EXPEDITION REPORT

Expedition dates: 23 – 29 October 2016
Report published: August 2017

Underwater pioneers: studying & protecting the unique coral reefs of the Musandam Peninsula, Oman.

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Authors:
Jean-Luc Solandt
Marine Conservation Society

Matthias Hammer (editor)
Biosphere Expeditions

Abstract

Coral reefs are important biodiversity hotspots that not only function as a crucial habitat for a multitude of organisms, but also provide human populations with an array of goods and services, such as food and coastal protection. Despite this, coral reefs are under threat worldwide from direct or indirect anthropogenic impacts, such as pollution, overexploitation and climate change. The coral reefs of the Musandam Peninsula (Oman), situated on the Arabian Peninsula in the Strait of Hormuz, endure extreme conditions such as high salinity and temperatures, existing – indeed thriving – in what would be considered marginal and highly challenging environments for corals in other parts of the world. This is remarkable and may hold they key to coral survival in the face of global warming and its devastating effects on reefs across much of the planet.

However, although Musandam corals currently appear to exhibit regional resilience, there is concern that any additional stress, as a result of natural disasters and/or anthropogenic impacts, for example, may induce coral die-off or ecosystem change. For the past decade, reefs within the Arabian Gulf, and wider Indian Ocean have been damaged by major coral bleaching events, cyclones, harmful algal blooms and extensive coastal developments. Fisheries of the area have also declined, with longlining significantly reducing shark numbers, whilst targeted hammour (grouper) fisheries are in decline in many regions.

Between 23 and 29 October 2016, Biosphere Expeditions conducted its eighth annual coral reef survey using the Reef Check methodology. Seven different dive sites along the northern Musandam Peninsula coastline were surveyed. The main objectives of the survey were to (1) monitor the health of and impacts on the Musandam Peninsula's coral reefs, (2) train local people in the Reef Check methodology and involve these individuals in surveys, and (3) use and disseminate these findings for the purposes of management, education and conservation by local government and non-governmental organisations (NGOs).

This particular expedition saw coral cover of between 25 and 89% at shallow (<10 m) depths. Perhaps more significantly, there was little evidence of any coral disease, bleaching or predation, which is in itself remarkable considering the impacts of the 2015/2016 El Niño event elsewhere in the region (e.g. Maldives). Corals appeared to be in a healthy 'climax' state on many of the shallow reefs, with many sites hosting very large *Porites* colonies, indicating no significant damaging events to these corals over the past 400 years.

The grouper populations varied from site to site, with an average of two animals over 30 cm per 500 m^3. Snappers are common (rather than abundant) at most shallow sites. At Faqadar Bay in particular their density is greater than at overseas marine reserves. We believe that local fishing is reducing the average size and abundance of grouper populations, with indications that the numbers of larger breeding adults is diminishing.

Shallow survey (1-5 m depth) invertebrate populations were dominated by *Diadema* urchins. Within the *Pocillopora* colony framework they appear not to exert significant grazing pressure. But their very high densities on many reef flats is causing structural erosion of the reef framework. *Symphyllia* brain corals appear to be particularly vulnerable in some shallow water areas. Pencil urchins were common in shallow waters, particularly in amongst *Pocillopora* coral. Giant clam remain absent from the Peninsula. Only three lobsters were seen on the surveys, mirroring the absence of lobsters seen and recorded by Reef Check from across the world and corroborating that overfishing is present.

To help secure the fishing of the area, we recommend a number of no-take zones that could be set up in the northern part of the Peninsula. As coastal development in the area continues to grow, the lack of investment in fisheries management, regulation and enforcement will result in severe overfishing, and impoverished local communities. The signs of this are already apparent. We therefore strongly urge government to work with the local fishing fleet to designate, enforce and control fishing at the sites recommended in this report, and to clarify and communicate clearly a number of marine protection zones and regulations.

ملخص

تعتبر الشعاب المرجانية أحد أهم النقاط الساخنة في مسألة التنوع البيولوجي، ليس فقط بوصفها موئلا بالغ الأهمية للعديد من الكائنات الحية، ولكن ايظا لكونها مصدرا هاما للبشر في توفير مجموعة من السلع والخدمات، مثل الغذاء، ولدورها الحيوي في حماية السواحل. ولكن وبالرغم من هذه الأهمية القصوى للشعاب المرجانية، فإنها تقع تحت تهديدات بشرية المنشأ بصورة مباشرة او غير مباشرة في جميع أنحاء العالم، مثل التلوث، الإستغلال المفرط، وتغير المناخ. ويبدو أن الشعاب المرجانية في شبه جزيرة مسندم (سلطنة عمان)، التي تقع على مضيق هرمز في شبه الجزيرة العربية، القائمة – في الواقع مزدهرة – في ما يمكن اعتباره بيئة هامشية وصعبة للغاية بالنسبة للشعاب المرجانية في أجزاء أخرى من العالم، حيث تعاني ظروف قاسية، مثل الملوحة العالية، وإرتفاع درجات الحرارة، ويعتبر هذا الأمر لافت للنظر ويحمل مفتاح بقاء وإستمرار الشعاب المرجانية فى مواجهة ظاهرة زيادة درجات الحرارة فى جميع أنحاء العالم.

على الرغم من ان الشعاب المرجانية في مسندم تظهر حاليا مرونة إقليمية، إلا ان هناك قلق عن مدى قدرة هذه الشعاب لتحمل أي ضغط اضافي قد ينتج عن الكوارث الطبيعية و/ أو الممارسات البشرية، التي قد تؤدي على سبيل المثال إلي تدهور وموت الشعاب المرجانية، أو تغيير النظام البيئي. على امتداد العقد الماضي، تعرضت الشعاب المرجانية الرئيسية المتواجدة في منطقة الخليج العربي خاصة ومنطقة المحيط الهندي بالعموم للأذى متأثرة بظواهر ابيضاض الشعاب المرجانية، وإنتشار الطحالب الضارة، و تكون الأعاصير، بالإضافة إلى أعمال التطوير والإنشاءات علي السواحل والشواطئ المستمرة بصورة مكثفة وعلى نطاق واسع. هناك ايضا انخفاضا في الثروة السمكية في المنطقة، فبسبب استخدام الصيد بالخيوط الطويلة فهذا ادى الى إنخفاض ملحوظ لأعداد اسماك القرش، في حين ان زيادة ضغط الصيد على اسماك الهامور (الوقار) ادى الى انخفاض اعدادها في العديد من المناطق.

في الفترة ما بين بين 23 و 29 أكتوبر 2016 ، أجرى فريق "بعثات بايوسفير الاستكشافية" مشروع مسح الشعاب المرجانية للعام الثامن على التوالي باستخدام "منهجية مراقبة الشعاب المرجانية" في سبعة مواقع غوص على امتداد الساحل الشمالي لشبه جزيرة مسندم. تتمحور الأهداف الرئيسية للبعثة حول (1) متابعة الحالة الصحية للشعاب، ورصد تأثير الأرصفة المرجانية في شبه جزيرة مسندم، (2) تدريب الباحثيين المحليين في منهجية مراقبة الشعاب المرجانية، واشراكهم في المسوحات، (3) واستخدام هذه النتائج لاتخاذ القرارات الإدارية والتعليمية ولغايات جمع بيانات علمية موثقة يمكن استخدامها مستقبلا من قبل الحكومات المحلية والجمعيات الأهلية.

شهدت هذه البعثة وجود 25 و 89% من الغطاء المرجاني في الأعماق الضحلة (اقل من 10 أمتار). والأهم من ذلك، كان هناك القليل من الأدلة لوجود اي مرض مرجاني، كابيضاض المرجان او آثار الإفتراس، والذي في حد ذاته يعتبر امر رائع عند الأخذ بعين الإعتبار احداث ظاهرة النينو خلال 2015 و2016 وتأثيرها على اماكن أخرى في المنطقة (كمثال جزر المالديف). في كثير من مناطق المياة الضحلة وجد ان الشعاب المرجانية كانت في أوج حالتها الصحية، مع وجود مستعمرات كبيرة من النوع Porites، مما يدل على عدم تأثر هذة الشعاب بأي احداث مدمرة خلال ال400 سنة الماضية.

لقد تباينت اعداد اسماك الهامور (grouper) من موقع لآخر، بمتوسط معدل 2 اسماك على طول 30 سم لكل 500 متر مكعب. كان وجود أسماك النهاش (snappers) شائع (بدلا من وفرة) في معظم المواقع من المياة الضحلة، وبالأخص فى منطقة خليج فكدارتزداد وفرة تلك الاسماك مقارنة بباقى مناطق المحميات البحرية. يعتقد أن انشطة الصيد المحلية تؤثر بالسلب على متوسطات أحجام أسماك الهامور وكذلك على أعدادها حيث ثبت بالأدلة أن أعداد الأسماك البالغة والقادرة على التكاثر تتضائل بصورة سريعة.

تهيمن القنافذ البحرية علي مسوحات اللافقاريات في المياة الضحلة (عمق 1 – 5 متر). ولا يبدوا ان هناك اي ضغط رعي في إطار مستعمرة (Pocillopora). ولكن وجودهم على الشعب المرجانية بكثافة عالية يسبب تآكل هياكل تلك الشعاب المرجانية. يظهر مرجان المخ ضعفاً بشكل خاص فى بعض مناطق المياه الضحلة، كانت قنافذ البحر من نوع قلم الرصاص (Pencil urchins) منتشرة في المياة الضحلة، ولا سيما في اوساط الشعاب المرجانية من النوع (Pocillopora). يبقى البطلينوس العملاق غائبا عن منطقة شبه جزيرة مسندم. خلال المسوحات تم رصد ثلاث من أفراد سرطان البحر ، ويعكس ملاحظة غياب سرطان البحر وعدم تسجيله خلال المسوحات من قبل Reef Check حول العالم هو دليل على وجود الصيد الجائر لهذا النوع.

وللمساهمة في الحفاظ على الصيد في المنطقة، فنحن نقترح عدد من المناطق يتم حظر الصيد فيها والتي يمكن ان تقام في الجزء الشمالي من شبه جزيرة مسندم. ومع استمرار نمو التنمية الساحلية فإن نقص الإستثمار في إدارة مهنة الصيد، من حيث وضع القوانين وتنفيذها، سيؤدي الى الإفراط الشديد في صيد الأسماك. حيث توجد حاليا علامات واضحة تدل على وجود مشكلة الصيد الجائر بالفعل في المنطقة. ولذا فإننا نحث الحكومة بشدة للعمل مع مجتمع الصيادين من خلال تعيين، وتنفيذ، ومراقبة المواقع الموصى بها في هذا التقرير، والتوضيح والتواصل بشكل واضح في ما يتعلق بعدد من مناطق المحميات البحرية ولوائحها.

Contents

Please note: Each expedition report is written as a stand-alone document that can be read without having to refer back to previous reports. As such, much of this section, which remains valid and relevant, is a repetition from previous reports, copied here to provide the reader with an uninterrupted flow of argument and rationale.

1. Expedition Review

M. Hammer (editor)
Biosphere Expeditions

1.1. Background

Biosphere Expeditions runs wildlife conservation research expeditions to all corners of the Earth. Our projects are not tours, photographic safaris or excursions, but genuine research expeditions placing ordinary people with no research experience alongside scientists who are at the forefront of conservation work. Our expeditions are open to all and there are no special skills (biological or otherwise) required to join. Our expedition team members are people from all walks of life, of all ages, looking for an adventure with a conscience and a sense of purpose. More information about Biosphere Expeditions and its research expeditions can be found at www.biosphere-expeditions.org.

This project report deals with an expedition to the Musandam Peninsula that ran from 23 to 29 October 2016 with the aim of monitoring the health of the Musandam Peninsula's reefs, fish and invertebrate communities so that informed management, education and conservation decisions can be made by the government and NGOs. Data on the current biological status of the reefs and on population levels of key indicator species are crucial for educational purposes and to be able to put forward ideas for future marine protection areas. Data collection followed an internationally recognised coral reef monitoring programme, called Reef Check, and will be used to make informed management and conservation decisions within the area. The expedition included training for participants as Reef Check EcoDivers.

Although popular myth has Arabia down as a vast, flat and empty expanse of sand (and oil), Oman is quite different. In fact, there is a wide range of contrasting landscapes: high mountains, beaches, the desert landscapes of the Empty Quarter, coral reefs, and even tropical habitats where the monsoon touches Oman in the extreme south.

The 650-kilometre coastline of the Musandam Peninsula is strewn with rocks and coves, gradual steps, steep rocky slopes and cliffs that plunge to great depths all over the fjord-like landscape. The coral reefs that grow along the margins of this stunning landscape are still relatively untouched as influences such as industrial-scale fishing, pearl or scallop extraction or large numbers of recreational divers have not wreaked their destructive influence there. The area is therefore a prime target for studying intact reef ecosystems, conserving them for future generations and using them for the education of people locally and all over the world.

1.2. Research Area

The Musandam Peninsula (sometimes also called the Norway of Arabia) is the northernmost part of Oman jutting out into the Strait of Hormuz at the entrance to the Arabian Gulf. The province, or Governorate of Musandam as it is officially known, is separated from the rest of Oman by various parts of the United Arab Emirates, including Ras al Khaimah and Fujairah. The Musandam Peninsula more or less begins where the mountains rise from the plains of Ras al Khaimah.

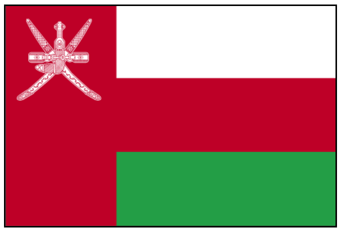

Figure 1.2a. Flag and location of Oman and study site.

An overview of Biosphere Expeditions' research sites, assembly points, base camp and office locations is at Google Maps.

The remote and rugged mountains, which rise straight out of the sea creating fjords and stunning landscapes, have been home to isolated communities for centuries. Many coastal villages can be reached only by boat, as there are no roads on much of the Peninsula. Pockets of flat land support subsistence agriculture. The population of approximately 29,000 is concentrated in the capital, Khasab (18,000 in 2004), in the north and Dibba (5,500) on the east coast. Fishing is the principal economic activity supported by employment in government jobs.

Geology

Rocks of the Hajar supergroup in the north appear to be flat-lying but are actually folded in a north–south trending anticline. Thinly bedded yellowish-orange dolomitic limestones and mudstones indicating a near-shore environment progress upwards into highly fossiliferous shelf limestones. Shell fragments, brachiopods and microfossils in limestone indicate continental shelf conditions. These limestones were deposited from the early Jurassic to the Cretaceous period and are believed to be older than 65 million years.

‘Round the bend’

The British arrived on a lump of rock they called Telegraph Island in the fjords back in the mid-19th century and stayed for five years. They were laying a telegraph cable from India to Basra in Iraq. Taking the cable ‘round the bend’ of the Gulf gave rise to this expression, since living on Telegraph Island in the extreme heat of summer must have sent them crazy! These days, the island is noted for its rich underwater life, and dhows (the local type of fishing boat), which stop off here.

1.3. Dates

The project ran over a period of one week, and was composed of a team of international research assistants, scientists and an expedition leader. Expedition dates were:

2016: 23 – 29 October

Dates were chosen when survey and weather conditions are most comfortable.

1.4. Local Conditions & Support

Expedition base

The expedition base was a modern and comfortable live-aboard dhow with eight air-conditioned cabins, some of them with en-suite toilet and shower facilities. The dhow had three decks, an air-conditioned lounge, a compressor and all facilities one would expect on a modern live-aboard boat. Tank refills and dive services were provided by the crew. A professional cook and crew also provided all meals, and vegetarians and special diets could be catered for.

Weather & water temperature

The climate is tropical and maritime. The day temperature during the expedition varied between 30 and 35°C with sunshine and no clouds on all but a few rare days. Water temperature during the expedition ranged from 26 to 28°C.

Field communications

The live-aboard boat was equipped with a satellite communication system. Mobile phones worked in some parts of the study site. The expedition leader also sent an expedition diary to the Biosphere Expeditions HQ every few days and this diary appeared on Biosphere Expeditions’ social media sites such as Facebook, Google+ and the Wordpress blog.

Transport, vehicles & research boats

Team members made their own way to the Dubai assembly point. From there onwards and back to the assembly point all transport and vehicles were provided for the expedition team, for expedition support and emergency evacuations.

Medical support and insurance

The expedition leader and the expedition scientist were trained first aiders, and the expedition carried a medical kit. The standard of medical care in Oman is very high with a clinic in Khasab. There is also a recompression chamber in Muscat and one in Dubai. Safety and emergency procedures were in place. There were no incidents during the expedition and emergency procedures did not have to be invoked.

Diving

The minimum requirement to take part in this expedition was a PADI Open Water or equivalent qualification. Team members who had not dived for twelve months prior to joining the expedition were required to complete a PADI Scuba Review before joining the expedition. Standard PADI diving and safety protocols were followed.

Dive groups were divided into different teams, each working on specific areas of survey work. Divers were allocated to teams based on a mixture of personal preference, diving skills and knowledge of the species.

1.5. Scientist

Dr Jean-Luc Solandt is a Londoner with a degree in Marine Biology from the University of Liverpool. After graduating, he spent a year diving on the Great Barrier Reef assisting field scientists in studies on fisheries and the ecology of soft corals and damselfish. He returned to the UK and enrolled in a Ph.D. in sea urchin ecology in Jamaica, based both in London and Jamaica. He went on to be an expedition science coordinator for projects in Tanzania, the Philippines and Fiji, and is now undertaking campaign and policy work in planning and developing Marine Protected Areas in the UK. He has been the Reef Check coordinator for the Maldives since 2005 and has thus far led three expeditions to undertake surveys inside and outside Marine Protected Areas on the islands. Jean-Luc has over 1,000 dives clocked up since he trained to be a marine biologist 20 years ago.

1.6. Expedition Leader

Biosphere Expeditions was founded in 1999 by Dr. Matthias Hammer. Born in Germany, he went to school there, before joining the Army, and serving for several years amongst other units with the German Parachute Regiment. After active service he came to the UK and was educated at St Andrews, Oxford and Cambridge. During his time at university he either organised or was involved in the running of several expeditions, some of which were conservation expeditions (for example to the Brazil Amazon and Madagascar), whilst others were mountaineering/climbing expeditions (for example to the Russian Caucasus, the Alps or the Rocky Mountains). With Biosphere Expeditions he has led teams all over the globe. He is a qualified wilderness medical officer, ski instructor, mountain leader, divemaster and survival skills instructor. Once a rower on the international circuit, he is now an amateur marathon runner and Ironman triathlete.

1.7. Expedition Team

The expedition team was recruited by Biosphere Expeditions and consisted of a mixture of all ages, nationalities and backgrounds. They were (with country of residence):

23 – 29 October 2016

Jenan Anwar Alasfoor* (Oman), Waleed Alkaabi* (Oman), Elaine Brown (Canada), Tanya Claringhold (UK), Lori Cottrell (USA), Andy Gahan (UK), Ali Saleh Ibrahim* (Oman), Patrick Jean-Martel (France), Rolf Niebur (Germany), Jon Okabayashi (USA), Angela Peetz (Germany), Patricia Silver (USA).

*Placement for local people. These were kindly sponsored by the Anglo-Omani Society and an anonymous foundation.

1.8. Other Partners

On this project Biosphere Expeditions is working with the Marine Conservation Society, Reef Check, local dive centres, businesses and resorts, the local community, Sultan Qaboos University, the Oman Ministry of Environment and Climate Affairs, as well as the United Nations Environment Programme, the World Conservation Monitoring Centre and the International Coral Reef Action Network (ICRAN). A special thanks to the Anglo-Omani Society and the Oman Ministry of Tourism for their support of the project.

1.9. Acknowledgements

This study was conducted by Biosphere Expeditions, which runs wildlife conservation expeditions all over the globe. Without our expedition team members (listed above) who provided an expedition contribution and gave up their spare time to work as research assistants, none of this research would have been possible. The support team and staff (also mentioned above) were central to making it all work on the ground. Thank you to all of you and to the ones we have not managed to mention by name (you know who you are) for making it all happen. Biosphere Expeditions would also like to thank members of the Friends of Biosphere Expeditions and donors. Biosphere Expeditions also gratefully acknowledges support from the Anglo-Omani Society, the Ministry of Tourism and the Friends of Biosphere Expeditions. Thank you also to two independent reviewers for their helpful comments and to Tamer Khafaga for translating the abstract.

1.10. Further Information & Enquiries

More background information on Biosphere Expeditions in general and on this expedition in particular including pictures, diary excerpts and a copy of this report can be found on the Biosphere Expeditions website www.biosphere-expeditions.org. Enquires should be addressed to Biosphere Expeditions via www.biosphere-expeditions.org.

1.11. Expedition Budget

Each team member paid a contribution of £1,280 per person per seven-day slot towards expedition costs. The contribution covered accommodation and meals, supervision and induction, special non-personal diving and other equipment and air, and all transport from and to the team assembly point. It did not cover excess luggage charges, travel insurance, personal expenses such as telephone bills, souvenirs etc., or visa and other travel expenses to and from the assembly point (e.g. international flights). Details on how this contribution was spent are given below.

Income	£
Expedition contributions	13,040
Grants	15,000
Expenditure	
Research vessel includes all board & lodging, ship's crew, fuel & oils, other services	9,410
Equipment and hardware includes educational & research materials & gear purchased in UK & Middle East	25
Staff includes local and international salaries, travel and expenses	11,490
Administration includes registration and other admin fees	135
Team recruitment Musandam as estimated % of PR costs for Biosphere Expeditions	6,430
Income – Expenditure	**550**
Total percentage spent directly on project	**98%**

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2. Reef Check Survey

Jean-Luc Solandt
Marine Conservation Society

2.1. Introduction

Study site description

The Musandam Peninsula, also known as Ru'us al-Jibal, is an exclave of Oman separated from Oman by the United Arab Emirates. It is situated on the Arabian Peninsula in the Strait of Hormuz, the narrow passage that links the Arabian Gulf (also known as the Persian Gulf) and the Gulf of Oman (Rezai et al. 2004).

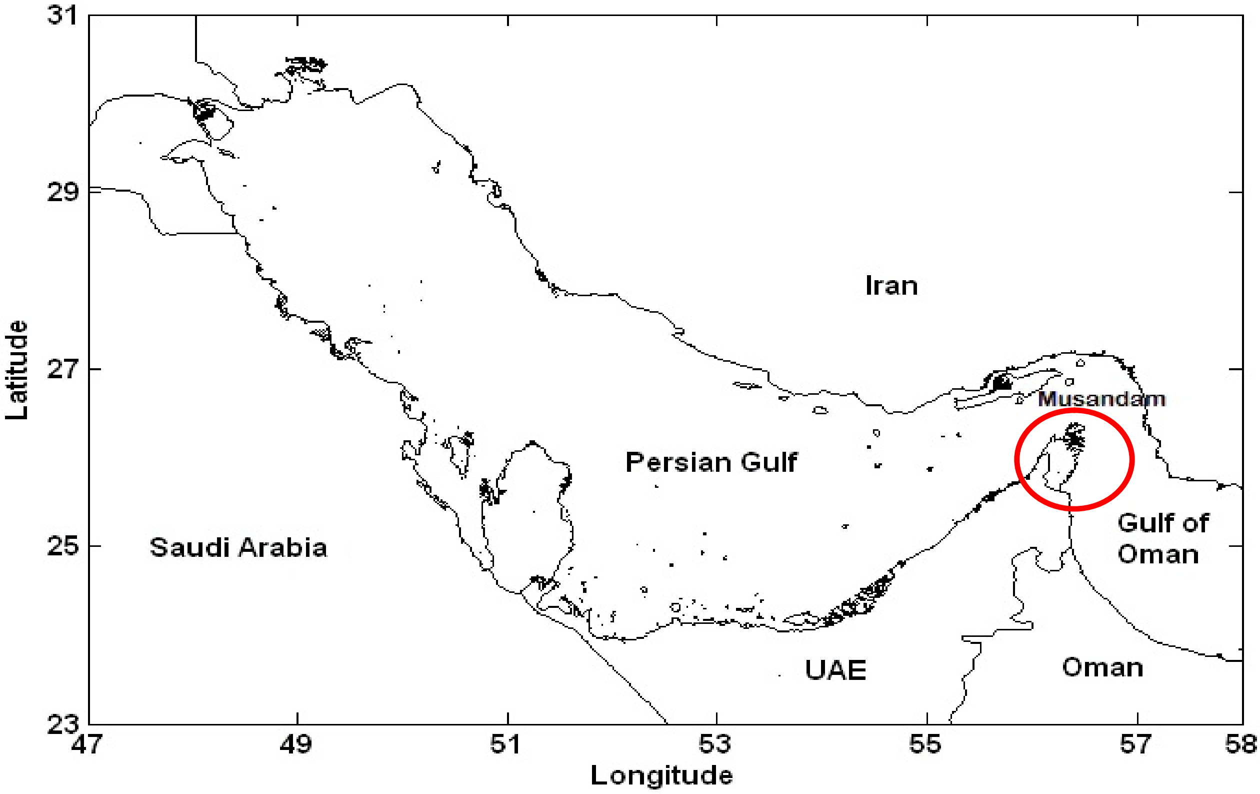


Figure 2.1a. Location of the Musandam Peninsula in the Middle East.

The Arabian Gulf is a shallow semi-enclosed basin measuring about 1,000 km by 200–300 km. It has an average depth of 35 metres, dipping down towards the north to a maximum of about 60 metres near Iran, and inclined downwards to about 100 metres deep at its entrance in the Strait of Hormuz, the only connection to the Gulf of Oman and the Indian Ocean (Sheppard et al. 1992; Carpenter et al. 1997; McClanahan et al. 2000; Pilcher et al. 2000).

As a result of its shallow depth and restricted water exchange, the Arabian Gulf is characterised by strong variations in sea surface temperatures (SSTs), ranging from 12ºC in winter to 36ºC in the summer, and high salinity values of 43 year-round (on the Practical Salinity Scale, PSS, which has no units), thereby influencing water density, currents, water mixing, and a host of other environmental parameters that therefore influence species composition (Price et al. 1993; Riegl 2001; Coles 2003). In contrast with the Arabian Gulf, the Gulf of Oman and Arabian Sea are deep seas (more than 2,000 metres deep) with more stable conditions (Wilson et al. 2002).

The Arabian Peninsula is among the hottest areas in the world, where temperatures above 49°C have frequently been recorded at some weather stations (SOMER 2003). The extremely arid nature of the Arabian region, the high temperatures and the constant and intensive sunshine, especially along the coastal areas, result in extremely harsh conditions for terrestrial life.

The region lies at the edge of two global weather systems, the Asian and the North Africa weather systems, whose fluctuations cause varied and severe environmental conditions; the summers are hotter and the winters colder than most subtropical zones (Sheppard et al. 1992; Carpenter et al. 1997; McClanahan et al. 2000).

Evaporation by dry winds is as intense in winter as it is during the hot summer. Over the whole Arabian Gulf, evaporation averages 144 to 500 cm/yr, most of which occurs in the shallow bays in the south where evaporation locally exceeds 2,000 cm/yr. In these shallow bays salinity exceeds 50 over hundreds of square kilometres, exceeding even 70 in large expanses (McClanahan et al. 2000). These large evaporation rates over the Arabian Gulf lead to the formation of warm and salty water masses, which flow into the Gulf of Oman through the Strait of Hormuz; the mass and salt budget in the Gulf are closed by an inflow of Indian Ocean Surface Water coming from the northern Arabian Sea (Figure 2.1b) (Pous et al. 2004).

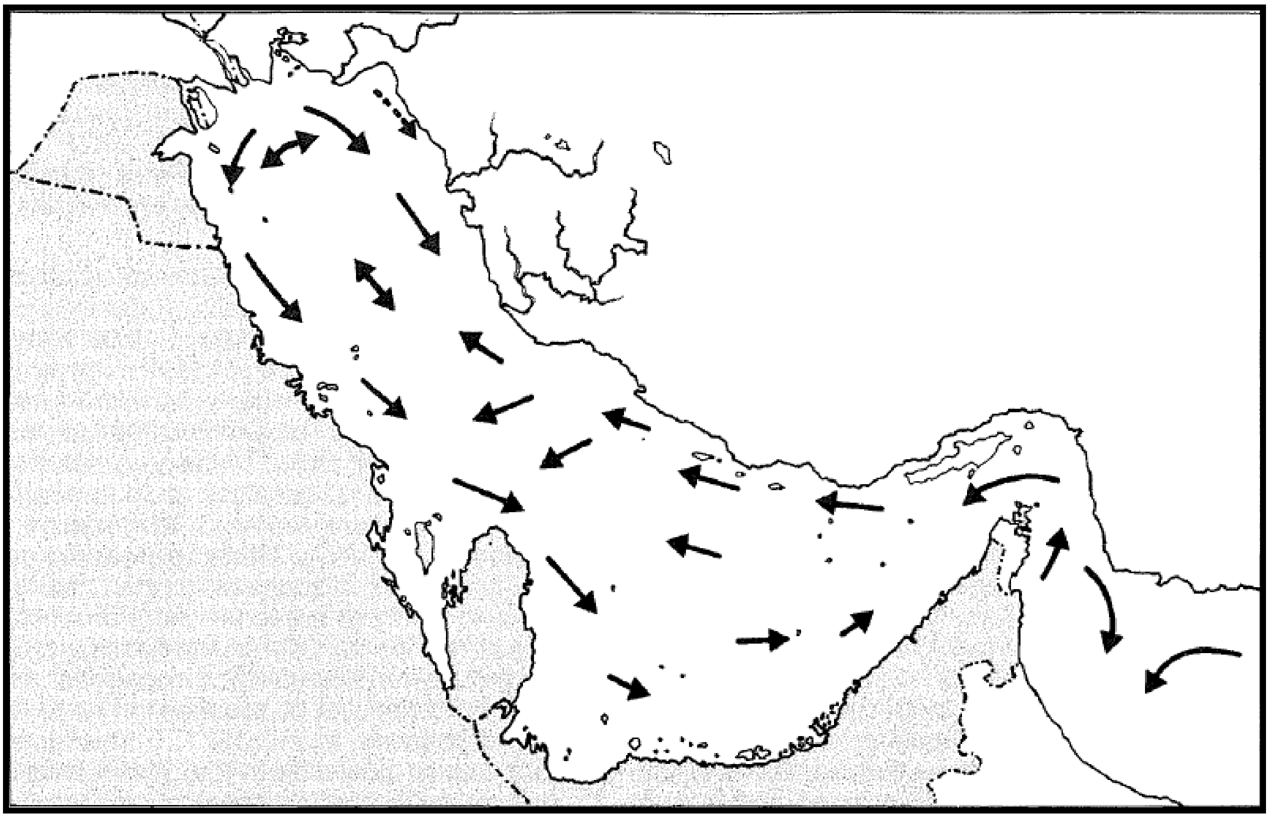


Figure 2.1b. Major current patterns of the Arabian Gulf and northern Arabian Sea (Reynolds 1993).

Tides in the Gulf of Oman and the Arabian Sea are oceanic in type where frictional effects are minimal. Tide heights can range from 1.5 metres in the Arabian Sea to 2.5 metres in the Gulf of Oman, being predominantly semi-diurnal and correlating closely with those of the Indian Ocean. However, tidal height is generally not very marked anywhere in the region, and ranges of 0.25 to 0.75 metres are most common, although tidal height can rise near land, especially in the far north and just outside the Strait of Hormuz (Sheppard et al. 1992).

In the Gulf of Oman water temperatures are moderate in comparison to the Arabian Gulf. Typical winter surface water temperatures fall to 22–23°C (minimum recorded of 12°C), while summer temperature is characterised by a highly fluctuating regime caused by the rise and fall of a shallow but strong thermocline. Summer water temperatures range between 23 and 31°C (maximum recorded of 35°C), and can often cover this range within one day (Rezai et al. 2004). In the Arabian Sea the seasonally reversing winds induced by the monsoon create a strong upwelling, which causes the remarkable low sea temperatures off the southeast Arabian Peninsula in the hottest summer months (Sheppard et al. 1992; Carpenter et al. 1997). In the Gulf of Oman the cool water influences are less constant, although occasional upwellings occur and can replace surface waters very rapidly such that falls of up to 10°C over one or two days can happen. Such upwellings have a significant impact on the marine ecology, and therefore areas of reef development are few (Randall 1995; Spalding et al. 2001).

Salinity in the Gulf of Oman is generally around 36.5‰, but, due to the influence of the Arabian Gulf, 38.9‰ has been recorded in the surface waters of the Strait of Hormuz, in the Musandam Peninsula, to Ra's Al-Hadd at the entrance to the Gulf of Oman (Rezai et al. 2004). Salinity values experienced in the Arabian Gulf exceed the optimum range for coral reefs in other tropical regions in the Atlantic and Pacific, which normally show a salinity interval of 35 to 37‰ and an upper tolerance range between 40 and 45‰ (Price et al. 1993; Coles 2003). The SST values observed in the Arabian Gulf are the highest encountered worldwide on reefs, varying by up to 25ºC annually (Sheppard and Loughland 2002; Coles 2003). In other tropical regions the range is normally only 19ºC, with the normal upper limits between 33ºC and 34ºC and the lower limits between 13 and 16ºC (Coles 2003). Species that establish populations in the area must therefore be capable of withstanding the stress of osmotic and temperature extremes. For this reason, many major shallow water taxonomic groups and species that are prevalent at similar latitudes elsewhere in the Indo-Pacific, and found in adjacent seas, are completely lacking in the area (Carpenter et al. 1997).

Although thought not to be present in extreme conditions beyond 23.5° north and south of the equator, the coral reefs found in the Arabian region are a unique and remarkable example of adaptation by marine organisms (SOMER 2003). The wide range of environment, latitude and geological formation all combine to produce very varied coral habitats within this region. This results in several different coral communities, which are distributed according to geographic location and depth (Sheppard et al. 1992).

Some corals have the ability to acclimatise by phenotypic changes to more stressful environmental conditions, resulting in the readjustment of the organism's tolerance levels. They have evolved temperature thresholds close to the average upper temperatures of their area, so thermal tolerance varies from region to region. Similar species in different regions can live under quite different temperature regimes and thus have different thermal tolerances (Grimsditch and Salm 2006; Marshall and Schuttenberg 2006). Corals and reef communities in some areas (such as the Arabian Gulf and Gulf of Oman) tolerate salinity and temperature conditions that are lethal when imposed rapidly on the same species in less extreme environments (Baker et al. 2004; Buddemeier et al. 2004; Riegl et al. 2006).

Rezai et al. (2004) describe coral communities of the Gulf of Oman and Arabian Sea as being in good condition, due in part to the mitigating effects of a summer upwelling that cools summer seawater temperatures, possibly protecting the corals from bleaching.

There is a fairly distinct Arabian coral species grouping, and within it there is a single, principal division into a Red Sea group and a Gulf of Oman/Arabian Sea group, which in turn fuses with the Arabian Gulf (Sheppard et al. 1992). Although the species composition of Arabian Gulf corals is typically Indo-Pacific, with a few regional endemics, the coral diversity in the Arabian Gulf and parts of the Gulf of Oman is relatively low compared to most parts of the Indian Ocean, where it can be up to four times higher (Riegl 1999; Rezai et al. 2004). Of the 656 species among 109 genera of zooxanthellate corals for the Indo-Pacific, only about 10%, or 68 species among 28 genera, occur in the Arabian Gulf, and 120 species among 33 genera in the Gulf of Oman (Rezai et al. 2004). Some combination of factors has probably limited the recruitment, settlement, survival and growth of reef corals in the region, eliminating many species and perhaps favouring the few that are adapted to the uniquely harsh conditions (Coles 2003).

Due to the varied coastline of Oman, where upwelling effects are attenuated by the many bays, reef growth is only apparent close to the more exposed headlands and islands. Even where reefs do not develop, prolific coral communities grow on many different types of non-limestone rock. Some coral growths develop into vast monospecific beds to a degree seen only in a few other cases in Arabian seas. Numerous areas of exposed, hard substrate are not dominated or even colonised by hard corals; instead, soft corals and macroalgae generally dominate (McClanahan et al. 2000).

Even though the Arabian Gulf's corals are unique and seem to endure extremely harsh conditions compared to corals in other parts of the world, scientists are increasingly concerned that any additional stress imposed by global climate change or regional coastal development may accelerate coral die-off (Wilkinson 2004; EWS-WWF 2008). Reefs in the Arabian Gulf have been devastated by major coral bleaching events (in 1990, 1996, 1998 and 2002) and recently by extensive coastal developments along the Arabian Peninsula (Burt et al. 2008; Wilkinson 2008). The impact extends beyond the shoreline, since suspended sediments are dispersed from the dredge or reclamation sites. In addition, coastal currents are diverted by coastal engineering, altering the movement of sediments and causing them to accumulate (Rezai et al. 2004).

The coral reef losses from climate-related devastation and massive coastal development in the Arabian Peninsula have made this region amongst the most damaged in the world, with the lowest predictions for recovery. According to recent estimates, 30% of the coral reefs are at a threatened-critical stage and up to 65% of the coral reefs may have been lost already due to natural causes (fluctuation of temperatures, diseases) and anthropogenic stresses (oil pollution, unmanaged coastal development, unregulated commercial and recreational fishing and diving) (Wilkinson 2004). Unfortunately coral reef research and monitoring in the region is often way behind other parts of the world (Wilkinson 2008). The 2015/2016 El Niño event has wreaked havoc on the coral reefs of the Indian Ocean and the Great Barrier Reef, the central Pacific and the Caribbean region. Yet the effects of bleaching during this survey were not apparent at all, even though NOAA (National Oceanic and Atmospheric Administration of the USA) signalled increased temperature[1] for the Gulf region in August 2015 (Eakin et al. 2016).

[1] http://coralreefwatch.noaa.gov/satellite/baa/images/crw_optw_bleachingalertarea_east_20150813.gif

Additional external factors affecting the area

On 6 June 2007 the first documented tropical storm occurred in the Arabian Sea. Tropical Cyclone Gonu was a category 5 storm and matched the strongest storm recorded in the northern Indian Ocean (Mooney 2007; UNEP 2008). The human and economic costs of Cyclone Gonu were considerable, with about 75 deaths and €2.88 billion of damage. In Oman, including Musandam, and on the east coast of the UAE, damage by the strong waves along the coast was noted. Corals on exposed shores were almost entirely destroyed and there was variable damage in sheltered bays, coves and islands. Before this natural catastrophe occurred, the Musandam Peninsula reefs were dominated by *Porites* and *Acropora*.

Rich coral communities such as *Porites lutea*, *P. solida*, *Acropora valenciennesi* and *A. valida* were common from Musandam to the capital area of Oman (Sheppard et al. 1992; McClanahan et al. 2000). Gonu affected colonies down to 7 metres with major impacts on *Sinularia*, *Sarcophyton* and *Acropora*. By March 2008 there was significant re-growth of some soft coral areas, although hard coral communities in shallow exposed areas have shown less resilience (Wilkinson 2008).

The existence of a harmful algal bloom (HAB), caused by the algal species *Cochlodinium polykrikoides*, between August 2008 and May 2009, when the marine life was still recovering from Cyclone Gonu, significantly changed the habitats and biodiversity in the area. Both the Arabian Gulf and Gulf of Oman have a high phytoplankton biodiversity, with 38 taxa being potentially bloom-forming or harmful (Subba-Rao and Al-Yamani 1998). The presence of *C. polykrikoides* in the region was noticed for the first time during this period. A pattern of subsequent recurrence of *C. polykrikoides* blooms has been observed in other parts of the world, suggesting that this species may become a persistent HAB problem in the region and that further monitoring and protection in Musandam is needed, according to Richlen et al. (2010). It is known that increasing human population and demand for resources and development is one of the main reasons for the rise in the distribution and size of harmful algal blooms and dead zones around the globe (Anderson 1997; Hinchley et al. 2007). Ballast water carried in ships has also been recognised as one of the main vectors for the translocation of non-indigenous marine organisms around the world. Based on preliminary analysis, it is suspected that the HAB on the east coast of the UAE and Oman from August 2008 to May 2009 was due to a non-native alga species and therefore that ballast water discharge was involved at some point (Richlen et al. 2010).

Reef Check

Reef Check's survey method uses simple techniques to collect scientifically robust data. This methodology is specially designed for recreational divers who might not have a scientific background, so training has to be precise, rapid and understandable in order to guarantee that organism identification is accurate (Hodgson et al. 2006). To understand the health of a coral reef, Reef Check bases its data collection on 'indicator organisms', which are defined as organisms that reflect the conditions of the ecosystem. These indicators can be individual species or even a family. The important thing is that each of these indicators has an economic or ecological value, is sensitive to anthropogenic impacts, and is easy to identify. A Reef Check team collects four types of data (Hodgson et al. 2006):

1. A site description referring to environment, socio-economic and human impact conditions.
2. Fish indicator species count.
3. Invertebrate indicator species count.
4. Record of different substrate types (including live and dead coral).

Data for points 2–4 are collected along a 100-metre transect, at two depth contours, between 2 and 5 metres and between 6 and 12 metres (Hodgson et al. 2006). Data for point 1 are collected prior to and after the dive.

Aims and objectives

The primary aim of this project was to continue to provide data on the health of, and current threats to, the Musandam Peninsula's coral reefs. When this project was established in Musandam in 2009 it became possible for the first time to collect data through Reef Check surveys in order to quantitatively assess benthic and fish communities and anthropogenic impacts. The data collected within this report are useful for comparison with previous surveys conducted at the Peninsula, as well as with future surveys and to provide important data from Musandam for the global Reef Check database.

2.2. Methods

Site selection and sampling design

Between 23 and 29 October 2016, seven dive sites were surveyed using the Reef Check methodology (Figure 2.2a). All sites were recorded by Global Positioning System (GPS) for future comparative Reef Check surveys. All positions were collected in degrees, minutes and seconds (Table 2.2a).

The chosen dive sites included well-known diving spots regularly visited by divers, areas that are known for their importance to fisheries and areas rarely visited by divers and fishermen. With this panoply of diving sites it was possible to have, for the first time, a general idea of the coral reef health of the Musandam Peninsula. Six out of the seven sites visited were repeat visits using the same Reef Check methodolody, allowing comparison of coral health to previous years. The seventh site (northwest Khayl Island) was completely new. An exploratory snorkel was also carried out at Sharktooth Island, but steep drop-off topography made undertaking line transect surveys too risky.

Training of expedition team members

All data were collected by team members who passed through an intensive Reef Check training and testing procedure. Team members on the expedition were coordinated by a project scientist and an expedition leader. The primary responsibilities of both were to train the team members in Reef Check methodology and to coordinate and supervise the subsequent surveys and data collection.

Survey procedures and data collection

The Reef Check survey protocol utilises two transects at depths of 2–5 metres (shallow) and 6–12 metres (medium), chosen for practical reasons concerning dive duration and safety. Along each depth interval, shallow and medium, four 20-metre-long line transects are surveyed with a 5-metre space interval between transects. The distance between the start of the first transect and the end of the last transect is, therefore, 95 metres.

An ideal Reef Check team includes six members (three buddy pairs, each pair responsible for fish, invertebrate and substrate data collection respectively) plus support crew, each with different specialities and experience.

Figure 2.2a. Location of the dive survey and training sites (Eagle Bay and Pipi Beach) around the Musandam Peninsula in October 2016.

Table 2.2a. Dive sites surveyed during the 2016 expedition.

Site name	Date surveyed	GPS location
Southwest Khayl Island	25 October 2016	26º 20' 33.7'' N; 56º 28' 10.7'' E
Northwest Khayl Island	26 October 2016	26º 22' 35.7'' N; 56º 26' 55.2'' E
Faqadar Bay	26 October 2016	26º 20' 15.1'' N; 56º 28' 49.4'' E
Eagle Bay	27 October 2016	26º 22' 56.45'' N; 56º 25' 4.15'' E
Pipi Beach	27 October 2016	26º 22' 31.71'' N; 56º 23' 7.36'' E
Coral Gardens	28 October 2016	26º 22' 33.3'' N; 56º 24' 58'' E
Faq Al Asad	28 October 2016	26º 21' 32.1'' N; 56º 29' 51.7'' E

Figure 2.2b. Typical sandstone geology of the region, with relatively steep slopes (often covered in seabird guano) falling into the sea. This is a photo taken from Telegraph Island to the south of the Peninsula (12.10.13).

The Reef Check methodology is adapted by region, and the area used for this expedition was the Indo-Pacific region. Full details of the methodology and regular updates can be found on the Reef Check website www.reefcheck.org.

Belt transect surveys

Four segments of 5 m high, 5 m wide and 20 m long (centred on the transect line) were sampled for fish that are typically targeted by fishermen or aquarium collectors and that are sensitive to impacts. In the Indo-Pacific these species and families are any grouper (Serranidae) over 30 cm, sweetlips (Haemulidae), snappers (Lutjanidae), parrotfish (Scaridae) over 20 cm, butterflyfish (Chaetodontidae) and moray eel (Muraenidae). Quantitative counts were made of each species/family. Three more species are counted in the Indo-Pacific Reef Check, but were not taken as species to look for since they do not exist in the Musandam area: the barramundi cod (*Cromileptes altivelis*), the humphead wrasse (*Cheilinus undulatus*) and the bumphead parrotfish (*Bolbometopon muricatum*).

The same four 5-metre-wide by 20-metre-long transects (centred on the transect line) were also sampled for invertebrate taxa typically targeted as food species or collected as curios. The taxa counted were: banded coral shrimp (*Stenopus hispidus*), long-spined black sea urchin (*Diadema* spp.), pencil urchin (*Eucidaris* spp.), collector urchin (*Tripneustes* spp.), three edible sea cucumber species (*Thelenota ananas*, *Stichopus chloronotus*, *Holothuria edulis*), lobster (all edible species) and triton shell (*Charonia tritonis*). Quantitative counts were made of each species/family. The giant clam (*Tridacna* spp.) was not included in the species to count since it does not exist in the Musandam Peninsula area.

During the invertebrate survey, anthropogenic impacts were also assessed. These included coral damage by anchors, dynamite, or ‘other’ factors, and the presence of trash. Trash is divided by type, i.e. fishing nets or simply ‘other’. Divers valued the damage caused by each factor using a 0 to 3 scale (0 = none, 1 = low, 2 = medium, 3 = high).

The percentage cover of bleaching and coral disease in the coral reef (both at the colony and population level) was also measured along each 20-metre transect.

Substrate line transect surveys

Four 20-metre-long transects were point sampled at 0.5 m intervals to determine the substratum types on the reef. The categories recorded at each 50 cm point were measured according to Reef Check definitions: hard coral (HC), soft coral (SC), recently killed coral (RKC), nutrient indicator algae (NIA), sponge (SP), rock (RC), rubble (RB), sand (SD), silt (SI) and other (OT).

Coral point count

Photo transects were undertaken at six locations. These photo transects capture images of the reef from a vertical view at about 2m from the seabed. Post hoc analysis occurs with the software CPCe (Coral Point Count with Excel extensions) (Kohler and Gill 2006). Various categories of substrate were then able to be recorded at greater resolution, including coral lifeforms.

Data analysis

All data were entered on underwater slates and subsequently transferred onto Reef Check Excel sheets. Belt transect data were used to calculate the mean abundance of each fish and invertebrate taxon. The substrate line transect data were converted to mean percentage cover of each substratum category per depth contour. Anthropogenic data were represented by mean abundance of each impact.

Analysis of 2016 data was compared to 2015 data for coral cover for four sites to give an indication over time of the general attributes of the reefs.

2.3. Results

General human use and surface observations

These observations were made using the 'site description' form. Air temperature varied between 30 and 35 degrees C. Water temperatures was around 28 degrees C (at 75% of sites) with one site having a temperature of 26 degrees C. Visibility ranged from 5 to 14 m.

The clearest observable human impacts at many of the sites were discarded pieces of fishing line used to catch reef-associated species (Figs. 2.3a).

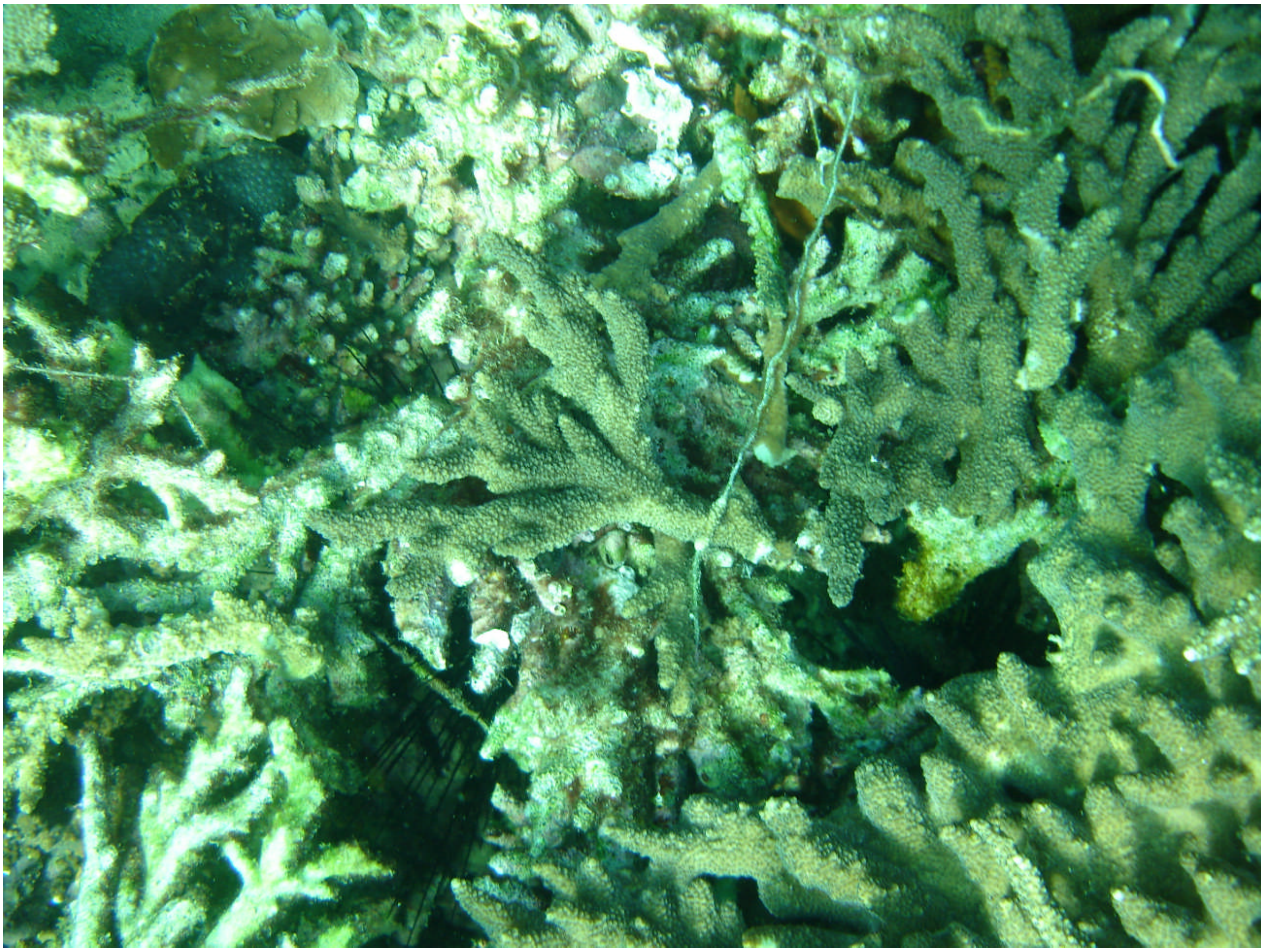


Figure 2.3a. Discarded fishing line, starting to be encrusted within the coral framework (at Coral Gardens).

Other impacts appeared to be at a relatively low level – particularly compared to other Arabian Sea reefs. Direct evidence of impact from human activities appeared to be only fisheries-related with small areas affected by discarded line. There was some potential anchor damage recorded at Pipi Beach (reported in the 2013 Musandam survey). Most corals appeared to be in good health (Fig. 2.3c), with very limited incidences of disease reported from the sites (Fig 2.3b).

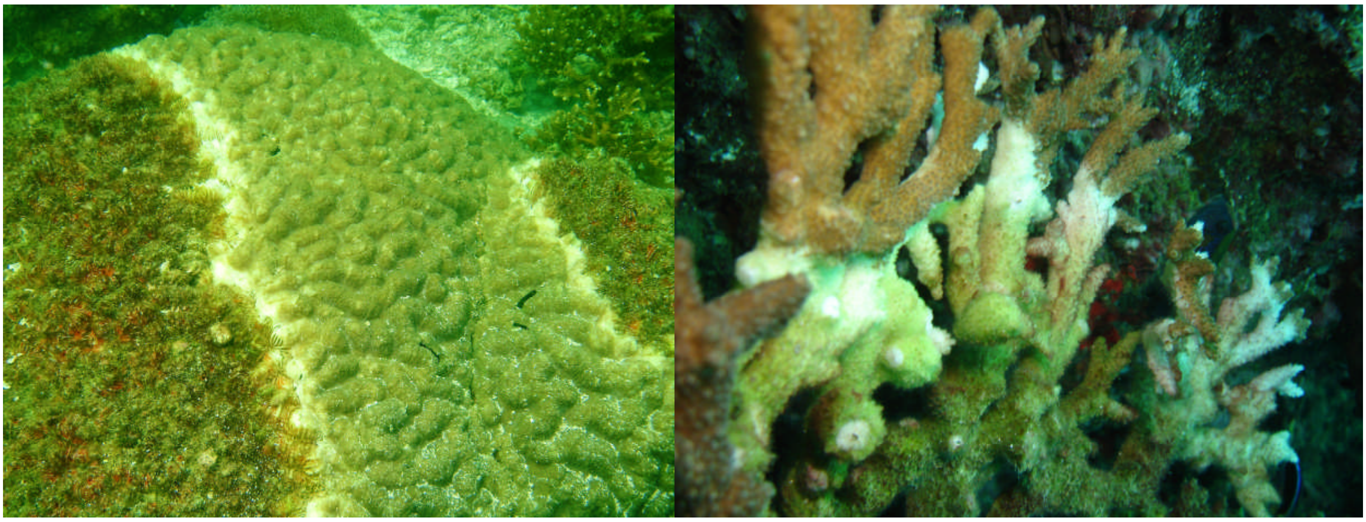
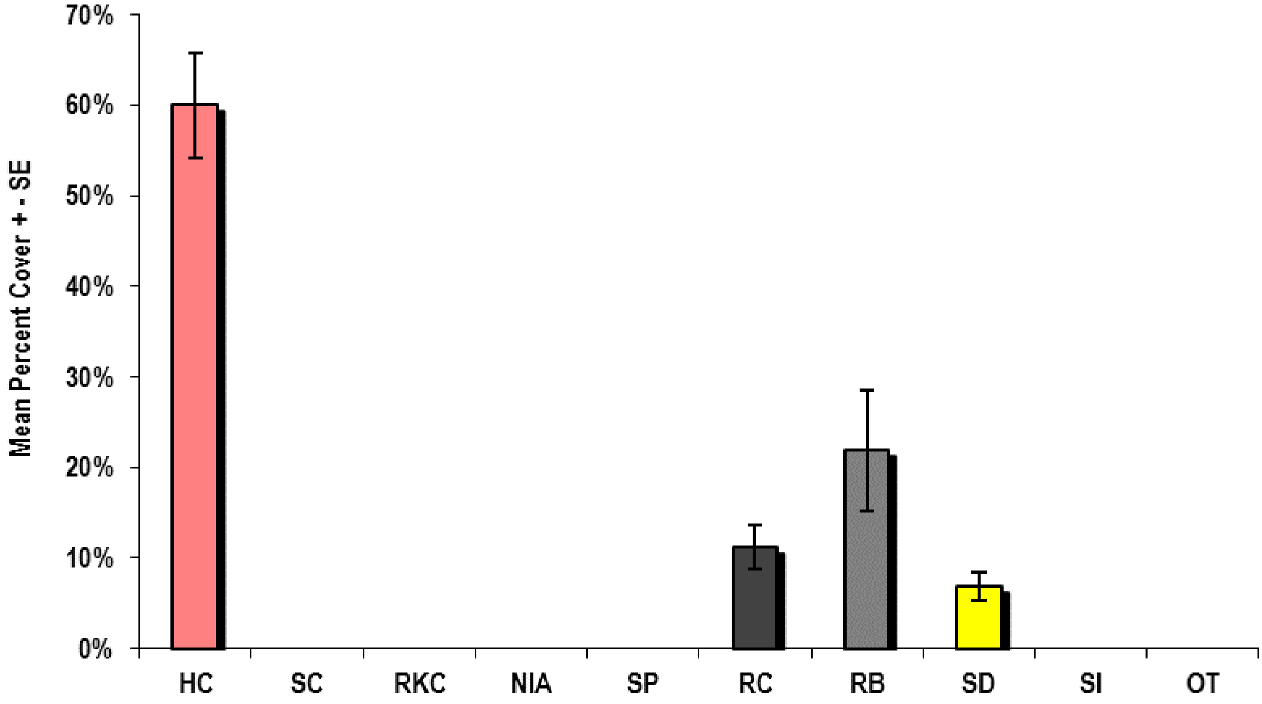


Figure 2.3b. White syndrome – photographed at Faqadar Bay (left) and Northwest Khayl Island (right).

Figure 2.3c. Healthy reef Faqadar Bay (left) and Southwest Khayl Island (right).

The nearest community is Kumzar, populated by about 500 people. It has no roads and is the major fishing village of the Peninsula. Here fishermen typically use outboard-driven open fibreglass 3–4 m skiffs from which they operate static wall nets and line fish. Occasionally inboard diesel-powered dhow fishing vessels (7–10 m) were observed. It is thought these vessels operate larger nets, typically targeting the tuna baitballs that so frequently occur in the waters of the Peninsula.



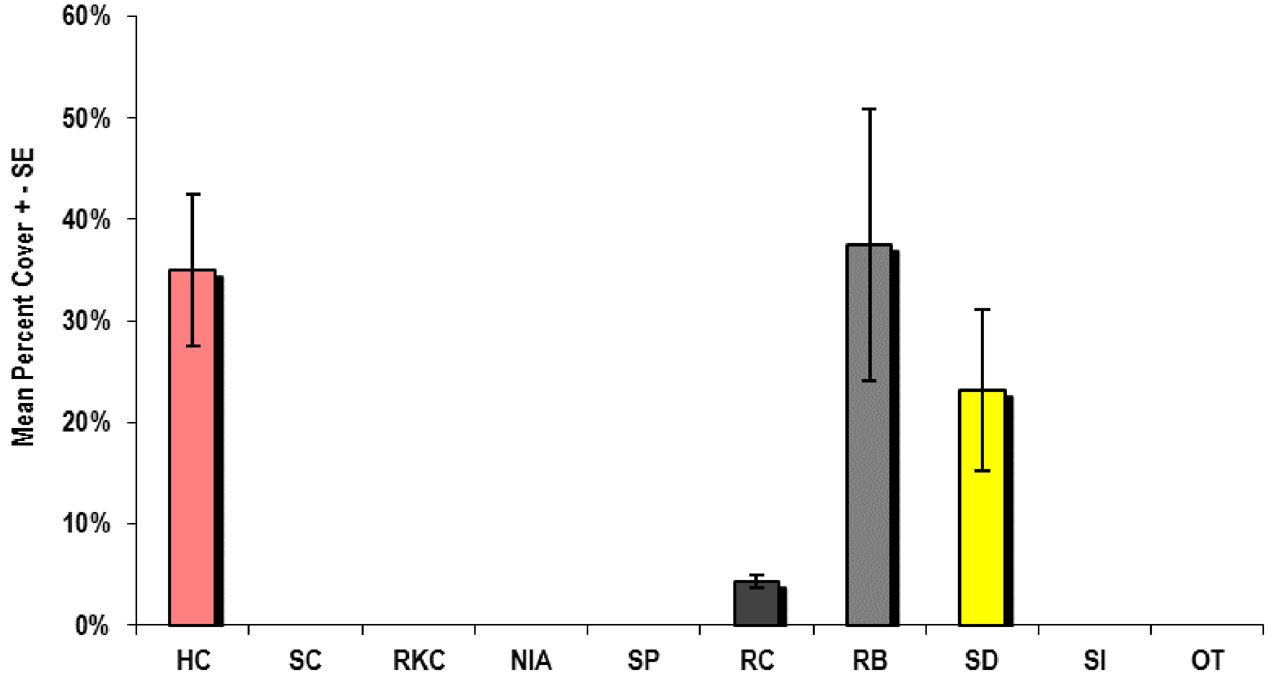
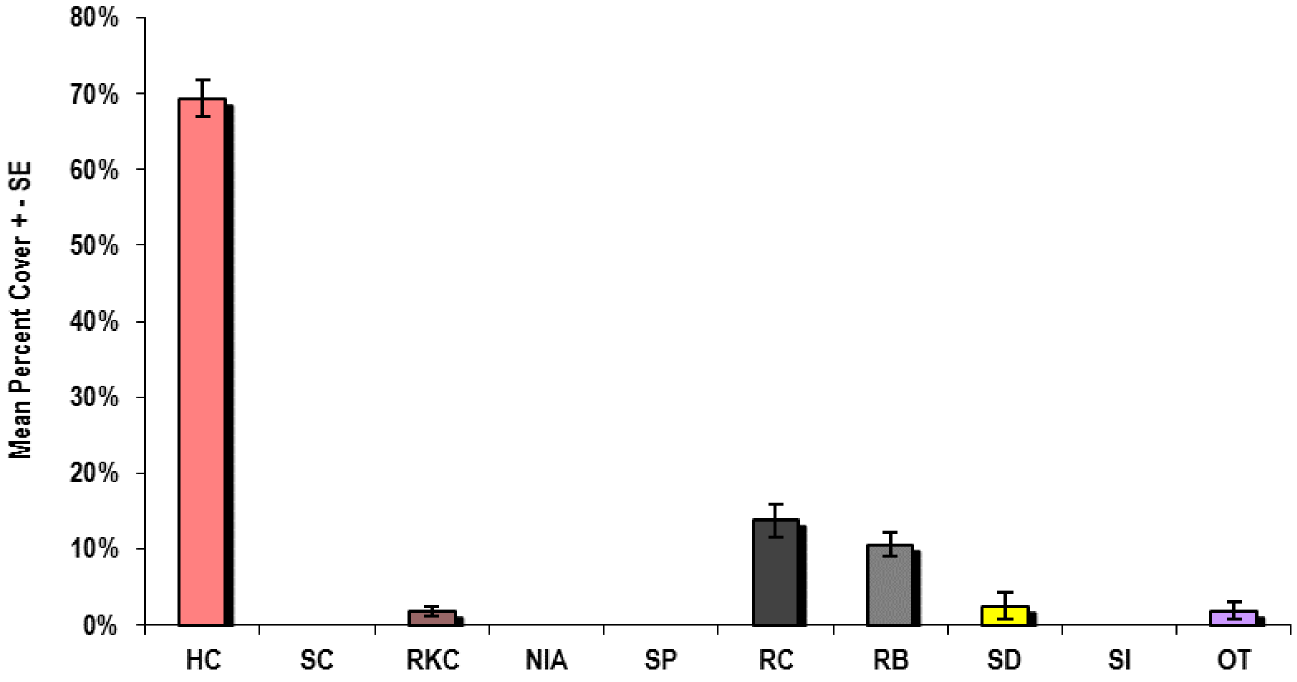


Figure 2.3d. Substrate at 4 m (above), and 7 m (below) at Pipi Beach.
(Bars are Standard Error that illustrates the relative variation about the mean population level).
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae;
SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other



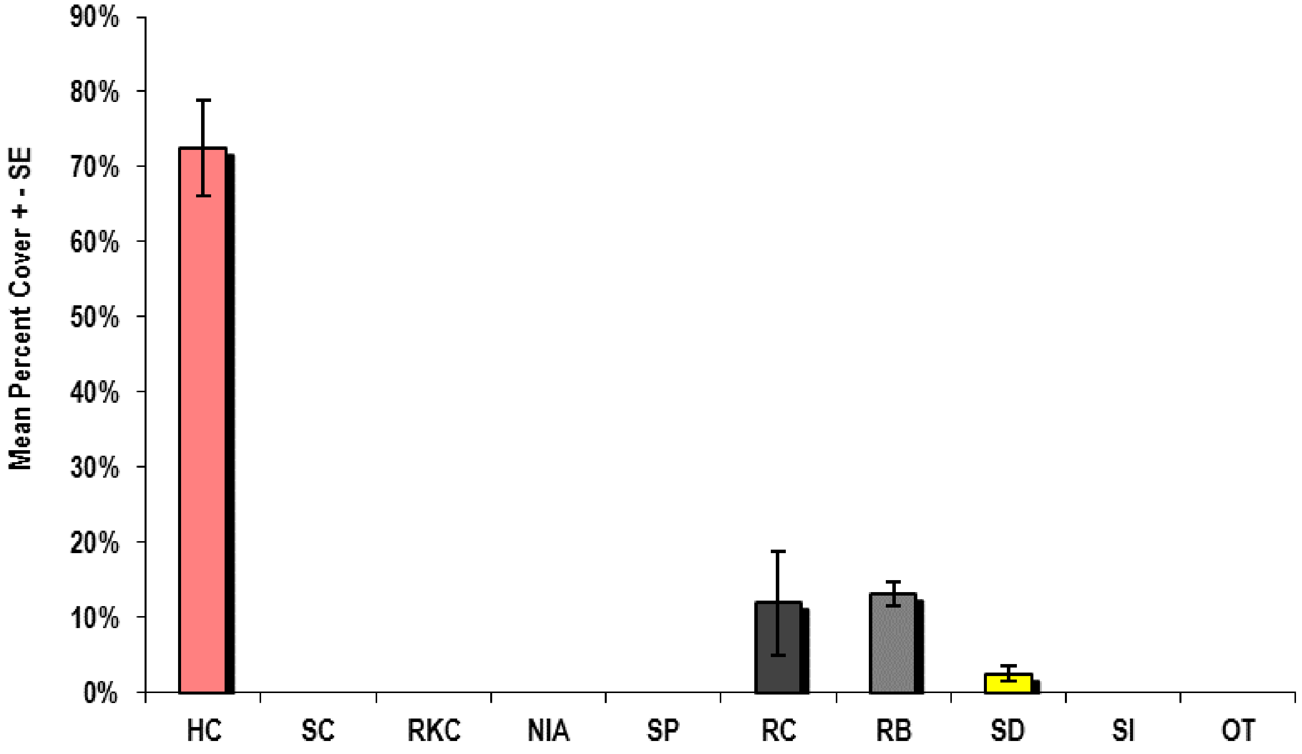
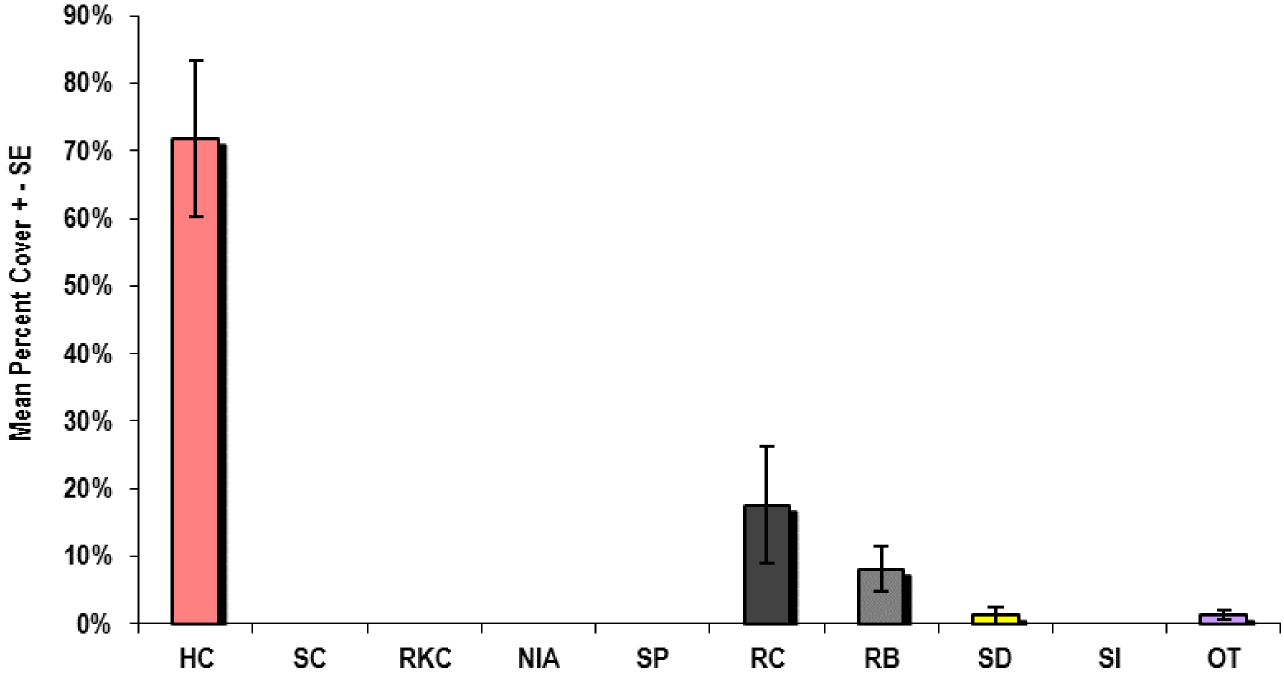


Figure 2.3e. Substrate at 3 m (above), and 8 m (below) at Coral Gardens.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae;
SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other



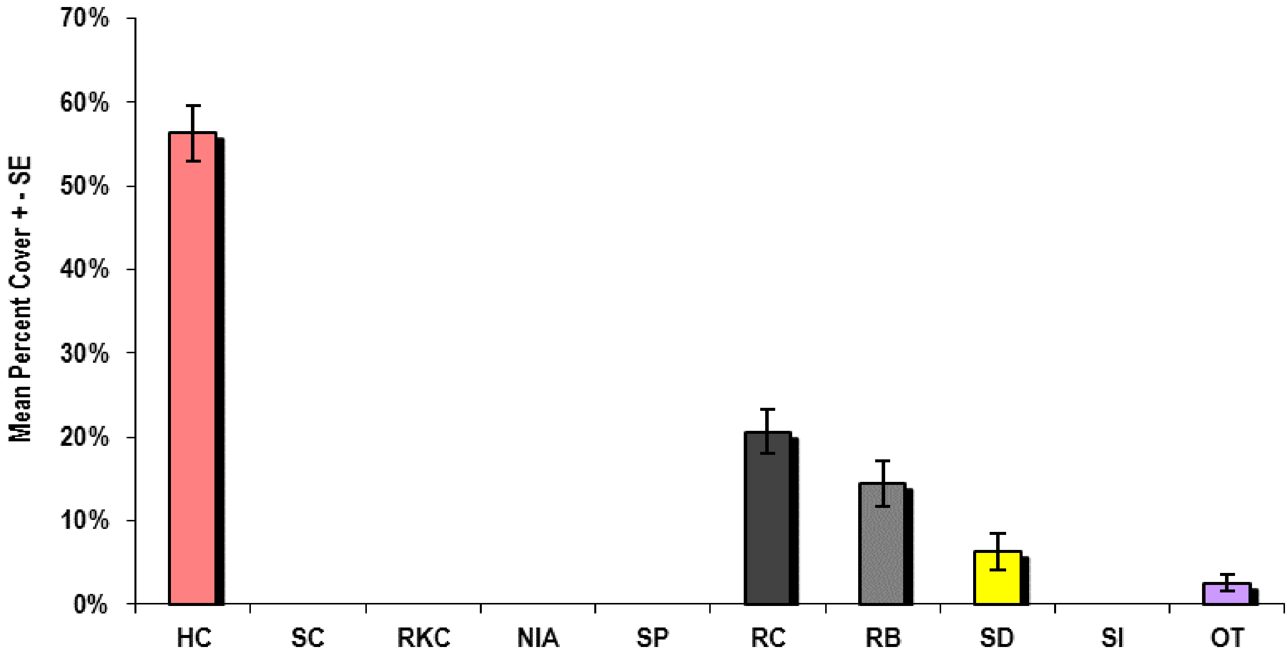
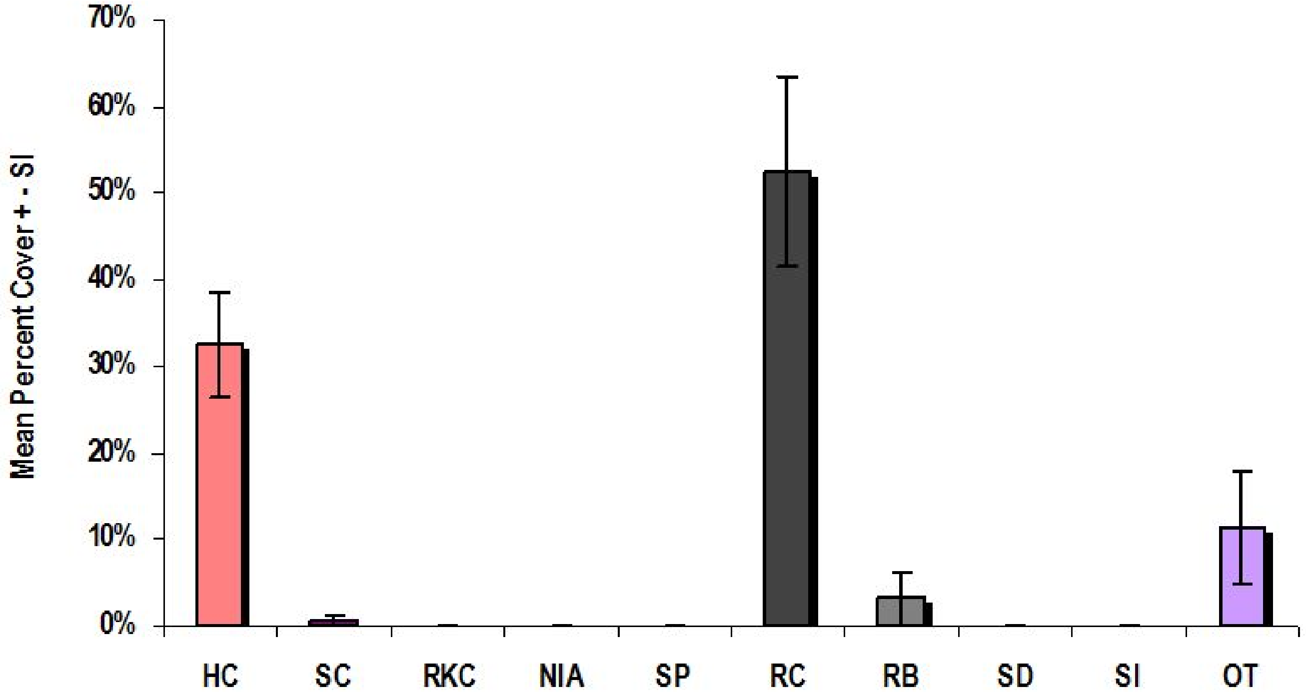


Figure 2.3f. Substrate at 3 m (above), and 8 m (below) at Eagle Bay.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae; SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other



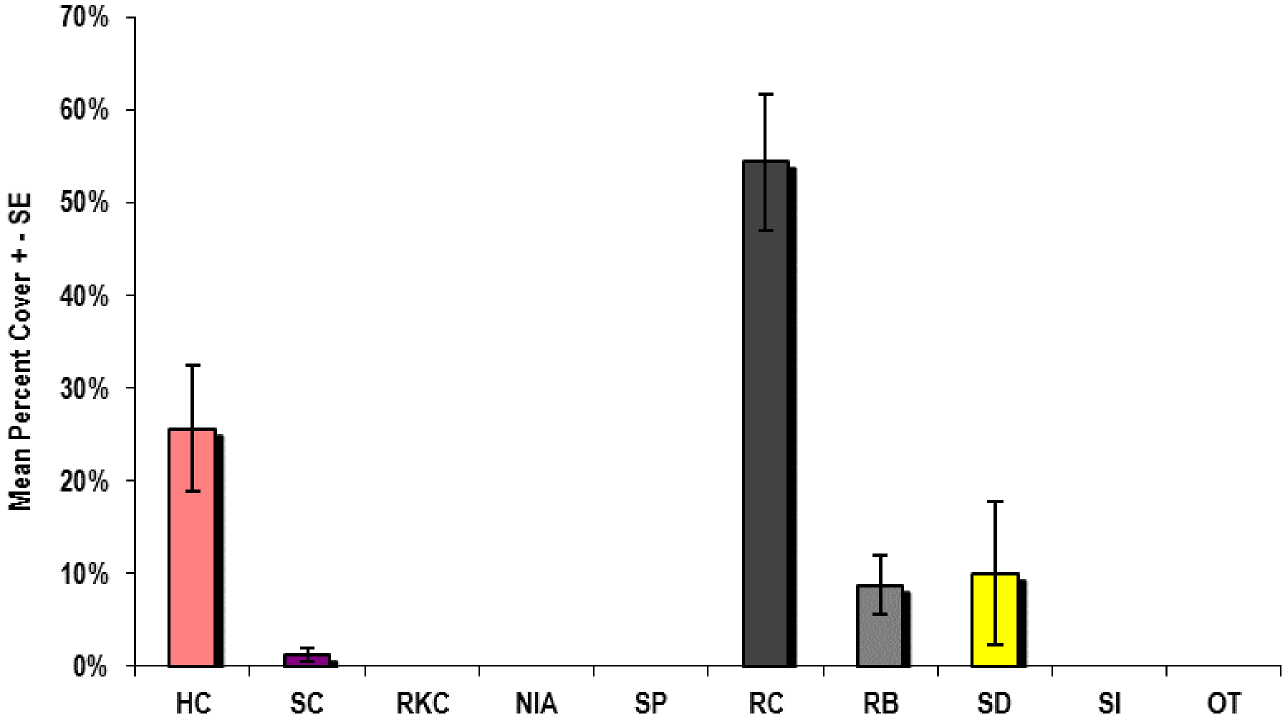
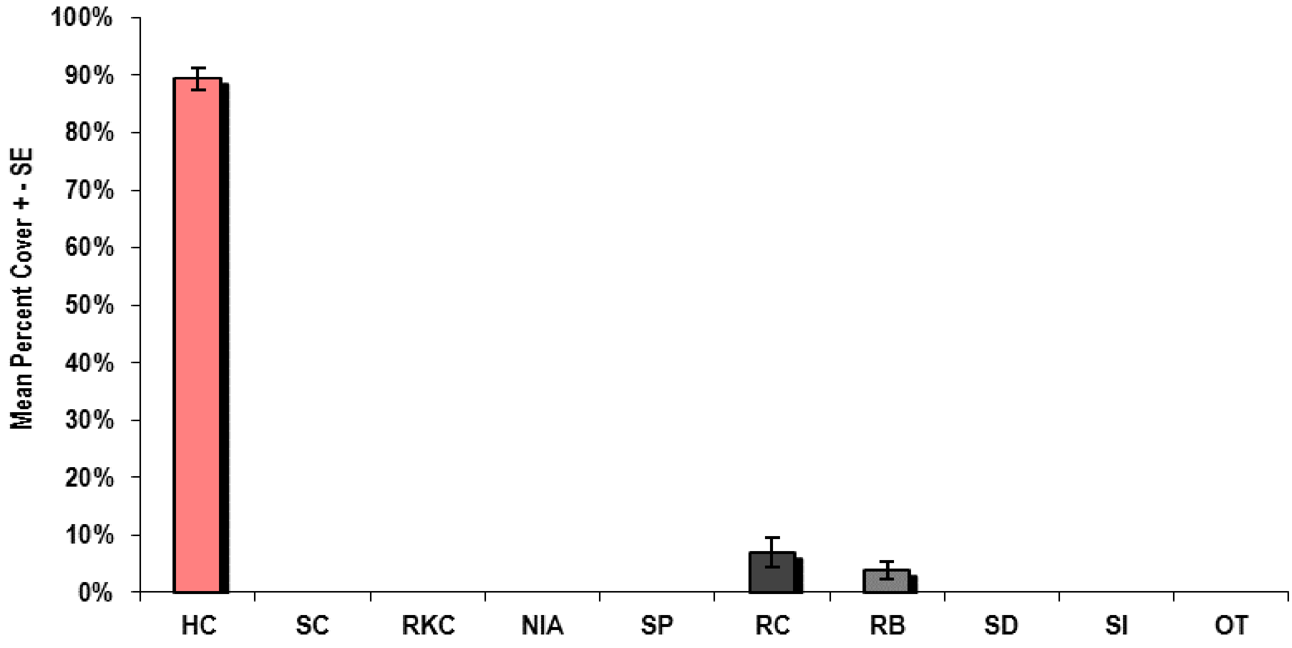


Figure 2.3g. Substrate at 3 m (above), and 8 m (below) at Northwest Khayl Island.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae;
SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other



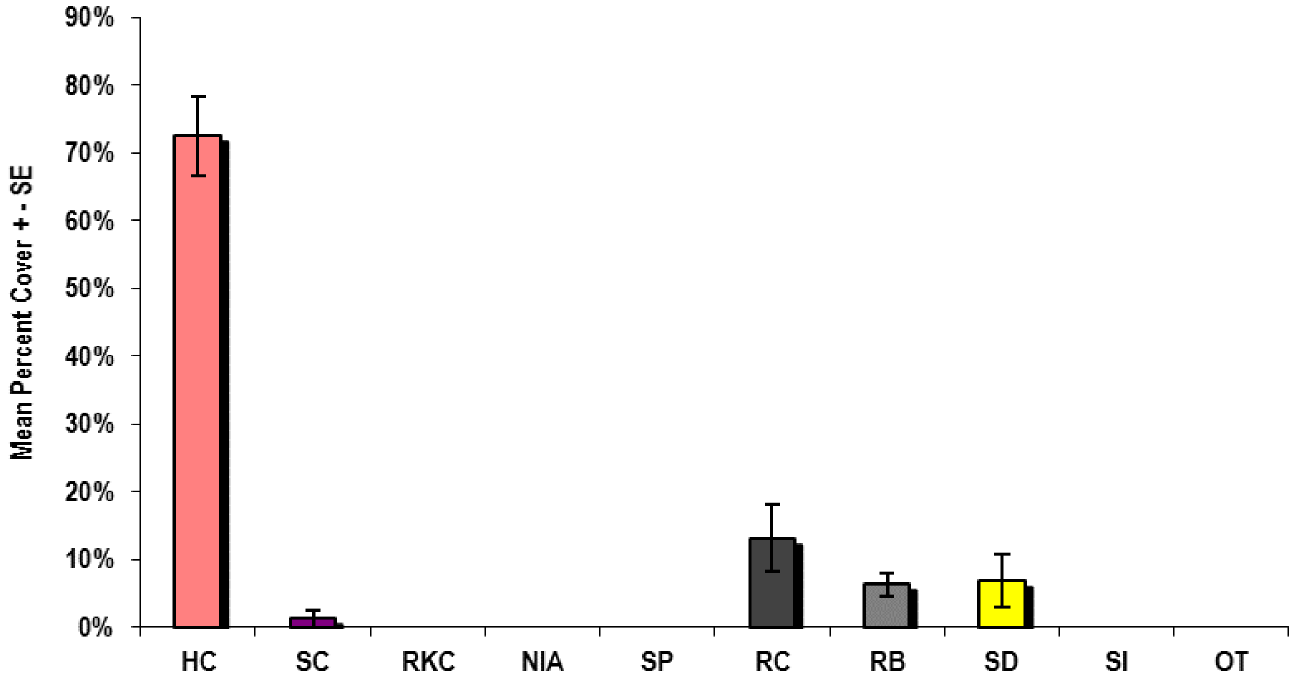


Figure 2.3h. Substrate at 3 m (above), and 8 m (below) at Southwest Khayl Island.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae;
SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other

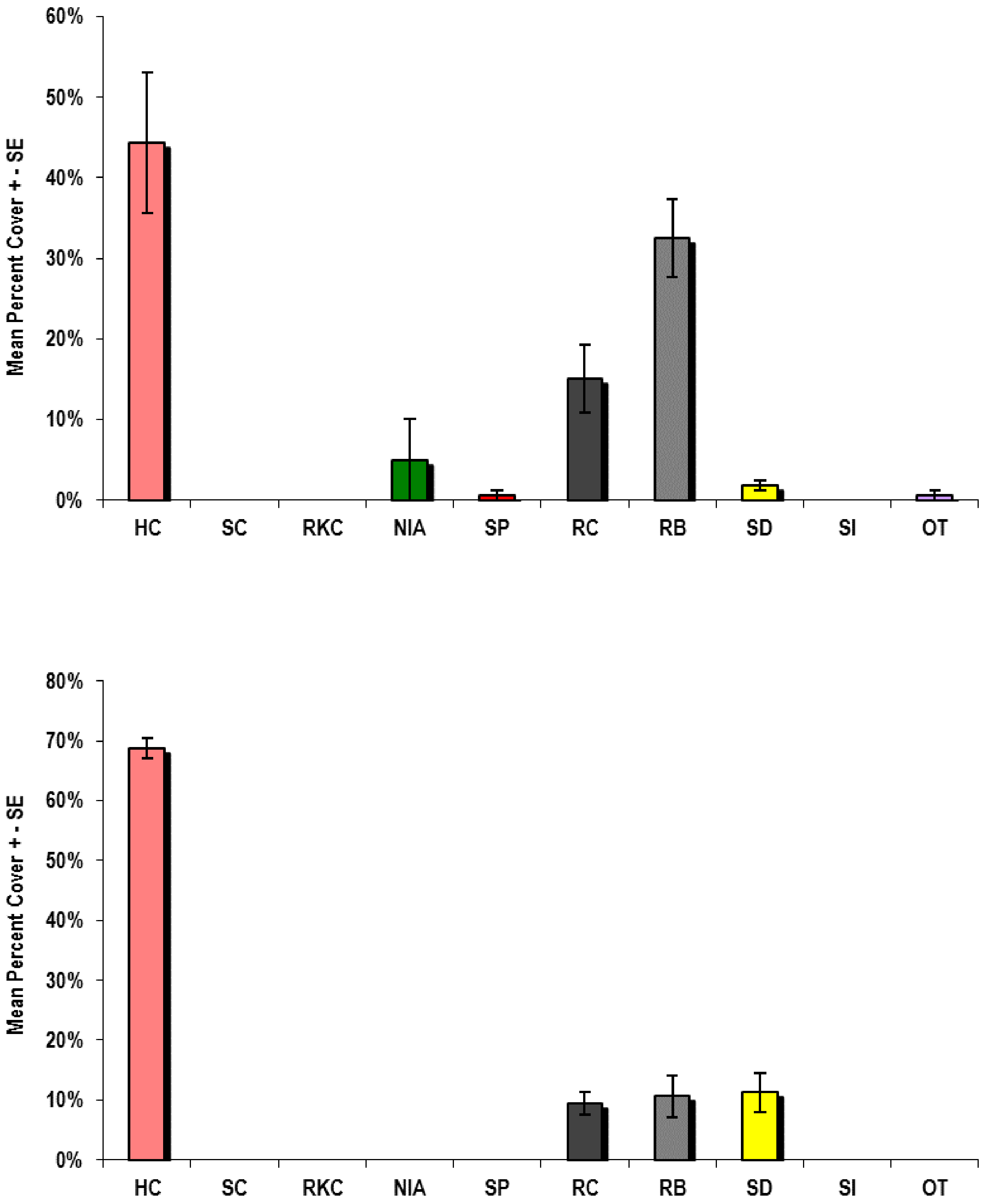
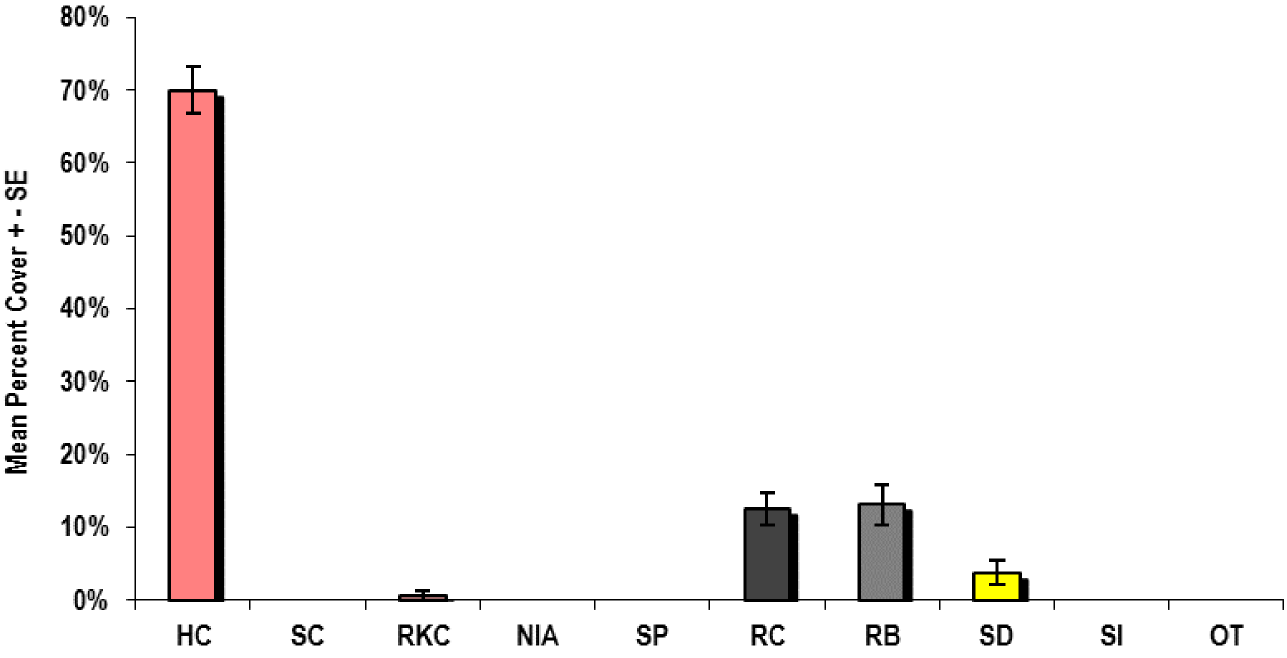


Figure 2.3i. Substrate at 3m (above), and 7m (below) at Faq Al Asad.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae;
SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other



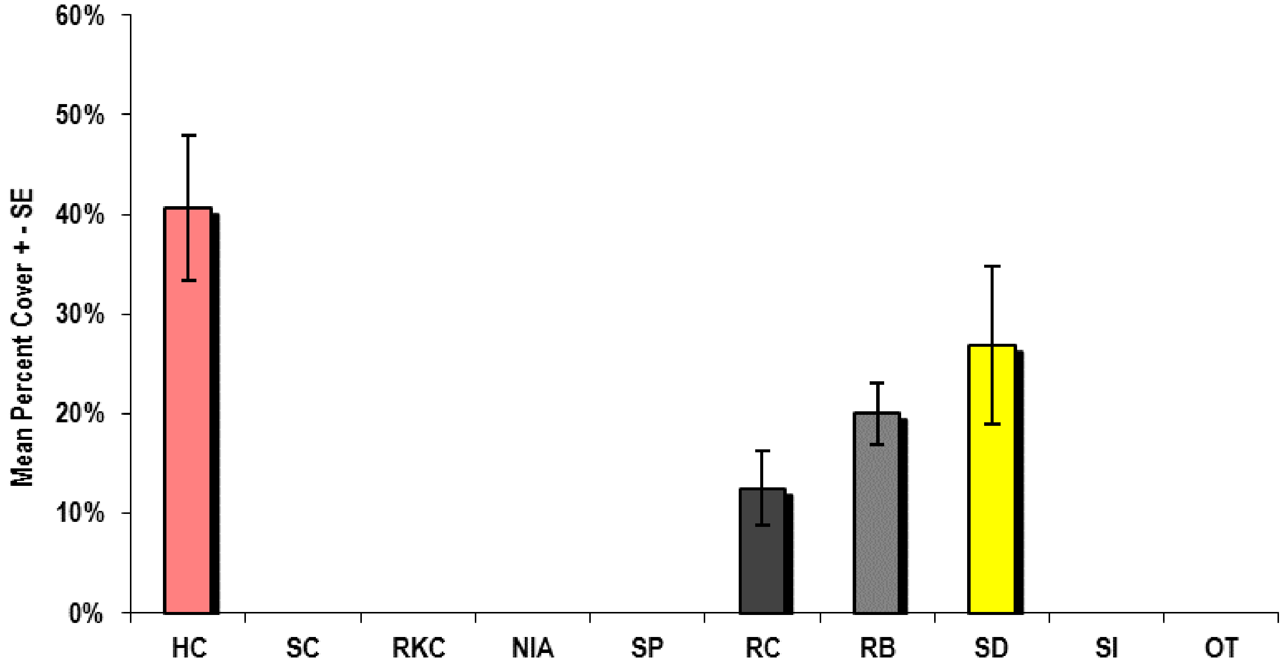


Figure 2.3j. Substrate at 3 m (above), and 6 m (below) at Faqadar Bay.
HC – Hard Coral; SC – Soft Coral; RKC – Recently Killed Coral; NIA – Nutrient Indicator Algae; SP - Sponge; RC – Rock; RB – Rubble; SD – Sand; SI – Silt; OT - Other

Fish populations

Fish populations of the Musandam peninsula show limited numbers of apex predators (e.g. sharks, large grouper, emperor, jack, tuna). The fish populations are largely dominated by snapper – with one site, Faqadar Bay, dominated by large numbers of small (average 20-25 cm) individuals. This may be a nursery for the species before the animals move into other areas These were almost all of the same species - *Lutjanus quinquelineatus* and another, *L. fulviflamma*, and possibly *L ehrenbergii* (see Fig. 2.3l). There were occasional sightings of the large two-bar sea bream (*Acanthopagarus bifasciatus*) that were generally cryptic – settling under rocks and reefs.

A snorkel was carried out at Sharktooth Island – deemed too vertiginous to undertake a Reef Check survey (there was almost no coral cover, as large boulders were stripped from the island by weather and littered the seabed between 10 and 30 m deep). Here, fish populations were more diverse than those closer to Kumzar (where it is likely there was an increased fishing effort). An observation of a large triggerfish (*Catnhidermis macrolepis*) suggested that the site was exposed.

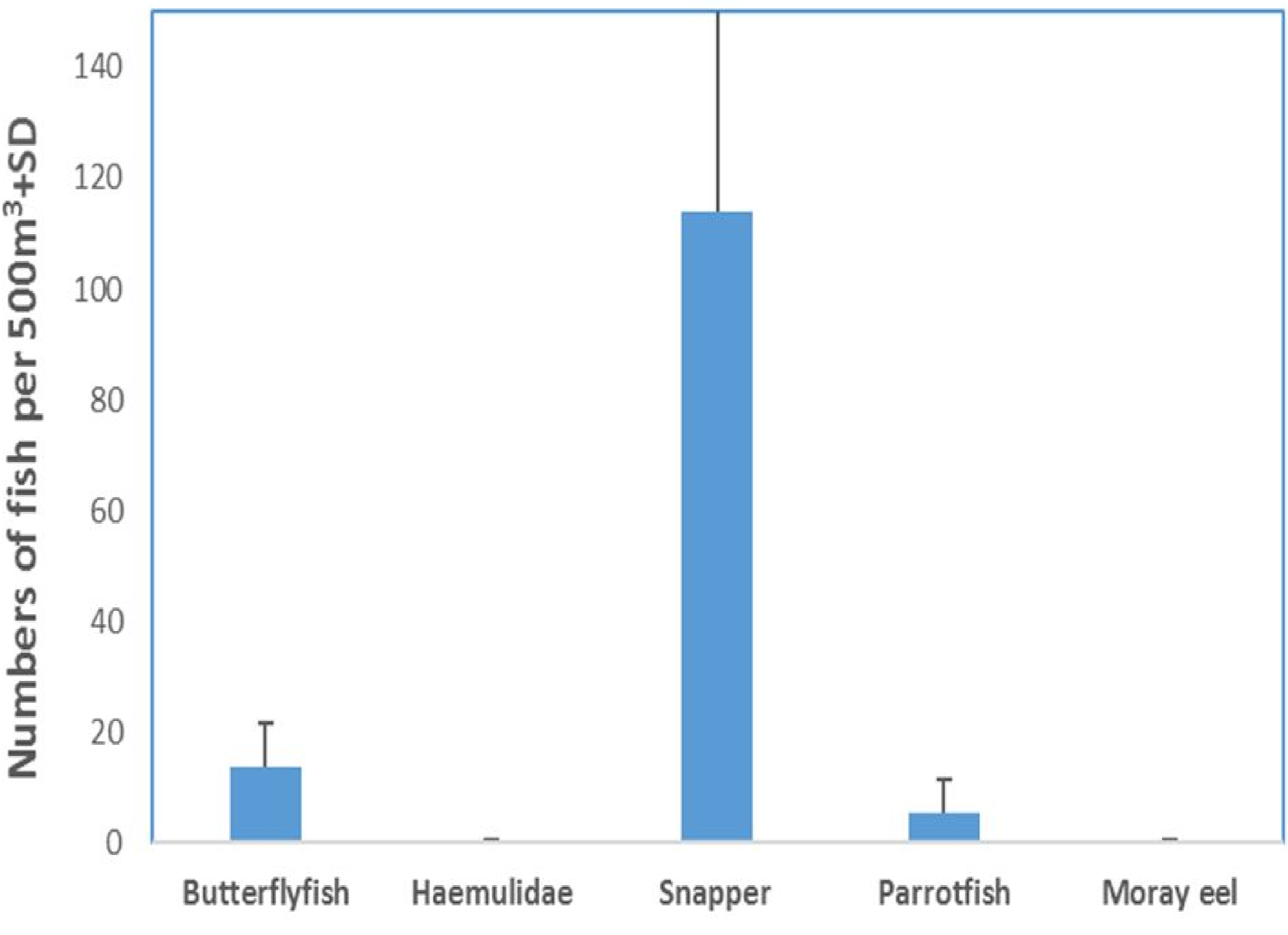


Figure 2.3k. Reef Check fish populations at all sites visited combined and averaged.
Note the high numbers of snappers, with a large standard deviation, caused by exceptional numbers at Faqadar Bay (mean of 476 individuals per 500 m^3 replicate).

Figure 2.3l. *Lutjanid* snappers schooling in large numbers at Faqadar Bay. The species appears to be *L. ehrenbergii*.

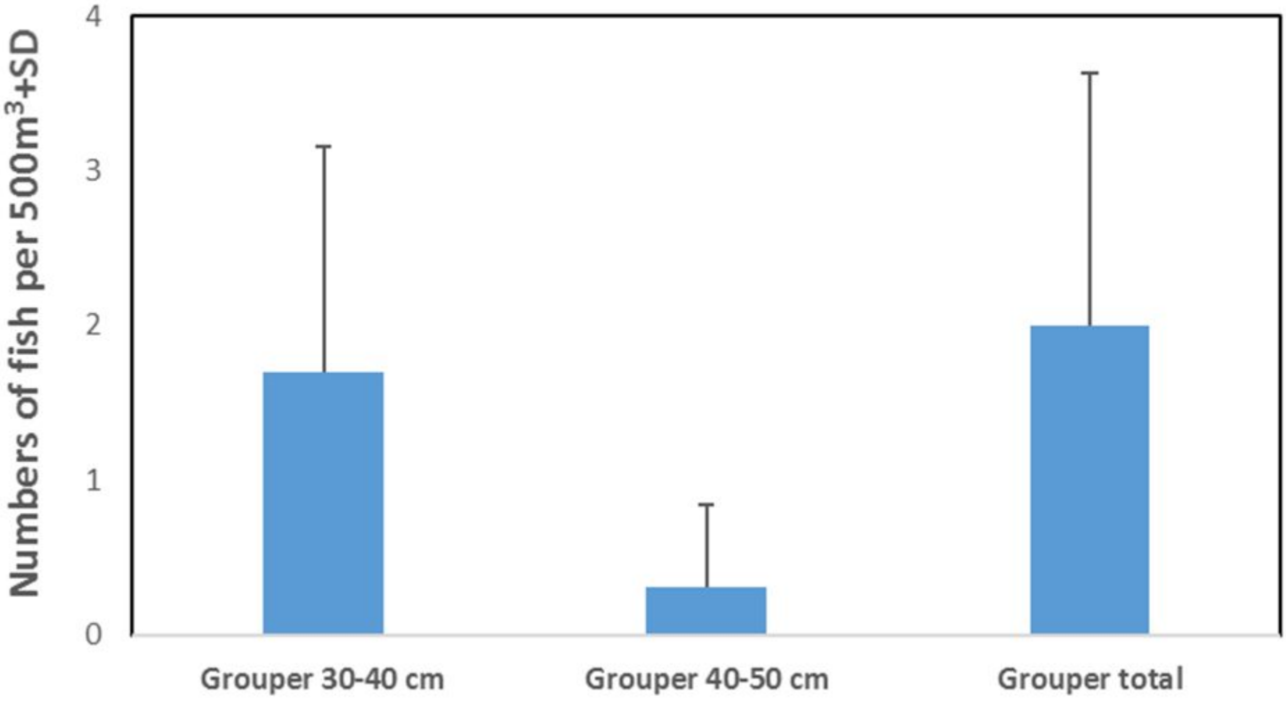


Figure 2.3m. Mean numbers of grouper per replicate at all sites combined and averaged.
Note the small numbers of large (>40 cm) groupers, with a complete absence of individuals over 50cm.

Grouper sizes are small. Many of the species recorded at Musandam do not naturally attain great size. The most common species encountered was *Cephalopholis hemistiktos*.

Figure 2.3n. *Cephalopholis hemistiktos* – the most commonly occurring grouper at the surveyed depths at Musandam.

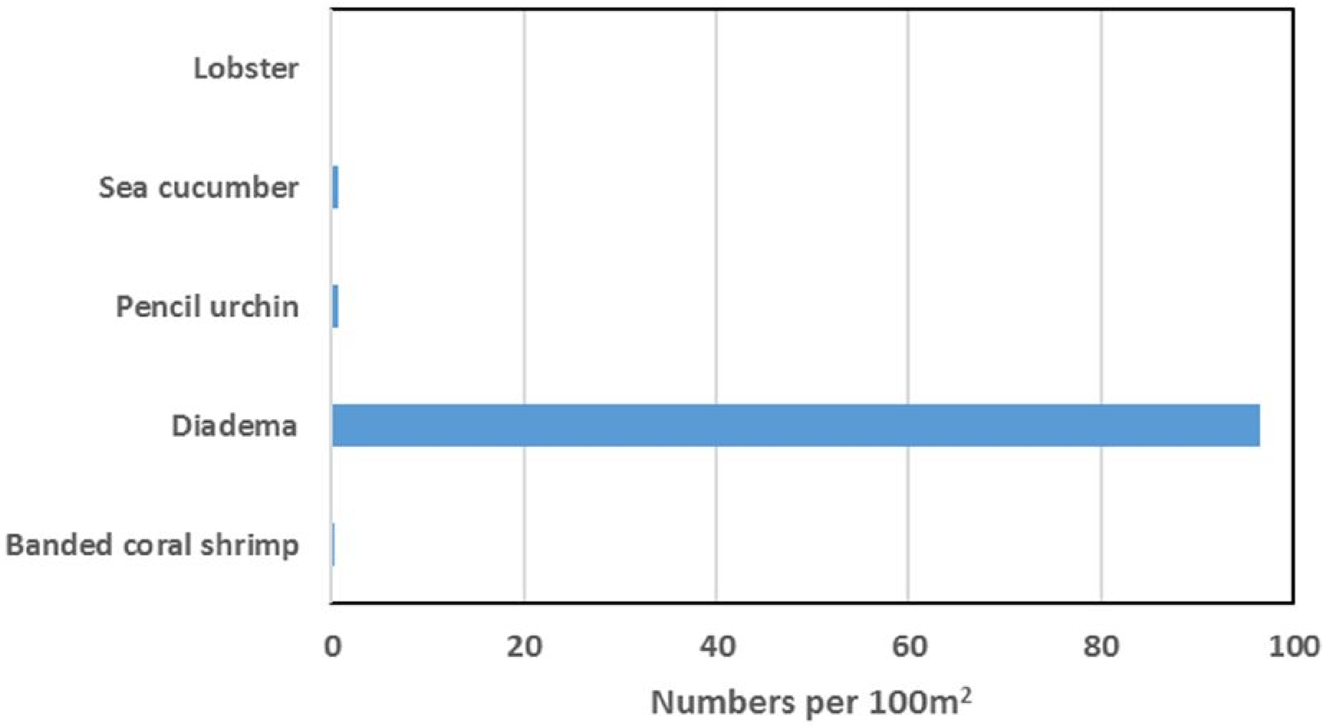


Figure 2.3o. Mean numbers of invertebrates per 100 m^2.
Note the small numbers of anything other than Diadema urchins.
Only three lobsters were recorded on the surveys – at NW Khayl Island and at Faqadar Bay.

Invertebrates on the Reef Check list are heavily dominated by large numbers of *Diadema* sea urchins – particularly in the shallower depths. They have been reported in the past to be one of the most important species in the shallow reefs, as they are a significant grazer of algae. The densities that we are seeing at Musandam are such that they are grazing into the substrate limestone of some of the massive brain coral bases. This is eroding the base of the colonies to the extent that, in certain instances, some are falling over.

‘Other’ fish and notable sightings

Table 2.3a. Unusual sightings either off or on transect during the expedition.

Site name	Unusual sightings / / environmental conditions / megafauna
Pipi Beach	Nothing of note compared to previous years. Large numbers (100s) of schooling yellowtail barracuda (*Sphyraena obtusata*) and schooling snapper remain at the site in similar densities to previous years.
Faq Al Asad	One barracuda (no species ID) and hawksbill turtle (*Eretmochelys imbricate*).
Faqadar Bay	Very large numbers of 20-30 cm snapper (an average of 476 animals per 500 m^3 compared to 54 in all other sites combined). Generally, *L. ehrenbergii*.
Southwest Khayl Island Northwest Khyal Island	Two large (60 cm) two-bar grunt (*Acanthopagarus bifasciatus*) under a coral rock. One small (100 cm) black tip reef shark (*Carcharhinus melanopterus*). Hawksbill off transect. Five Pinjalo snapper (*Pinjalo pinjalo*) off transect.
Eagle Bay	Seven lemon sweetlips (*Plectorhincus flavomaculatus*) and a hawksbill turtle (off transect).

2.4. Discussion

All Musandam sites appear healthy in terms of coral populations (Fig. 2.4a) of all genera. This is in stark contrast to the Maldives, where bleaching has killed well over 50% of the coral population (see Biosphere Expeditions reports of those expeditions).

Figure 2.4a. Typical scene at Musandam (Khayl Island). *Porites lobata* in the foreground, leading to a shallow water field of *Pocillopora damicornis* (in the background in shallower water). To the left is another *Porites* (a branching form), whilst the middle of the picture shows three forms of branching *Acropora*.

The global bleaching event of 2015/2016 appears not to have affected the corals of the northern Musandam region. Local experts believe this is because of the nature of the natural upwelling associated with the region, bringing cooler waters from deeper parts of the continental shelf to the west coast of Oman (Praveen et al. 2016). Also, as the waters around Musandam are within a relatively narrow channel, with Iran only a matter of 40 miles to the north, Musandam sits at a bottleneck, where currents are forced through the Strait of Hormuz. This means hot water does not build to the level that can cause bleaching elsewhere, where warmer waters can build up in shallow waters (e.g. the Maldives). Also, previous expedition reports (Bento & Hammer 2010) have argued that the coral reefs of the Musandam Peninsula have the ability to endure very harsh conditions such as high salinity and temperatures, existing in what would be considered marginal and highly challenging environments for corals in other parts of the world.

Diversity of the coral species is relatively low, dominated in shallow bays by *Acropora* (and *Pocillopora*) and in slightly deeper waters by *Porites*. In some sites that are exceptionally (naturally) silty such as some bays and inlets (e.g. Pipi Beach), species such as *Acropora* are absent as these corals require clear water, free from sediment, and with high light input relative to *Porites* corals (Crabbe and Smith 2005). *Porites* and many other more massive life forms (and genera such as *Goniopora*) are better adapted to both sloughing off sediments and attaining the organic nutrient matter from sediments that supplement their diet (Crabbe and Smith 2005). This is why there is a form of zonation amongst the coral reefs of Musandam that is natural and resembles many other Arabian regions.

The Gulf further to the west lacks a high diversity and abundance of *Acropora* species, because of the increased natural sedimentation. In places, dominance of *Acropora* – as is seen in the clear waters of the Maldives – is replaced by *Pocillopora*, often at 100% coral cover largely because of the impact of sediments (Crabbe and Smith 2005). *Pocillopora* are more tolerant of low light and sediment than *Acropora* (Dhal and Lamberts 1978).

Long-term monitoring and Reef Check

Reef Check enables us to use simple techniques to study and record the same places year after year. This allows comparative analysis of sites between years (Fig. 2.4b).

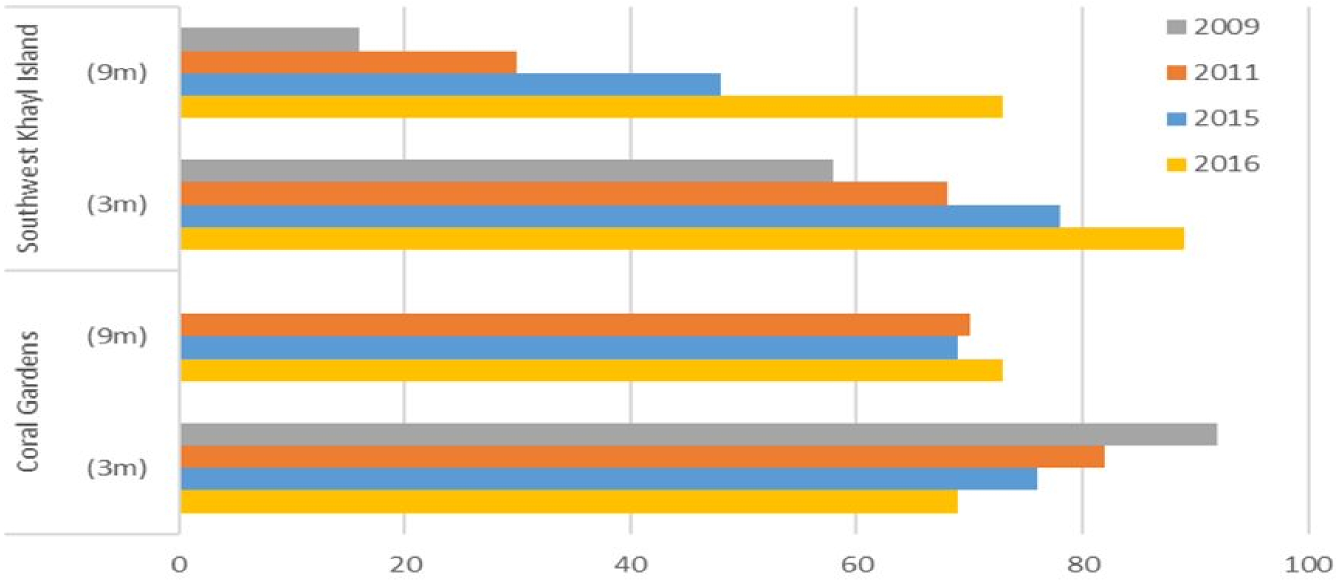


Figure 2.4b. Trends of hard coral percentage cover occurring for two long-term monitoring sites. Southwest Khayl Island is showing recovery, particularly in deeper (9 m) waters. Shallow water (3 m) communities at Coral Gardens are showing a decline in live coral cover of 92% to 69%.

For this expedition we revisited a number of sites that had been surveyed during previous years. Although we cannot lay the transect tape at the exact start and end points of survey sites from previous years, latitude and longitude positions of sites allows us to mark the start and end points of dives relatively accurately. Whilst Southwest Khayl Island is showing a remarkably positive change in coral cover, Coral Gardens is showing a decline in coral cover in shallow waters. We will continue to visit this site to see if this 'change' is real, or an artefact of laying the transect tape in a slightly different place each year.

Fish populations

The most interesting finding of this year's survey was the number, density and biomass of snapper recorded at Faqadar Bay. Here there was an order of magnitude more snapper than at other sites (an average of over 400 animals per 100 m^2 replicate). We cannot be sure of the absolute numbers of animals recorded at each section – anything above recording 50 individuals is unreliable from such dives, particularly when the individuals within a school resemble each other and regularly move in and around the outer limit of the transect. However, it is clear from this site – and the prevalence of very significant numbers of individuals through all replicates (range 106-1,500 individuals / 100 m^2 over eight replicates) – that this is an exceptional site. Indeed, looking at densities of fishes (of all species) in Mediterranean marine reserves from a recent paper (Guidetti et al. 2014), densities of all fish species reached something like 200 individuals per 100 m^2. On the reefs of Faqadar Bay Musandam, recorded densities during this trip were 2.5x that – for snapper alone. On the reefs of Moreton Bay, Australia (Olds et al. 2013), within a marine reserve near to mangroves, densities of snapper, sweetlips and bream combined were approximately 75 individuals per 100m^2 – with similar densities at Rovlana lagoon in the Solomon Islands and Palm Islands of Australia. These three families resemble species that occupy the same part of the food pyramid as the snappers observed at Faqadar Bay. It is clear from these numbers – at sites that have received conservation status – that the densities of individuals at Faqadar Bay are exceptional and should merit protection. Indeed, the literature indicates, and common beliefs amongst the academic community and tropical reef fisheries managers agree, that fish benefit from protection and conservation of nearby mangroves in coral reef rich countries (e.g. Serafy et al. 2015). The waters of Musandam are not especially well adapted to dense mangroves as a recruitment and nursery habitat (as they have relatively low tides and extreme temperatures). This also makes the high snapper densities at Faqadar Bay exceptional.

Table 2.4a. Densities of reef fish in Mediterranean marine reserves, and Australian and Soloman Islands MPAs compared to Faqadar Bay.

Site	Faqadar Bay, Musandam	Mediterranean marine reserves (from 5 sites)	Rovlana lagoon (Solomon Islands)	Moreton Bay (Australia GBR)	Palm Islands (Australia GBR)
Data	All snapper	All fishes combined	SN; SL; BR; RF[1]	SN; SL; BR; RF	SN; SL; BR; RF
Density (per 100 m^2)	476±444 (SD)	~200	~25	~75	~63
Authors	Solandt et al. 2017 (this report)	Guidetti et al. 2014	Olds et al. 2013	Olds et al. 2013	Olds et al. 2013
Habitat	Sheltered bay coral reef	Rocky reefs and seagrass beds	Reefs w/ nearby mangroves	Reefs w/ nearby mangroves	Reefs w/ nearby mangroves
Conservation status	Not protected	Marine Reserve (no take)	Marine Reserve (no take)	Marine Reserve (no take)	Marine Reserve (no take)

1 - SN – Snapper; SL – Sweetlips; BR – Bream; RF - Rabbitfish

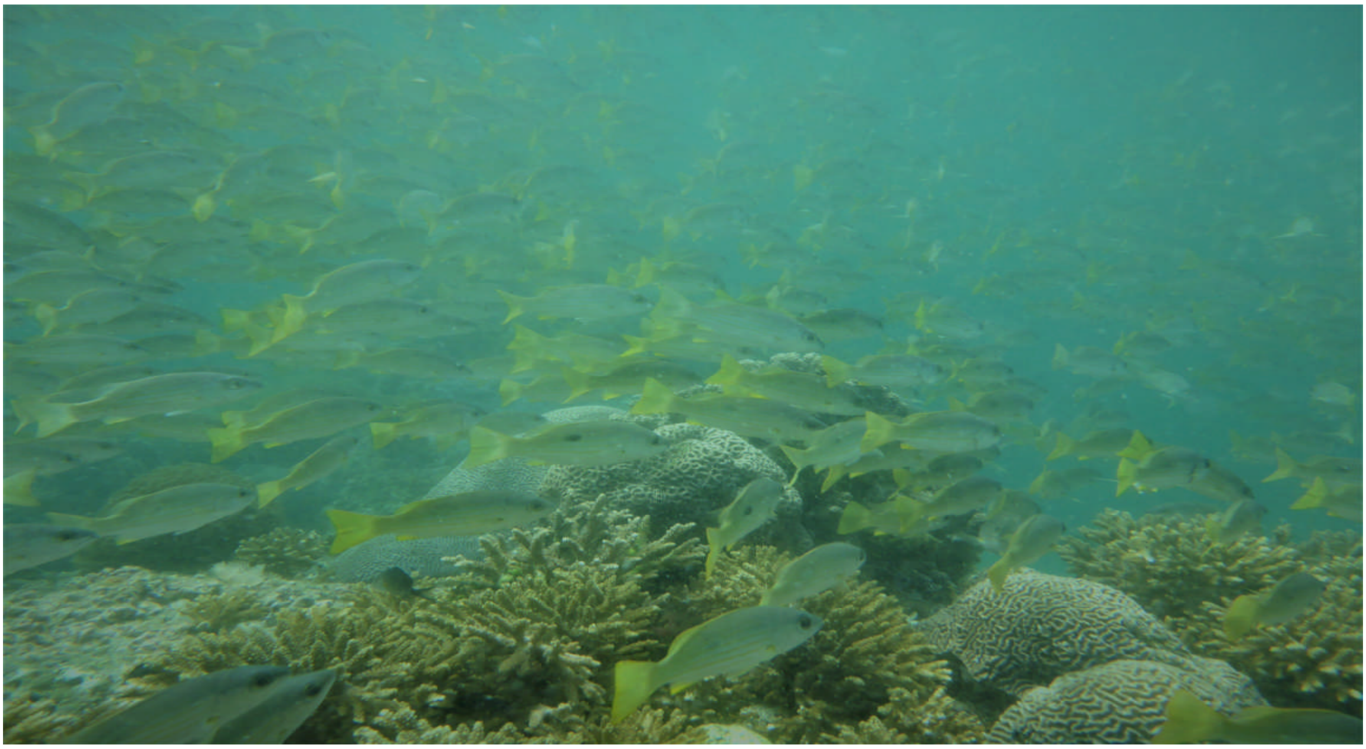


Figure 2.4c. Large densities of snapper at Faqadar Bay.

Other observations

The great numbers of *Diadema* urchins at some sites appear to have a negative impact on corals. The base (skeleton) of large colonies of *Symphyllia* (Fig. 2.4d) are particularly vulnerable to grazing. It is not known why the *Diadema* population is so high in Musandam. However, in other countries it is thought to be related to the lack of competitors (such as parrotfish) and a lack of predators such as emperors and triggerfish, which are able to prey on small urchins (McClanahan 2000).

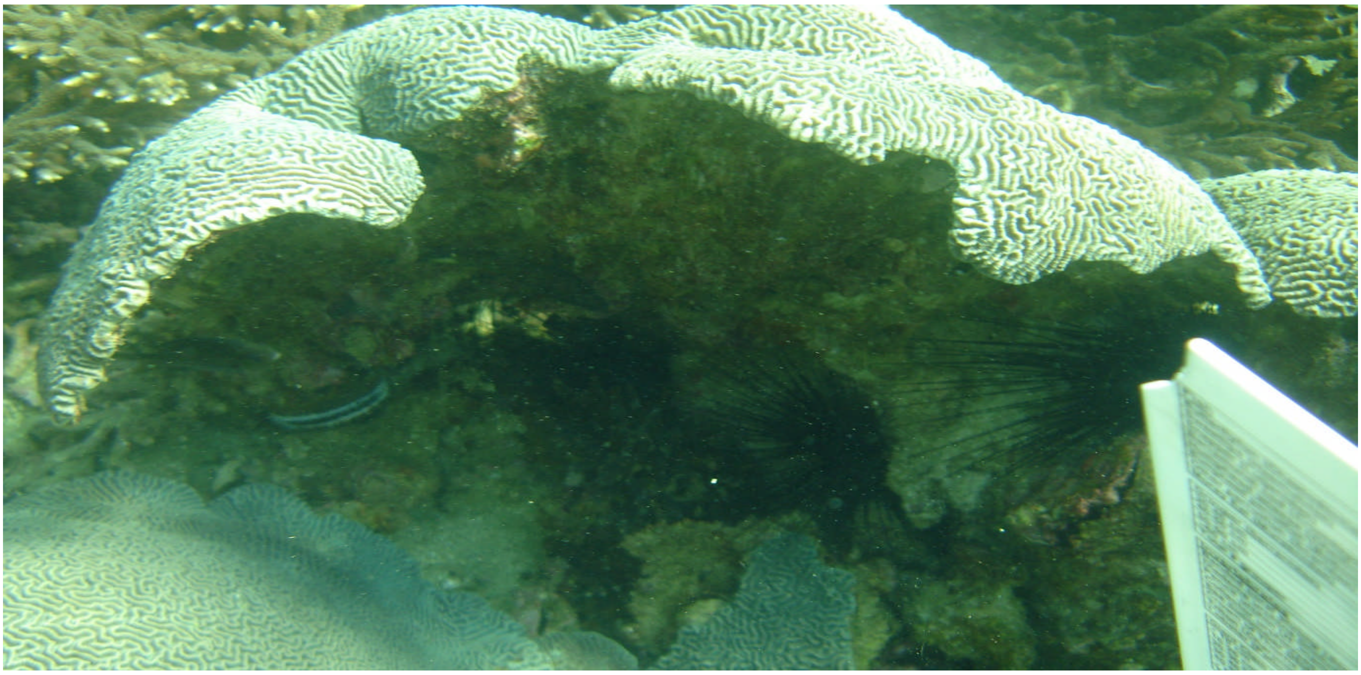


Figure 2.4d. Overgrazing by high densities of *Diadema* echinoids is leading to fast erosion of some of the coral skeleton. *Symphyllia* brain corals appear to be particularly vulnerable in some shallow water areas.

2.5. Conclusions and Management Recommendations for Northern Musandam

The reefs of the Peninsula remain in a uniquely healthy condition relative to many other Gulf and Indian Ocean regions and are naturally resistant to the ravaging impacts of global climate change that have badly affected the vast majority Indian Ocean reefs over recent decades. We strongly recommend that management is forthcoming to the area to prevent overfishing and trophic cascades (e.g. where urchin grazing becomes an even bigger problem than it already appears to be). MPA (Marine Protected Area) status will also allow the numbers of fish herbivores such as parrotfish to exist at high levels – species that are imperative to maintaining a good coral-algal balance on the reefs.

Groupers are not common or large. We strongly recommend that significant areas are closed to all forms of fishing, particularly areas in strong current, where fish are likely to spawn and where fishers probably find it more difficult to find reasonable shelter to allow for fishing from small boats (Fig. 2.5a). We also recommend a 1 nm exclusion of net fishing from the coast to ensure populations of reef fish are allowed to recover.

Without management of the natural resources of the peninsula, there will be a decline in both the quality and quantity of food resources from the area. Hammour (grouper) are already rare in other areas of the Gulf where greater human population pressure relative to reef area has overfished the species or driven them to local extinction. It would be negligent for this to occur in Oman at Musandam, where Biosphere Expeditions has been urging management action since 2009.

Musandam as a Marine Protected Network

A number of Marine Nature Reserves were declared in the 1990s by the Ministry of Municipality and Environment to protect vulnerable marine habitats in Oman (Siddeek 1999). There is Ras Al Hadd Nature Reserve for the protection of green turtle nesting grounds, Daymaniyat Island Nature Reserve for the protection of green and hawksbill turtle nesting grounds, coral reefs, birds and fish, and Dhofar Khowrs Nature Reserve (fresh as well as brackish water lagoons) for the protection of seabirds and fish. All of these reserves are located outside Musandam Governorate and no protected area has been declared there yet. However, it is a stated government policy to have more reserves in each governorate. The government announced management measures around the Khor Najd and Khor Hablain inlets to the southwest of the Peninsula in 2013, but we understand that these measures have not yet been put to local communities, or been implemented in any way, and exist only on paper. Lack of communication of such measures has been confusing for conservationists, local fishermen and stakeholders. Indeed, this year, we have heard that the Khor Najd and Hablain reserves are being considered to be opened to many forms of fishing, which would make their designation as Marine Protected Areas meaningless. Our recommendations below (and in Fig 2.5a) are specific and can provide the local context needed to make management work. The consideration of entire Khors as MPAs is good in principle, but we recommend small, more highly protected management units, These would allow protection at high levels, whilst allowing small boats access to adjacent areas for fishing, benefiting from spill-over of surplus animals from within the reserves to outside the reserves, whilst maintaining a healthy biomass of individuals that would provide a permanent export to the surrounding fishery. This is an accepted management approach that has been adopted in many other reef-associated countries, such as the Mediterranean (Guidetti et al. 2014).

We therefore recommend:

1. Minimum and maximum landing sizes for reef fish, particularly groupers, snappers, emperors and breams based on size at sexual maturity (see Fishbase[2]).
2. Minimum landing sizes for invertebrates (particularly molluscs).
3. Closed fishing during grouper spawning seasons and at spawning points.
4. Closed seasons for fishing baitballs.
5. Entire closed areas for reef- and pelagic-associated fisheries (see Fig. 2.5a).
6. Reference areas where no extraction or deposition is allowed for preservation of all biodiversity (such as fish, motile invertebrates and coral populations).
7. Restrictions on longlining in the entire area, with potential full closures of this fishery in the area out to 1 nm from the nearest landmass.
8. Clarification and/or declaration of protected areas with clear communication of boundaries, management measures, rules and regulations and enforcement of all of the above in place.

The strong military presence in the area, due to its proximity to the Strait of Hormuz, is also significant for the implementation of an MPA, since military exclusion zones could form part of an MPA and policing of protected areas could be done by the military with relatively little additional training. The implementation of a wider MPA around the whole peninsula will help to mitigate the impacts of stresses found by the expedition, as well as create benefits such as:

1. Conserving biological diversity and associated ecosystems that cannot survive in most intensely managed seascapes.
2. Promoting natural age structures in populations, increasing fish catches locally (by protecting critical spawning and nursery habitats) and in surrounding fishing grounds.
3. Providing refuge for species that cannot survive in areas that continue to be fished.
4. Providing alternative incomes for local communities and alleviating poverty.
5. Protecting sensitive habitats from disturbances and damage from fishing gear.
6. Eliminating ‘ghost fishing’ by lost or discarded gear.
7. Serving as a point of reference for adjacent fished areas sites that can subsequently be used as baselines for scientific research and also to measure fishery effects in other areas and thereby help to improve fisheries management.
8. Acting as focal points for public education and awareness on marine ecosystems and human impacts upon them (IUCN-WCPA 2008).
9. More attractive diving.
10. Enhanced tourism ‘status’.

Involving the local community in future studies and MPA design is extremely important in order to mitigate for any current lack of awareness and knowledge of conservation management measures. If awareness can be created in time and if the impacts can be controlled, then there is a good chance that the number of species can be held stable or increased.

Studies on Musandam ports fisheries landings will help our understanding of the demands on this ecosystem, as well as its biodiversity and population levels. More information about the existence of triton shells (such as *Charonia* spp.) is also needed, since their harvesting could lead to an outbreak of crown-of-thorns starfish in the region.

Future Reef Check surveys of the Musandam Peninsula are required in order to understand the average number of indicator species with lower standard error. Further surveys will also yield a better understanding of trends, population sizes and pressures for the area.

[2] http://www.fishbase.org/search.php?region=redsea&lang=Arabic

Figure 2.5a. Areas we recommend as no-take zones or fish sanctuaries or fish spawning zones. Protecting these sites permanently from all forms of fishing will seed other areas of reef with fish for the benefit of fishers. By not protecting these sites, the grouper populations of Musandam are running the very real risk of being fished out. We also recommend a total exclusion ban for net fishing gear to 1 nm out from the coast.

2.6. References

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Appendix I: Expedition diary and reports

A multimedia expedition diary is available at https://biosphereexpeditions.wordpress.com/category/expedition-blogs/musandam-2016/

All expedition reports, including this and previous expedition reports, are available at www.biosphere-expeditions.org/reports