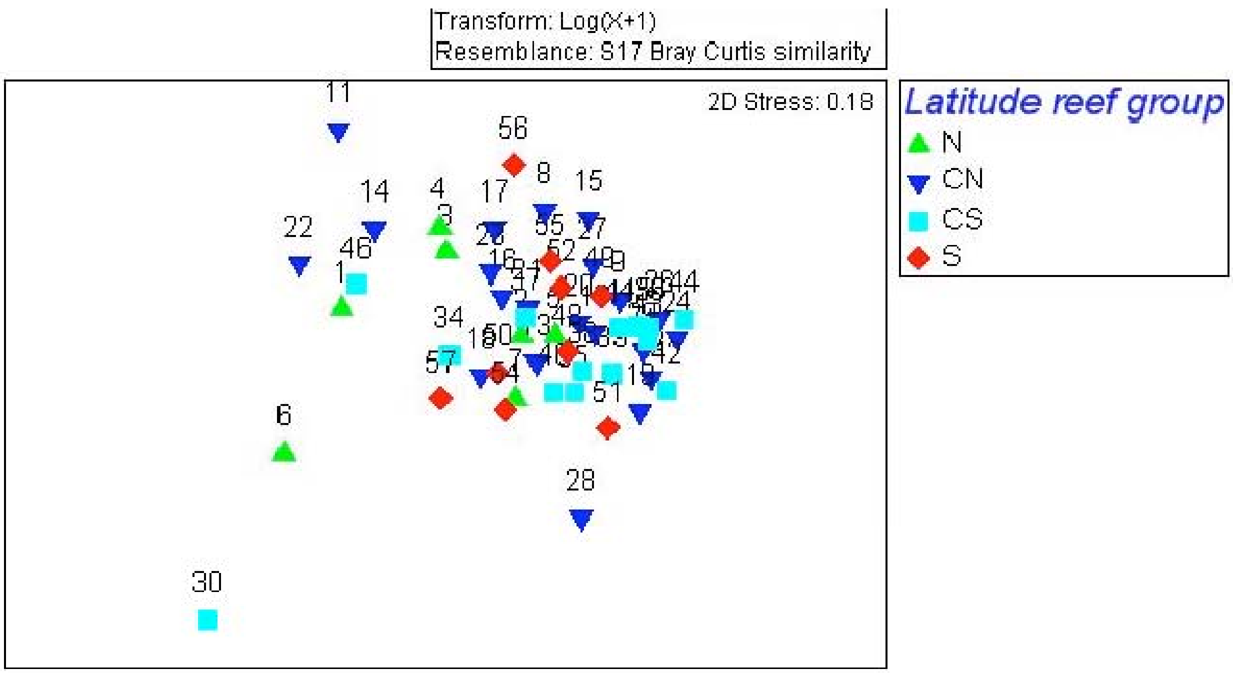


Fig. 7.5d. nMDS plot showing relationship between fish functional groups on reef groups with distance from north to south of the study area (CN or Central North Reef Group, CS or Central South Reef Group and S or South Reef Group (Log transformation with Bray Curtis Similarity).

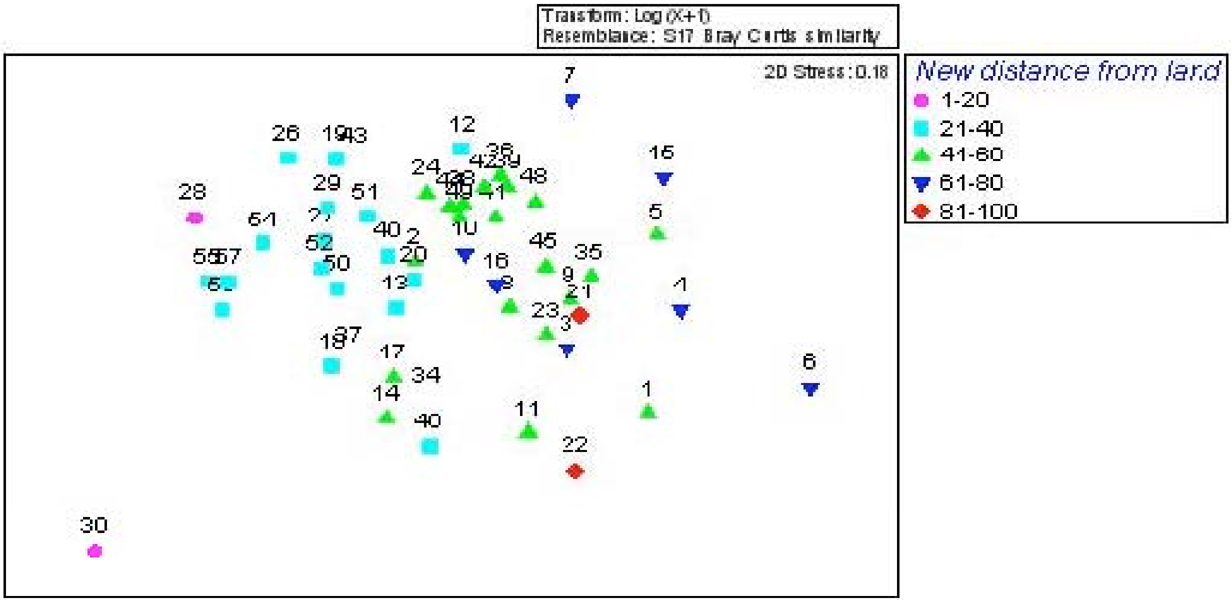


Fig. 7.5e. nMDS plot showing fish species composition in relation to distance from the mainland (Log transformation with Bray Curtis Similarity).

Distance (km)	*R*	*Significance Level %*	*Possible Permutations*	*Actual Permutations*
41-60, 61-80	**0.241**	**2.9**	**888030**	**999**
41-60, 21-40	**0.408**	**0.1**	**Very large**	**999**
41-60, 81-100	0.233	10.4	231	231
41-60, 1-20	**0.942**	**0.4**	**231**	**231**
61-80, 21-40	**0.658**	**0.1**	**346104**	**999**
61-80, 81-100	**-0.201**	**80.6**	**36**	**36**
61-80, 1-20	**0.929**	**2.8**	**36**	**36**
21-40, 81-100	**0.825**	**0.6**	**171**	**171**
21-40, 1-20	**0.598**	**2.3**	**171**	**171**
81-100, 1-20	1	33.3	3	3

Table 7.56. Pairwise comparison of fish species with distance from the mainland. Categories in bold represent significant differences.

	Distance 81-100km	Distance 1-20km				
Species	*Av.Abund*	*Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Ctenochaetus striatus	2.99	0.85	4.21	1.47	6.47	6.47
Acanthurus gahm	0.55	2.77	3.86	1.78	5.93	12.40
Caesio lunaris	2.06	0.00	3.40	0.85	5.22	17.62
Naso elagans	1.76	0.00	3.26	3.05	5.01	22.63
Chlorurus sordidus	1.79	0.00	3.25	5.56	5.00	27.62
Caesio striata	0.00	1.79	2.79	0.86	4.29	31.91
Chaetidon larvatus	0.35	1.67	2.46	1.84	3.78	35.69
Pomacanthus asfur	0.00	1.35	2.40	8.52	3.69	39.39

Table 7.57. Pairway comparisons between innermost and outermost reefs that were surveyed. These 8 species explain approximately 39% of the total variation between these reefs.

An additional statistical analysis of the fish survey data was performed using PRIMER v6 (Clarke & Gorley 2006). Data was examined at 4 levels: functional group, family, genus and species. Data was log transformed before analysis in order to prevent data skewing due to high abundances of one or two taxa. The Bray-Curtis similarity index (Bray & Curtis 1957) was used to determine similarity among sites based on abundance of fish group (functional group, family, etc.). Habitat variables (distance from shore, latitude, reef exposure and midshelf vs. farshelf) were analyzed to determine which factors were responsible for differences in fish group composition among sites in the Farasan Banks. Variation in fish group composition with respect to habitat variables was tested using a 1-way Analysis of Similarity (ANOSIM). Non-metric multidimensional scaling (NMDS) was used to provide a visual summary of the Bray-Curtis similarity matrix. Similarity Percentages (SIMPER) analysis was used to determine which fish taxa/functional groups were most responsible for the variation seen among habitats. The Shannon-Wiener diversity index (H) (Shannon 1948), Pielou's evenness (J) (Pielou 1966) and species richness (S) were calculated for each site.

The fish group composition varied significantly at all four levels, functional group, family, genera and species (

Table 7.587.58). These results show that the location of reef habitat with respect to land was the main factor in determining fish community composition. The separation of sites is evident in the MDS plots (Fig. 7.5f), especially the plots of midshelf vs farshelf. Furthermore, the similar results between the genera (and to a lesser extent family) and species level analysis supports other studies that have shown higher taxon analyses to be an accurate proxy for species level biodiversity (Brien et al. 1998, Adrain & Westrop 2000, Pandolfi 2001, Mandelik et al. 2007). This is particularly beneficial for marine park managers who might not have the time or expertise to identify fish to the species level.

	Distance to shore	Latitude	Reef exposure	Mid vs. far
Functional group	**p=0.028, R=0.101**	p=0.472, R=0.004	p=0.433, R=0.007	**p=0.036, R=0.107**
Family	**p=0.022, R=0.118**	p=0.268, R=0.033	p=0.265, R=0.026	**p=0.002, R=0.189**
Genera	**p=0.001, R=0.196**	p=0.178, R=0.056	p=0.163, R=0.046	**p=0.001, R=0.285**
Species	**p=0.001, R=0.238**	p=0.072, R=0.080	p=0.302, R=0.024	**p=0.001, R=0.259**

Table 7.58 - 1-way ANOSIMS performed on the various fish groups and habitat variables. R and p values are reported and significant results are in bold.

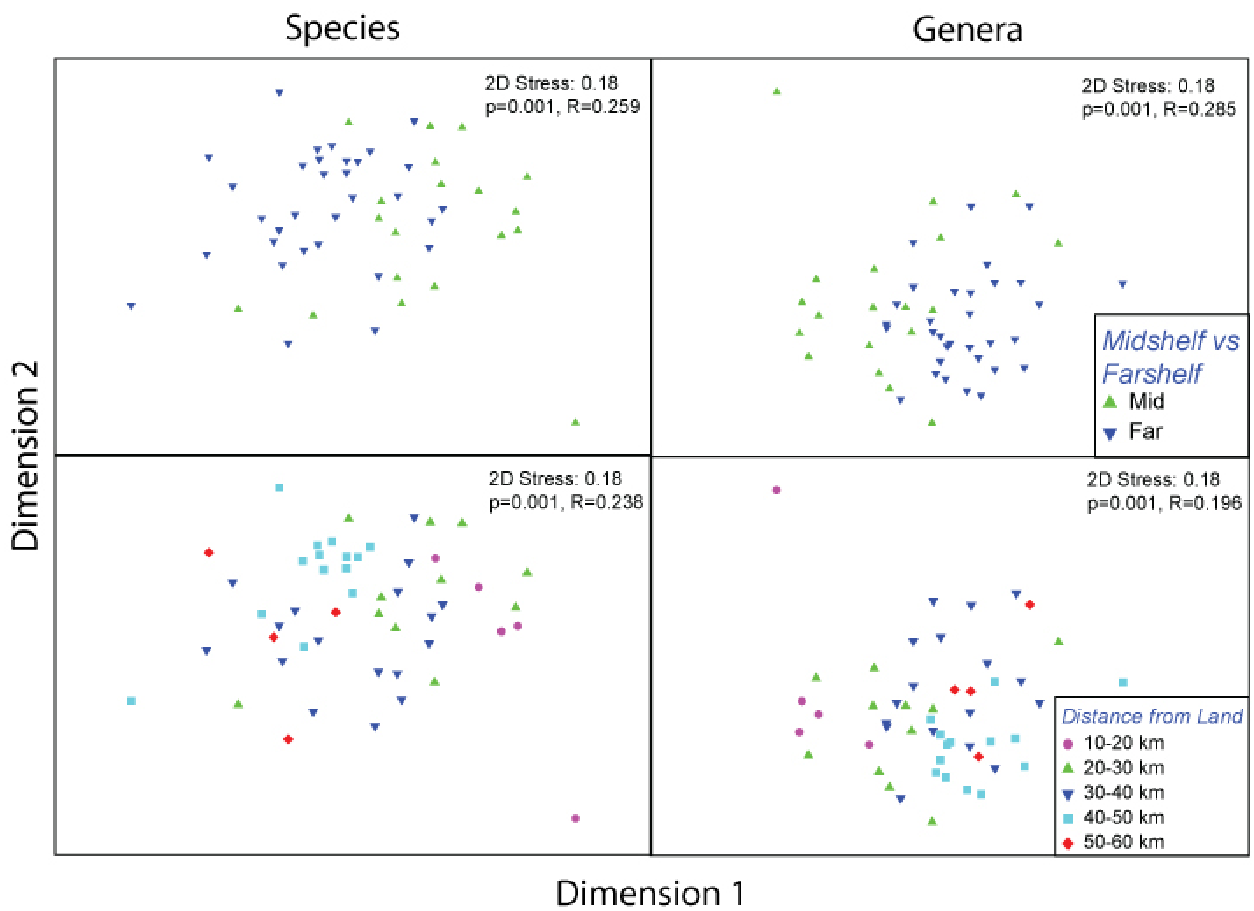


Fig. 7.5f . Nonmetric multidimensional scaling (NMDS) of fish taxonomic composition (species and genera) in the Farasan Banks. Each dot represents a site with the top graphs distinguishing between midshelf and farshelf and the bottom graphs distinguishing distance from shore.

Similar results are seen in Figure 7.5g with both the species and genus level results showing the same pattern of low species richness close to shore followed by a peak in richness found 20-30 km from shore. Then there is a gradual decline in richness with increasing distance from shore. When examining the other diversity measures for distance from shore (Figure 7.5g) there is no significant difference in these measures with respect to distance from shore. Also, there is no discernable difference between any of the diversity measures when comparing midshelf to farshelf reef habitats (Fig. 7.5g). Excluding the changes in richness seen in Figure 7.5g, the lack of variation in diversity statistics suggests that the significant results seen in the ANOSIMs are due to taxonomic composition of these groupings.

Examining the species level SIMPER results for distance from shore (

), three species of fish, *Caesio lunaris*, *Lutanus fulvilflamma* and *Ctenochaetus striatus*, are most responsible for the significant differences seen in the ANOSIM results. *Caesio lunaris* is found in very low abundances close to shore and increases further from shore. *Lutjanus fulvilflamma* shows an opposite pattern as it is very abundant close to shore and decreases in abundance further from shore. *Ctenochaetus striatus* is one of the most abundant species of fish seen in all distance categories except for the 10-20 km range where it is found in lower abundance. The SIMPER results for midshelf vs farshelf reef (

Table) show the same patterns as was seen in the results for distance from shore.

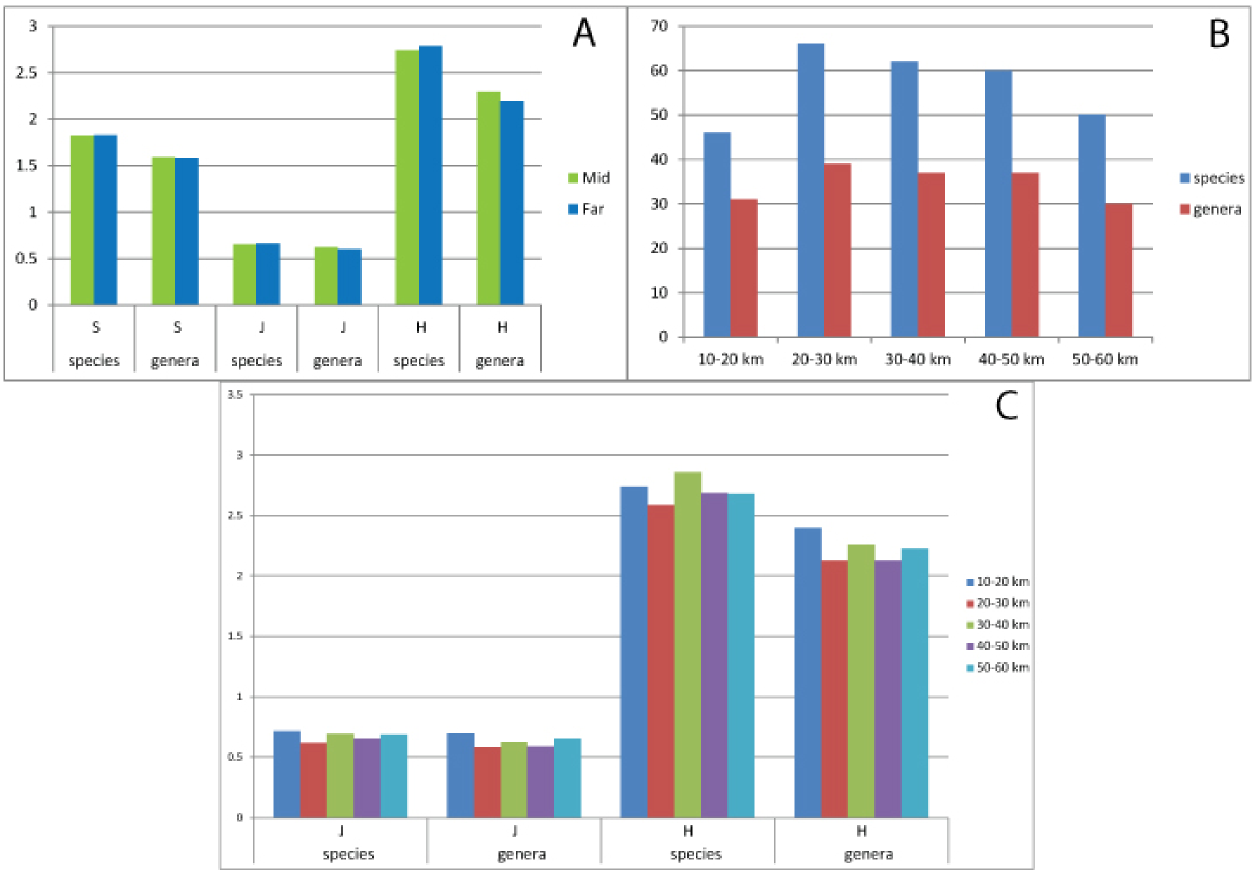


Figure 7.5g. Diversity plots for the Farasan Banks. A) Plots of richness (S)(log transformed to better fit on axes of graph), evenness (J), and Shannon-Wiener diversity index (H) comparing midshelf (Mid) and farshelf (Far) localities for both species and genera. B) Plots of S comparing species and genera with distance from shore. C) Plots of J and H comparing species and genera with distance from shore.

	Contrib. %	Cum. %	Av. Abund. %
10-20 km			
Caesio striata	9.73	9.73	5.56
Cheilinus quinqueinctus	9.00	18.73	2.48
Scarus ferrugineus	8.34	27.07	2.39
Chaetodon larvatus	8.28	35.35	2.27
Pomacanthus asfur	7.96	43.31	2.62
Lutjanus fulviflamma	7.91	51.22	3.54
Cephalopholis hemistiktos	7.63	58.86	2.07
Scarus niger	4.93	63.79	2.14
Ctenochaetus striatus	4.47	68.26	1.99
Acanthurus gahm	3.47	71.73	2.06
20-30 km			
Caesio striata	12.59	12.59	7.48
Ctenochaetus striatus	9.79	22.38	3.43
Scarus ferrugineus	6.29	28.67	2.13
Chaetodon larvatus	6.18	34.86	2.21
Scarus niger	6.08	40.94	2.21
Lutjanus fulviflamma	5.36	46.30	3.05
Acanthurus gahm	5.10	51.40	3.04
Cheilinus quinqueinctus	4.54	55.94	1.91
Scarus frenatus	3.95	59.89	1.36
Cephalopholis hemistiktos	3.91	63.81	1.48
30-40 km			
Ctenochaetus striatus	12.26	12.26	4.04
Scarus niger	8.50	20.75	2.69
Scarus ferrugineus	7.26	28.01	2.35
Cephalopholis hemistiktos	5.60	33.62	1.94
Chaetodon larvatus	5.23	38.85	1.93
Caesio striata	5.17	44.01	4.17
Chlorurus sordidus	4.22	48.24	1.76
Scarus frenatus	4.19	52.43	1.38
Cheilinus quinqueinctus	4.16	56.59	1.83
Balistapus undulatus	3.83	60.42	1.41
40-50 km			
Caesio lunaris	12.39	12.39	6.57
Caesio striata	10.68	23.07	7.38
Ctenochaetus striatus	9.93	33.00	4.39
Scarus niger	5.11	38.11	2.55
Scarus ferrugineus	5.03	43.14	2.42
Acanthurus gahm	5.01	48.16	3.24
Cephalopholis hemistiktos	4.78	52.94	2.42
Balistapus undulatus	4.35	57.29	2.00
Cephalopholis argus	3.96	61.25	1.92
Zebrasoma desjardini	3.14	64.39	1.57
50-60 km			
Ctenochaetus striatus	13.85	13.85	4.30
Caesio lunaris	11.20	25.04	5.67
Scarus niger	8.47	33.51	3.04
Naso elagans	7.58	41.10	2.27
Cephalopholis hemistiktos	7.07	48.17	2.24
Balistapus undulatus	4.66	52.83	1.47
Scarus ferrugineus	4.51	57.34	1.49
Calotomus viridescens	4.44	61.78	1.35
Cheilinus quinqueinctus	4.15	65.94	1.43
Chaetodon austriacus	4.07	70.00	1.56

Table 7.59 – Within group similarity SIMPER results for the species level data examining distance from shore. Top ten contributing species for each distance grouping are listed with contributing percentage, cumulative percentage and average abundance. Species are ranked by contribution percentage.

	Contrib. %	Cum. %	Av. Abund. %
Midshelf			
Caesio striata	10.15	10.15	6.10
Ctenochaetus striatus	9.21	19.36	3.29
Scarus ferrugineus	7.48	26.84	2.25
Chaetodon larvatus	6.89	33.73	2.19
Scarus niger	6.58	40.31	2.29
Cheilinus quinqueinctus	6.47	46.78	2.15
Lutjanus fulviflamma	5.75	52.53	2.95
Cephalopholis hemistiktos	5.34	57.87	1.72
Acanthurus gahm	3.44	61.30	2.30
Scarus frenatus	3.43	64.73	1.24
Farshelf			
Ctenochaetus striatus	11.25	11.25	4.14
Caesio lunaris	9.48	20.73	5.69
Caesio striata	7.17	27.90	5.43
Scarus niger	6.88	34.77	2.66
Scarus ferrugineus	5.75	40.52	2.26
Cephalopholis hemistiktos	5.31	45.83	2.18
Balistapus undulatus	4.36	50.19	1.72
Naso elagans	3.51	53.7	1.57
Acanthurus gahm	3.34	57.04	2.35
Chaetodon austriacus	3.30	60.33	1.42

Table 7.510. - Within group similarity SIMPER results for the species level data examining midshelf vs farshelf habitats. Top ten contributing species for each distance grouping are listed with contributing percentage, cumulative percentage and average abundance. Species are ranked by contribution percentage.

7.6 Threats and resilience indicators

Even though a number of degraded sites had very few remaining adult corals, the sites appeared to be highly resilient as defined by the sensitivity of the coral assemblages, exposure to abnormal environmental parameters, and adaptive capacity of the corals. Biological attributes included the diversity and size structure of corals, including the abundance of large corals and numbers of recruits, condition of the substrate especially the amount of macroalgae and other competitors, and presence of intact functional groups of fishes. Representatives of most of the key functional groups of fishes were present, especially herbivorous surgeonfish, rabbitfish and parrotfish which are important in controlling algae. Pest species were generally uncommon on Farasan Banks reefs, with exception of a few cases of overgrowth by clionid sponges and high cover of *Xenia*.

Substrate quality and reef morphology, including the topographic complexity, sediment composition and depth, and the amount of rubble are also important resilience indicators.

Substrate composition is a useful metric to determine the amount of space available for the settlement of new corals and the likelihood of their survival. In general, most reefs had relatively high rugosity, several canopy layers (which helps shade corals), and low amounts of loose rubble (which makes the substrate unstable and reduces the settlement of corals), and little macroalgae (which overgrows and smothers slower growing corals).

The region also exhibits a number of physical factors that confer resilience. These included: 1) the presence of strong currents and high wave action on outer reefs; 2) extension of reef environments into deep water which can help maintain cooler water temperatures, especially during periods of thermal stress. The aspect of reef slope, facing direction of the reef, and presence of cliffs and above-water features, as well as larger canopy corals reduce light levels, potentially reducing the likelihood of coral bleaching during periods of thermal stress. Analytical classes include the relative width of the platform, whether it is linked or not to the mainland, the degree of circulation within a platform, the orientation of habitat features and relative wind exposure, the depositional environment, and depth of the habitat patch under question and the latitude.

Hard coral genera composition: Genera composition varied with latitude (Global R = 0.182; P = 0.001; Fig. 7.6a). Note that the assessment of latitude did not include Group N because no genus level data were collected from this reef group. Pairwise comparisons suggested that only the CS and S reef groups did not differ statistically (Table 7.61). Differences between CN and the more southerly reef groups (CS and S) were largely influenced by greater mean abundances of *Millepora*, *Pocillopora* and *Acropora* recorded in the CN reef group. It is not entirely clear why abundances of these genera varied with latitude. Abundances of some genera may be correlated with turbidly, total suspended solids (TSS), nutrients and primary productivity all of which increase southward in the Red Sea (Edwards & Head 1987; Price et al. 1998; Weikert 1987). Hard corals vary in their tolerance to different levels of turbidity and TSS (Fabricius 2005) and to sedimentation rates. Turbidity and sedimentation rates increase with distance down the Saudi Arabian Red Sea because the shelf gets wider and shallower, and there is a greater prevalence of unconsolidated sediment (Sheppard & Sheppard 1991; Sheppard et al. 1992; Price et al. 1998). TSS is a measure of the mass of fine inorganic particles suspended in the water. TSS and other material (e.g. plankton) in the water column attenuates light, decreasing the light available to corals for photosynthesis. Paradoxically, high levels of material in the water column may benefit some species by increasing levels of suspended particulate food (Anthony & Fabricius 2000). We do not have data of these environmental variables to test these hypotheses and thus can only speculate as to their importance.

Groups Statistics	*R Statistic*	*Significance level*	*Actual permutations*
CN, CS	**0.217**	**0.001**	**999**
CN, S	**0.231**	**0.006**	**999**
CS, S	0.057	0.22	999

Table 7.61. Pairwise comparison of reef groups. Note the most northerly reef group (N) is not included due to the absence of genera data. Statistically significant differences are in bold. Reef groups are classified as CN = Central North; Central South and South.

Genera composition also varied with distance from the mainland (Global R = 0.173; P = 0.006; Figure 7.6b). Reefs were classified as those 1-20 km from the mainland, 21-40 km from the mainland and so forth. Pairwise comparisons were statistically significant for all pair comparisons of distant groups (Table 7.61). Differences between reefs 21 to 40 km and reefs 41-60 km offshore were highly influenced by the abundance of *Pocillopora*, *Acropora* and *Millepora*. The former was more abundant on reefs 41-60 km offshore, while *Acropora* and *Millepora* were more abundant on reefs 21-40 km offshore. In contrast, abundances of *Favia*, *Favites* and *Astreopora* differed between reefs 21 to 40 km with reefs 61 to 100 km offshore. Reefs closer to the mainland are more likely to be exposed to greater levels of turbidity, TSS and higher sedimentation rates, which may, in part, explain variation in the composition of hard coral genera with distance from the mainland.

Groups Statistics	*R Statistic*	*Significance level*	*Actual permutations*
21-40 km vs. 41-60 km	**0.126**	**0.01**	**999**
21-40 km vs. 61-100 km	**0.243**	**0.03**	**999**
41-60 km vs. 61-100 km	**0.282**	**0.03**	**999**

Table 7.62. Pairwise comparison of distance groups from the mainland. Statistically significant differences are in bold.

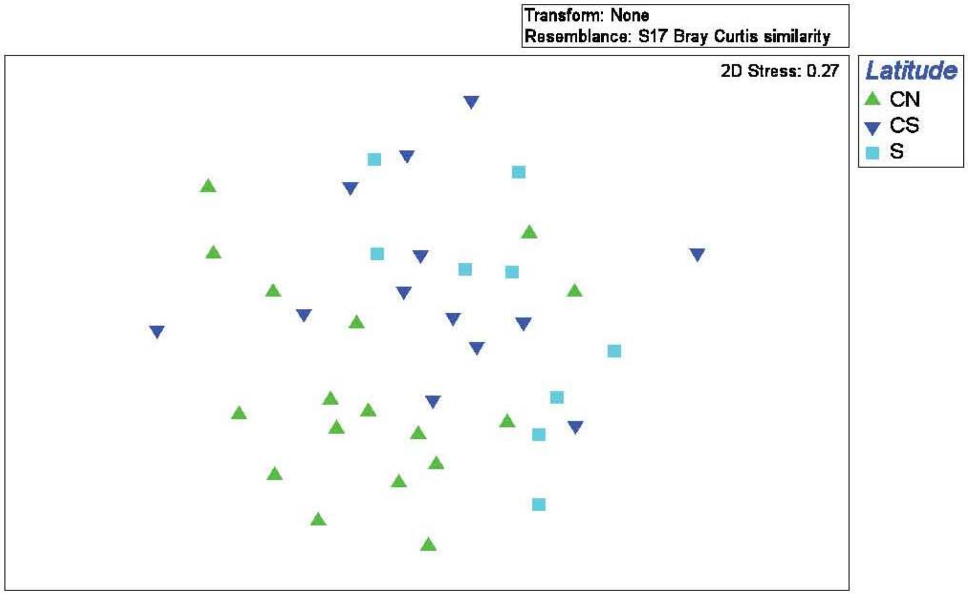


Fig. 7.6a. nMDS plot showing relationship between reef groups with distance from north to south of the study area (CN or Central North Reef Group, CS or Central South Reef Group and S or South Reef Group (no transformation with Bray Curtis Similarity).

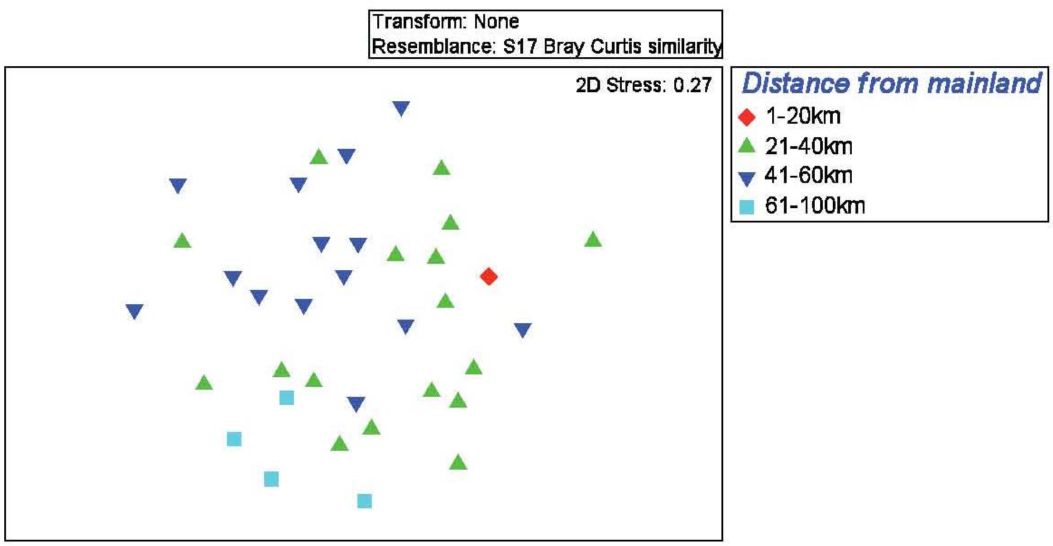


Fig 7.6b. nMDS plot showing relationship between reefs found 1-20, 21-40, 41- 60 and 61-100 km offshore (no transformation with Bray Curtis Similarity).

There was no evidence to suggest that genera composition varied with exposure to prevailing wind and wave action (Global R = 0.026; P = 0.3). This differed from results reported from more northerly regions of Saudi Arabia (DeVantier et al. 2000a) and the western Red Sea in Egypt (Riegl & Velimirov 1994) and Sudan (Edwards & Head 1987). In these regions, sheltered or leeward reefs were characterized by large *Porites* colonies, while windward or exposed reefs were characterized by *Acropora* and *Pocillopora*. Such patterns were not evident on reefs in the Farasan Banks. We propose three hypotheses to explain why genera composition did not vary between north and south facing reefs, but these are not mutually exclusive. First, we did not sample assemblages at shallow depths (<5 m), which are more likely to be influenced by wave action than those at 10 m. Second, many of the reefs sampled were small and circular shaped, which are unlikely to provided adequate shelter on the leeward side from extreme wave action. Third, in the southern and central Red Sea, winds prevail from north in summer, but south in winter (Edwards & Head 1987). Therefore, in this region categorizing reefs into exposed or sheltered may be irrelevant. Lastly, there was no evidence that variation could be attributable to distance to nearest reef (Global R = 0.116; P = 0.09) or with reef size (Global R = 0.001; P = 0.45). Thus, there was no evidence to suggest that genera composition was similar at reefs of similar size or between nearest neighbors.

General lifeform composition: In this analysis we focused on compositional change of hard coral, recent dead standing coral, soft coral, macroalgae, turf algae, crustose coralline algae, rubble and other (e.g. sponges, uncolonized rock). As with the coral genera level data, biological patterns were correlated with some environmental factors. Composition varied with latitude (Figure 7.6a; Global R = 0.17; P = 0.001), distance from land (Figure 7.6b; Global R = 0.14; P = 0.009) and reef size (Global R = 0.101; P = 0.01). Pairwise comparisons were used to identify which reef group pairs (North versus North Central, North versus South Central etc.) differed statistically. All pairwise comparisons were statistically different: reef group N compared with S (R = 0.534; P = 0.001), CN compared with CS (R = 0.221; P = 0.001) and CN compared with S (R = 0.199; P = 0.02). A SIMPER analysis suggested that benthic lifeforms discriminating between the N reefs and S reefs were soft coral, old dead standing coral and turf algae. Soft coral and turf algae were more abundant in the N reefs, while dead standing coral was more abundant in the S reefs. An important source of coral mortality on reefs surveyed during the study was the starfish *Acanthaster planci*. Large numbers were observed on reefs exhibiting high abundances of recent and old coral mortality. Other potential sources of mortality could be attributable to bleaching induced by thermal stress. DeVantier et al. (2000b) surveyed reefs north of Jeddah and reported widespread bleaching and associated mortality during 1998. Lifeform composition varied among reefs with increasing distance from the mainland. To recall, reefs were grouped into four categories, those 1-20 km from the mainland, 21-40 km and so on up till 81-100 km. Pairwise comparisons were used to identify which 'reef distance' groups varied according to their lifeform composition. Reefs in the range 1-20 km from the mainland differed from reefs 21-40 km ($R = 0.24$; $P = 0.02$), 41-60 km ($R = 0.38$; $P = 0.005$) and 61-80 km ($R = 0.58$; $P = 0.004$). As with genera composition, variation is potentially attributable to variation in TSS levels and sedimentation rates which will be negatively correlated with distance from the mainland. However, we have no quantitative data to assess these hypotheses conclusively. Other factors potentially contributing to this variation could include episodic disturbance. Corals closest to the mainland would be at greatest risk from the effects of freshwater discharge from wadis (valleys) after thunderstorms in the adjoining mountains. Composition also varied among reefs of different size. Size was based on the maximum width, and reefs classified as those with a maximum width of 0 to 1km (small reef), 1.1 to 3km (medium sized reef) and > 3.1km (large reef). Lifeform composition at medium sized reefs were statistically different from large reefs ($R = 0.111$; $P = 0.002$). Interpreting this result was not straightforward because composition on small reefs did not differ from the larger reefs. In other words, there is no clear biological explanation why medium size reefs would differ in their lifeform composition from large reefs, while smaller reefs would have similar composition to larger reefs. It may actually reflect a sampling artifact associated with different amounts of replication within the 'reef size' categories. Lifeform composition at 10m water depth did not vary with exposure to northerly winds (Global $R = -0.044$; $P = 0.82$) or with distance to nearest reef (Global $R = 0.047$; $P = 0.16$). These results are consistent with the genera data and can be explained similarly.

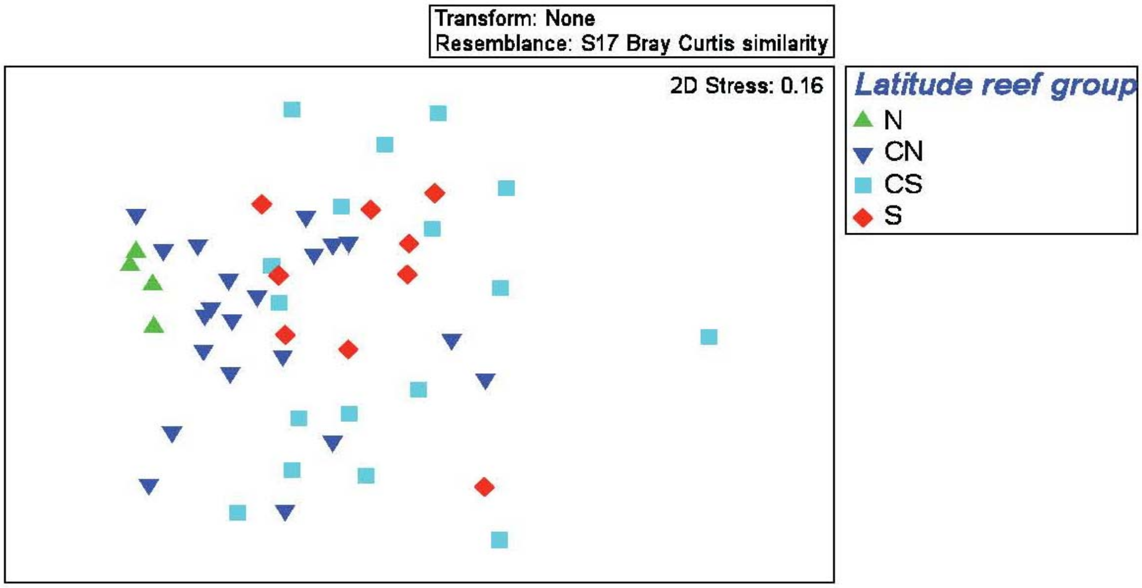


Fig. 7.6c. nMDS plot showing lifeform composition in relation to latitude (no transformation with Bray Curtis Similarity)

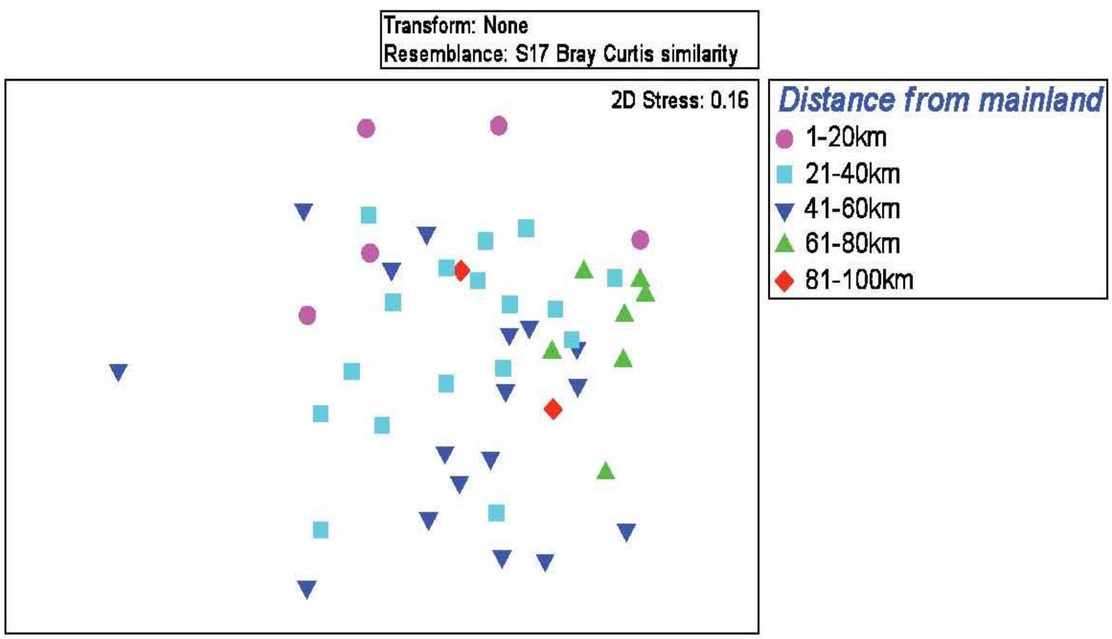


Fig. 7.6d. nMDS plot showing lifeform composition in relation to distance from the mainland (no transformation with Bray Curtis Similarity)

17.0 Resilience analysis: comparison of Al Wajh, Yanbu, Farasan Banks and Ras Qisbah

17.1 Introduction

The following analysis was completed by IUCN using data collected by Dr. David Obura, Dr. Ameer Abdulla and Dr Tony Raphael during the Living Oceans Foundation 2008 and 2009 research missions. At each site the Living Oceans Foundation examined, one researcher assessed fish and fishing related resilience indicators while the second assessed corals and ranked all other resilience attributes. These data do not include quantitative measurements of coral size or any of the quantitative data collected on benthic cover (corals, algae and substrate type) measured using photo-transects (these data are presented above). It is important to note that the assessment is also based on resilience to bleaching and not resilience in the overall context of all acute stressors (e.g. COTs, physical impacts from ship groundings or storms) or chronic stressors (pollution). Other limitations of this assessment are as follows:

- Some field attributes represent surrogates, and it is unclear how accurately they are correlated with the actual factor of interest. For example, water depth adjacent to the site is used to predict the potential for cool water upwelling and the maintenance of water temperatures below bleaching thresholds. However, the strength of this link remains inconclusive as daily and seasonal water temperature variability was not measured at sampled sites and scientific literature presents cases where depth does not play an important role in stemming bleaching. Second, there is insufficient information on many anthropogenic attributes at the scale of a site or an individual reef within the site. Accurately quantifying the level of fishing activity was, in most situations, impossible at the scale of site and reef (although using a surrogate such as the number of entangled fishing lines may be useful).
- Third, one-off visits to a site are unlikely to provide accurate assessment of variables that are variable naturally, particularly over short temporal scales (e.g. tidal, diurnal or even seasonal cycles).
- Fourth, unequal sample size (replicate sites among regions) may confound interpretation. For example, a region with more replicate sites is likely to exhibit greater between site variation than a region with less site replication.

Obura & Grimsditch (2009) defined resistance and resilience in context of climate change impacts to coral reefs. Resistance is defined as the ability of individual corals to resist bleaching, and if bleached to survive. Resilience is defined as the ability of the reef community to maintain or restore structure and function and remain in an equivalent 'phase' as before coral mortality. Combined, both resistance and resilience determine the sensitivity of a coral assemblage to abnormally high water temperatures. The term "exposure" in Figure 1 relates to the duration to which a coral assemblage is exposed to abnormally high water temperatures and or UV. High water temperature and UV are the primary triggers associated with mass bleaching events (Baker et al. 2008) although other stressors such as freshwater input, pollution, and nutrient introduction may increase the probability of bleaching. The sensitivity of a coral assemblage and the level of exposure to stress will determine the potential impact. Potential impact and the adaptive capacity of coral assemblages to thermal or UV stress will define the vulnerability of a reef system to climate change.

17.2 Study locations and sampling approach

Reefs in four regions of the Eastern Red Sea were assessed: Al Wajh Bank North (hereafter Wajh North); Al Wajh Bank south (Wajh North), Yanbu and Farasan Banks. A fifth region, Ras Qisbah, was sampled during a Living Oceans Foundation expedition in September 2007, but is not included here. Reefs within each region were haphazardly selected for sampling. Two sites were normally sampled per reef; a site on the windward (north facing) and on the leeward side. At each site, two replicate transects were sampled at depths between 9 to 11 m.

17.3 Attributes and resilience index

Within each belt transect a range of attributes were measured (Obura and Grimsditch 2009). Measured attributes can be classified as those relating to sessile organisms on reefs, physical or environmental characteristics relating to reefs or to human activities. Biological attributes included hard coral genera composition and abundances of herbivores. Hard coral genera vary in their susceptibility to being bleached (McClanahan et al. 2004) and therefore, biological attributes may help confer resistance. The abundances of herbivores are important indicators of resilience (Green et al. 2009) because their feeding reduces the risk of large algae over-growing and smothering corals and maintains algae free-space on reefs for coral larvae to settle thus promoting recruitment and reef recovery. Physical attributes, including potential for upwelling and shading, can reduce the risk of corals being exposed to stressful levels of water temperature or UV. Anthropogenic attributes that were measured relate to human actions that may reduce the resistance or resilience of a coral assemblage to thermal and UV stress such pollution or fishing. All attributes are listed in Appendix A and theoretical justification for their inclusion is given in Obura & Grimsdith (2009). Benthic life forms that were sampled included: living hard coral, recent dead coral, old dead coral, soft coral, turf algae, macroalgae, crustose coralline algae, rubble and other. Percentage cover was estimated for each of these life forms. Other attributes, such as temperature and slope were measured on continuous scales. As was the case with percentage cover, temperature and slope were rescaled to an ordinal scale. All other attributes were ranked on an ordinal scale ranging from 1 (minimum or negative score) to 5 (maximum score). All raw scores were transformed in order to be consistent with the resilience index score developed by IUCN (Obura & Grimsdith 2009). For instance, a transformed score of 1 would confer low resistance, resilience, or high risk of exposure to thermal or UV stress. Conversely, a score of 5 would confer high resistance or resilience.

17.4 Statistical analysis and interpretation

17.41 Multivariate analyses

Principal Components Analyses (PCA) were performed on normalized data (all measures on the same scale) using a Euclidean distance matrix. PCA is an ordination approach used to help visualize patterns in the responses of whole sets of variables simultaneously. It is a projection of sample points onto axes that minimize residual variation in Euclidean space. The first principal component axis is defined as the straight line drawn through the cloud of points such that the variances of sample points, when projected onto the axis, is maximized. Assumptions relating to the distribution of the variables (e.g. skewness and outliers) were checked using Draftman Plots. To help interpret the PCA plots, vector overlays were used to highlight linear relations between the variables and each principal component axes. Vectors were based on Pearson’s correlation coefficient.

17.42 Univariate analyses

For each site the average resilience index score was calculated and plotted on a line graph. This was done to create an aggregate score (combining all attributes: physical, biological, and anthropogenic). Line graphs were also created separately for biological, physical and anthropogenic attributes in order to understand what type of attributes are the major drivers of the average resilience index score. The advantage with these univariate plots compared with the multivariate plots is that they have the capacity to indicate directionality in scores and thus allow a quantitative (spatial) comparison of resilience among regions and among sites.

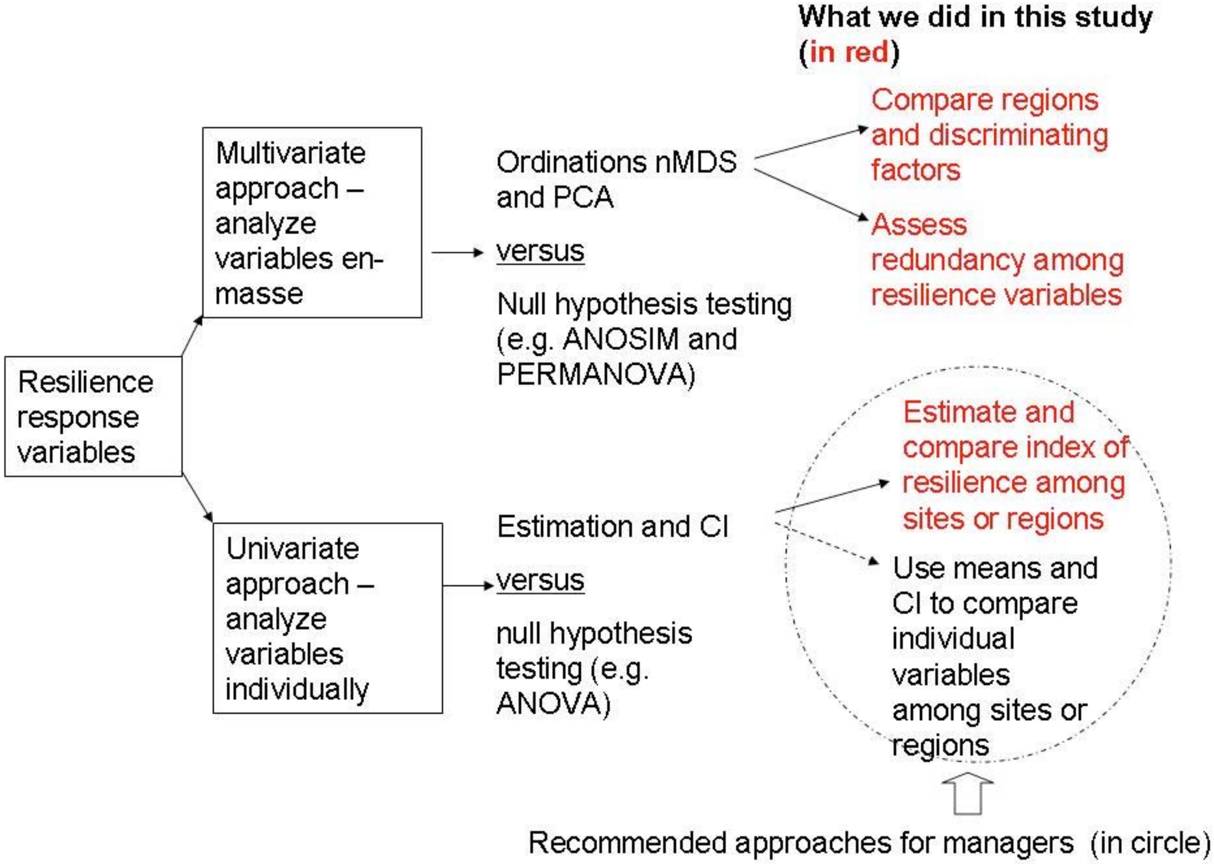


Fig. 17.4a. Statistical approaches used in this study and recommended approaches for managers when analyzing resilience data

A multivariate approach was used to compare regions and to identify attributes that were important discriminators of regional differences. A multivariate approach to assess for redundancy in attributes that characterize patterns in the data. This was achieved by analyzing the samples to higher 'taxonomic' levels and visually comparing the resulting patterns to assess their level of similarity (see Farasan Banks). Two benefits of multivariate approaches are that they can conveniently summaries numerous response variables (Wonnacott 1987) and may be more sensitivity to discriminate treatment or site differences compared with univariate approaches (Clarke & Warwick 2001). A difficulty with these approaches is that the statistical assumptions of some approaches (e.g. PCA) are not always easy to fulfill. Also, PCA and nMDS do not necessarily indicate directionality in terms of which sites are more or less resilient.

A univariate approach was also used to rank regions according to their resilience index score. This is referred to as a univariate approach because for each region the attribute data was summarized into a single-variable extract, namely an average attribute score. Attributes scores were based on an ordinal (Likert) scale 1 = low resilience and 5 = high resilience. An advantage of this approach, compared with the multivariate approaches, is that final scores can indicate directionality. For example, regions with high scores indicate high resilience potential. Similar to multivariate approaches, it can also be used to show site variability within a region. This is important if managers need to select or negotiate for individual sites or reefs in a region for protection.

17.5 Results

17.51 Regional variability

Due to the large number of sites examined, a subset was used for the analysis of regional differences. Figure 17.5a shows the PCA plot for a subset of the data. The most salient feature was the clustering of the Farasan Bank sites and their separation from the other three regions. The first principal component axis (PO1) explained 27% of the variation in the data and discriminated between the Farasan sites and those in the other three regions. The second principal component axis (PO2) explained another 15% of the variation, which accounted for variation among Wajh North, Wajh South and Yanbu. The third principal component, not shown, accounted for another 12% of the variation. So the first three axes accounted for 50% of the variation in the data set.

The lines (called vectors) are correlations between a particular variable (e.g. turf algae) and each of the principal component axes. The size and position of the circle is arbitrary, but the length and direction of each vector indicates the strength and sign of the relationship between the variable and the PC axis. For example, the variable turf algae had a strong negative relation with PC1 and was indicative of Al Wajh South. Another example is CCA, which was positively correlated with PO2 and was more characteristic of the Farasan Banks. Figure 17.5a also indicates that turf algae, urchins, rubble and water movement were highly correlated.

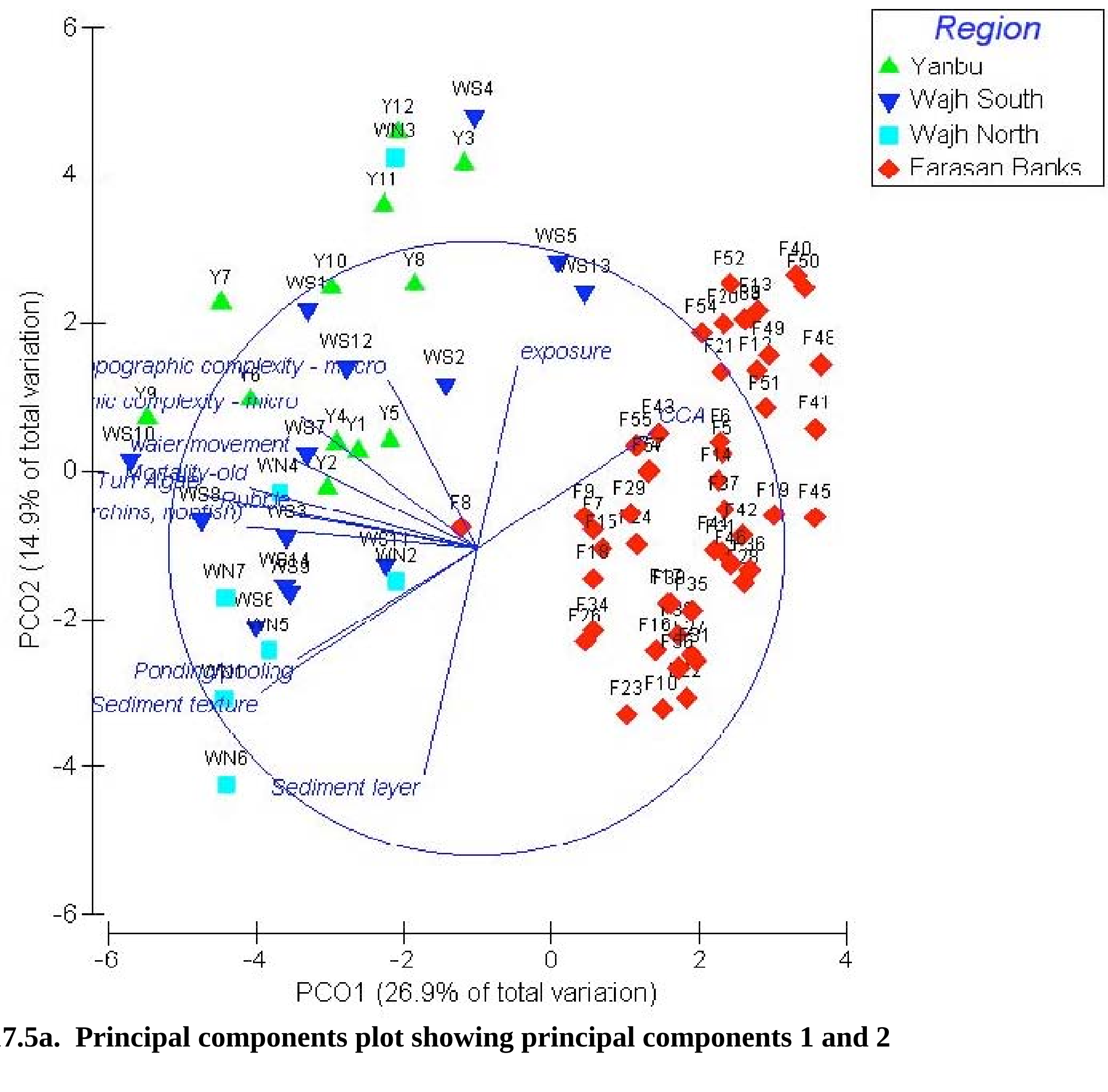


Fig. 17.5a. Principal components plot showing principal components 1 and 2

17.52 Ranking region sensitivity to climate change

Figure 17.5b illustrates the average resilience index score of all attributes for regions. As it is an average score of all three types of attributes, we also refer to it as the resilience aggregate score. Figure 17.5b also indicates variability in the aggregate score between sites within each region. To remain consistent with Obura and Grimsdith (2009) the term 'resilience' aggregate score is used, whereas in fact it includes attributes other than those that confer resilience per se. The 'resilience' aggregate score also includes attributes that confer resistance and those that influence the risk of corals being exposed to thermal or UV stress. The Farasan Banks has the largest average resilience index score, while Wajh North has the lowest index score. However, absolute differences between the largest and smallest index score are not great, and more importantly in such a large spatial scale assessment is the sequence and relative differences between regions. A more informative assessment is obtained when examining the resilience index scores individually for the anthropogenic (Figure 17.5c), biological (Figure 17.5d) and physical attributes (Figure 17.5e).

The anthropogenic index score is particularly informative to environmental managers because it relates to those attributes that can be directly influenced through management or regulatory action to enhance the anthropogenic score and consequently the overall resilience aggregate score. The anthropogenic index score is relatively high for all regions, suggesting human pressure on these areas is minimal. Low fishing pressure combined with a lack of pollution run-off from land contributed to these positive scores. Improving these scores is not currently a critical management objective for these regions, but managers can be pro-active and plan to prevent the scores from deteriorating. The low within region variability (or site variability see Figure 17.5c) resulted from many attributes being scored the same for all sites within a region. This reflects the great level of uncertainty in regards to the level of human activity and impacts in these regions. Indeed, although fishing was predicted to be low for the study regions, our prediction, at least for the Farasan Banks, was not based on substantial evidence in the form of fishery statistics or interviews with local fishers. A priority management action could include providing an accurate assessment of fishing activity in these regions and recalculating the anthropogenic index score. The biological index score represents hard coral genera, hard coral abundance and connectivity. These attributes are useful for predicting the resistance of a coral assemblage to climate change because hard coral genera show differential responses to thermal and UV stress. *Acropora* and *Pocillopora* are particular sensitive, while *Goniopora* and *Galaxea* are highly resistant (McClanahan et al. 2007). Also, reefs with high abundances of living coral are more likely to have greater levels of survivorship of living coral tissue following a bleaching event.

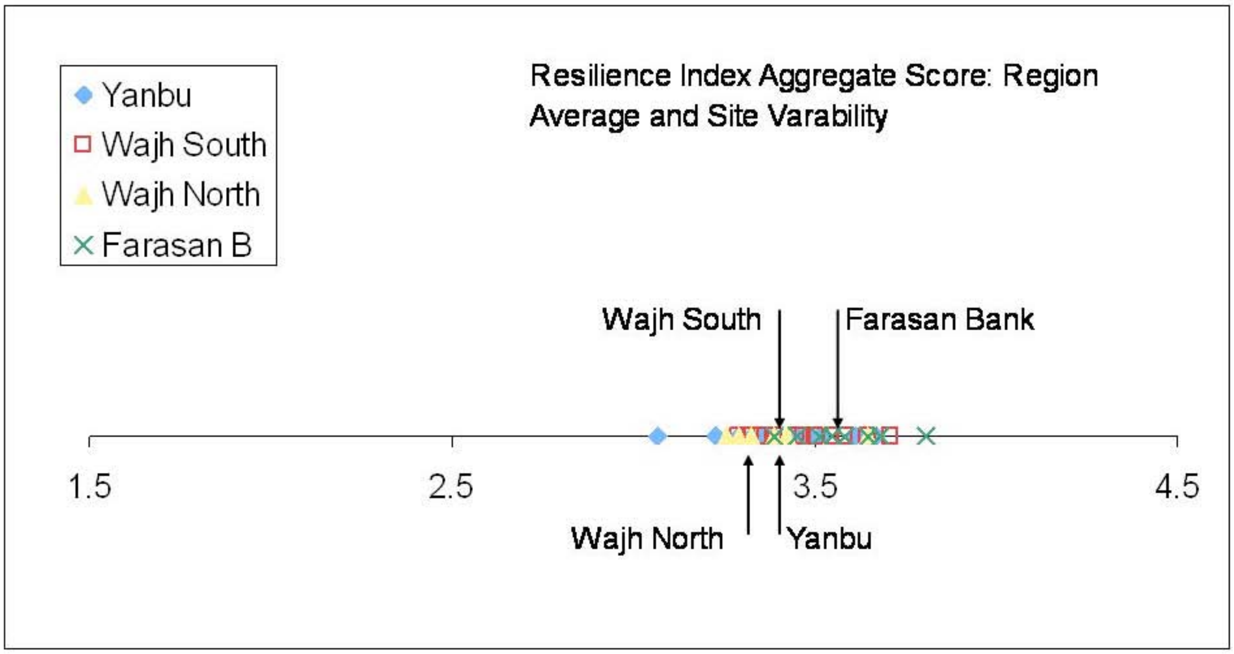


Fig 17.4b. Mean resilience index score for all attributes.

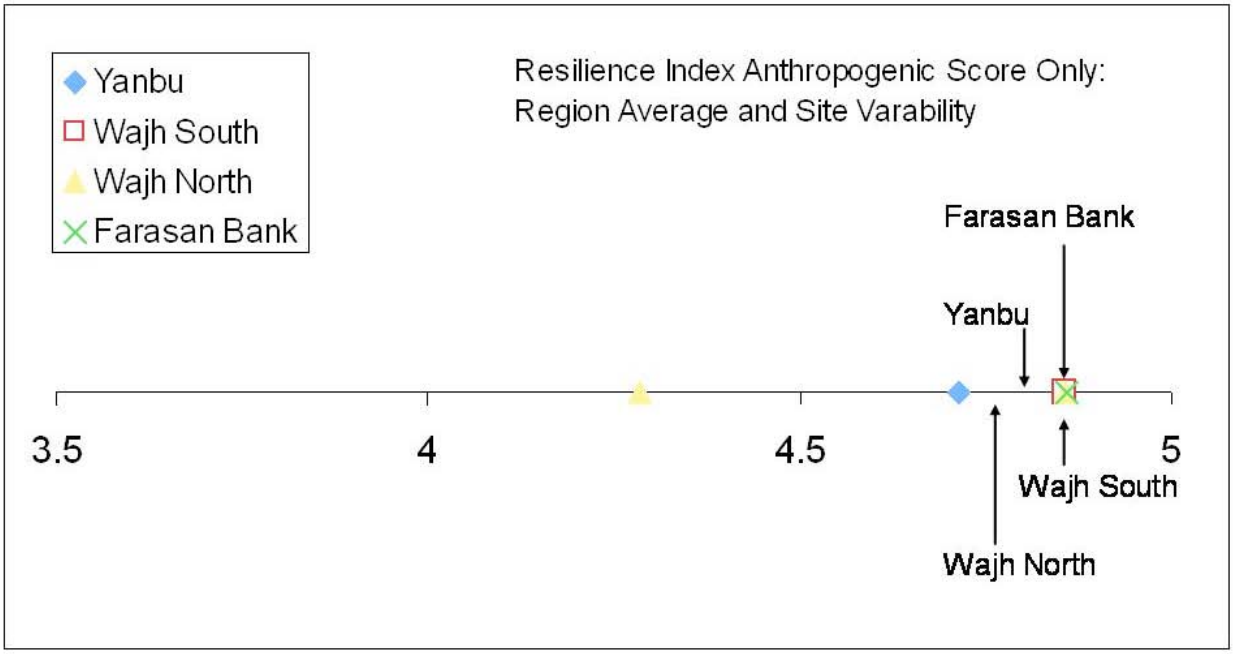


Fig. 17.5c. Mean resilience index score for anthropogenic attributes

Figure 17.5d shows that the Farasan Banks had the highest biological index score and most sites clustered in isolation from sites in other regions. The physical index score addresses factors that may reduce the risk of corals being exposed to abnormally high water temperatures or levels of UV. The physical index score includes attributes measuring screening potential from UV or the potential for cool water upwelling. The most salient feature is the considerable site variability exhibited in the Farasan Banks compared with the other regions. Overall, the region level scores were similar.

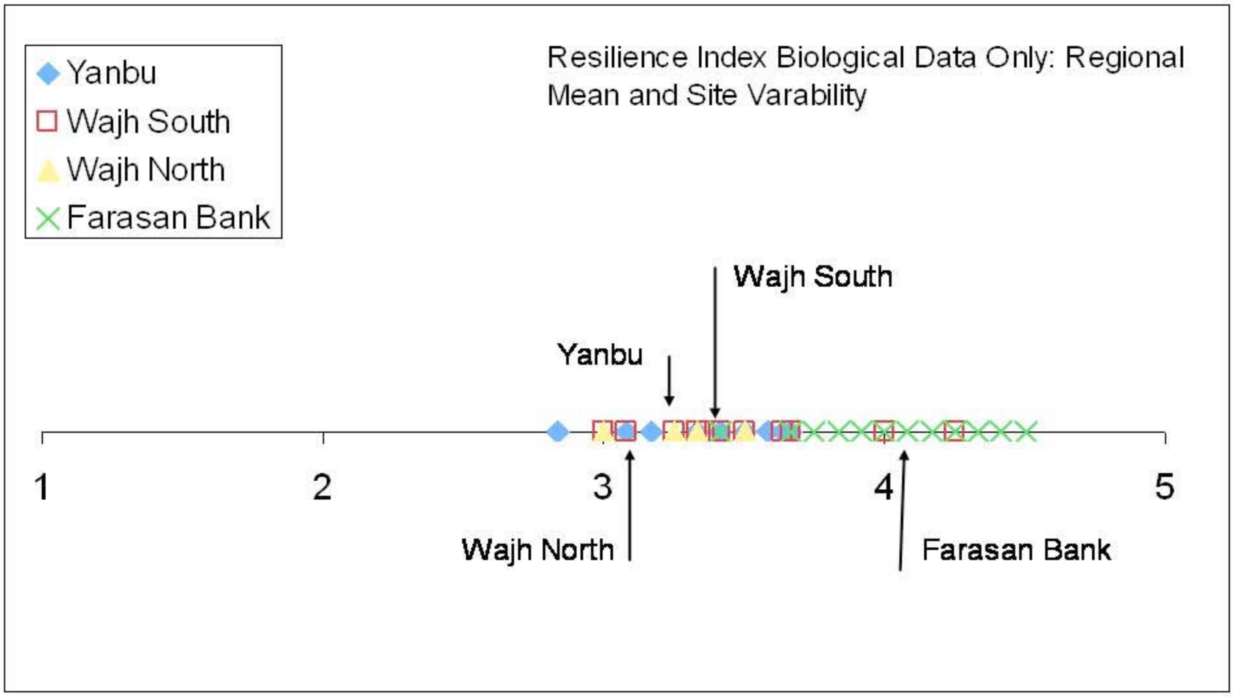


Fig 17.5d. Mean resilience index score for biological attributes

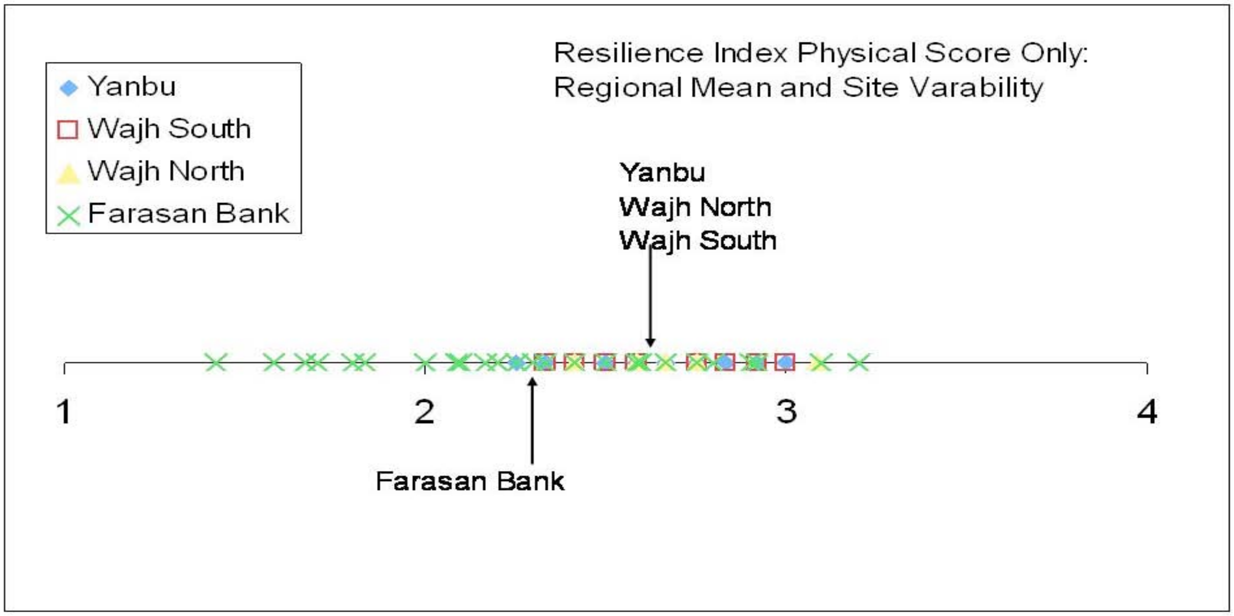


Fig 17.5e. Mean resilience index score for physical attributes

20. Conclusions and conservation recommendations

20.1 Fishes and fisheries

Throughout the Red Sea, reef fish communities are reported to be overfished or at their limit of exploitation, with few large predatory fishes observed, and most herbivores of a small size. Exceptions occur, especially in MPAs and in certain offshore sites, such as the Yanbu Barrier Reef north of Jeddah, Saudi Arabia, where fishing is prohibited (Kedidi 1984, Gladstone 1994, Gladstone et al. 1999, Marine Fisheries Department 2008). Many deeper and more remote locations, especially those sites with high structural relief and adjacent deep water (e.g., Farasan Banks) often have larger populations of predatory fishes due to reduced access by small coastal fishing vessels. For instance, a large number of juvenile and sub-adult humphead wrasse (*Cheilinus undulates*) are found in shallow habitats surrounding Al Wajh and the Farasan Banks. This is a species is listed as endangered on the IUCN Red List and is now protected through CITES due to heavy fishing pressure in support of the live reef food fish trade. Giant clams also appeared to be very abundant, although the largest individuals were generally <20 cm, possibly because these were formerly important targets of artisanal fisheries. Populations of small groupers and snappers still occur in most locations, except degraded reefs, and are generally found at higher numbers than that reported from other IndoPacific locations. However the size structure of these may be unnatural as most are now <30 cm in length. Sharks were rare throughout the Saudi Arabian Red Sea, with low numbers observed in offshore sites at the edge of the reef, adjacent to deep water. The shark fishery poses fairly recent threats to reefs of Egypt and Saudi Arabia, mainly due to increased international demand for shark fins. Once the major predators become overfished, fishery targets often shift to lower trophic level species; this may increase biomass landed, with cascading impacts on reef health. As coral reefs that are relatively close to the mainland are degraded, artisanal and investor fishers are targeting more remote locations. Expanded use of fish traps and nets with small mesh sizes is of concern due to the sensitivity of corals to physical impacts and the associated removal of a high diversity of lower trophic level species, especially juveniles, that help maintain proper functioning of these sites.

Management of Red Sea coral reef fisheries will benefit from the direct involvement of chief fishermen with local knowledge of the marine environment and local customs and politics, their respected position among other fishermen and their ability to communicate between government agencies and their community (Gladstone 2002).

20.2 Use of MPAs for conservation and protection

During the past decade, Saudi Arabia and most other countries bordering the Red Sea have taken important steps towards developing a coordinated multi-national network of MPAs, encompassing a wide variety of reef types and other marine and coastal habitats (DeVantier et al. 2000a, PERGSA 2003). In many cases, these MPAs were identified without a thorough baseline understanding of the reefs, or the needs and desires of the user groups, and management plans are largely absent. Furthermore, fishing activities by non native fishermen have continued unabated in MPAs (due to lack of enforcement and other factors), lessening the benefits of MPAs to marine conservation (Gladstone 2002). Natural resource management and conservation organizations in the Red Sea typically site the lack of data or the inability to use available data as the reason for the lack of marine management.

Marine ecosystem management in situations of uncertainty or constrained resources and capacity can still be achieved through the use of decision support tools such as the high resolution habitat maps created for the Saudi Arabian Red Sea coastline. The habitat maps, in concert with a GIS database compile recent information on reef health and resilience, providing a framework for spatially-based ecosystem-based approaches to management. Presence of certain resilience indicators in key ecological areas in the Red Sea that were undamaged by past disturbances and. Because the Red Sea may contain coral reefs that exhibit unusually high resilience due to their tolerance to extreme temperatures, these sites may be of global ecological importance as sites resistant to future climatic events and priority areas for conservation and MPA designation. Effective management through rigorously enforced no-take zones and concurrent efforts to mitigate pollution and other coastal threats is a critical tool for managing fisheries associated with coral reefs and other habitats. This effort must be inclusive since reef fish use multiple habitat types during their lives, such as offshore spawning aggregation sites and inshore nursery habitats.

Science and research play major roles in coral reef management by providing the information required to plan and implement actions. For example, the dominance of reefs by small coral colonies as observed throughout these assessments (most corals were 1-30 cm diameter), suggests a high turnover and frequent disturbance regime. Maintenance of these populations, and the habitat they create, depends on local sources of recruitment, which may diminish following regional perturbations.

Furthermore, management depends on transparent communication of scientific results to the broader public. These approaches allow managers to consider the status of the reefs, recent changes to reefs, associated habitats and resources contained therein, and drivers of changes in decision-making processes. When combined with a socioeconomic evaluation of various user groups, along with strengthened institutional capacity for management and enforcement, and involvement by key stakeholders and community groups, management decisions provide greater confidence that future levels of exploitation do not compromise the sustainability of reef resources or the associated food security for humans dependent on these resources.

20.3 Farasan Banks

The reefs in the Farasan Banks represent an area of high global importance because of the high levels of endemism, and the role these communities serve as important regional stepping stones for gene flow within the Red Sea. The abundance and distribution of fish, hard coral genera and other sessile organisms in the Farasan Banks are now known to vary with latitude and distance from the mainland. The Farasan Banks forms a biogeographic boundary separating the northern and southern Red Sea fauna, with distinct species assemblages observed during our surveys on inshore and offshore sites as well as minor latitudinal variations in species composition and abundance. The Farasan Banks are also subject to large latitudinal and seasonal extremes in temperature (up to 38º C), and above-average salinities, which would typically kill corals in other regions. The presence of flourishing coral communities in many of the locations we examined suggests local populations are adapted to temperature stress, but the environmental extremes in this region are likely to be close to their physiological tolerance maxima, which may make them particularly vulnerable to climate change. Such information may aid in site selection of marine protected areas or no-take zones for purposes of biodiversity protection. The map products will also help quantify the size of habitat types, their distribution and the physical boundaries between habitats, identify potential conservation areas and/or vulnerable ecosystems, and assist managers to define procedures and select sites for monitoring.

20.4 Farasan Islands

The area spanning the Farasan Islands to Haql in the Gulf of Aqaba is one of the most important coral reef areas for marine protected areas management on a global scale. Most of the region is presently little affected by local human impact. The only direct human impact, with exception of fishing, occurs in the vicinity of coastal cities and towns where land reclamation, urban run-off and coastal littering have occurred. In addition, areas near populated islands are under some of the greatest pressures from fishing in the Saudi Arabian Red Sea. Major additional threats include ship wrecks and oil spills and global impacts from future climate change (bleaching and reduction in reef-building capacity from projected changes in ocean alkalinity). Reefs in some areas of the region appear to be naturally buffered against the worst effects of coral bleaching, because of the prevalence of cool water upwelling. In the seven areas covered in these surveys, a total of 105 fish in the 31-40cm size class were recorded. This represents less than 0.5% of the total fish count. Additionally, only two individual fish were counted in the 40 cm and over size class.

20.5 Ras Qisbah:

The region, extending from the mainland coast north of Duba to the entrance to the Gulf of Aqaba, contains a wide variety of different biotopes and reef types with high zoogeographic significance. These reef complexes support a high species diversity including Red Sea endemic corals, presently undescribed coral species and species with restricted distributions otherwise rare or absent in the Red Sea. The area examined in this study is in need of additional protection because it is highly vulnerable to future climate change impacts, as it lacks certain key resilience factors that would help moderate water temperatures.

20.6 Al-Wajh Bank:

Al Wajh bank is an important conservation target because it contains the greatest range of reef types (and other marine and coastal habitats) in the region. As with the Tiran area, reefs of the Al-Wajh Bank support Red Sea endemic corals, undescribed coral species and species with apparently restricted distributions. Its size and diversity of reef habitats, and likely high level of ecological connectedness in terms of larval dispersal in ocean currents, both within the Bank and to other parts of the Red Sea, afford it great conservation significance.

CONCLUSIONS

The Khaled bin Sultan Living Oceans Foundation implemented four research missions in the Saudi Arabian Red Sea between 2006 and 2009 aboard the M/Y Golden Shadow as a research platform. The research was undertaken to improve the understanding of the spatial distribution, size and condition of shallow marine habitats, and to identify options to enhance the conservation and management of Saudi Arabian coral reef ecosystems. The research focused on three priorities:

1) Characterization and mapping of shallow marine habitats off the Saudi Arabian Red Sea coastline,

2) Assessment of the composition, population structure, cover and health of key reef species, including stony corals and soft corals, algae, and fishes, and

3) Characterization of past impacts, patterns of recovery, ongoing stressors and resilience indicators.

The program included research and educational components and outputs included a Geographic Information System (GIS) database, detailed high resolution habitat maps, a Red Sea coral reef book entitled "*Conservation of Coral Reef Ecosystems of the Saudi Arabian Red Sea*", an atlas of marine habitats, a movie on the Farasan Islands, and numerous scientific presentations and publications.

QuickBird multispectral satellite imagery (DigitalGlobe, Inc.) was acquired for 25,000 km^2 of coastal and offshore marine habitats in the Saudi Arabian Red Sea, from the shoreline to depths of 20-30m, extending up to 100km offshore. Satellite imagery was supplemented with hyperspectral imagery in the Farasan Islands (3200km^2) and Al Wajh lagoon (approximately 2000km^2). Detailed groundtruthing focused on acquisition of data needed to identify, characterize and validate habitats (through recorded observations, photographs and tethered video images of the seafloor), derive depth (acoustic depth soundings), determine reflectance of various objects and habitats (optical measurements), validate the position on the ground with the imagery (deployment of targets and use of geographical positioning system), remove artifacts associated with atmosphere and water conditions, and improve accuracy of the resulting maps.

All of the habitat maps, imagery, data, photographs and video were compiled into a GIS database. The GIS database and associated habitat maps provide a spatially-based platform for management. These maps identify at least seven different geomorphologic reef structures in the Red Sea, including barrier reef systems, lagoonal patch reefs, reticulate reefs, submerged limestone platforms, coral pinnacles, atoll-like structures, and island and mainland fringing reefs. Shallow marine areas are subdivided into 8-12 distinct marine habitat types, including specific reef environments, grassbeds, mangroves, algal flats, and sand-bottom communities. The habitats are discriminated to depths of about 20-30 m. In addition, detailed assessments of wave and tide height, sediment characteristics, turbidity, reflectance of corals, algae and non-living substrates, and sediment and hard bottom profiling were conducted. These data and other historic datasets (e.g. temperature) were used to determine linkages between species assemblages and community structure of coral reef ecosystems with the environmental drivers, geological features and biological attributes that shape these ecosystems.

SCUBA assessments were completed in representative reef environments to determine 1) what organisms were present; 2) the status and health of these organisms and threats affecting them; 3) the potential for recovery from past disturbances; 4) factors and processes that control the health of these communities, are likely to help them persist into the future, and ensure they rebound following acute disturbances; and 5) actions needed to enhance the health and resilience of specific sites examined. One component of the work involved the development and testing of new methodologies to address the factors (1-5) listed above. In addition to quantitative data on the cover, size frequency, and abundance of major coral functional groups, the rapid assessment protocol utilized here allows characterization of reefs on the basis of their health and resilience. This approach incorporates key ecological and physical attributes related to the reef structure (rugosity, slope, and habitat condition), oceanographic and environmental parameters (upwelling, circulation, wave exposure, water clarity) and biological attributes including the composition and abundance of reef fishes, corals and algae. Major results of this project include the identification of Red Sea indicators of resilience, ecological areas that exhibit high resilience, as well as the major causes of degradation of these ecosystems. The research missions provide key information on resilience principles and tools to facilitate place-based management actions.

In order to obtain an insight into the dynamics of Red Sea coral communities, data from habitat maps are linked with in situ SCUBA survey data. Habitat maps provide information on the locations and spatial extent of different habitat types, including the potential area of critical habitat for reef building corals. An analysis of the spatial distribution of corals in the landscape, and the sizes and abundance of corals within various habitat types provides an indication of the spatio-temporal functioning of the coral community. From the maps, it is possible to quantify the overall size (spatial coverage) of coral reefs along the Red Sea coastline, and the amount of suitable habitat for corals. Transect data provides an indication of the density of corals per defined spatial unit, colony size structure, number of different life stages, and health status, for each genera. Together, these two data sources can be used to estimate the total number of corals expected to occur in the system, and the total carrying capacity of the system if every available and useable spatial unit was occupied.

Ras Qisbah: Shallow marine habitats in the northern Red Sea east of Ras Qisbah, around the islands of Al Farshah, Umm Qusur and Burqan, contain a wide variety of reef types, including fringing, platform, pinnacle and small barrier reef systems. These reefs often exhibit a reticulated or honeycomb structure built on a *Porites* framework, with seagrass beds, algal flats, soft coral areas and sandy lagoons surrounding the reefs. Living coral cover was highest at 3-4m (approx. 30%), with much lower cover (<5-20%) in deeper reef environments (5-17 m depth). Reefs showed evidence of a past mortality event in 1998 or 1999, affecting 50-75% of the corals. Most of the *Porites* colonies in deeper areas had died prior to this event, with replacement by foliose and plating corals, most of which subsequently died in the last 3-9 years. Living corals were typically small in size (<1m diameter), with exception of isolated colonies on the exposed outer slopes at Al Farshah that reached sizes of 4-5m diameter. Most sites were dominated by highly fragmented remnants of large *Porites* colonies, with dead skeletal surfaces colonized by small massive faviid corals and branching corals, especially in the genus, *Acropora*, *Montipora*, *Stylophora*, *Seriatopora* and *Millepora*, and the soft coral *Xenia*. Most sites were conducive to future colonization and growth of corals, with low amounts of fleshy algae and moderately high levels of herbivory, although coralline algal cover was also low.

The resilience of these reefs was lower than areas examined in the central and southern regions. Sites at the edge of the platform along the extensive bank and reticulate reef systems at Al Farshah, Umm Qusur and Burqan were affected by pooling of water over shallow reefs, and high outflows of sediment and super-heated water may prevent recovery of these sites and exacerbate the impacts of future bleaching events. The area showed evidence of overfishing, as most sites had a relatively low diversity of species, and most fishes were predominantly of a small size and low abundance. Reefs located at the edge of the platform, off Al Farshah appeared to be the healthiest and most resilient in this region.

Al Wajh and Yanbu: The central Red Sea includes two unique and diverse coral reef ecosystems, Al Wajh Bank and Yanbu Barrier Reef. Al Wajh contains about 50 islands with associated grassbeds, mangrove communities and coral reefs located along the bank and the adjacent coastline consisting of fringing, platform, reticulate and submerged patch reefs, along with offshore pinnacle reefs and an extensive barrier reef system. The highest coral cover occurred in the shallow reef crest and fore reef (1-5 m depth; 30-70%); dense *Acropora* thickets were also identified on some shallow inner patch reefs in the northern sector (1-3 m depth, 50-80% cover). Moderate cover was observed at mid depths (7-12 m depth; 20-30%) and low cover at the base of the reef slope (<5-30%) on outer sites, and reefs located near channels, while most lagoonal patch reefs exhibited low cover (0-5%).

Fifty five genera of corals were recorded, with 52 genera observed in Al Wajh and 44 at Yanbu. The dominant corals were massive *Porites*, which made up about 25% of all corals recorded and 25% of the living coral cover. Next highest in benthic cover was *Acropora* and then *Montipora*, while *Montipora* and *Goniastrea* were the second and third most abundant numerically. Yanbu was similar in coral composition, with a dominance by *Porites* and *Acropora* (respectively), although *Goniastrea, Favia* and *Pocillopora* were the next most abundant. Most corals were 20cm or smaller in diameter, while colonies from 20-80 cm made up most of the benthic cover. The largest corals were found in turbid nearshore areas within Al Wajh lagoon (*Acropora* thickets), in outer reefs off Yanbu (tabular acroporids), and on the reef slope along the outside of the barrier reef of Al Wajh, where large foliose corals dominated. Most of the framework consisted of dead or partially dead columnar *Porites* colonies, with mortality affecting 60-90% of their surface. Many inner reefs in Al Wajh had experienced a mass mortality event within the past 6-9 years, with coral communities dominated by small, fragmented tissue remnants. These disturbances appear to have affected many of the important framework corals, as evidenced by the extensive amount of dead coral, and bioerosion of these colonies. However, most reefs appear to be fairly resilient, as indicated by the high levels of recruitment and high cover of small corals, and surviving tissue remnants on larger colonies that are beginning to resheet over denuded skeletal surfaces.

Several diseases, two coral predators (*Drupella* snails and *Acanthaster* sea stars) and competitive interactions (with algae, cyanobacteria and sponges) were recorded in both locations, but recent tissue loss from these factors was low in all species except *Pocillopora*, isolated *Acropora* colonies and massive *Porites* colonies. Fleshy macroalgal cover was low (<5%) throughout the region, suggestive of low nutrient conditions and/or high herbivory. Soft corals, turfs and crustose coralline algal cover accounted for 5-20% of the bottom cover, although cover of *Xenia* soft coral exceeded 50% in some deeper reef environments, especially sites that had been damaged by previous disturbances. In general, a low abundance of fishes was recorded in most locations, and most fish were less than 30 cm total length. Many reefs had a high diversity of reef fishes, but most were small in size and large predators were rare. The lowest diversity and abundance, and the smallest fish overall were recorded within lagoonal habitats of Al Wajh. Offshore sites tended to have a more diverse fish community, including groupers, snappers, jacks, large wrasses and occasional predatory sharks, as did Yanbu reefs in area where fishing was prohibited.

Indicators for resilience suggest that reefs of the Al Wajh bank are more diverse and complex than those of Yanbu. This may be associated with the presence of an extensive bank and barrier reef system in Al Wajh, where the reefs at Yanbu are a string of linear reef complexes parallel to the coast. Al Wajh has more shallow and differentiated habitats, while Yanbu has steeper linear slopes. As a result, water temperature are likely to be cooler at Yanbu (as observed during the surveys), with more highly fluctuating temperatures in the shallows, higher sediment transport, lower visibility, stronger/more variable currents, and also greater degree of ponding of waters in Al Wajh bank. Other potential stressors included moderate to high levels of turbidity (especially in lagoonal sites), moderate levels of fishing pressure (Al Wajh), and industrial development (Yanbu area). Both fish traps and fishing boats were very common within Al Wajh, but were rare on outer reefs and around Yanbu region.

Farasan Banks: The Farasan Banks is an extensive area of small islands, shoals and reef platforms in the southern Red Sea, occupying a total area of approximately 30,000 km^2. The predominant reef types include fringing reefs along the mainland coast, nearshore algal reefs, circular or elongated patch and platform reefs, barrier reefs, coral pinnacles, and emergent or submerged atoll-like structures. Reefs had steep, often vertical walls descending to depths of more than 60 m at midshelf and offshore sites, while inshore areas had a more gradual slope, with reef growth terminating in a sand flat at 15-30 m depth. Shallow and deeper reef habitats were often dominated by a high cover of living *Porites* (50-70% of the living coral cover), while nearly one-third of the sites examined contained large areas of dead *Porites* framework as well as signs of recent mortality from disease and predation. Massive colonies of *Porites* taxa were numerically dominant (38% of all corals over 10 cm diameter) and often the largest corals in the population, except for four sites that exhibited close to 100% cover of multiple species of branching and table *Acropora* colonies. Nearshore sites often had a high abundance of macroalgae in the reef flat, while substrates on offshore reef flats was generally barren, hard bottom or covered predominantly by turf algae. The reef crest, from the seaward edge of the reef flat (0.5m depth) to about 3-5m depth on the reef slope was the most diverse area, exhibiting a high cover (20-70%) of branching, massive and plating corals, including dense assemblages of *Acropora*, *Porites, Pocillopora*, *Montipora*, *Goniastrea*, *Pavona*, *Echinopora*, *Favia* and other species. Interesting differences in dominant coral taxa were observed between the northern and southern portions of the Farasan Banks, and also between inner and offshore sites. Plating corals such as *Montipora, Echinopora, Echinophyllia,* and *Mycedium* were common on vertical slopes in offshore sites, but rare on inner sites. *Pocillopora* was much less common in the Farasan Banks than in central and northern sites. Coral density ranged from a low of 0.5 colonies/m^2 up to a maximum of 19.5 colonies/m^2. Juvenile corals (<10cm diameter) accounted for 99.0% of the total number of hard coral colonies, but only 21.1% of the total hard coral surface area.

Although many sites appeared degraded, with near total loss of adult colonies, the region exhibited numerous factors that confer resilience. First, numbers of coral recruits were 2-10 times higher than that observed elsewhere in the Red Sea and up to 100 times higher than that reported from adjacent areas in the Indian Ocean. Substrate quality was high and conducive to coral settlement, with low amounts of unstable rubble, very low macroalgal cover, relatively low cover of soft corals and higher amounts of crustose coralline algae than observed in other areas along the Saudi Arabian Red Sea coastline. Nuisance species that overtake corals and monopolize the bottom were generally uncommon on Farasan Banks reefs, with exception of a few cases of overgrowth by clionid sponges and high cover of *Xenia*. Coral diseases were relatively uncommon, with exception of a disease affecting massive *Porites* colonies. Several outbreaks of *Acanthaster* (crown of thorns) were noted in midshelf reefs, and these sea stars were negatively impacting sites with the highest live cover of branching acroporid corals.

Reef fish populations in the Farasan Banks differed considerably from fish assemblages documented in the central and northern reefs, especially in terms of the abundance of surgeonfish damselfish and butterflyfish. In general reef fish were more abundant and larger in size on offshore reefs as compared to more northern reefs, which is indicative of lower fishing pressure. Representatives of most of the key functional groups of fishes were present, especially herbivorous surgeonfish, rabbitfish and parrotfish which are important in controlling algae. However, these species also varied in abundance with distance from shore with more herbivorous species seen on turbid inner reefs where macroalgae predominated. Despite the presence of commercial fishing activity in the Banks, populations of fish and echinoderm herbivores remain high.

Reefs also exhibited a number of environmental and physical factors that confer resilience. In general, most reefs had relatively high rugosity, several canopy layers (which helps shade corals), and low amounts of loose rubble (which makes the substrate unstable and reduces the settlement of corals), and little macroalgae (which overgrows and smothers slower growing corals). The aspect of reef slope, facing direction of the reef, and presence of cliffs and above-water features, as well as larger canopy corals reduce light levels, potentially reducing the likelihood of coral bleaching during periods of thermal stress. The midshelf and offshore reefs were surrounded by deep water, strong currents that seasonally change directions, and numerous physical attributes such as steep vertical walls and overhangs; these features help moderate temperature extremes and UV penetration, and reduce the potential for bleaching.

Farasan Islands: The Farasan Islands archipelago consists of about 176 islands, surrounded by algae-covered pavements close to shore, sand flat communities, seagrass meadows, mangroves, patch reefs, and fringing reefs. Patch reef and fringing reefs were coral-dominated on windward and leeward coral crests, located seaward of the major islands, currently outside the boundaries of the existing MPA. The highest live coral cover was found in habitats referred to as “dense *Acropora* thickets”, which made up 3% of the submerged habitats found in the north-west. Rather than a coral-dominance, many of the hardground areas consisted of accumulations of crustose coralline algae, colonized by *Sargassum* and *Turbinaria* (brown macroalgae). Algal-dominated fringing reefs tended to occur close to the shoreline, and in areas with high sediment loading.

Coral cover on fringing reefs was highest at depths of 3-8m, with numerous sites having over 60% live coral cover. However, live coral typically formed small patches on individual reefs, ranging in cover from <1% to >80%, and surrounded by rubble fields and pavements with a layer of sediment. In deeper water (9-12m) most sites had low cover of living corals (0.1-5%). Most coral reefs consisted of a dead *Porites* framework with a mix of living massive and branching corals, high cover of *Xenia* and other soft corals, encrusting sponges, and a high abundance of macroalgae and cyanobacterial mats. Areas with dense *Acropora* thickets, dominated by large tabular growth forms, were restricted to the outer sites at the northwest end of the Farasan Islands. In non-acroporid habitats the dominant taxa was *Porites*, with some unusually large colonies measuring over 1.5m in diameter, although most colonies had extensive areas of previously killed, exposed skeletal surfaces.

There were few large reef fish observed throughout the fish surveys (<1%), while close to 75% of all fishes were 10cm or smaller in size. The dominant species overall were damselfish (50% of all species) followed by wrasses (10%), while the largest fish were predominantly parrotfish. In general, herbivores were much less common than expected due to the abundant food resources (fleshy algae) The relative rarity of groupers (1% of all fish identified) and other predators is indicative of a reef system that has been subjected to intense fishery harvests.

Nearshore reefs of the Farasan Islands tend to exhibit lower resilience than all other sites observed due to 1) an extensive shallow platform with high amounts of sediment transport and a high potential for heating of surface waters; 2) high abundances of macroalgae and low cover of coralline algae; 3) poor substrate quality consisting of rubble and pavements with fine turfs and trapped sediments; 4) unusually high cover of *Xenia*; 5) relatively low abundances and small sizes of most reef fishes and a near absence of many functional groups; 6) large numbers of dead corals and few large colonies. The exception to this are the extensive *Acropora*-dominated reefs found off the main set of islands, at the seaward edge of the archipelago to the northwest of the existing MPA. These sites are critical for the persistence of other reefs in the area; they are in great need of protection from fishing and other human impacts and would benefit from inclusion in the existing Farasan Islands MPA.

The research conducted by the Living Oceans Foundation provides much needed new information from central and northern reefs and baseline data for reefs located within the Farasan Islands. The work includes the largest habitat mapping program for shallow marine habitats ever undertaken in the Red Sea. Outputs include a detailed GIS database containing high resolution habitat maps for use in marine spatial planning, bathymetric maps, and photographic and video images of the seafloor, combined with layers depicting historic datasets on sea surface temperature, chlorophyll and other environmental parameters; the database can be used in landscape-scale analysis to determine the spatial extent of different habitat types, their distribution and potential linkages between habitats, and also as a platform for future monitoring programs, management actions, and conservation initiatives. Novel uses of remote sensing were also applied to this region to characterize the major agents that shape these communities, including 1) detailed hyperspectral surveys and associated groundtruthing, 2) characterization of the physical and environmental factors on an ecosystem scale to determine major structuring agents; 3) evaluation of coral cover and cover of other benthic organisms using spectral unmixing; and 4) acoustic sediment profiling to identify buried reef structures, age these structures, and determine how they affect existing reefal environments. Rapid assessments and detailed photographic transects allow an analysis of the community composition and structure of representative reefs, including the cover, abundance and size of reef building corals, population dynamics of reef fishes, and relationships with other benthic attributes. Finally, the evaluation of resilience indicators provides a unique ability to identify impacts from past disturbances, predict the likelihood of recovery, and characterize reefs on the basis of resilience to future disturbances. By combining all of these data and tools, managers have a powerful toolbox to define objectives of management, increase protection of the most valuable sites, and identify mechanisms to reduce the vulnerability of sites to future disturbances associated with climate change.

Fig. 20. Fore reef slope on the Al Wajh Barrier Reef.

21. REFERENCES

Adrain, J. M. and S. R. Westrop. 2000. An empirical assessment of taxic paleobiology. Science 289:110-112.

Al-Yami, H.M. and A.B. Rouphael. 2000. Patterns of coral mortality across the Farasan Shelf, Saudi Arabia. In: H. Tatwany, ed. Proceedings of the International Workshop on the Extent and Impact of Coral Bleaching in the Arabian Region. National Commission for Wildlife Conservation and Development, Riyadh.

Anthony KRN and K.E. Fabricius 2000. Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity.. J Exp Mar Biol Ecol 252:221-253.

Antonius, A. 1985. Coral diseases in the Indo Pacific: a first record. P.S.Z.N.I. Mar. Ecol. 6: 197-218.

Antonius, A., G. Scheer and C. Bouchon, 1990. Corals of the Eastern Red Sea. Atoll Research Bulletin 334: 1-22.

Awad, H.E., 2000. Oil pollution and coral reef diseases. in H. Tatwany, ed. Proceedings of the International Workshop on the Extent and Impact of Coral Bleaching. the Arabian Region (National Commission for Wildlife Conservation and Development, Riyadh

Ayre D.J. and T.P. Hughes 2004. Climate change, genotypic diversity and gene flow in reef-building corals. Ecology Letters 7: 273-278.

Baker, A. C., P. W. Glynn , and B. Riegl. 2008. Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook . Estuarine, Coastal, and Shelf Science 80: 435-471.

Behairy, A.K.A., C.R.C. Sheppard, and M.K. El-Sayed. 1992. A review of the geology of coral reefs in the Red Sea. UNEP Regional Seas Reports and Studies No. 152, 39 pp.

Bellwood, D, T.R. Hughes and A.S. Hoey. 2006. Sleeping functional groups drives coral reef recovery. Current Biology 16:2434-2439.

Bemert G, and R.F.G. Ormond. 1981. Red sea coral reefs, London, Kegan Paul International.

Braithwaite, C.J.R. 1987. Geology and Paleogeography of the Red Sea region. In: Head S.M. (ed) Red Sea – Key Environments, Pergamon, 22-45

Bray, J. R. and J. T. Curtis. 1957. An Ordination of the Upland Forest Communities of Southern Wisconsin. Ecological Monographs 27:326-349.

Brien, E. M. O., R. J. Whittaker, and R. Field. 1998. Climate and Woody Plant Diversity in Southern Africa: Relationships at Species, Genus and Family Levels. Ecography 21:495-509.

Child, G. and J. Grainger. 1990. A System Plan for Protected Areas for Wildlife Conservation and Sustainable Rural Development in Saudi Arabia. National Commission for Wildlife Conservation and Development – World Conservation Union, Gland, Switzerland.

Clarke, K. R. and R. N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. Primer-E: Plymouth.
Davison L, I. Davison, M. Al-Kadasi, S. Al-Khirbash, A.K. Al-Subbary, J. Baker, S. Blakey, D. Bosence, C. Dart, R. Heaton, K. McClay, M. Menzies, G. Nichols, L. Owen and A. Yelland. 1994. Geological evolution of the southeastern Red Sea Rift margin, Republic of Yemen. GSA Bulletin 106; no. 11; p. 1474-1493;

Debelius, H. 1998. Red Sea reef guide. IKAN, Frankfurt, Germany.

DeVantier, L. and N. Pilcher . 2000. The Status of Coral Reefs in Saudi Arabia. . Global Coral Reef Monitoring Network (GCRMN)

DeVantier, L., E. Tourak, K. Al-Shaikh, and G. De'ath. 2000a. Coral communities of the central-northern Saudi Arabian Red Sea. Fauna of Arabia 18:23-66.

DeVantier, L., E. Tourak, and K. Al-Shaikh. 2000b. Coral bleaching in the central-northern Saudi Arabian Red Sea, August-September 1998. *In* H. Tatwany, ed. Proceedings of the International Workshop on the Extent and Impact of Coral Bleaching in the Arabian Region . National Commission for Wildlife Conservation and Development, Riyadh, Saudi Arabia.

Dicks, B. 1987. Pollution. Pages 383-404, *In:* A. Edwards and S.M. Head, eds. Key environments: the Red Sea. Pergamon Press, Oxford, United Kingdom.

Edwards, A.J. and S.M. Head. 1987. *Red Sea (Key Environments).* 441pp. Pergamon Press in collaboration with IUCN. Oxford.

English, S., C.R. Wilkinson & V. Baker, 1997. Survey Manual of Tropical Marine Resources. 2nd Edition. Australian Institute of Marine Science.

Gladstone, W. 1994. The Farasan Islands Marine Protected Area: biological resources, conservation values, human uses and impacts. National Commission for Wildlife Conservation and Development, Riyadh, Saudi Arabia.

Gladstone, W. 1996. Unique annual aggregation of longnose parrotfish (*Hipposcasus harid*) at Farasan Island (Saudi Arabia, Red Sea). Copeia 2:483-485.

Gladstone, W. 2000. The ecological and social basis for management of a Red Sea marine-protected area. Ocean and Coastal Management 43:1015-1032.

Gladstone, W. 2002. Fisheries of the Farasan Islands (Red Sea). Naga, World Fisheries Center 25(3&4):3034.

Gladstone, W., N. Tawfiq, D. Nasr, I. Andersen, C. Cheung, H. Drammeh, F. Krupp, and S. Lintner 1999. Sustainable use of renewable resources and conservation in the Red Sea and Gulf of Aden: Issues, needs and strategic actions. Ocean and Coastal Management 42:671-697.

Green, A.S., D. Bellwood, and H. Choat. 2009. Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience.

Guilcher, A. 1988. A heretofore neglected type of coral reef: the ridge reef: morphology and origin. Proceedings of the 6th International Coral Reef Symposium, Australia, 1988, Vol. 3. 399-402.

JICA/NCWCD, 2000. The Study on coastal/marine habitat and biological inventories in the northern part of the Red Sea coast in the Kingdom of Saudi Arabia .JICA/NCWCD report, Riyadh, March 2002.

Kedidi, S.M. 1984. Description of the artisanal fishery at Tuwwal, Saudi Arabia. Catches, efforts and catches per unit effort survey conducted during 1981-1982. UNDP/FAO RAB/81/002/16. 17 pp.

Kotb, M., M. AbdulAziz, Z. Al-Agwan, K. Al Shaikh, H. Al-Yami, A. Banajah, L. DeVantier, M. Eisinger, M. Eltayeb, M. Hassan, G. Heiss, S. Howe, J. Kemp, R. Klaus, F. Krupp, N. Mohamed, T. Rouphael, J. Turner, and U. Zajonz. 2004. Chapter 4: Status of coral reefs in the Red Sea and Gulf of Aden. Pages 137 154, *In:* Wilkinson, C.R. editor. Status of Coral Reefs of the World: 2004. Vol. 1: Australian Institute of Marine Science publ., Cairns, Australia

Kotb, M.M, M. H. Hanafy, H. Rirache, S. Matsumura, A. A. Al-Sofyani, A. G. Ahmed, G. Bawazir, and F. A. Al-Horani. 2008. Status of coral reefs in the Red Sea and Gulf of Aden region. Pages 67-78. *in* WC. Wilkinson, editor. Status of coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia.

Lang, J.C. 2003. Status of coral reefs in the Western Atlantic: results of initial surveys, Atlantic and Gulf Rapid Reef Assessment (AGGRA) Program. Atoll Research Bulletin 496:1-630.

Mandelik, Y., T. Dayan, V. Chikatunov, and V. Kravchenko. 2007. Reliability of a higher-taxon approach to richness, rarity, and composition assessments at the local scale. Conservation Biology **21**:1506-1515.

Marine Fisheries Department. 2008. Fisheries statistics of Saudi Arabia 2006. Ministry of Agriculture and Water, Kingdom of Saudi Arabia, Jeddah.

McClanahan, T.R., M. Ateweberhan, N. A. J. Graham, S. K. Wilson, C. R. Sebastian, M. M. M. Guillaume, and J. H. Bruggemann. 2007. Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. Marine Ecology Progress Series 337:1–13.

Nystrom, N., N. A. J. Graham, J. Lokrantz, and A.V. Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. Coral Reefs 27:795-809.

Obura, D.O., and G. Grimsdith. 2009. Resilience Assessment of coral reefs – manual. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland.

Ormond, R.F.G., A. Dawson-Sheppard, A. Price and R.G. Pitts. 1984a. Report on the distribution of habitats and species in the Saudi Arabian Red Sea. International Union for Conservation of Nature / Meteorological and Environmental Protection Administration / PERSGA, Kingdom of Saudi Arabia. 123 pp.

Ormond, R.F.G., A. Dawson-Sheppard, A. Price and R.G. Pitts. 1984b. Report on the distribution of habitats and species in the Saudi Arabian Red Sea. 2. International Union for Conservation of Nature / Meteorological and Environmental Protection Administration / PERSGA, Kingdom of Saudi Arabia. 151 pp.

Ormond, R.F.G., A. Dawson-Sheppard, A. Price and R.G. Pitts. 1984c. Management of Red Sea coastal resources: recommendations for protected areas International Union for Conservation of Nature / Meteorological and Environmental Protection Administration / PERSGA, Kingdom of Saudi Arabia. 113 pp.

Pandolfi, J. M. 2001. Numerical and taxonomic scale of analysis in paleoecological data sets: Examples from neo-tropical Pleistocene reef coral communities. Journal of Paleontology **75**:546-563.

PERGSA. 2003. Regional action plan for the conservation of coral reefs in the Red Sea and Gulf of Aden. PERGSA Technical Report Series 3:1-50.

Perrin, C., J.-C. Plaziat, and B.R. Rosen. 1998. Miocene coral reefs and reef corals of the south-western Gulf of Suez and north-western Red Sea: distribution, diversity, and regional environmental control. Purser, B.H., and D.W.J. Bosence (eds.) Sedimentation and Tectonics in Rift Basins. Red Sea – Gulf of Aden. Chapman & Hall, pp.296-320

Pielou, E. C. 1966. Measurement of Diversity in Different Types of Biological Collections. Journal of Theoretical Biology **13**:131-&.

Pilcher, N. and A. Alsuhaibany 2000. Regional Status of Coral Reefs in the Red Sea and the Gulf of Aden. In : Status of Coral Reefs of the World : 2000. AIMS, Townsville

Price, A.R.G., G. Jobbins, A. Dawson Shepherd, and R.F.G. Ormond. 1998. An integrated environmental assessment of the Red Sea coast of Saudi Arabia. Environmental Conservation 25: 65-76.

Purkis, S.J. 2005. A 'reef-up' approach to classifying coral habitats from IKONOS imagery. IEEE Transactions on Geoscience and Remote Sensing 43: 1375-1390.

Purkis S.J. and R. Pasterkamp 2004. Integrating in situ reef-top reflectance spectra with Landsat TM imagery to aid shallow-tropical benthic habitat mapping. Coral Reefs 23 (1): 5-20.

Purser, B.H., and D.W.J. Bosence. 1998. Sedimentation and Tectonics in Rift Basins. Red Sea – Gulf of Aden. Chapman & Hall.

Riegl, B. and W.M. Piller 1997. Distribution and environmental control of coral assemblages in Northern Safaga Bay (Red Sea, Egypt). Facies 36; 141-162.

Riegl, B. and B. Velimirov. 1994. The structure of coral communities at Hurghada in the Red Sea. Marine Ecology 15, 213-231.

Roberts, C.M. 1986. Aspects of Coral Reef Fish Community Structure in the Saudi Arabian Red Sea and on the Great Barrier Reef. D. Phil. Thesis University of York, U.K.

Roberts, C.M. and Ormond, R.F.G. 1987. Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. Marine Ecology Progress Series 41, 1-8.

Roupheal, A.B. and H. Al-Yami. 2000a. Spatial abundances of marine organisms in the Farasan Islands Marine Protected Area, Saudi Arabia. Proceedings of the international symposium on the extent and impacts of coral bleaching in the Arabian region. Riyadh, Kingdom of Saudi Arabia.

Roupheal, A.B. and H. Al-Yami. 2000b. Temporal variation in abundances of marine organisms, Farasan Islands Marine Protected Area, Saudi Arabia. Report 4, National Commission for Wildlife Conservation and Development. Jeddah, Saudi Arabia.

Shannon, C. E. 1948. A Mathematical Theory of Communication. Bell System Technical Journal **27**:379-423.

Sheppard, C.R.C. 1985. Reefs and coral assemblages of Saudi Arabia, 2. Fringing reefs of the southern region, Jeddah to Jizan. *Fauna of Saudi Arabia* 7: 37–58.

Sheppard, C.R.C. and A.L.S. Sheppard, 1985. Reefs and coral assemblages of Saudi Arabia 1. The central Red Sea at Yanbu al Sinaiyah. Fauna of Saudi Arabia 7: 17-36.

Sheppard, C.R.C. and A.L.S. Sheppard. 1991. Corals and coral communities of Arabia. Fauna of Saudi Arabia 12: 3-170.

Sheppard, C., A. Price, and C. X. Roberts. 1992. Marine ecology of the Arabian Region. Patterns and processes in extreme tropical environments. Academic Press, New York.

Smith, L., J. Gilmour, and A. Heyward. 2008. Resilience of coral communities on an isolated system of reefs following catastrophic mass-bleaching. Coral Reefs 27:197–205.

Stumpf R.P., K. Holderied, and M. Sinclair. 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology. Oceanography. 48 (1, part 2): 547–556.

Veron, J.E.N. 1993. Corals of Australia and the Indo-Pacific. University of Hawaii Press.

Veron, J.E.N. and M. Stafford Smith. 2000. Corals of the world. Australian Institute of Marine Science.

Weikert, H. 1987. Plankton and pelagic environment. In: Key Environment The Red Sea. Ed. A. J. Edwards and S. M. Head. Pergamon Press. pp. 90-111.

Wilkinson, C. 2008. Status of Coral Reefs of the World: 2008. Townsville, Australia: Global Coral Reef Monitoring Network and Reef and Rainforest Research Center.

Appendix I. Partners

Farasan Islands. Survey Dates: May 3- May 24, 2006

Affiliated Organizations

1. The Saudi Wildlife Commission (SWC), Kingdom of Saudi Arabia
2. The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), Kingdom of Saudi Arabia
3. Lantra, the UK Sector Skills Council for the Environmental and Land-based Sector,
4. The Trident Trust,
5. The University of Cambridge, Cambridge Coastal Research Unit and Unit for Landscape Modeling, United Kingdom
6. NOVA Southeastern University, National Coral Reef Institute (NCRI), Florida USA
7. College of Ocean and Fishery Sciences, the University of Washington, Washington, USA
8. Spanish Oceanographic Institute, Madrid, Spain
9. University of Hawaii, Hawaii, USA
10. Hyperspectral Data International, Inc. (HDI) – Halifax, Nova Scotia, Canada
11. BirchHill GeoSolutions, Canada

Ras Qisbah. Survey Dates: September 1-September 11 2007

Affiliated Organizations

1. The Saudi Wildlife Commission (SWC), Kingdom of Saudi Arabia
2. The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), Kingdom of Saudi Arabia
3. NOVA Southeastern University, National Coral Reef Institute (NCRI), Florida USA
4. The University of Cambridge, Cambridge Coastal Research Unit and Unit for Landscape Modeling, United Kingdom
5. The International Union for Conservation of Nature (IUCN), Geneva, Switzerland
6. Coastal Ocean Research and Development in the Indian Ocean (CORDIO)

Yanbu/Al Wajh Survey dates: May 7-May 24, 2008

Affiliated Organizations

1. The Saudi Wildlife Commission (SWC), Kingdom of Saudi Arabia
2. The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), Kingdom of Saudi Arabia
3. National Coral Reef Institute (NCRI),
4. Coastal Ocean Research and Development in the Indian Ocean (CORDIO),
5. The International Union for Conservation of Nature (IUCN), Geneva, Switzerland
6. NOVA Southeastern University, National Coral Reef Institute (NCRI), Florida USA
7. University of Cambridge, Cambridge Coastal Research Unit and Unit for Landscape Modeling

Farasan Banks Survey dates: April 3-April 27, 2008

Affiliated Organizations

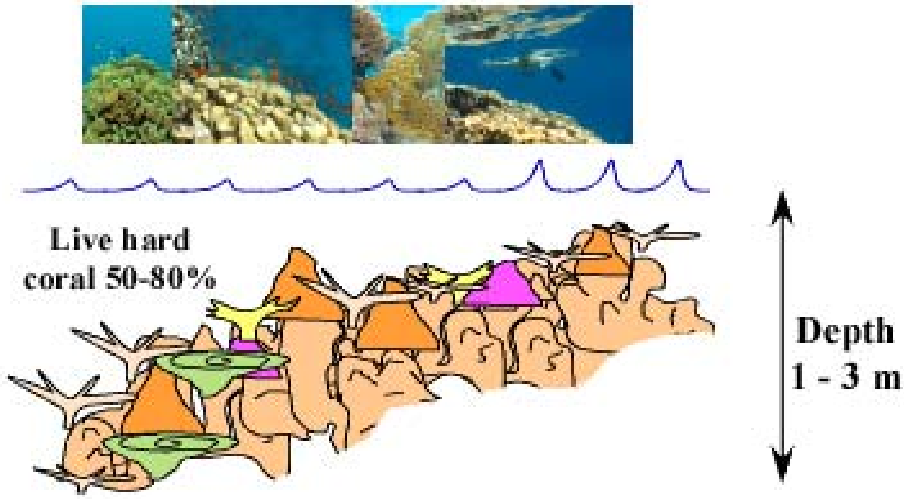
1. The Saudi Wildlife Commission (SWC), Kingdom of Saudi Arabia
2. The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), Kingdom of Saudi Arabia
3. Ministry of Agriculture, Marine Fisheries Department (MFD), Kingdom of Saudi Arabia
4. The International Union for Conservation of Nature (IUCN), Geneva, Switzerland
5. NOVA Southeastern University, National Coral Reef Institute (NCRI), Florida USA
6. Blue Ventures, United Kingdom

Appendix 2. List of scientists conducting research during the four year Red Sea Expedition.

Researcher	Farasan Islands	Ras Qisbah	Yanbu/Al Wajh	Farasan Banks
Captain Philip Renaud	X	X	X	X
Dr. Annelise Hagan	X	X	X	
Dr. Andrew Bruckner			X	X
Dr. Sam Purkis	X	X	X	X
Mr. Gwilym Rowlands		X	X	X
Dr. Bernhard Reigl	X		X	X
Dr. David Obura		X	X	
Dr. Ameer Abdulla		X	X	X
Dr. Sarah Hamylton		X	X	
Dr. Tony Raphael				X
Dr. Alastair Harris				X
Mr Omar Al-Khushaim	X	X	X	X
Mr. Khalid Al-Shaikh	X	X	X	X
Dr. Ahmed Al Mansi	X		X	X
Mr. Hatem Al-Yami	X	X		
Mr. Hussein Alnazry				X
Mr. Anas Sambas	X			
Mr Abdullah Alsuhaibany	X			
Mr. Ray Buckley	X			
Mr. Glenn Page				X
Mr. D.J. Rollers			X	
Ms. Frederique Kandel	X			
Dr. Ben Stobart	X			
Mr. Martin Callow	X			
Mr. Alastair Kennel	X			
Mr. Peter Scoones	X			
Mr. Nicholas Claxton	X			
Mr Herbert Ripley	X			
Mr Jeff Parks	X			

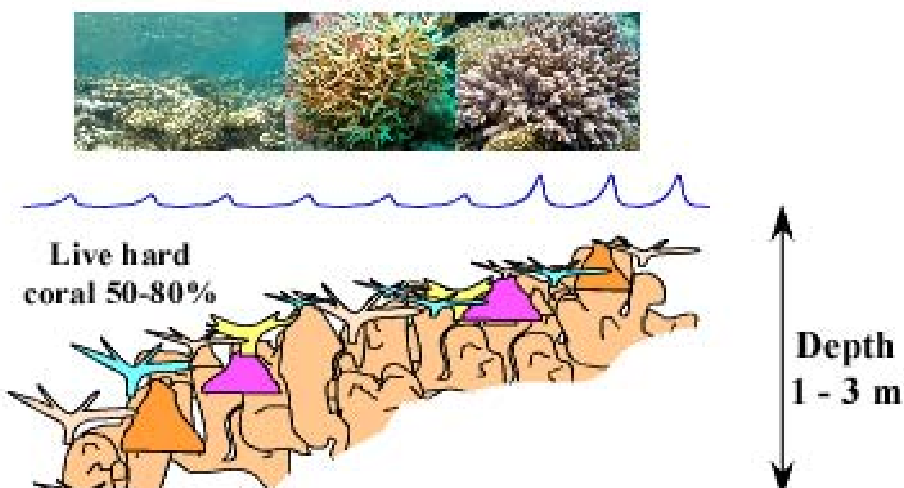
Appendix 3. Habitat Classification Scheme

Windward coral crest



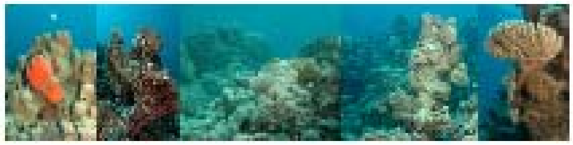
A diverse high-energy assemblage of hermatypic corals dominated by columnar *Porites* frameworks, interspersed with *Acropora* , *Pocillopora*, *Stylophora*, and occasional *Favia, Favites, and Fungia* spp. Live cover typically up to 50-80%. Macroalgae dominate windward fringes with the algae *Sargassum* and *Turbinaria* most common. Depth 1 - 3 m

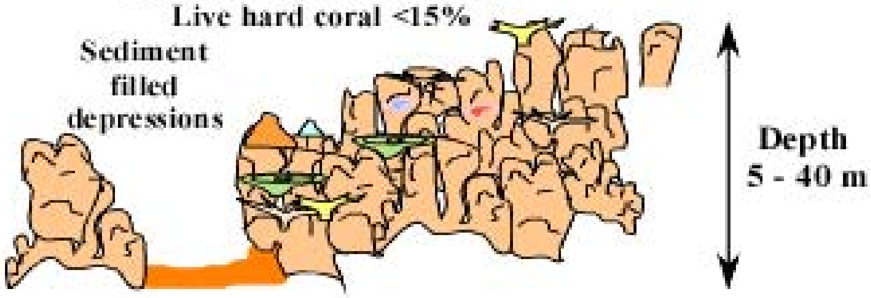
Leeward coral crest and patch reef



Rich hermatypic coral cover dominated predominantly by small *Acropora spp.* colonies, also *Porites* spp., *Favia* spp., *Favites* spp., and *Seriatopora hystrix*. Live cover typically 50-80%. The richest crests are found on shallow lagoonal fringes. Depth 1 - 3 m.

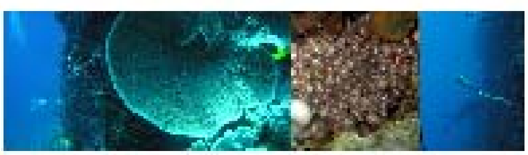
Columnar *Porites* assemblage



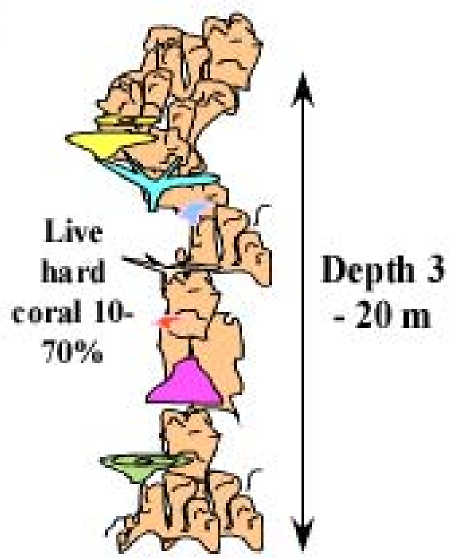


Topographically complex structure constructed of high-relief columnar *Porites*. Live cover is low and generally less than 15%. Current and past *Porites* growth accounts for >70% of live and dead cover. Columns covered with numerous plating, encrusting, and submassive coral forms. Columnar structure becomes shorter and fatter with depth. Depressions in the framework are sediment filled with deeper areas characterized by finer-grained to muddy sediment sheets. Morphology could be karstic, but the sediment-filled depressions also evoke the possibility that the landscape is purely accretional. Depth 5 - 40 m

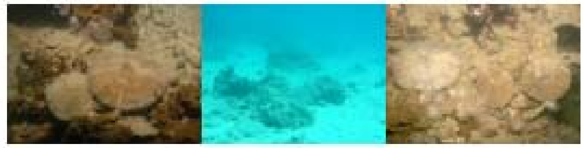
Reef Wall



Steep near-vertical wall, with coral cover ranging from 10-70%. All coral forms present but mainly encrusting and foliose on exposed points. Coral community mainly *Pachyseris*, *Echinopora*, *Mycedium*, *Favia*, *Favites*, and *Milleopora spp.*, but variable. Wall covered in places by rubble. Space between coral colonies can be bare or filled predominantly with sponge, macro and coralline algae, and *Xenia* soft coral. z = 3 - 20 m.

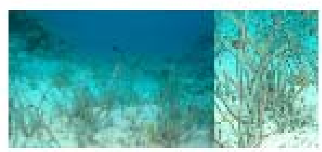


Mixed coralline rubble on sand, with sparse corals



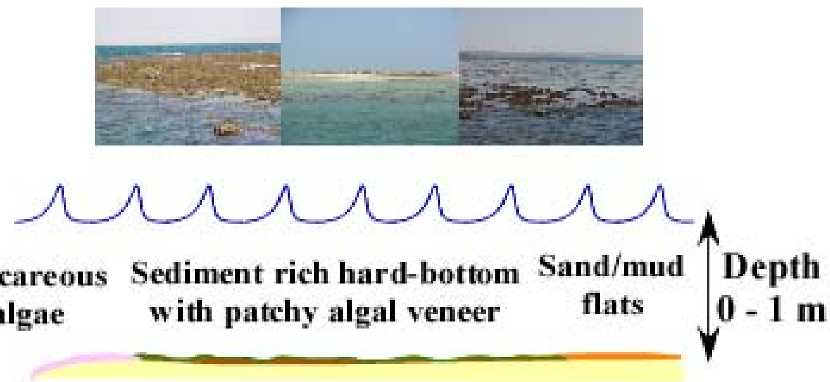
A largely unconsolidated matrix of coarse sand and coralline rubble extending down-slope from the live coral crest. Areas that are cemented host sparse coral cover, composed mainly of *Favia* , *Favites*, and *Fungia* spp., with occasional *A. clathrata*. Much consolidated substrate covered with *Xenia* soft coral. Depth 3 - 10 m

Seagrass meadows



Meadows of dense *Thalassodendron ciliatum* interspersed with sparse *Halophila ovalis* and occasional *Caulerpa racemosa* atop muddy organic-rich carbonate sands. Density ranges from 15 - 60%. Depth 1 - 40 m

Reef flat



Expansive shallow reef flats emergent at low tide. The interior has a thin veneer of sediment with patches of small macro-algae and filamentous algae. The periphery of these flats is characterized by a zone of calcareous red algae. Near-shore reef tops grade into intertidal mud flats. Depth 0 - 1 m

Sand

Unconsolidated coralgal sand sheets consisting of debris from corals and calcareous red algae, along with skeletal debris from other organisms. This facies is sparsely populated with stands of macro-algae (*Laurencia, Caulerpa racemosa, Cladophora*) and isolated patches of sediment resistant corals such as *Favia* sp.. In areas of low energy, sands are frequently covered by a thin algal mat veneer (*Rhizoclonium tortuosom, Chaetomorpha gracilis, Cladophora coelothrix*). Depth 1 - 40 m

Appendix 4. Final list of fish included in resilience assessments

Function	family	Genus	species
Predator	**DASYATIDAE**	*Taeniura*	*lymma*
Predator	**SPHRAENIDAE**	*Sphyraena*	*sp*
Predator	**SPHYRNIDAE**	*Sphyrna*	*lewini*
Predator	**CARCHARHINIDAE**	*Triaenodon*	*obesus*
Predator	**CARANGIDAE**	*Carangoides*	
Excavator	**SCARIDAE**	*Bolbometapon*	*muricatum*
Excavator	**SCARIDAE**	*Chlorurus*	*sordidus*
Excavator	**SCARIDAE**	*Chlorurus*	*gibbus*
Excavator	**SCARIDAE**	*Chlorurus*	*genozonatus*
Excavator	**SCARIDAE**	*Cetoscarus*	*bicolor*
Scraper	**SCARIDAE**	*Scarus*	*niger*
Scraper	**SCARIDAE**	*Scarus*	*ferrugineus*
Scraper	**SCARIDAE**	*Scarus*	*frenatus*
Scraper	**SCARIDAE**	*Hipposcarus*	*harid*
Browsers	**SCARIDAE**	*Calotomus*	*viridescens*
Browsers	**SCARIDAE**	*Leptoscarus*	*vaigiensis*
Grazer/Detritivore	**ACANTHURIDAE**	*Acanthurus*	*gahm*
Grazer/Detritivore	**ACANTHURIDAE**	*Acanthurus*	*sohal*
Grazer/Detritivore	**ACANTHURIDAE**	*Acanthurus*	*nigrofuscus*
Grazer/Detritivore	**ACANTHURIDAE**	*Acanthurus*	*mata*
Grazer	**ACANTHURIDAE**	*Zebrasoma*	*xanthurum*
Grazer	**ACANTHURIDAE**	*Zebrasoma*	*desjardini*
Grazer/Browser	**ACANTHURIDAE**	*Naso*	*elagans*
Grazer/Browser	**ACANTHURIDAE**	*Naso*	*unicornis*
Grazer/Browser	**ACANTHURIDAE**	*Naso*	*hexacanthus*
Grazer/Browser	**ACANTHURIDAE**	*Naso*	*brevirostris*
Grazer/Browser	**ACANTHURIDAE**	*Ctenochaetus*	*striatus*
Grazer/Browser	**SIGANIDAE**	*Siganus*	*luridus*
Grazer/Browser	**SIGANIDAE**	*Siganus*	*argenteus*
Grazer/Browser	**SIGANIDAE**	*Siganus*	*stellatus*
Grazer/Browser	**POMACANTHIDAE**	*Pomacanthus*	*maculosus*
Grazer/Browser	**POMACANTHIDAE**	*Pomacanthus*	*asfur*
Grazer/Browser	**POMACANTHIDAE**	*Pomacanthus*	*imperator*
Grazer/Browser	**POMACANTHIDAE**	*Pygoplites*	*diacanthus*
Browsers	**POMACANTHIDAE**	*Centropyge*	*acanthops*
Grazer/Browser	**KYPHOSIDAE**	*Kyphosus*	*sp*
Browsers	**EHIPPIDAE**	*Platax*	*orbicularis*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*austriacus*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*semilarvatus*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*larvatus*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*paucifasciatus*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*melannotus*
Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*trifascialis*
Generalist/Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*auriga*
Generalist/Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*lineolatus*
Generalist/Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*fasciatus*
Generalist/Corallivore	**CHAETODONTIDAE**	*Chaetodon*	*mesoleucos*
Planktivore	**CAESONIDAE**	*Caesio*	*lunaris*
Planktivore	**CAESONIDAE**	*Caesio*	*striata*
Omnivores	**LABRIDAE**	*Cheilinus*	*lunulatus*
Omnivores	**LABRIDAE**	*Cheilinus*	*undulatus*
Omnivores	**LABRIDAE**	*Cheilinus*	*abudjubbe*
Omnivores	**LABRIDAE**	*Cheilinus*	*quinqueinctus*
Omnivores	**LABRIDAE**	*Oxycheilinus*	*digrammus*
Omnivores	**LABRIDAE**	*Bodianus*	*anthiodes*
Omnivores	**LABRIDAE**	*Anampses*	*twistii*
Omnivores	**LABRIDAE**	*Coris*	*sp*
Omnivores	**LABRIDAE**	*Hemigymnus*	*sp*
Omnivores	**LABRIDAE**	*Gomphosus*	*caeruleus*
Omnivores	**LABRIDAE**	*Epibulus*	*insidiator*
Omnivores	**LABRIDAE**	*Thalassoma*	*sp*
Omnivores	**LABRIDAE**	*other*	

Function	**Family**	**Genus**	**species**
Omnivores	**BALISTIDAE**	*Balistapus*	*undulatus*
Omnivores	**BALISTIDAE**	*Sufflamen*	*albicaudatus*
Omnivores	**BALISTIDAE**	*Rhinecanthus*	*assasi*
Omnivores	**BALISTIDAE**	*Pseudobalistes*	*flavimarginatus*
Omnivores	**BALISTIDAE**	*Odonus*	*niger*
Omnivores	**LETHIRINIDAE**	*Lethrinus*	*microdon*
Omnivores	**LETHIRINIDAE**	*Lethrinus*	*mahsena*
Omnivores	**SPARIDAE**	*Acanthopagrus*	*sp*
Omnivores	**SPARIDAE**	*other*	
Predator	**SERANIDAE**	*Aethalaperca*	*rogaa*
Predator	**SERANIDAE**	*Epinephelus*	*tauvina*
Predator	**SERANIDAE**	*Epinephelus*	*fasciatus*
Predator	**SERANIDAE**	*Epinephelus*	*summana*
Predator	**SERANIDAE**	*Epinephelus*	*areolatus*
Predator	**SERANIDAE**	*Epinephelus*	*tukula*
Predator	**SERANIDAE**	*Cephalopholis*	*argus*
Predator	**SERANIDAE**	*Cephalopholis*	*sexmaculata*
Predator	**SERANIDAE**	*Cephalopholis*	*miniata*
Predator	**SERANIDAE**	*Cephalopholis*	*hemistiktos*
Predator	**SERANIDAE**	*Plectropomus*	*sp*
Predator	**SERANIDAE**	*Variola*	*louti*
Predator	**SERANIDAE**	*Anyperodon*	*leucogrammicus*
Predator	**HAEMULIDAE**	*Plectrohinchus*	*albovittatus*
Predator	**HAEMULIDAE**	*Plectrohinchus*	*gaterinus*
Predator	**HAEMULIDAE**	*Diagramma*	*pictum*
Predator	**LUTJANIDAE**	*Lutjanus*	*kasmira*
Predator	**LUTJANIDAE**	*Lutjanus*	*fulviflamma*
Predator	**LUTJANIDAE**	*Lutjanus*	*bohar*
Predator	**LUTJANIDAE**	*Lutjanus*	*ehrenbergi*
Predator	**LUTJANIDAE**	*Lutjanus*	*monostigma*
Predator	**LUTJANIDAE**	*Macolor*	*niger*

Appendix 5. Educational Components

The Living Oceans Foundation conducted various aspects of education and outreach during the four year research mission. A variety of educational components were included, such as web-based outreach and dissemination of information and imagery, daily web blogs, scientific presentations at international and national meetings, popular articles and scientific articles, cd-roms, and training for students and researchers. The scientific team conducted a national and international education and outreach campaign relating the importance of this project to the scientific community at large and, more importantly, to schools, and the general public with the aim of enhancing marine conservation awareness. The Foundation developed a novel web-site and content management system, which allowed daily 'near-real-time' scientific updates to be offered to the expeditions audience. These updates were mapped as closely as possible to the United Kingdom KS4 Science Curriculum, and also offered significant learning opportunities for an international audience of young people. The educational component of this research expedition also highlighted a model for the effective delivery of Work Related Learning.

Farasan Islands

The educational component of the Farasan Islands Research Expedition was directed by Mr. Martin Callow of Lantra: the UK-based Sector Skills Council for the Environment. Fifteen local and international schools were engaged to take part in a "live" web-cast during the expedition to promote conservation awareness. On the local level, one of the Saudi Arabian scientists visited various schools in the Farasan Islands to talk with the students about the importance of conserving the fish, mammals, turtles, seabirds, and corals of their beautiful islands. On the international level, the science team embarked on the research ship, *Golden Shadow*, interacted with a select group of high schools in the United States and the United Kingdom. The expedition scientists updated the Living Oceans Foundation website daily from the ship with a 'Science Diary', 'Fact of the Day', 'Vessel Log', and 'Questions and Answers.' This interactive website provided 'real-life' scientific information directly aligned with established science curriculum. Eighty-eight 'live' pages of information were created during the expedition containing over 300 digital images and 21 video clips. Over 580,000 'hits' to the website reflect the great popularity and effectiveness of this exciting program.

An additional facet of the education and outreach mission of the Farasan Islands Habitat Mapping Expedition was production of a high definition film documentary by First Watch Television (UK). The work included filming, editing and translating a 45 minute documentary in two languages (English and Arabic). The film crew from the UK included Director Nicholas Claxton and underwater cameraman, Peter Scoones. Expedition scientists were filmed as they worked above and below the water. The film crew documented the Foundation's quest to survey the shallow water environments of the Farasan Islands as the scientists assessed coral health, conducted a fish census, and surveyed sea turtles and mammals in the natural environment.

Appendix 6. List of resulting publications

Hagan, A. (2006) Benthic habitat assessment and mapping in the Farasan Islands marine protected area, May 2006. Preliminary Field Report. 23 pp.

Renaud, P. (2006) "Coral Reef Rapid Habitat Mapping." Sea Technology, Sept., 2006: editorial.

Rowlands, G., Goodman, J., Riegl,B., Renaud, P., and S. Purkis.(2008). Habitat mapping in the Farasan Islands (Saudi Arabia) using CASI and QuickBird imagery. Proceedings of the 11th International Coral Reef Symposium, Ft Lauderdale, Florida, 7-11 July 2008 - Session number 17

Riegl, B., Bruckner, A., Coles, S., Renaud, P. and R. Dodge. (2009) Coral reefs: Threats and conservation in an era of global change. The Year in Ecology and Conservation Biology. pp136-186.

Hamylton, S. (2009) Determination of the separability of coastal benthic assemblages of the Al Wajh barrier reef, Red Sea, from hyperspectral data. European Journal of GeoSciences. pp95-105.

Hamylton, S (2008) Airborne Remote Sensing of the Al Wajh Barrier Reef, Saudi Arabia, Red Sea. In: Expedition Field Techniques: GIS, GPS and Remote Sensing Manual. Royal Geographical Society-Institute of British Geographers.

Hamylton, S. (2009) Modelling the structure and function of tropical coastal communities at the landscape scale. University of Cambridge PhD.

Hamylton, S. (2010) Estimating the coverage of coral reef benthic communities in the Al Wajh, Red Sea from airborne hyperspectral remote sensing data: Multiple discriminant function analysis and linear spectral unmixing, International Journal of Remote Sensing.

Hamylton, S. (2010) The Al Wajh Bank reef system, Saudi Arabia, Red Sea, pp. 28 – 37. In: Harris, P & Baker, E (Eds.) (2009) Atlas of Seafloor Geomorphology as Habitat, Elsevier, Chatswood, Australia. 600pp

Hamylton, S. and T. Spencer (2010) An integrated approach to landscape ecology in marine systems: Remote sensing, patches and spatial statistics. Continental Shelf Research, Special Issue on Coastal Remote Sensing (DOI:10.1016/j.csr.2010.02.003).

Hamylton, S. (2010) Spatial modelling of live coral cover using hyperspectral remote sensing data in the Al Wajh lagoon, Red Sea. Coral Reefs.

Purkis, S., Rowlands, G. ,Riegl, B. andP. Renaud (2010).The paradox of tropical karst morphology in the coral reefs of the arid Middle East. Geology38:227-230.

Rowlands, G., Goodman, J., Riegl, B., Renaud, P. and S. Purkis. (2010) Habitat mapping in the Farasan Islands (Saudi Arabia) using CASI and QuickBird imagery. Proceedings of the 11th International Coral Reef Symposium, Ft Lauderdale, Florida, 7-11 July 2008, p 642-646.

Bruckner, A., Alnazry, H., and M. Faisal. (2011) A paradigm shift for fisheries management to enhance recovery, resilience, and sustainability of coral reef ecosystems in the Red Sea. Sustainable Fisheries: Multi-Level Approaches to a Global Problem, pp. 85–111.