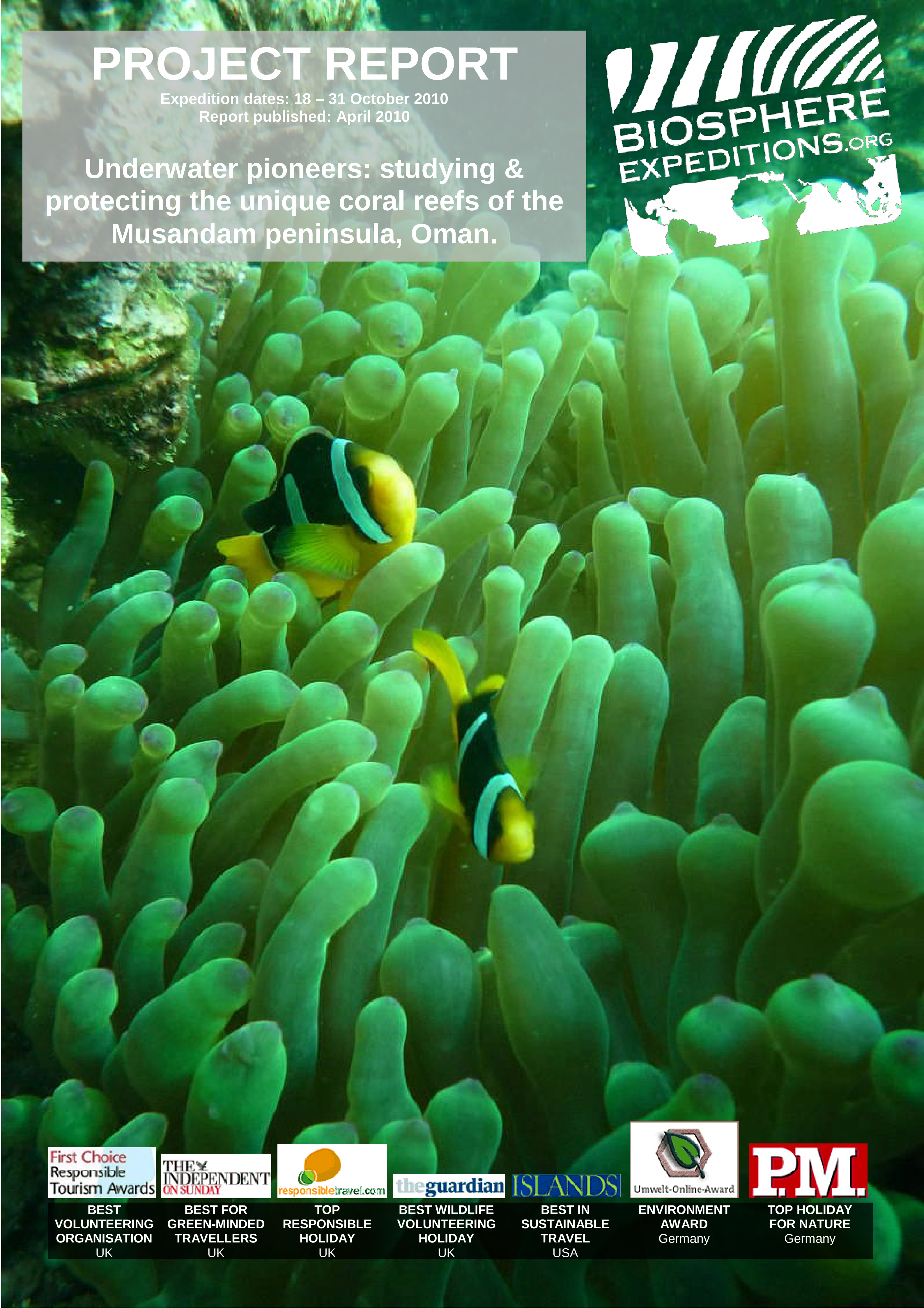

PROJECT REPORT

Expedition dates: 18 – 31 October 2010
Report published: April 2010

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

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EXPEDITION REPORT

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

Expedition dates:
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Authors:
Rita Bento
Emirates Diving Association

Matthias Hammer (editor)
Biosphere Expeditions

Abstract

The Musandam peninsula, situated on the Arabian peninsula in the Strait of Hormuz, comprise of coral reefs that appear to endure extremely harsh conditions when compared to corals in other parts of the world. Although resilience seems to exist among corals, scientists are increasingly concerned that any additional stress, imposed by global climate change or regional coastal development may accelerate coral die-off. In the past decade reefs in the Arabian Gulf have been devastated by major coral bleaching events and recently by extensive coastal developments.

Between 18 and 31 October, 2009, Biosphere Expeditions ran a research project along the Musandam peninsula coastline during which a coral reef survey using the Reef Check methodology was conducted in 18 dive sites, at two different depths. The main objective of the expedition was to provide data on reef health and current threats.

In accordance with what is encountered elsewhere in the Indo-Pacific, the Musandam also shows higher abundance of fish from the families Chaeodontidae (butterflyfish) and Lutjanidae (snappers) than Haemulidae (sweetlips) and Scaridae (parrotfish). However, the number of snappers in Musandam is substantially higher than the average for the Indo-Pacific. Serranidea (groupers) were found to be low in abundance due to the known fishing value of this family in the region. Curio collection and aquarium trading, as well as blast fishing and destructive fishing appear not to be a threat around the Musandam peninsula. In the invertebrates surveys the number of Diadema urchins was found to be significantly above the average number observed in the Indo-Pacific. This high density population is a concern, since it increases bioerosion activity in the area, making new coral recruitment difficult. The mean hard coral coverage of 34% found is slightly above the worldwide calculated average of 30%.

Further Reef Check surveys and fisheries landings studies should be done around the Musandam peninsula in order to address in more detail the main impacts found during the expedition. The application of a Marine Protected Area (MPA), or a network of MPAs, would also help to overcome the principal problems encountered, such as the lack of available data on natural resources, the absence of proper fixed and marked mooring buoys and the low public awareness. Declaring the Musandam peninsula a UNESCO Biosphere Reserve and eventually a UNESCO World Heritage Site is also something that should be considered at government level.

ملخص

شبه جزيرة مسندم ، التي تقع في شبه الجزيرة العربية في مضيق هرمز ، تتألف من الشعاب المرجانية التي يبدو أنها تتحمل ظروف قاسية للغاية بالمقارنة مع الشعاب المرجانية في أجزاء أخرى من العالم. على الرغم من المرونة بين الشعب المرجانية فأن العلماء قلقون على نحو متزايد أن أي ضغط إضافي على هذه البيئة الهشة ، والتي يفرضها تغير المناخ العالمي أو الإقليمي و التنمية العمرانية الساحلية قد تسارع بموت هذه الشعاب المرجانية.

في العقد الماضي الشعاب المرجانية في منطقة الخليج العربي تعرضت للعديد من الكوارث الطبيعية و الانسانية مثل ابيضاض الشعاب المرجانية ، ومؤخرا التطورات الساحلية واسعة النطاق.

ما بين 18 و31 تشرين الأول 2009 ، قامت حملة البيوسفير بحملة دراسة الشعاب المرجانية في شبه جزيرة مسندم حيث تم جمع المعلومات من اكثر 18 موقع غوص ، على اثنين من الأعماق المختلفة. وكان الهدف الرئيسي للبعثة توفير بيانات عن صحة الشعاب المرجانية في شبه جزيرة مسندم والتهديدات الحالية القائمة على النظام البيئي في هذه المنطقة.

و كما هو موجود في المحيطين الهندي والهادئ ، ففي شبه جزيرة مسندم وأعلى أيضا وفرة الأسماك من عائلات Chaeodontidae ، Lutjanidae ، sweetlips،Haemulidae وScaridae ، على الرغم من أن عددا من النهاش في مسندم هي كبيرة أعلى من المتوسط بالنسبة للالمحيطين الهندي والهادئ. على الجانب الآخر Serranidea (الهامور) تم العثور عليها في وفرة منخفضة نظرا لقيمة الصيد المعروفة من هذه العائلة في المنطقة.

الغريب أن الصيد وتجارة احواض الاسماك ، فضلا عن الانفجار والصيد المدمرة لا يبدو أن يكون التهديد الرئيسي في شبه جزيرة مسندم ، من خلال المسوحات في اللافقاريات وجد أن عدد القنافذ البحرية (دياديما) وجد أن للغاية أعلى من متوسط العدد في المحيطين الهندي والهادئ. هذه الكثافة السكانية العالية تشكل مصدر قلق لأنه يزيد نشاط bioerosion في المنطقة ، مما يجعل من الصعب على المرجان بناء الحيود الجديدة.

تغطي الحيود المرجانية الصلبة 34 ٪ من شبه جزيرة مسندم ويتفق مع المتوسط المحسوب في جميع أنحاء العالم بنسبة 30 ٪. مزيد من التحقق من الدراسات الاستقصائية للشعاب المرجانية والدراسات الإنزال السمكية وينبغي أن تتم في شبه جزيرة مسندم من أجل معالجة الآثار الرئيسية التي عثر عليها أثناء الرحلة.

ومن شأن تطبيق خطة ادارة المناطق المحمية البحرية ، أو شبكة من المناطق البحرية المحمية ، يساعد أيضا على التغلب على المشاكل الرئيسية التي واجهتها ، مثل الافتقار إلى البيانات المتاحة عن الموارد الطبيعية ، وعدم وجود حدود ثابتة وسليمة ملحوظ والجمهور الواعي بيئيا .

Contents

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.

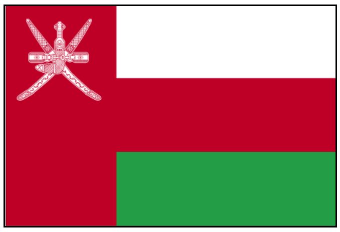
This project report deals with an expedition to the Musandam peninsula that ran from 18 to 31 October 2009 with the aim of monitoring the health of the Musandam peninsula's reefs, its fish and invertebrate communities so that informed management, education and conservation decisions can be made by the government and NGOs. Data on the current biological status of the reefs and of 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 a Reef Check EcoDiver.

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 in 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 more or less begins where the mountains rise from the plains of Ras al Khaimah.



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 had 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 micro-fossils in limestone indicate continental shelf conditions. These limestones were deposited from the early Jurassic to the Cretaceous period and are reckoned 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, staying 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 the 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) stop off here.

1.3. Dates

The project ran over a period of two weeks divided into two one-week slots, each composed of a team of international research assistants, scientists and an expedition leader. Slot dates were:

2009: 18 - 24 October | 25 - 31 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 on-suite toiled 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. 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 average day temperature during the expedition were 35-40°C with sunshine and no clouds on all but a few rare days. Water temperature during the expedition is ranged from 21-31°C.

Field communications

The live-aboard 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 www.biosphere-expeditions.org/diaries.

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 serious medical incidences during the expedition.

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. Local Scientists

Biosphere Expeditions was working with Rita Bento of the Emirates Diving Association on this project.

Rita Bento was born in Portugal. She has a degree in Marine Biology from the University of the Azores and a Masters in Science of the Sea – Sea Resources from Porto University. Her first area of research was bioacoustics of baleen whales, working in the USA with Oregon State University and NOAA (National Oceanographic and Atmospheric Administration). In the last few years she has focussed her research on Marine Protected Areas (MPA) currently working with the Emirates Diving Association on the management plan of Dibba MPA in the UAE. Rita is also a Reef Check instructor with hundreds of Reef Check dives. Besides her scientific career, she is also a CMAS diving instructor and published the first Portuguese diving guide in 2007.

1.6. Expedition Leader

This expedition was led by Dr. Matthias Hammer, who founded Biosphere Expeditions in 1999. Born in Germany, he went to school there, before joining the Army at 18, 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):

8 – 14 October 2009

Adel Abu Haliqa (UAE), Berit Albiez (Germany), Robert Beaumont (UAE), Cornelia Beisel (Germany), Dörthe Dräger (The Netherlands), Anke Hofmeister (Malidves), Lars Krueger (Germany), Wayne Lunt (Oman), Michele Steffey (USA), Gordon Thomson (UK), Stephen Tredwell (UK), Phillippa Jayne Tredwell (UK).

15 – 31 October 2009

Adel Abu Haliqa (UAE), Ken Atkinson (UAE), Cornelia Beisel (Germany), Jan Biekehoer (Germany), Dan Clements (USA), Susannah Cogman (UK), Hellen Griffiths (UK), Yara Helena Ogawa Silva (USA), Mara Silvia Ogawa Silva (Brazil), Melani Pipo (USA), Detlef Rausch (Germany), Jay Sprenger (USA)

Also: journalist Homa Khaleeli (UK).

Staff during the expedition: Ali (boat captain), Poli (cook), Chandu (deck hand), Mohammed (deck hand), Badah (dive guide).

1.8. Other Partners

On this project Biosphere Expeditions is working with Reef Check, the Emirates Diving Association, local dive centres, businesses & resorts, the local community, Sultan Qaboos University, the Oman Ministry for Environment and Climate Affairs, the Oman Tourism Board, as well as the United Nations Environment Programme, the World Conservation Monitoring Centre and the International Coral Reef Action Network (ICRAN).

Biosphere Expeditions also gratefully acknowledges corporate support from a Six Senses (Zighy Bay) environmental grant, as well as a grant from HSBC Oman.

1.9. Expedition Budget

Each team member paid towards expedition costs a contribution of £1090 per person per 7 day slot. 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., as well as 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	22,215
Grants & sponsorship	37,614

Expenditure	
Research vessel includes all board & lodging, ship's crew, fuel & oils, other services	20,190
Transport includes transfers & visas	1,494
Equipment and hardware includes educational & research materials & gear purchased in UK & Middle East	3,840
Biosphere Expeditions staff includes salaries, travel and expenses to the Middle East	2,818
Local staff includes Divemaster and other locally staffed services, except boat crew	3,219
Administration includes registration fees, educational materials design & distribution & sundries	2,244
Team recruitment Musandam as estimated % of PR costs for Biosphere Expeditions	4,210
Set-up of expedition includes consultants, travel, research, vessel hire & staff time	18,940

Income – Expenditure	**2,874**
Total percentage spent directly on project	**95%**

1.10. Acknowledgements

This study was conducted by Biosphere Expeditions which runs wildlife conservation expeditions all over the globe. Without our expedition team members (who are 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 the ones we have not managed to mention by name (you know who you are) for making it all come true. Biosphere Expeditions would also like to thank members of the Friends of Biosphere Expeditions and donors, Land Rover, Swarovski Optik, Cotswold Outdoor, Motorola and Gerald Arnhold for their sponsorship.

1.11. 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 at the address given below.

2. Reef Check Survey

Rita Bento
Emirates Diving Association

2.1. Introduction

Study site description

The Musandam peninsula, also known as Ru'us al-Jibal, is an exclave of Oman separated by 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 and the Gulf of Oman (Rezai et al. 2004).

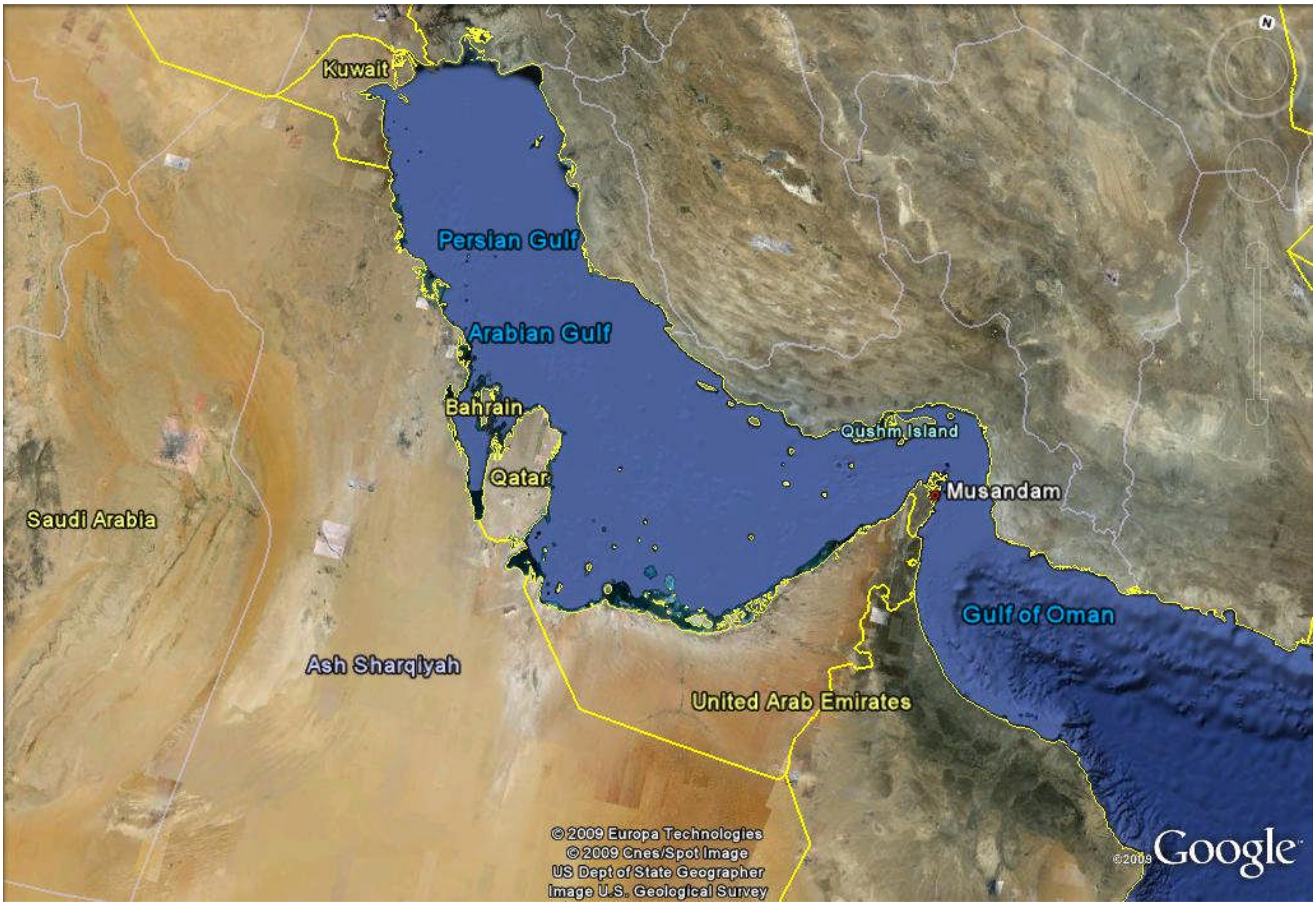


Figure 2.1a. Location of the Musandam peninsula in the Middle East. © Google Maps.

The Arabian Gulf is a sedimentary 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 (Sheppard et al. 1992; Carpenter et al. 1997; McClanahan et al. 2000; Pilcher et al. 2000). Coastal waters of the Gulf of Oman stretch from the Strait of Hormuz in the northwest to the eastern tip of the Arabian peninsula (Ras Al-Hadd) on the Oman side, and to Gwatar near the Pakistani border on the Iranian side (Siddeek 1999). 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 in the region (SOMER 2003). The extremely arid nature of the Arabian region, the high temperatures and the constant and intensive sunshine, especially along the coastal areas, results in some parts in a lack of four season variability.

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).

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 that of the Indian Ocean. But generally, tidal height is 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 23-31°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 Arabia 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 at 36.5 (on the Practical Salinity Scale, PSS, which has no units), 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). 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 occurring in the shallow bays in the south where evaporation locally exceeds 2000 cm/yr. In these shallow bays salinity exceeds 50 over hundreds of square km, exceeding even 70 in large expanses (McClanahan 2000). These large evaporation rates over the Arabian Gulf lead to the formation of a 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 Gulf of Oman (Figure 2.1b) (Pous et al. 2004).

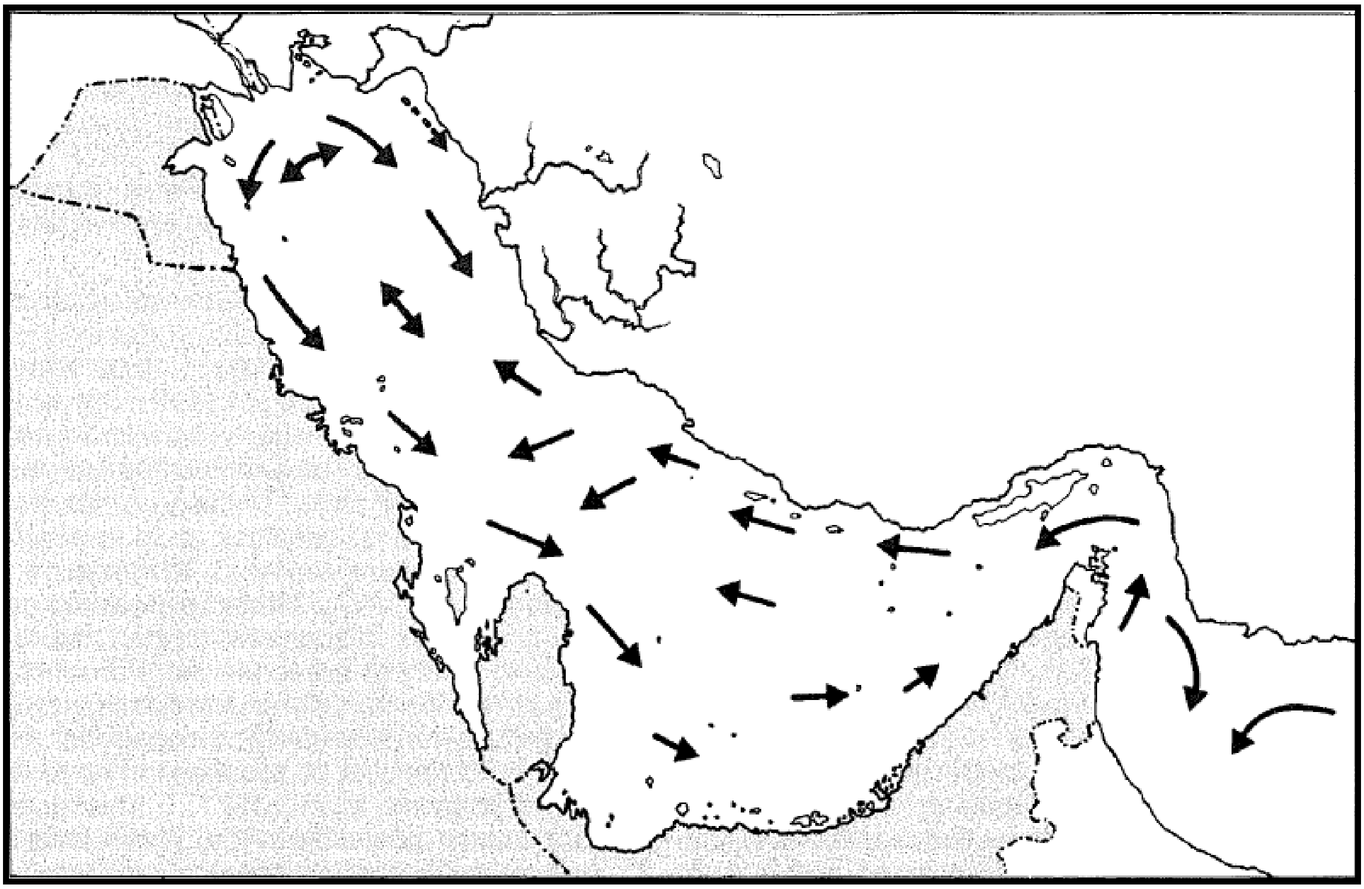


Figure 2.1b. Major current patterns of the Arabian Gulf and northern Arabian Sea (Reynolds 1993).

The Arabian region comprises a large marine environment, which is shallow and, because of the arid climate regime it is exposed to, also undergoes wide fluctuations in different parametres. Strong variations in temperature and salinity influence water density, currents, water mixing, and a host of other environmental parametres that in turn influence species composition. Species that establish populations in the area must be capable of withstanding the stress of osmotic and temperature extremes. 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 example of adaptation by marine organisms (SOMER 2003). The range of environment, latitude and geological formation 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 corals in each location 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 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 then 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 is 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 a few that are adapted to the uniquely harsh condition of the region (Coles 2003).

Due to the varied coastline of Oman, where upwelling effects are attenuated by bays, reef growth continues with typically reef flat and reef slope development. 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).

At the entrance to the Arabian Gulf, the Musandam peninsula contains reefs dominated by Porites and Acropora. Rich coral communities such as *Porites lutae*, *P. solida*, *Acropora valenciennesi* and *A. valida* are common from Musandam to the capital area of Oman (Sheppard et al. 1992; McClanahan et al. 2000).

Even though the Arabian Gulf's corals are unique and seem to endure extremely harsh conditions when 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 turbidity and suspended sediments are dispersed from the dredge or reclamation sites. In addition, coastal currents are diverted by coastal engineering, altering the movement of sediments causing them to accumulate (Rezai et al. 2004).

The coral reef losses from climate-related devastation and massive coastal development on 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 is often way behind other parts of the world (Wilkinson 2008).

Reef Check

Reef Check's survey method uses simple techniques to collect scientifically robust data. This methodology is specially designed for recreational divers that might not have 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" that 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 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. Recording different substrate types (including live and dead coral).

Data for 2-4 are collected along a 100 metre transect, at two depth contours, between 2 to 5 metres and between 6 and 12 metres (Hodgson et al. 2006).

Aims and objectives

The primary aim of this project was to provide data on the health of the Musandam peninsula's reefs and current threats. Through this project it was possible, for the first time in Musandam, to collect data through Reef Check surveys in order to quantitatively assess benthic and fish communities and anthropogenic impacts. The data collected are also useful for comparison with future surveys and to provide data from Musandam for the global Reef Check database.

During the expedition interviews with local people & fishermen and a local dive guide were conducted with the objective of understanding the issues and knowledge of the main stakeholders of the coral reefs of Musandam.

2.2. Methods

Site selection & sampling design

Between 18 and 31 October, 2009, 18 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 diving sites included well-known diving spots regularly visited by divers, areas that are known for their importance to fisheries and areas where divers and fishermen are rare. 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.

Figure 2.2a. Location of the 18 dive survey sites around the Musandam peninsula.

Table 2.2a. Names and geographic coordinates of the 18 dive sites where Reef Check surveys were undertaken.

Site name * indicates new site not used by pleasure divers and therefore named by the expedition	GPS log number & indicates the only site where it was not possible to do two depth contours, so a "left" and "right" survey were conducted.	Coordinates	
Lobster's Demise*	D1&	N 26˚17'48''	E 056˚20'05''
Little Reef Check*	D2	N 26˚17'51.8''	E 056˚19'57.3''
Ra's Shuraytar	D3	N 26˚23'04''	E 056˚22'46''
Pipi Beach	D5	N 26˚22'30''	E 056˚23'01''
Coral Garden	D7	N 26˚22'33''	E 056˚24'59''
Eagle Ray	D9	N 26˚22'55''	E 056˚25'06''
Khayl Island	D13	N 26˚21'56''	E 056˚27'08''
Faqadar Bay	D19	N 26˚20'50''	E 056˚28'51''
Ballerina Cliffs*	D24	N 26˚19'42.4''	E 056˚27'38.2''
Death Valley*	D27	N 26˚15'50''	E 056˚24'38''
Snapper's Tragedy*	D29	N 26˚13'49''	E 056˚26'09''
Rockface Bay*	D31	N 26˚14'08''	E 056˚27'36''
Khesa	D32	N 26˚13'51.8''	E 056˚28'56.0''
Grouper's Escape*	D34	N 26˚11'21.0''	E 056˚28'16.7''
Cuttlefish Love*	D36	N 26˚08'39.2''	E 056˚28'24.3''
Osprey Point*	D38	N 26˚07'55.8''	E 056˚28'25.6''
Gargoyle Cliffs*	D42	N 26˚05'01.8''	E 056˚25'27.3''
Habalayan Island	D45	N 26˚09'45.6''	E 056˚21'19.8''

Training of expedition team members

All data were collected by team members that 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 22 team members in Reef Check methodology and also to coordinate and supervise the subsequent surveys and data collection.

Survey procedures & data collection

The Reef Check survey protocol utilises two transects at depths between 2 - 5 metres (shallow) and 6 - 12 metres (medium), chosen for practical reasons of 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 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 specialties and experience.

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.

Site description

The Site Description Sheet includes basic, impacts and protection information of the site that is based on observational and historical data. These data are important for interpreting local, national and global trends in the dataset, especially to understand the impacts in the area (Table 2.2b).

Table 2.2b. Impacts found on the 18 dive sites surveyed.

Site name	Harvest invert. for food	Tourist diving/ snorkelling	Sewage pollution	Commercial fishing	Artisanal/ Recreational
Lobster's Demise	Low	Low	Low	Medium	Low
Little Reef Check	Low	Medium	Low	Low	Low
Ra's Shuraytar	Low	None	Low	Medium	Low
Pipi Beach	Low	Medium	Medium	Medium	Low
Coral Garden	Low	Medium	Low	Low	Low
Eagle Ray	Low	Medium	Low	Medium	Low
Khayl Island	Low	None	Low	Low	Low
Faqadar Bay	Low	None	Low	Low	Low
Ballerina Cliffs	Low	Low	Low	Medium	Low
Death Valley	Low	None	Medium	Medium	Low
Snapper's Tragedy	Low	None	Medium	Medium	Low
Rockface Bay	Low	None	Low	Medium	Low
Khesa	Low	Medium	Low	None	Low
Grouper's Escape	None	None	Low	Medium	Low
Cuttlefish Love	Low	None	Low	Low	Low
Osprey Point	Low	Medium	Low	Low	Low
Gargoyle Cliffs	None	None	Low	Low	Low
Habalayan Island	None	Low	Low	Low	Low

Fish belt transect

Four segments of 5 metres height, 5 m wide by 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 undulates*) and the Bumphead parrotfish (*Bolbometopon muricatum*).

Invertebrate belt transect

Four 5 m wide by 20 m long transects (centred on the transect line) were 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 urchins (*Diadema* spp.), pencil urchin (*Eucidaris* spp.), collector urchin (*Tripneustes* spp.), three edible sea cucumbers 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 invertebrates survey, anthropogenic impacts were assessed. These included coral damage by anchors, dynamite, or ‘other’ factors, and for 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 (colony and population) was also measured along each 20 metre transect.

Substrate line transect

Four 20 m 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 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).

Data analysis

All data were entered on special 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 taxa. 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.

In order to elucidate the differences among the data collected, quantitative assessment of trends was achieved using Friedman and Kruskal-Wallis tests for data with non-normal distribution. A Spearman correlation test was also conducted.

Note on statistical conventions: the results of statistical tests are given by showing the ‘p’ (probability) value of the test. Results that are significant at the p <.01 level are commonly considered statistically significant, and p <.005 or p <.001 levels are often called "highly" significant.

Socio-economic survey

The socio-economic monitoring aims to understand the perceptions and uses by community members with respect to the coastal ecosystems of the Musandam. It is impossible to separate human activities and ecosystem health, especially when the marine habitat is important to the livelihoods of the local community. Socio-economic monitoring can measure community resource needs as well as the social, cultural, and economic conditions in Musandam communities.

Fishermen from the village Shaisah, located in the Musandam fjords, as well as locals and a divemaster from Khasab were interviewed by the project scientist using a pre-prepared questionnaire.

2.3. Results

Basic oceanographic and climatic conditions were recorded during the two weeks expedition. The mean air temperature was 34.2˚C with standard deviation of 0.6˚C, mean sea surface temperature was 27.8˚C with standard deviation of 1.1˚C, mean sea temperature at 3 metres was 27.8˚C with standard deviation of 1.1˚C, mean sea temperature at 10 metres was 26.9˚C with standard deviation of 1.1˚C, and the mean estimated underwater visibility was 9.9 metres with standard deviation of 2.5 metres.

Fish community

During the Musandam expedition a total of 4618 fish were counted. From the total 2550 were snappers (55.2%), 1479 butterflyfish (32%), 381 parrotfish (8.3%), 149 groupers (3.2%), 46 moray eels (1%) and 13 Haemulidae (0.3%) (Figure 2.3a).

Of the six categories of indicator fish used in the Reef Check methodology of this expedition, snappers and butterflyfish were the most abundant species seen on transects. The next most abundant were parrotfish (P<.001). Groupers were lower in abundance than these three indicator species (P<.001), but Haemulidae and moray eels are the category of indicator species with least abundance (P<.001) (Figure 2.3b).

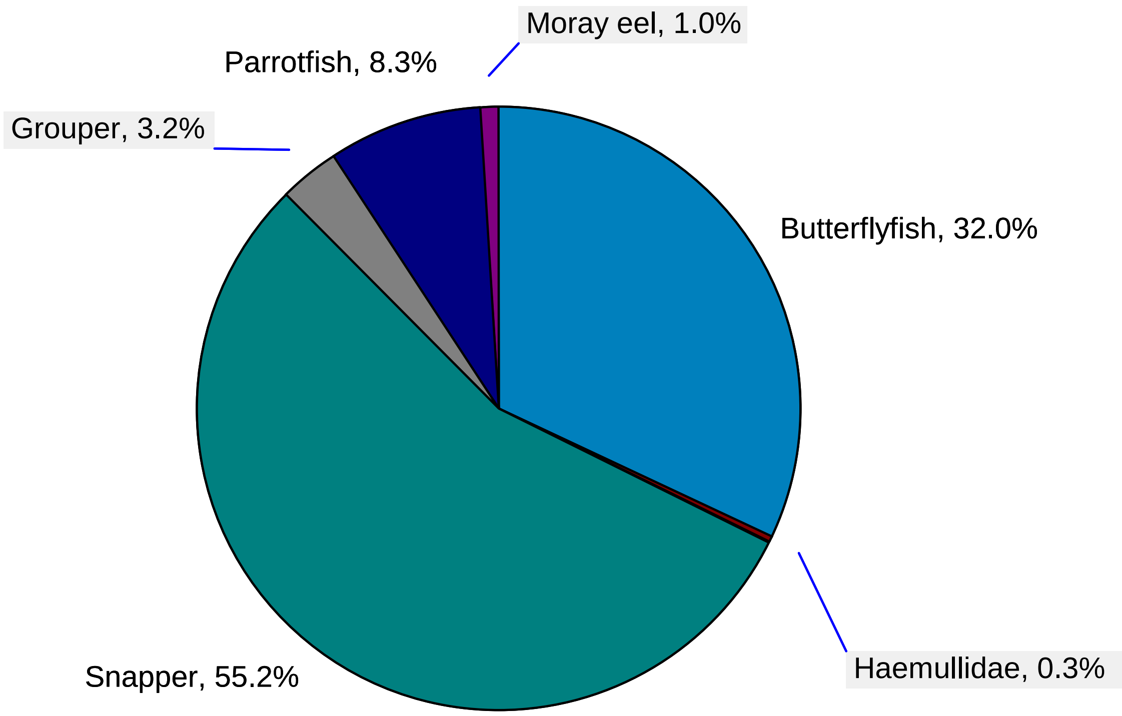


Figure 2.3a. Total percentage of fish categories counted in Musandam.

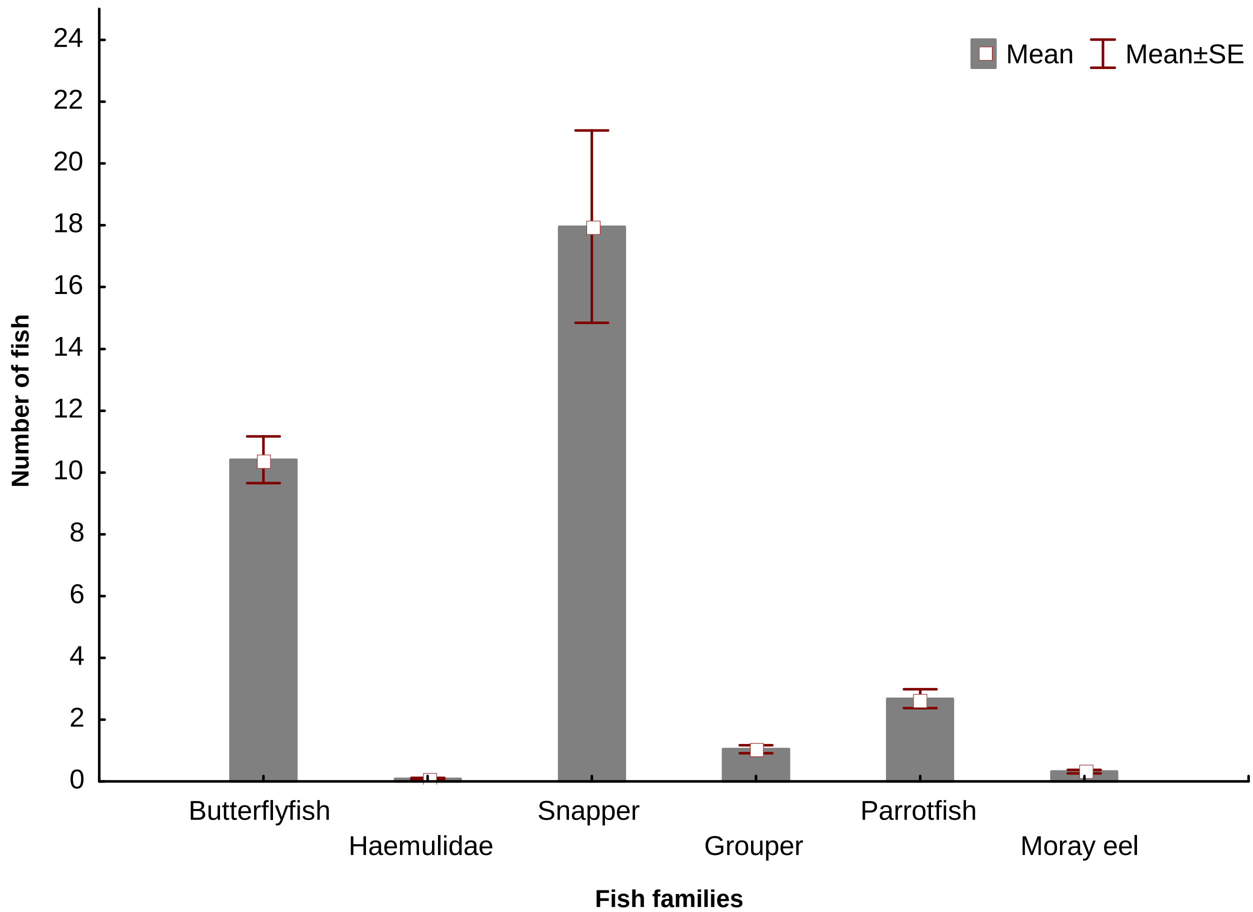


Figure 2.3b. Pooled average numbers of Reef Check indicator fish categories seen in Musandam.

When comparing the total number of fish counted in shallow and medium surveys, the mean number of fish in Musandam at shallow waters (2 to 6 metres) was higher than at medium water (6 to 12 metres) (p<.005) (Figure 2.3c).

Comparing the different categories of fish at the two different depths, the average number of butterflyfish was significantly higher in the shallow dives compared to the medium ones (p<.001), as well as the number of snappers (p<.001) and parrotfish (p<.001). Groupers, on the other hand, were more frequent in the medium dives (p<.005) (Figure 2.3d).

Regarding the mean total number of indicator fish, per 20 metre transect, per dive site, Lobster Demise, on the left side (D1l), had the highest mean value of 16.92. This value is significant higher than Faqadar Bay (D19) and Grouper's Escape (D34), the dive sites with lowest mean total number of fish, 1.83 and 1.85 respectively (p<.001) (Figure 2.3e).

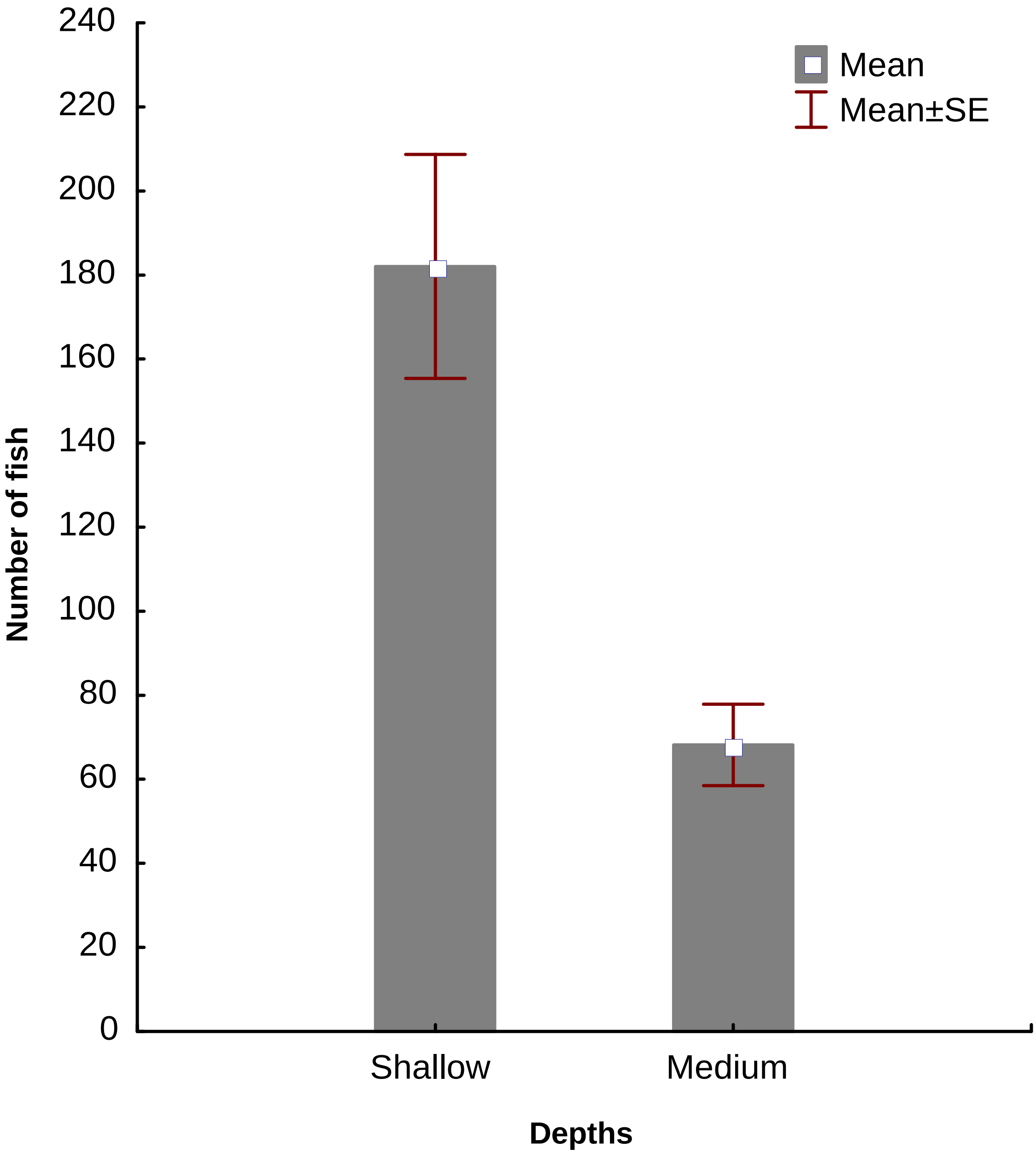


Figure 2.3c. Pooled average numbers of fish in shallow and medium surveys.

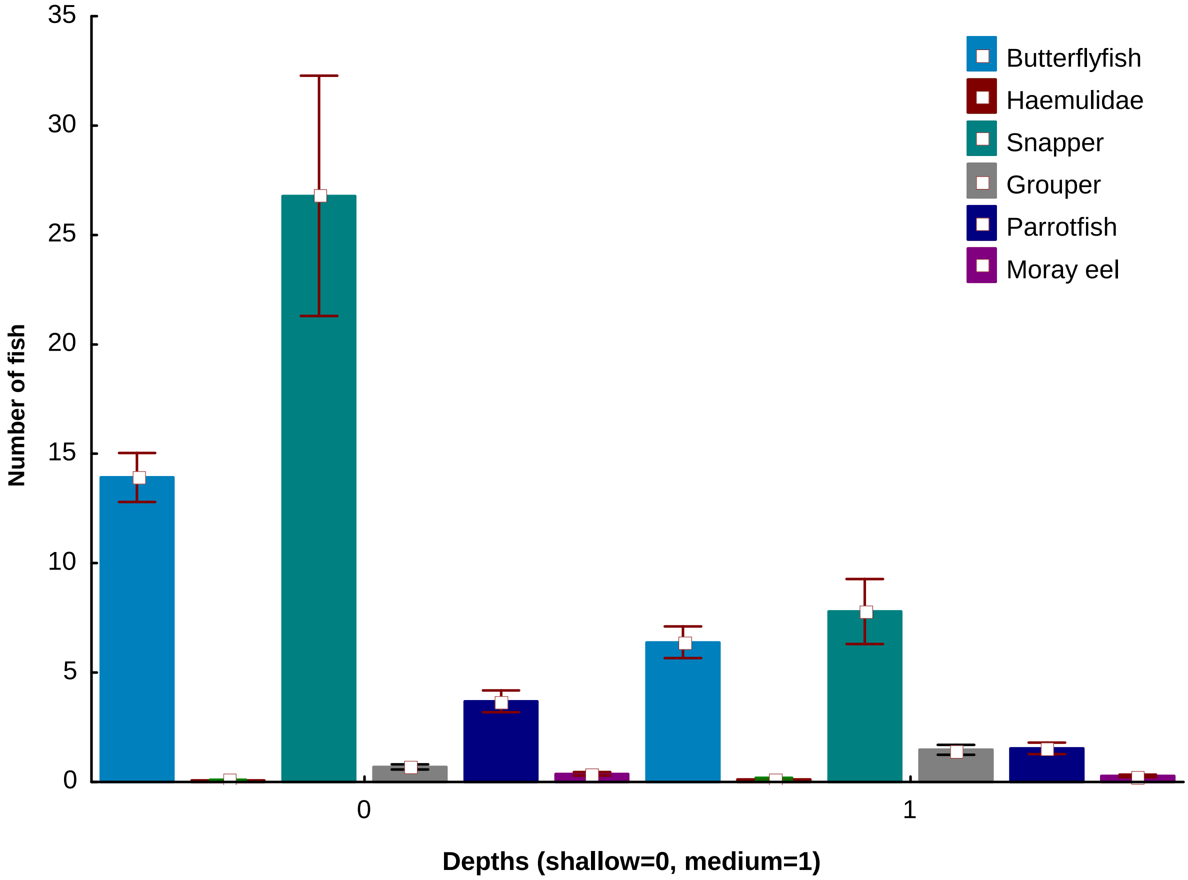


Figure 2.3d. Average numbers of the six fish categories in shallow and medium waters.

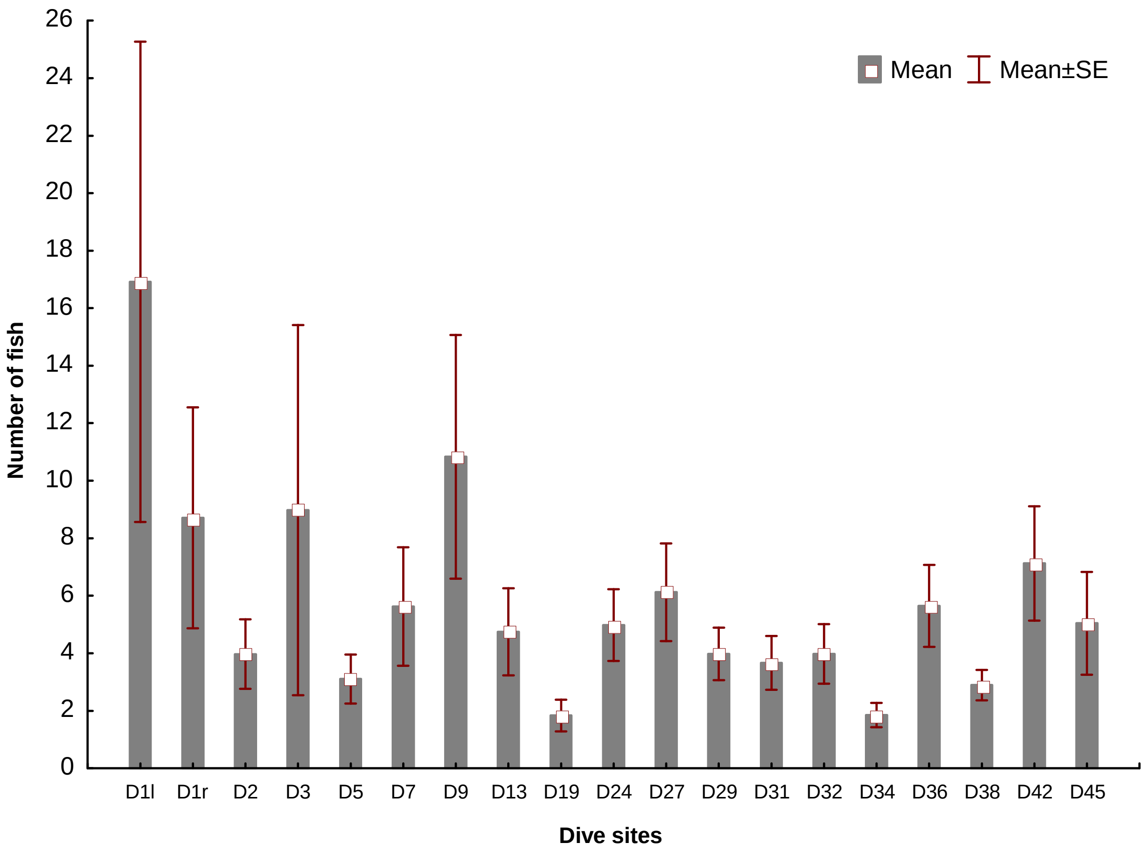


Figure 2.3e. Pooled average numbers of Reef Check indicator fish seen in each dive site in Musandam.

The main group of groupers observed belonged to the size class of 30-40 cm. A significant difference was also noticed in groupers of 40-50 cm, which were observed in higher numbers than groupers of 50-60 cm and those larger than 60 cm ($p<.001$). On the other hand, no significant difference was noticed between groupers of 50-60 cm and groupers larger than 60 cm, both of which were encountered in low numbers Figure 2.3f).

There was also a significant difference in the average numbers of groupers from 40-50 cm according to water depths, being in higher number in the medium waters ($p<.01$) (Figure 2.3g).

Correlation between categories was significant in groupers of different sizes, the higher the number of smaller groupers, the higher the observation of groupers with bigger sizes ($p<.001$). There was also a positive correlation between most fish categories: snappers with parrotfish ($p<.005$), butterflyfish with Haemulidae ($p<.05$), butterflyfish with parrotfish ($p<.05$) (Table 2.3a).

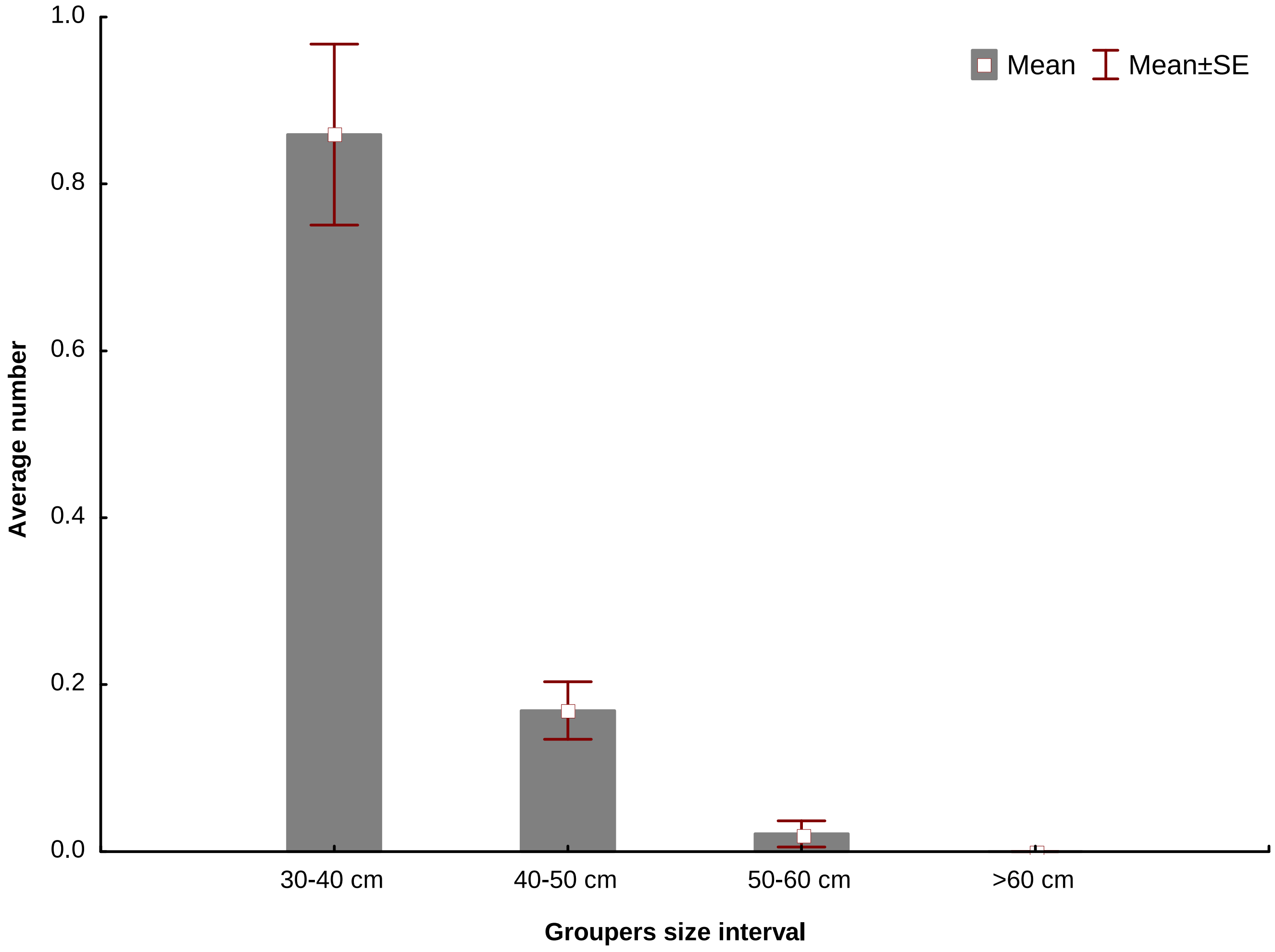


Figure 2.3f. Average numbers of groupers by size categories.

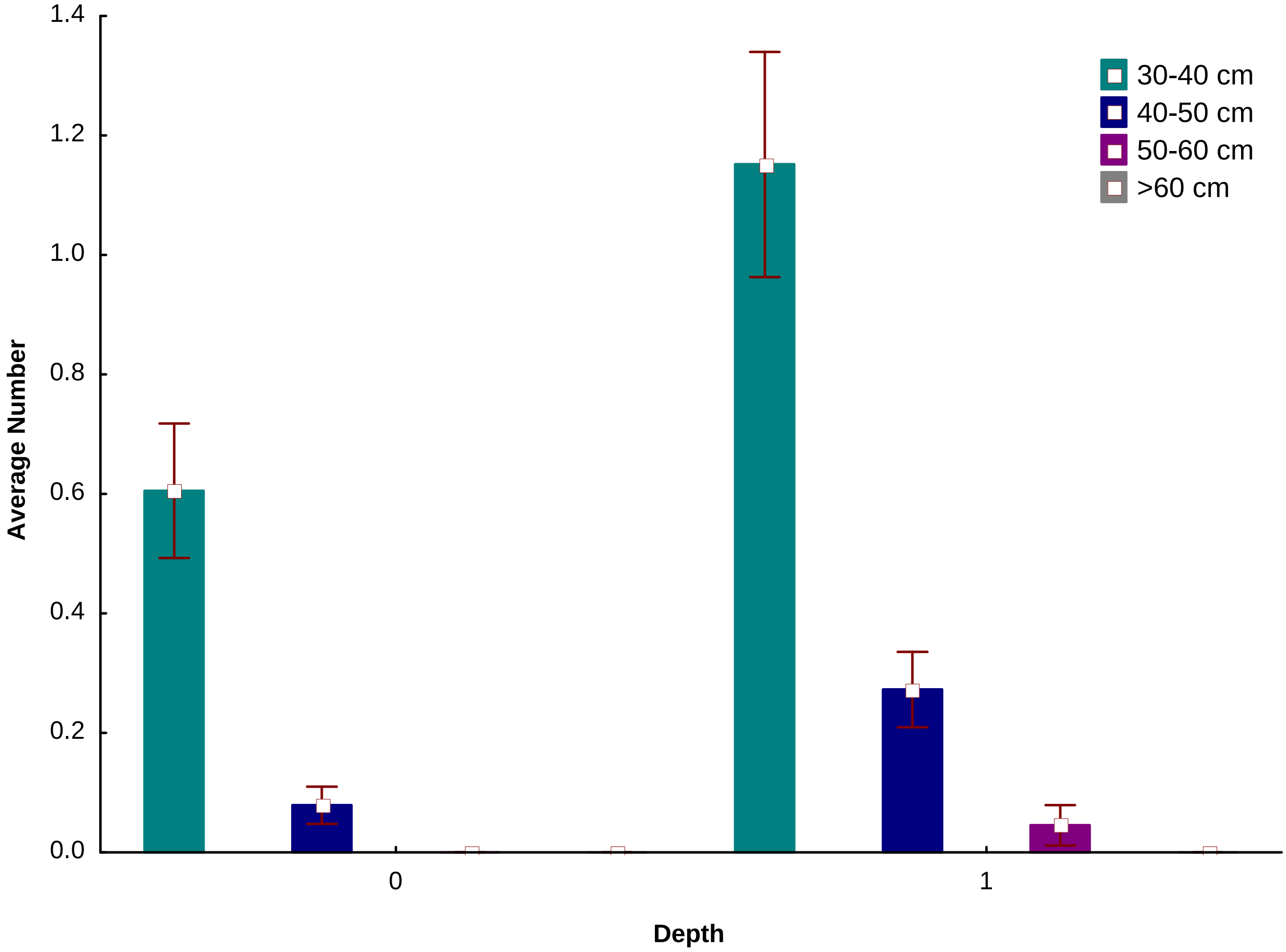


Figure 2.3g. Average numbers of groupers by size categories in shallow and medium waters.

Table 2.3a. Significant correlations according to Friedman analysis between fish categories.

Categories	Correlated with	R^2	P value
Groupers 30-40	Groupers 40-50	0.31	p <.001
Groupers 40-50	Groupers 50-60	0.27	p <.001
Snapper	Parrotfish	0.24	p <.005
Snapper	Butterflyfish	0.20	p <.05
Snapper	Haemulidae	0.18	p <.05
Butterflyfish	Parrotfish	0.21	p <.05

Invertebrate community

A total of 23320 invertebrates were counted. From the total, 22490 were diadema urchins (96.4%), 577 sea cucumber (2.5%), 169 pencil urchins (0.7%), 55 banded coral shrimps (0.2%), 16 lobsters (0.1%), 9 crown-of-thorns (0.04%) and 4 collector urchins (0.02%) (Figure 2.3h). Of all the invertebrates, diadema urchin was the highest observed (p<.001) and collector urchin was the lowest (p<.001) (Figure 2.3i).

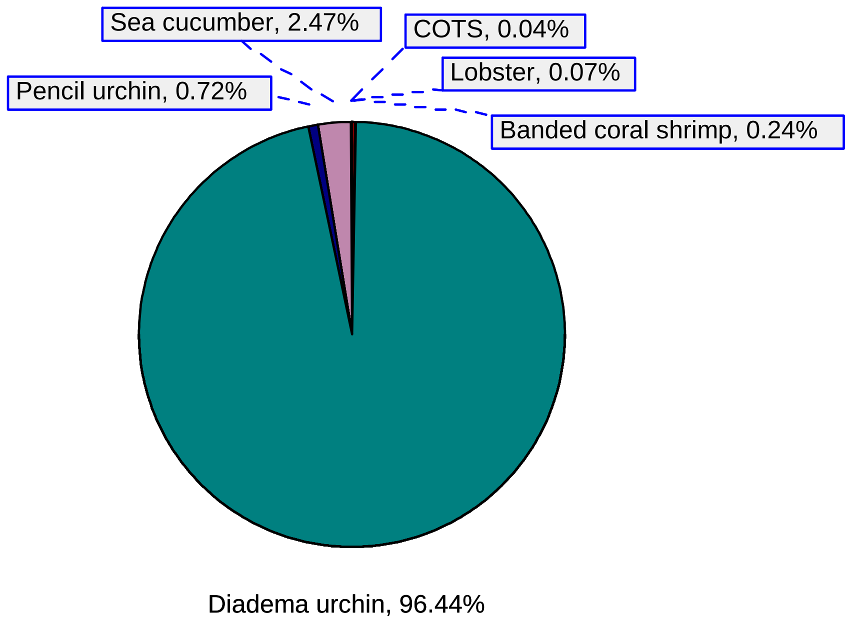


Figure 2.3h. Total percentage of invertebrate categories counted in Musandam.

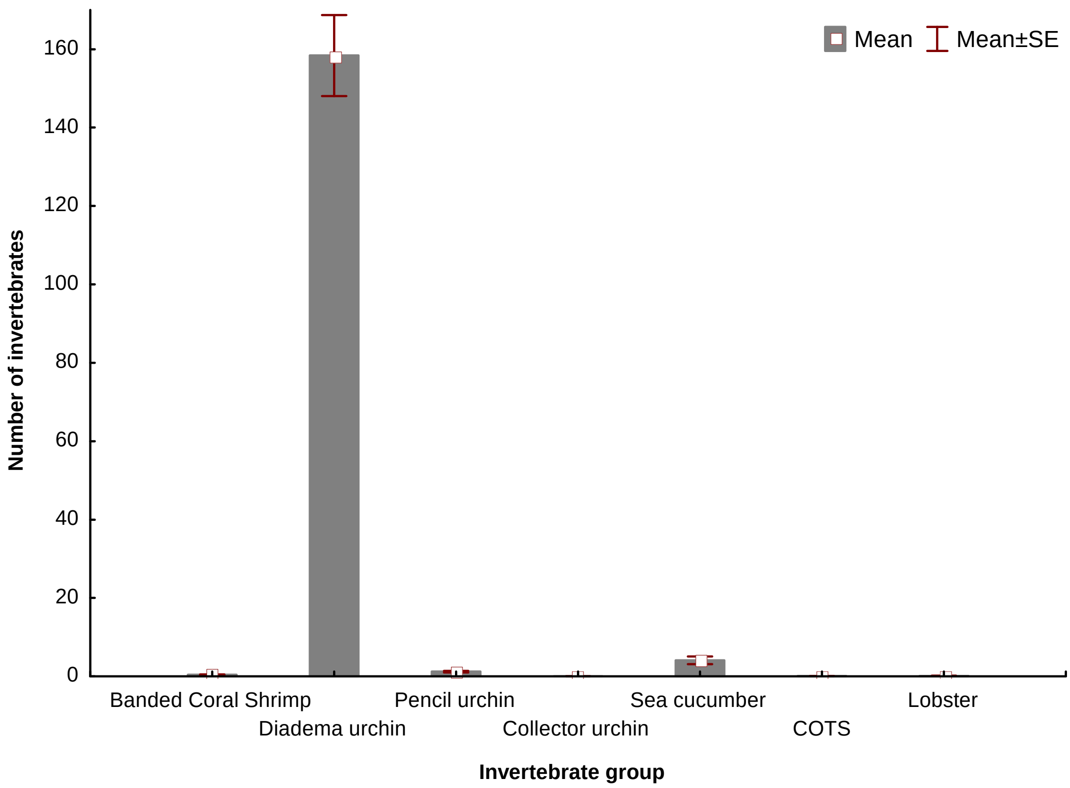


Figure 2.3i. Pooled average numbers of Reef Check indicator invertebrate categories seen in Musandam.

Invertebrate numbers were higher at shallow waters than in medium waters. Diadema urchins had higher numbers in shallow waters ($p<.001$) but, on the other hand, sea cucumbers were slightly in higher number in the medium dives ($p<.001$) (Figure 2.3j).

When comparing the different 18 dive sites surveyed, the number of Diadema urchins were significantly higher in Eagle Ray (D9) compared to Pipi Beach (D5) and Faqadar Bay (D19) ($p<.01$) (Figure 2.3k). Pencil urchins were significantly higher in Khayl Island (D13) than in Ra's Shuraytar (D3) and also Faqadar Bay (D19) ($p<.005$) (Figure 2.3l). Sea cucumbers were significantly higher in Gargoyles Cliffs (D42) compared to Coral Garden (D7), Eagle Ray (D9) and Death Valley (D27) ($p<.01$) (Figure 2.3m).

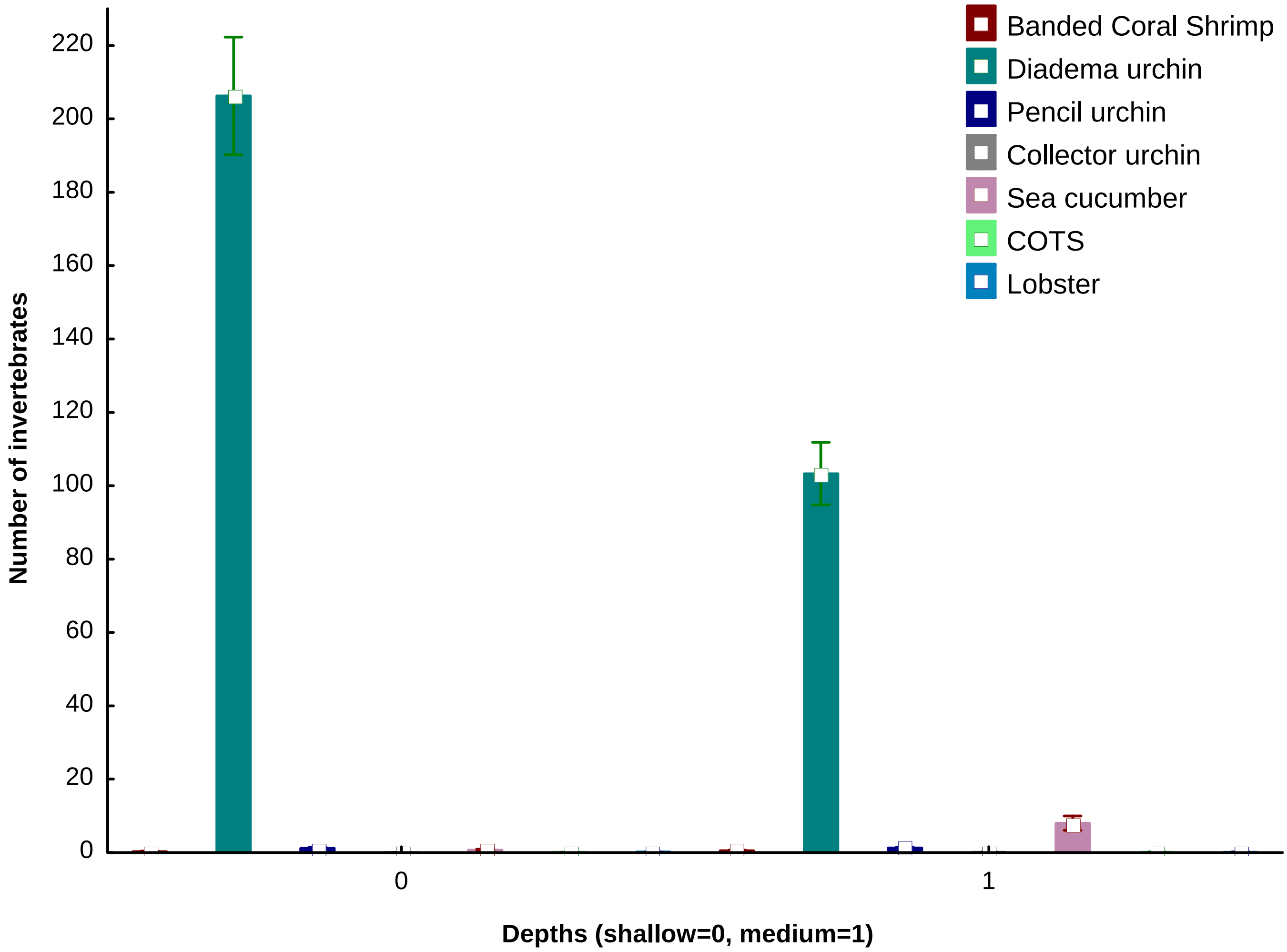


Figure 2.3j. Average numbers of invertebrate categories in shallow and medium waters.

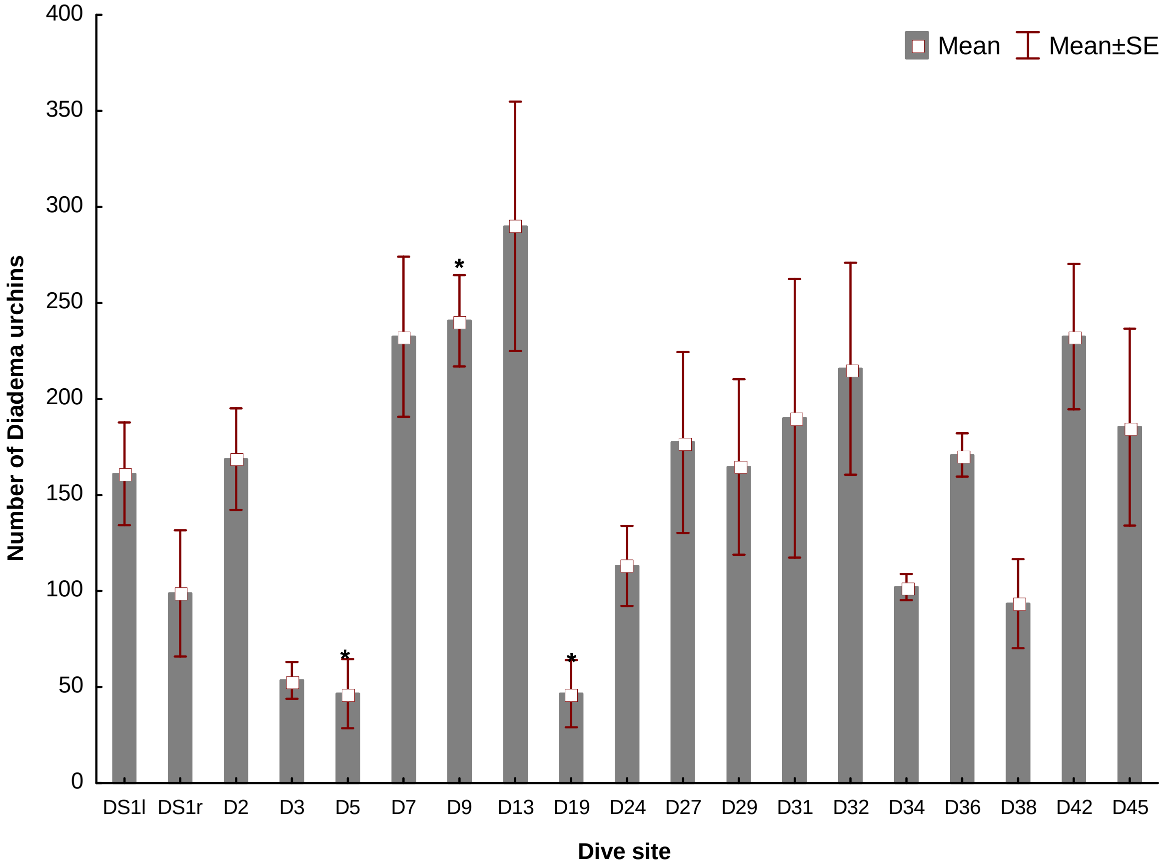


Figure 2.3k. Average numbers of diadema urchins in each of the sites surveyed.

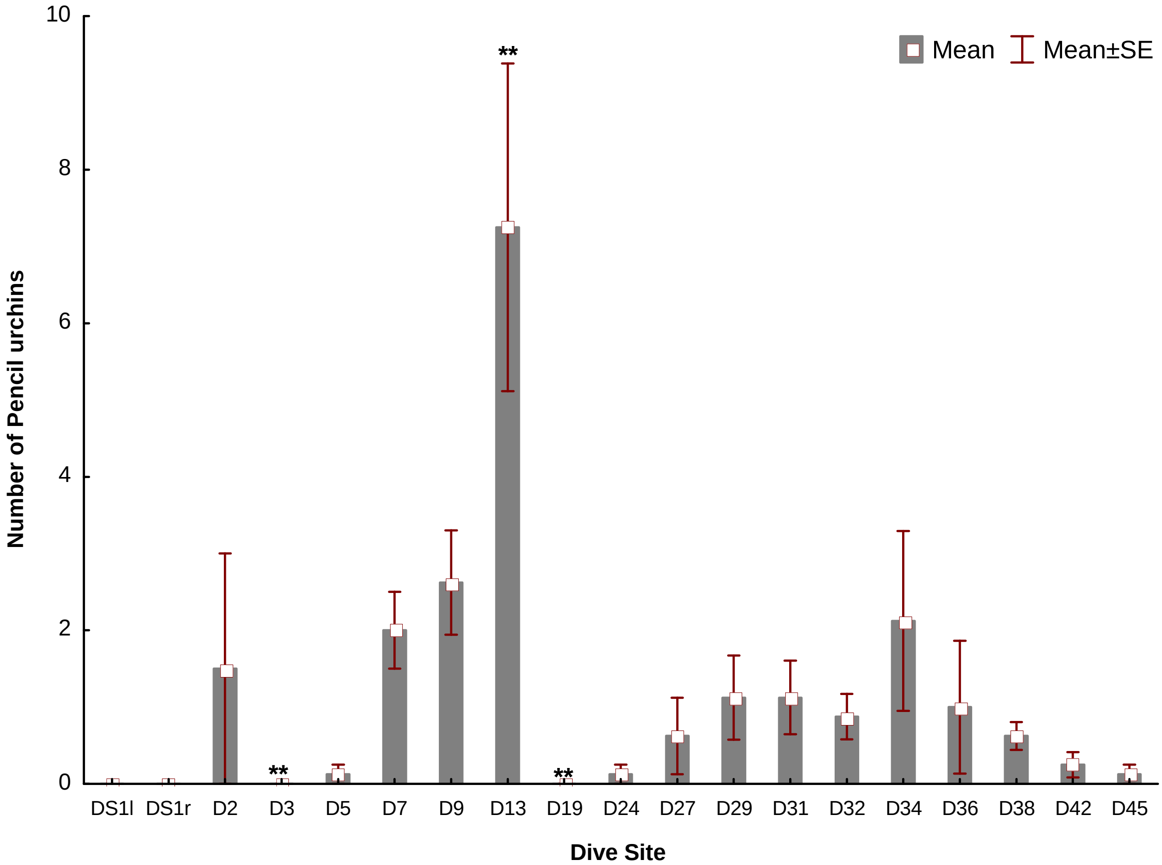


Figure 2.3l. Average numbers of pencil urchins in each of the sites surveyed.

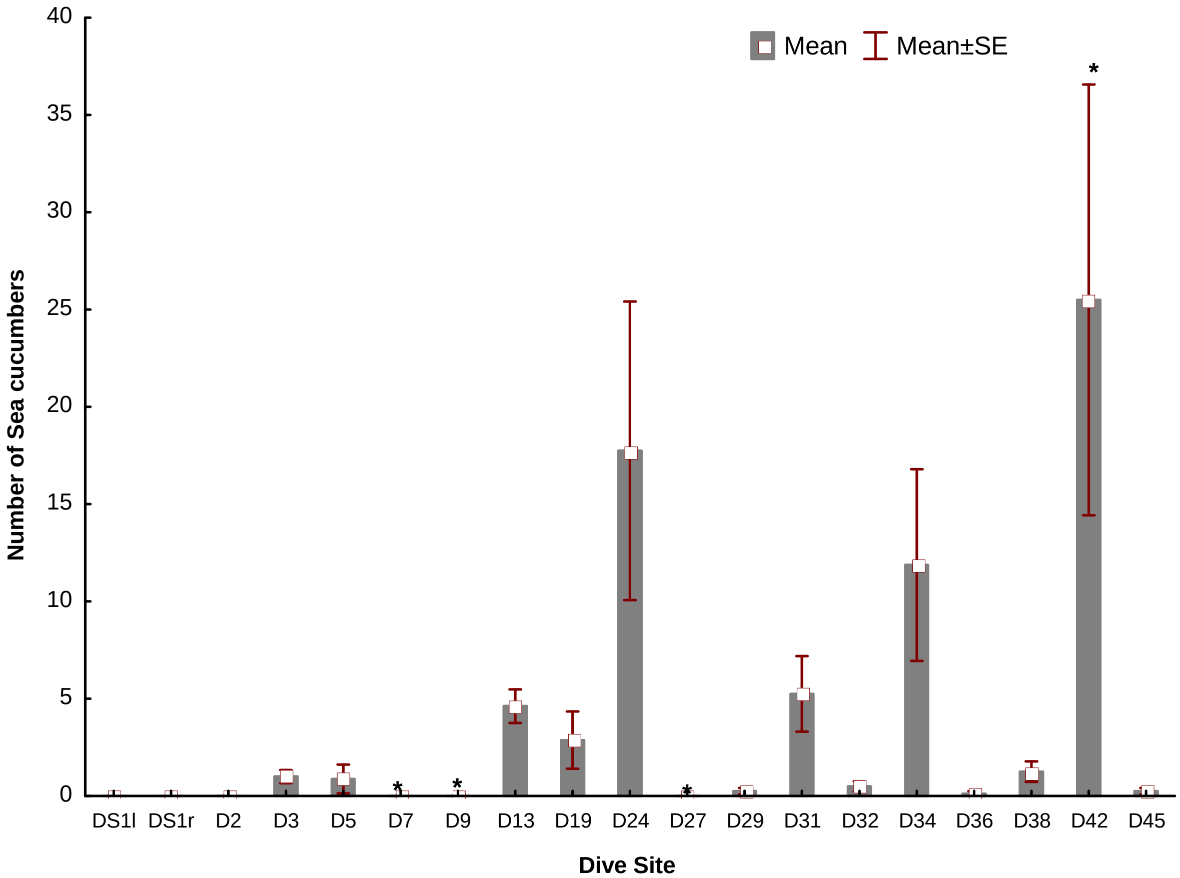


Figure 2.3m. Average numbers of sea cucumbers in each of the sites surveyed.

The number of diadema urchins and pencil urchins are significantly positively correlated. However, the number of diadema urchins is negatively correlated with the number of sea cucumbers (Table 2.3b).

Table 2.3b. Significant correlations according to Friedman analysis between invertebrate categories.

Categories	Correlated with	R^2	p value
Diadema urchin	Pencil urchin	0.22	p <.01
Diadema urchin	Sea cucumber	-0.20	p <.05

When correlating invertebrates with fish, there is a significant positive correlation between diadema urchins and butterflyfish, snapper (p<.001) and parrotfish (p<.005). Sea cucumbers, on the other hand, have a negative correlation with butterflyfish and parrotfish (p<.05). There is also a positive correlation of coral banded shrimps with moray eels (p<.005) and pencil urchins with groupers (p<.05) (Table 2.3c).

Table 2.3c. Significant correlations according to Friedman analysis between invertebrate and fish categories.

Categories	Correlated with	R^2	p value
Diadema urchin	Butterflyfish	0.37	p <.001
Diadema urchin	Snapper	0.31	p <.001
Diadema urchin	Parrotfish	0.24	p <.005
Coral banded shrimp	Moray eel	0.24	p <.005
Pencil urchin	Groupers	0.17	p <.05
Sea cucumber	Butterflyfish	-0.19	p <.05
Sea cucumber	Parrotfish	-0.20	p <.05

Substratum / benthic community

Regarding the 9 different substrate classifications done for each survey, a total of 1892 counts (34.3%) were done for hard coral (HC), 1452 (26.3%) for rock (RC), 1088 (19.7%) for sand (SD), 992 (18.0%) for rubble (RB), 29 (0.5%) for others (OT), 18 (0.3%) for recently killed coral (RKC), 17 (0.3%) for sponges (SP), 17 (0.3%) for silt (SI), 13 (0.2%) for soft coral (SC) and 0 for nutrient indicator algae (NIA) (Figure 2.3n). HC was significantly higher than RC, RB and SD (p<0.005), as well as the remaining categories (p<.001) (Figure 2.3o).

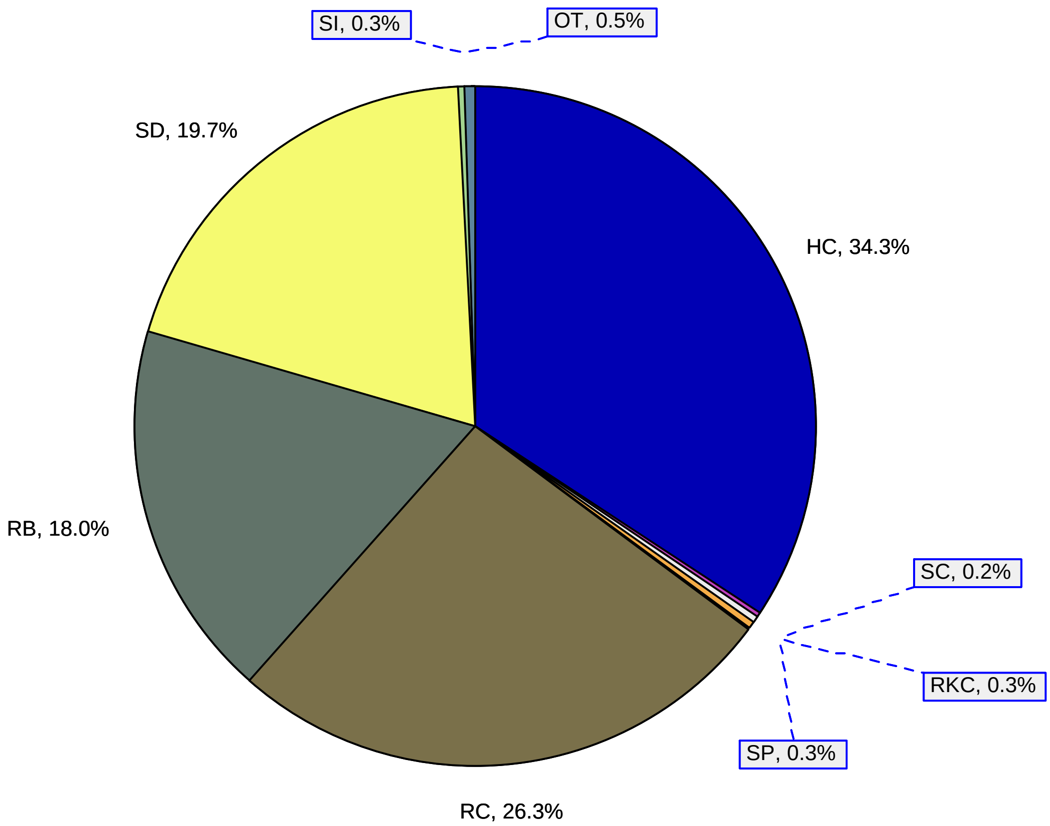


Figure 2.3n. Total percentage of substrate categories counted in Musandam.

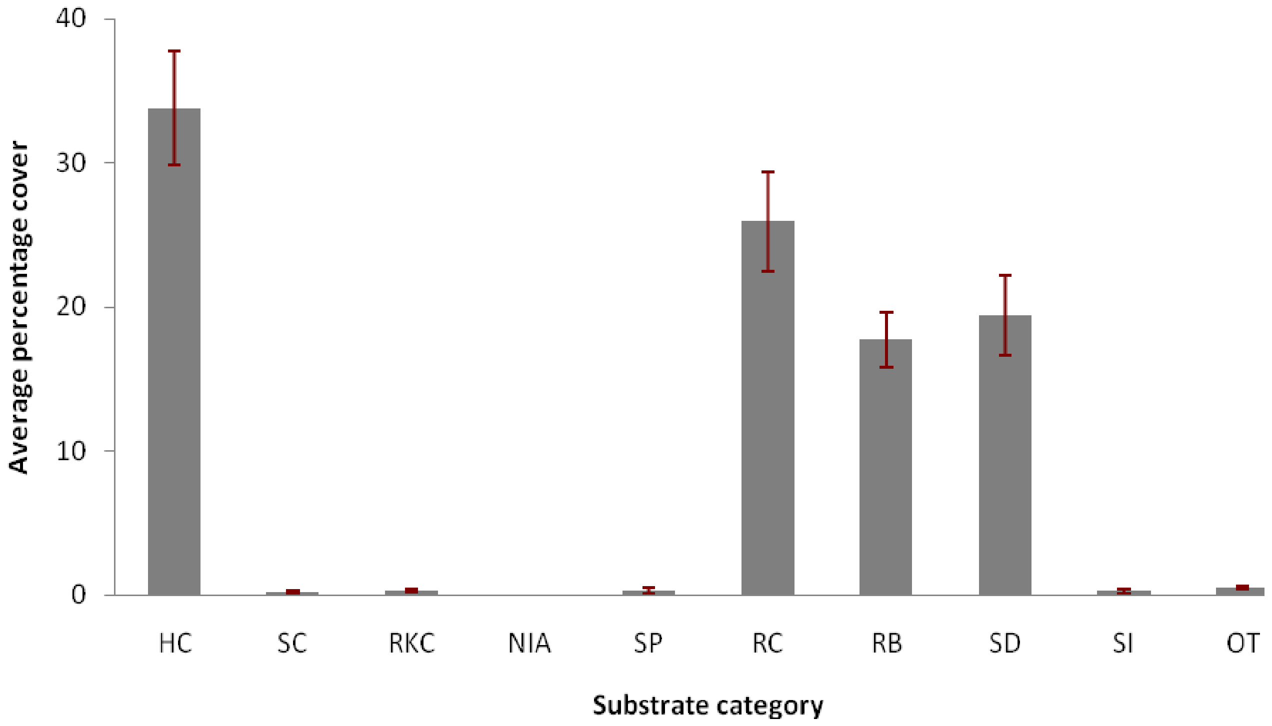


Figure 2.3o. Pooled average numbers of Reef Check substrate categories counted in Musandam.

The dive sites with higher cover of HC where mainly located in the extremities of the fjords on the north of Musandam (D7, D9, D13 and D19) and in the extremities of the fjords on the east side of Musandam (D32, D34, D36, D38 and D42) (Figure 2.3p).

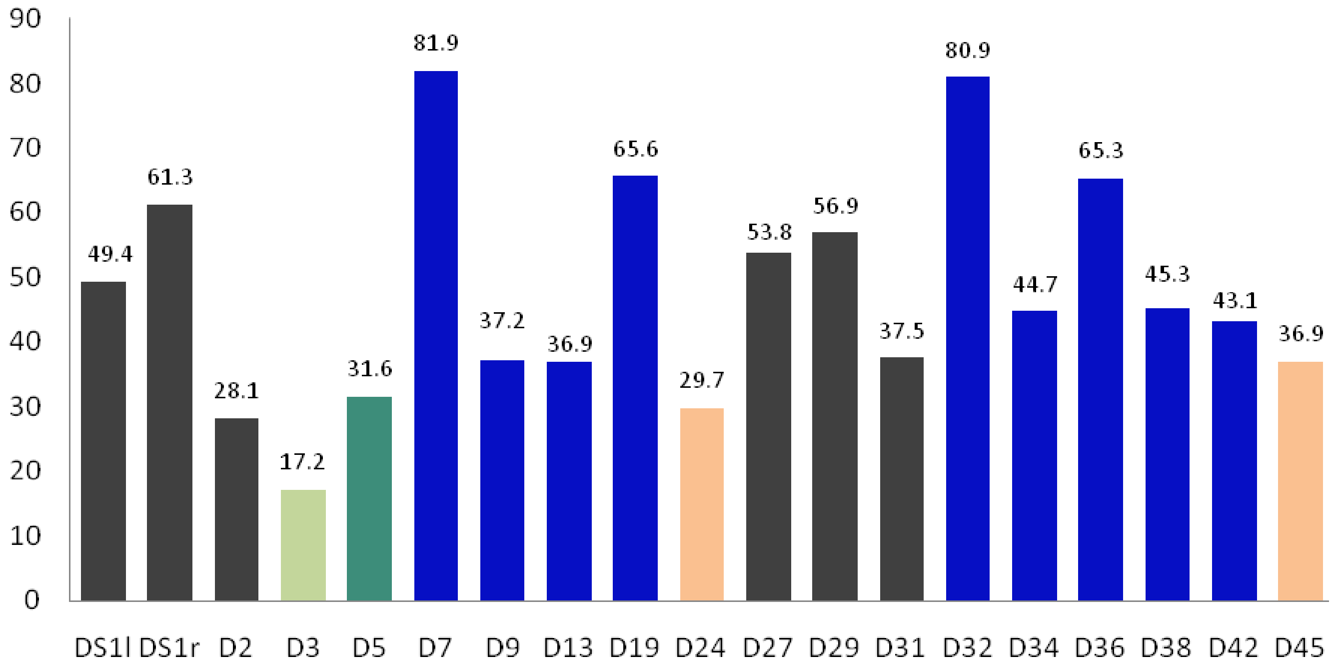


Figure 2.3p. Dominant substrate categories in percentages, per 20 m transects, in every dive site.
HC, RC, RB, SD, and HC/RB.

To assess correlations between substrate, fish and invertebrates, a Friedman analysis was conducted. Table 2.3d summarises the significant correlations that were distinguish by this analysis.

Table 2.3d. Significant correlations from Friedman analysis between substrate, invertebrates and fish categories.

Categories	Correlated with	R^2	P value
Hard coral	Groupers	0.35	p<.001
Hard coral	Pencil urchin	0.32	p<.001
Hard coral	COTS	0.28	p<.001
Hard coral	Diadema urchin	0.28	p<.001
Hard coral	Butterflyfish	0.22	p<.01
Soft coral	Rubble	0.24	p<.005
Soft coral	Diadema urchin	-0.22	p<.01
Sand	Butterflyfish	-0.49	p<.001
Sand	Sea cucumber	0.47	p<.001
Sand	Diadema urchin	-0.32	p<.001
Sand	Parrotfish	-0.30	p<.001
Sand	COTS	-0.25	p<.005
Rock	Parrotfish	0.40	p<.001
Rock	Butterflyfish	0.37	p<.001
Rock	Sea cucumber	-0.34	p<.001
Rock	Diadema urchin	0.28	p<.001
Rubble	Diadema urchin	-0.38	p<.001
Rubble	Butterflyfish	-0.35	p<.001
Rubble	Pencil urchin	-0.22	p<.01

Coral damage, site condition and coral disease

During the site description of the 18 dive sites surveyed, commercial fishing was the highest trend found in Musandam, with an average value between low and medium impact classification. A low impact of sewage pollution and artisanal / recreational fishing was also found, followed by tourist impact and invertebrate harvest for food at lower levels (Figure 2.3q).

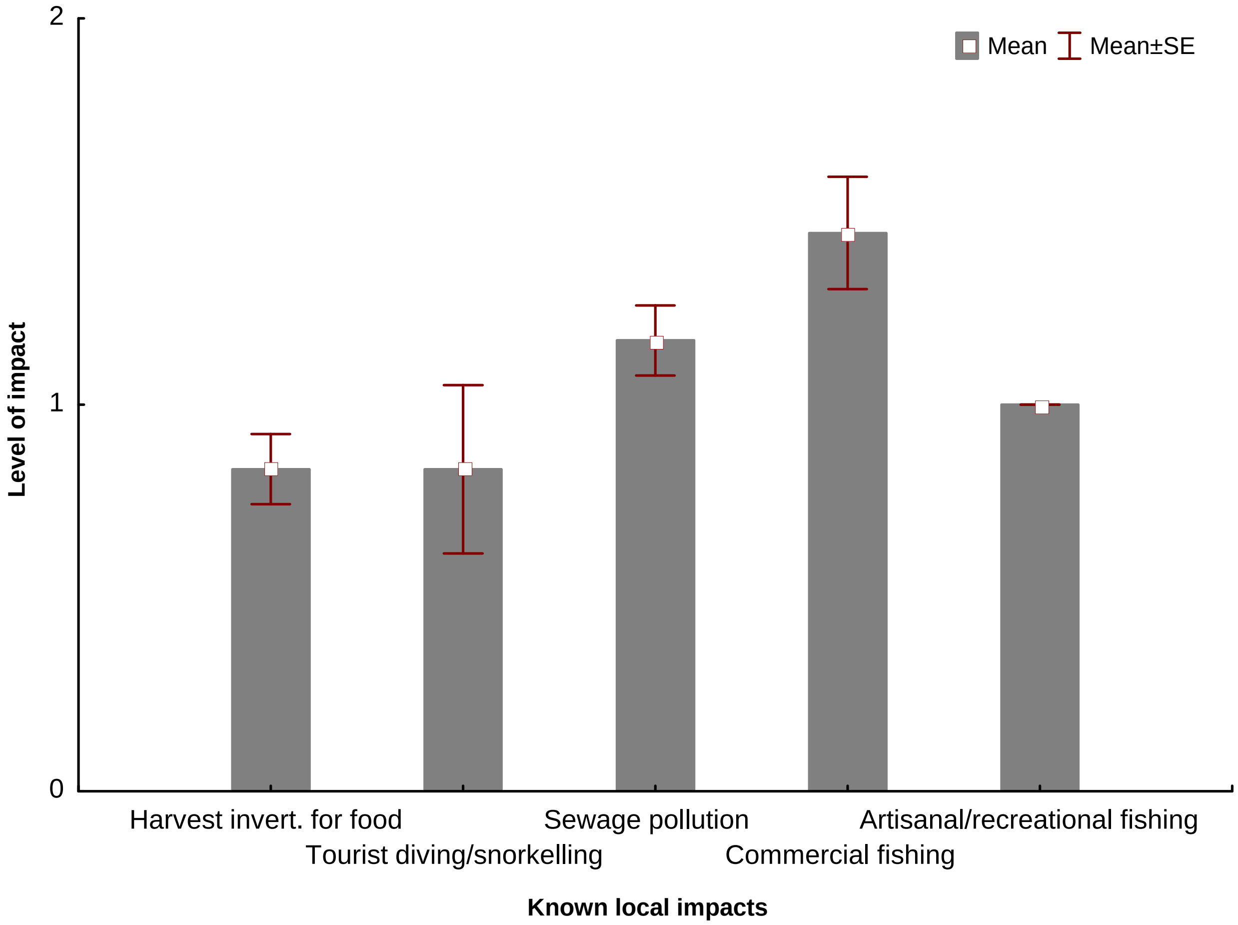


Figure 2.3q. Average level of impacts found in Musandam surveys during site description (0= none, 1= low, 2= medium and 3= high).

Regarding the impacts counted underwater during the surveys, when pooling all data, the main impact with an impact rank of one (low) was “others” due to the difficulty in sometimes classifying the origin of impact. With an average impact ranging between none and low follow trash nets, fish nets and boat/anchor damage. There was no significant difference between fish nets and general trash, but there is a significant differences between all the others ($p<.005$) (Figure 2.3r). There is also no significant difference between impacts when related to depth.

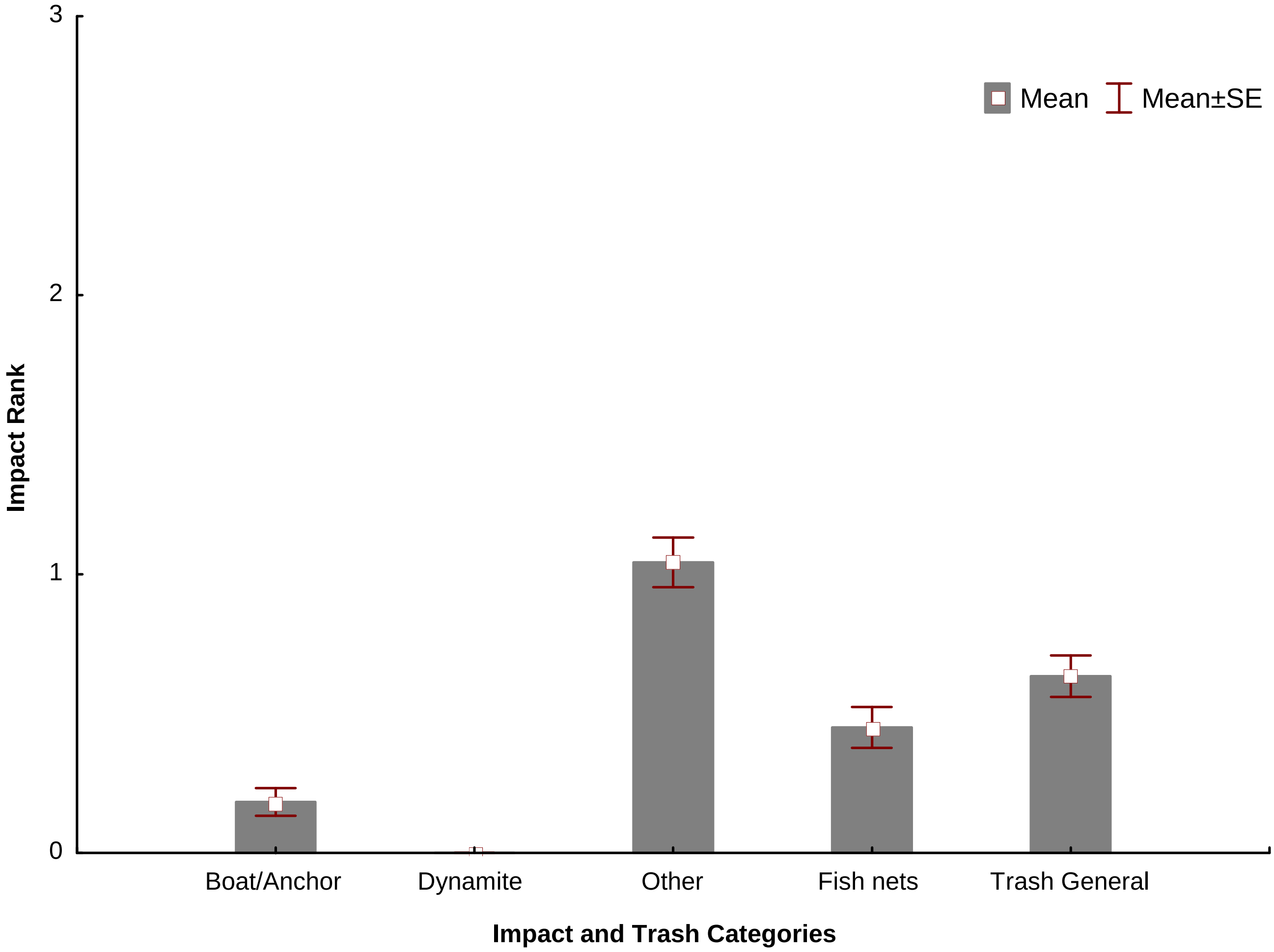


Figure 2.3r. Pooled average number of Reef Check impacts/trash categories seen in all transects for all sites in Musandam (0= none, 1= low, 2= medium and 3= high).

When pooling all the impacts together, Lobster's Demise on the left side (D1l) and Death Valley (D27) were the dive sites with the highest impact rank, reaching near high impact on average. Habalayan Island (D45) had the least average impacts when compared with these two ($p<.005$) (Figure 2.3s).

Coral bleaching, the paling of coral tissue due to the loss of the symbiotic algae zooxanthellae, was very low in the coral populations surveyed in Musandam, with only an average percentage of 0.39 per 20 metres (Figure 2.3t). Coral disease was also very low with an average percentage of 0.33 per 20 metres of substrate. Also, there was no significant difference observed between bleaching and disease among the two different depths and among different dive sites.

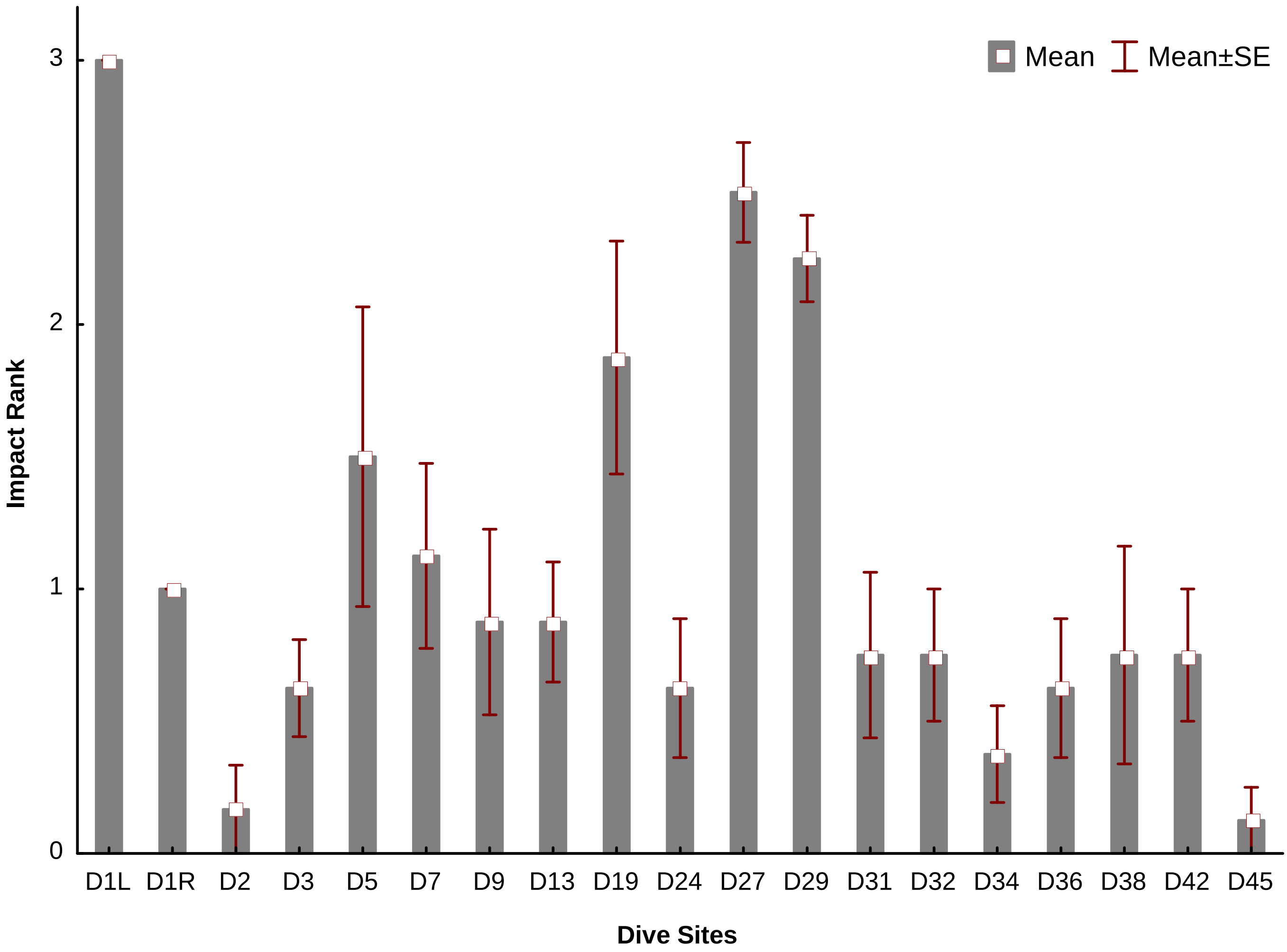
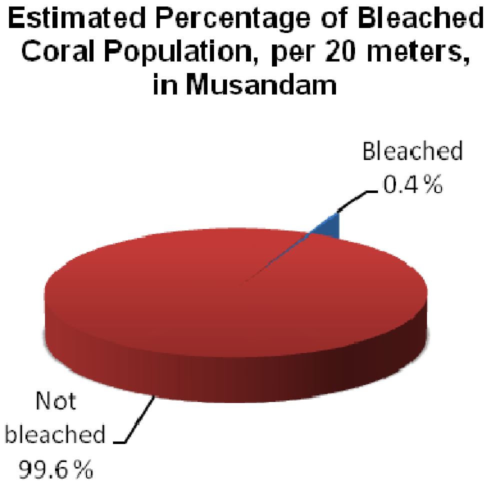


Figure 2.3s. Average of total impact ranks for each dive site surveyed in Musandam.



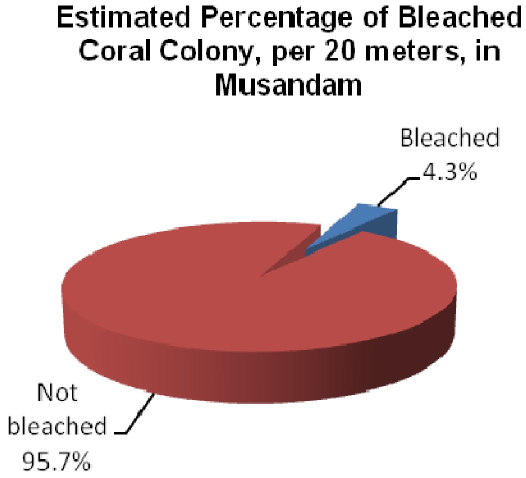


Figure 2.3t. Estimate percentages of bleached coral population (on left) and colony (on right), per 20 metres, in Musandam.

Correlation between fish, invertebrates, substrate and impacts

In order to assess correlation between all the different categories collected during the surveys, a Friedman analysis was performed. Table 2.3e summarises the significant correlations that were found by this analysis.

A positive correlation was noticed between diseases, bleaching and sponges ($p<.001$). A negative correlation was also observed between groupers and bleaching ($p<.05$) and other impacts ($p<.005$). A negative correlation was also found between fish nets and snappers ($p<.05$), but on the other hand fish nets are positively correlated with hard corals ($p<.005$).

Table 2.3e. Significant correlations from Friedman analysis between impacts, substrate, invertebrates and fish categories.

Categories	Correlated with	R^2	P value
Disease	Sponge	0.52	p<.001
Disease	Bleaching (pop)	0.42	p<.001
Disease	Snappers	0.24	p<.005
Disease	Collector urchin	0.24	p<.005
Bleaching (pop)	Sponge	0.39	p<.001
Bleaching (pop)	Hard coral	-0.22	p<.05
Bleaching (pop)	Groupers	-0.20	p<.05
Fish nets	Hard coral	0.25	p<.005
Fish nets	Snappers	-0.19	p<.05
Boat / anchor	Moray eel	-0.20	p<.05
Boat / anchor	Diadema urchin	-0.20	p<.05
Boat / anchor	Trash	0.18	p<.05
Boat / anchor	Fish nets	0.17	p<.05
Trash	Disease	-0.18	p<.05
Trash	Soft corals	-0.18	p<.05
Other impacts	Groupers	-0.26	p<.005
Other impacts	Trash	0.21	p<.05
Other impacts	Bleaching (pop)	0.21	p<.05

Additional external factors effecting 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 (Harrison 2008; Mooney 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 were noted. Corals on exposed shores were almost entirely destroyed and there was variable damage in sheltered bays, coves and islands. 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*, before the period of data collection (August 2008 to May 2009), in Musandam, 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 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 in 2008 and 2009. 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 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 algae species and therefore that ballast water discharge was involved at some point (Richlen et al. 2010).

Socio-economic survey

Interviewing the fishermen was the most challenging of all the surveys. Language difficulties, as well as cultural differences were always encountered. Not all questionnaires could be completed, because some interviewees found the questions too challenging or did not want to provide answers. In total 8 fishermen were interviewed as well as one divemaster from the only dive centre in Khasab.

Most of the fishermen interviewed have been fishing the coast of Musandam for 40 to 60 years. All fishermen use the “gargoor” technique to catch their fish, together with other techniques such as hadaq and manshalla (see Table 2.3d. for a description of these techniques). Spear fishing was also mentioned for lobsters. The main fish families caught by fishermen were Scombridae (tuna), Serranidae (summan and hamoor), Mullidae (Sultan Ibrahim) and Carcharhinidae (sharks). One of the fishermen also mentioned the fact that shark finning is also practiced in Musadam and the fins are sold to the UAE.

Table 2.3d. Most common traditional fishing techniques used in Musandam.

Fishing gear	Description
Gargoor	Baited basket traps, often dome-shaped with a cone-like entrance, the whole trap being made from interwoven palm fronds in the past and nowadays from steel wire.
Hadaq	Hook and line method particularly used for the capture of groupers (Serranidae), cobias (Rachycentridae), jacks/trevallies (Carangidae), grunts (Haemulidae), emperors (Lethrinidae), seabream (Sparidae), and Spanish mackerel (*Scomberomorus commerson*).
Manshalla	Longlines, which may have 10-20 smaller lines and hooks. These are reputed to be good for catching requiem sharks (Carcharhinidae), tuna (Scombridae) and groupers (*Epinephelus* spp.).

Most of the fishermen thought that their fish catch has been decreasing over the past years, except one fisherman who said the number and diversity has been the same for the past few years. The reasons the fishermen cited for the decrease were the increase in the number of fishermen in the area, the presence of bigger boats coming from the UAE and the recurrent harmful algal bloom. None of the fishermen had any ideas on how these issues could be resolved in the future or what changes there would need to be in order to reverse the decline of stocks.

Regarding the diving industry and the fact that more divers are visiting the Musandam peninsula, most of the fishermen were against this increase, most of them blaming divers for destroying their fishing nets and gargoors.

All fishermen were dependant on fishing for their family income, except for one single fisherman who had another source of income.

The divemaster from the only dive centre in Khasab, mentioned that a briefing with the costumers is always done before any dive, where safety, procedures, possible currents and environmental ethics are always referred. High season for diving in the Musandam peninsula is between October and May when the number of diver rises significantly.

2.4. Discussion & conclusions

In the past decades there have not been many studies on the Musandam peninsula coral biodiversity. The last published scientific study done exclusively in Musandam was conducted in 1971 and 1972 (Fraser et al. 1973). It is therefore difficult to know if the data collected by the current study show any increase or decline in coral biodiversity and impacts. Low abundance of certain fish and invertebrates do not immediately indicate the presence of a particular pressure, but it can indicate in which direction future expeditions and studies should be taken.

One of the main objectives of this expedition, besides elucidating the possible impacts on and the health of the Musandam coral reefs, was to understand the coral characteristics of the area. Due to the lack of prior studies for Musandam, some of the results are here compared with the 2002 Reef Check report, which pooled five years of studies, with 921 Reef Check surveys done in the Indo-Pacific (including Bahrain, Yemen and Iran) and calculated a representative average for the Indo-Pacific area (Hodgson & Liebeler 2002).

Fish and invertebrate community

Higher abundance of fish of the families Chaeodontidae (butterflyfish) and Lutjanidae (snappers), compared to Haemulidae (sweetlips) and Scaridae (parrotfish), in Musandam are in conformity with what is expected on Indo-Pacific reefs (Hodgson & Liebeler 2002). Although the Musandam is known for being frequently visited by fishermen from different areas, the average number of snappers (17.96 ± 37.11 per 100 m^2) in Musandam is substantially higher than the average for the Indo-Pacific (1.7 ± 5.2 per 100 m^2). Nevertheless, more data need to be collected in the future to understand if this number is decreasing, increasing or stable over the years.

The low abundance of groupers around the Musandam (1.05 ± 1.50 per 100 m^2) is mainly due to the high value of this family for fishermen in the region. Many species of groupers, such as *Epinephelus coioides*, are important commercially exploited species in the Arabian Gulf (Siddeek 1999; Grandcourt et al. 2005). The highest grouper size class observed was also the smallest class, 30-40 cm, when compared to the number of groupers with more than 40 cm counted. This is likely to be related to fishing pressure, which is not allowing this species to grow. Some sites with more groupers in the size class 30-40 cm also had more groupers with bigger sizes, 40-50 cm and 50-60 cm, most likely due to lower overall fishing pressure in these places, allowing this population to grow. This was clear in sites with low fishing pressure such as Khayl Island (D13), Khesa (D32), Cuttlefish Love (D36), Osprey Point (D38), Gargoyle Cliffs (D42) and Habalayan Island (D45). However, Pipi Beach (D5) showed higher pressure (tourism and fishing) than other sites, but also higher numbers of groupers of 30-40 cm and 40-50 cm. Since this was the only site where such a correlation was noticed, it is possible that the pressures were recent and in the future will affect grouper size and numbers. Nonetheless, the grouper size findings above give sufficient indication of a troubled system and the need for conservation and management measures, as well as more research. Many of the fish populations in the Arabian Gulf have been heavily exploited and concerns that fishing effort may already have exceeded optimum levels for most demersal species are now receiving some attention from local communities (Grandcourt et al. 2005). Fisheries that remove large individuals can easily eradicate all sexually mature fish and/or create a highly skewed sex ratio making reproduction improbable (Sadovy, 1997).

The presence of Crown-of-thorns starfish (COTS) (*Acanthaster planci*) in one dive site, during the data collection in Musandam, was not high enough to be of concern. However, COTS abundance needs to be monitored in future, firstly since coral mortality caused by COTS predators can be catastrophic or near-catastrophic in scale, and secondly because during the expedition no tritons (COTS predator) were found. Predator plagues of COTS are increasingly reported around areas of human activities with two strong hypotheses advanced: the plagues may be initiated and certainly exacerbated by either overfishing of key starfish predators; and/or increases in nutrient runoff from the land may favour the planktonic stages of the starfish (Goldberg & Wilkinson 2004).

The absence of lobster on the shallow reefs monitored by the expedition is a good indicator of human predation (Hodgson & Liebeler 2002). Although the number of lobsters found during the expedition (0.11 ± 0.32 lobster per 100 m^2) looks low when comparing to other areas around the world, as for example Australia and the Atlantic, the abundance calculated from expedition data is slightly higher than the Indo-Pacific average of 0.05 ± 0.26 lobster per 100 m^2 (Hodgson & Liebeler 2002). It is known that lobsters are caught in significant quantities on the south coast of Oman and Yemen by trammel net and lobster pots (Siddeek 1999), who has also shown that lobster landings in the region have been dropping steadily, from a peak of 4570 tons in 1991 to 2032 tons in 1996. More fisheries landings studies need to be conducted in the region to understand if this number is still decreasing.

Curio and aquarium trading appears not to be a main threat at the moment around the Musandam peninsula. The average number of pencil urchins (1.19 ± 2.57 per 100 m^2) is above the average for the Indo-Pacific (0.40 ± 3.1 per 100 m^2) indicating that there seems to be no pressure from the curio trading in the region. The average number of banded coral shrimps (0.39 ± 0.42 per 100 m^2) found by the expedition is also well above the Indo-Pacific average (0.09 ± 3.1 per 100 m^2). Surprisingly, the number of Diadema urchins (158.38 ± 124.48 per 100 m^2) is also significantly above the Indo-Pacific average (17.1 ± 58.3 per 100 m^2). Although Diadema urchins are responsible for grazing algae from the reef surface, maintaining the balance between algae and coral in a healthy reef system, a high density population of Diadema increases bioerosion activity, thereby making it difficult for new coral to settle. Urchins can also graze around the bases of large colonies, destabilizing coral heads and increasing their susceptibility to get knocked over by storm waves (Hodgson & Liebeler 2002).

Substrate and benthic community

Knowing that many of the world's best reefs have a hard coral coverage of 32% (Hodgson & Liebeler 2002), the 34% of hard coral coverage found by the expedition is encouraging. However, coral cover percentage may not be a very useful indicator of reef health unless permanent transects are resampled regularly (Hodgson & Liebeler 2002). The existence of more hard coral coverage in the extremities of the Musandam fjords is probably due to the presence of stronger currents, bringing new nutrients and preventing the corals from being covered by sediments. Rubble is the fourth most abundant substrate due to cyclone Gonu in June 2007. Gonu was the strongest tropical cyclone recorded in the Arabian Sea, damaging large areas of coral reefs, which are still recovering today (Wilkinson 2008; Fritz et al. 2010).

Since corals require clear, sediment-free water to ensure sufficient sunlight for photosynthesis by symbiotic algae, siltation is one of the most important parametres to measure. The low incidence of siltation found by the expedition shows that dredging in this area is not an issue at the moment. The low, but increasing, coastal development, and relatively confined populated areas along the coast of the Musandam is also shown in the coral reefs' health by low coverage of nutrient indicator algae and sponges. However, due to the fast coastal growth in the region, it is important to monitor closely the level of sediments, nutrient indicator algae and sponges in order to understand if dredging for future coastal developments is affecting the reefs, and if effluents and waste run-off treatment stations need to be installed in order to avoid nitrification and excessive algal growth along the reefs.

Impacts and coral damage

Blast fishing and destructive fishing is not used in the region. The biggest impact found by the expedition was commercial fishing, albeit at a low level of pressure. Artisanal and recreational fishing is also present, adding another negative influence to the number and sizes of groupers in the region. The fact that ghost fishing nets were found in higher number in places with higher hard coral coverage shows the impacts that fishermen are having on reef health. Since coral reefs serve has a major habitat for a diverse number of fish, this positive correlation is easily understood. At the same time, the recurrent use of the same fishing grounds by fishermen is noticed by the lower number of snappers and the higher number of ghost nets in these areas.

The Musandam peninsula is an area of low population and sewage pollution was only noticed in areas near villages or areas with hotels and resorts. Diving tourism is not a problem at the moment, but with current coastal development and increasing number of hotels and dive centres planned, this impact level is likely to change significantly. Physical damage from boat anchors is quite noticeable among the sites that were known dive spots, as well as in the areas that are frequented by fishermen. Diving activity is on the increase in Musandam, and in some popular dive sites the level of activity is extremely high. Unfortunately, mooring buoys have been only installed in one dive site, Telegraph Island, and even these two are not nearly enough for the number of boats that arrive during the weekends.

Underwater, most of the time it is hard to identify the source of the impacts, so the pressure found in higher numbers was classified as "others" when there was uncertainty about its origin. When pooling these data together with fish nets and boat/anchor damage, this impact usually ranges between low and medium. The two places with a high level of impact, Lobster's Demise (D1l) and Death Valley (D27), are located near populated areas and are also known as fishing grounds. One of the most important results regarding impacts is the significant negative correlation between the number of groupers and the number of impacts. This shows the sensitivity of this family and also the fishing pressure that they are subjected to.

Besides human impacts, the most powerful determinants of coral reef health are temperature and salinity. Surface seawater temperature (SST) higher than normal stress corals and cause coral bleaching, frequently with large scale mortality. In the 4th Intergovernmental Panel on Climate Change (IPCC) in 2006, it was stated that "*corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1–3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals*". When SSTs exceed the summer maximum by more than 1°C for four weeks or more under clear tropical skies, corals bleach. If warmer conditions persist for longer periods, corals can die in large numbers (Bernstein et al. 2007).

Sea surface temperature anomalies around reefs in the Indian Ocean region have increased through the 20th century by 0.50°C/century in the Middle East and Western Indian Ocean and by 0.59°C/century in the Central and Eastern Indian Ocean. Although most of the bleaching is associated with higher sea temperatures and coral death, an alternative hypothesis exist saying that corals, via their symbiont zooxanthellae, may evolve rapidly by acquiring more thermally tolerant symbionts within a few decades. This would make corals more thermally tolerant and keep pace with rapid climate change. But this would require an adaptation at a rate of at least 0.2–0.4°C per decade and there is no evidence that corals can change their symbiotic relationships or develop temperature tolerance so quickly.

It would be interesting to study this hypothesis in the region, since the local coral communities are already used to high temperatures in the summer and low levels of bleaching were found by the expedition. There might be a resistance of local coral communities in Musandam to wide temperature variation since corals with higher SST temperature variation exist in the region, as for example the Arabian Gulf and Eritrean corals where local salinity regularly exceeds 45, and SSTs can fluctuate annually from winter lows less than 12°C to summer highs above 36°C , or even water temperatures that can reach 37.5°C in summer at 10 m depth (Burt et al. 2008; Wilkinson 2008).

Coral disease can be described as the disability of the coral vital functions or systems, and it can affect the individual organism as well as the community where it lives. The corals become more susceptible to diseases from natural and anthropogenic physical and chemical alterations in the environment. In the Arabian Gulf, several coral diseases occur that can be a factor of coral mortality: black band disease (BBD) is a common disease on branching corals during summer, but tends to disappear in winter. Infection rates of 25% in some areas on *Acropora* species have been reported in the region. White band disease (WBD) is usually rare and not infectious, even in physical contact situations and appears to infect all species. Yellow band disease (YBD) is the most widespread and contagious disease both in summer and winter and has a fast within-colony spread (Al-Cibahy et al. 2008). YBD is not species-specific and was found on two sites in the Gulf of Oman by Rezai et al. (2004). Low coral disease coverage was found in Musandam by the expedition, but further monitoring should be done of the high temperature, salinity and contact with alien species.

Socio-economic

Most of the villages located on the Musandam peninsula are only inhabited for some months of the year, normally during the fishing season from October to May. During the period of the expedition, the number of fishermen was low and only a few were interviewed. A lack of knowledge about sustainable fishing practices and threats to fisheries among fishermen was obvious. However, the interview with the dive guide of the only dive centre located in Khasab showed that concern and awareness are beginning to form.

2.5. Recommendations & future expedition work

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.

The lack of awareness and knowledge observed among local communities shows the importance of involving locals in future studies. Some sites surveyed during the expedition yielded high numbers of indicator species, despite the pressures. 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. Special attention is is drawn to Pipi Beach (D5) and Grouper's Escape (D34), where high species diversity was observed.

Studies on Musandam ports fisheries landings would help our understanding of the demands on this ecosystem, as well as its biodiversity and population levels. More information about the catch of shells (such as *Charonia* spp.) is also needed, since this can lead to an outbreak of COTS in the region.

Although reefs in wealthier nations are subjected to more intense exploitation and damage, reefs in developing countries generally receive much less and more trivial attention (Hodgson & Liebeler 2002). It is therefore important not to neglect the Musandam and ensure that its marine environment is preserved. Involving local people in the surveys and explaining results, such as the relationship between high coral coverage and high species diversity, might be enough for the empiric understanding of a healthy ecosystem. In order to understand the full impact of fishing in this region, the impacts of selective mortality on specific size classes, colour phases or morphs, and social structure in target population, such as groupers, should be studied (Sadovy & Vincent 2002). Actual concern needs to be created around the two sites with the highest impacts: Lobster's Demise (D1) and Death Valley (D27) and more studies need to be conducted regarding groupers, a species known to be in high demand due to its value.

By understanding the existing threats to the coral reefs of the Musandam peninsula it is possible to improve the local biological resilience, by helping coral reefs to improve their 'immune system', increasing their ability to absorb or resist impacts of stress and increasing their ability to recover. But it is also essential to improve the social resilience by helping local communities to adapt to changes in their location by new policies and regulations. More strategies and approaches, done by management activities and planning for change are needed to minimise impacts and build resilience. To achieve this resilience, focus should be placed on land-based sources of pollution, overfishing and climate change.

A number of Marine Nature Reserves were declared in the nineties by the Ministry of Environment and Municipality to protect vulnerable marine habitats in Oman (Siddeek 1999). These were Ras' Al-Had Nature Reserve for the protection of green turtle nesting grounds, Damaniyat Island Nature Reserve for the protection of green and hawksbill turtle nesting grounds, coral reefs, birds, and fish, Dhofar Khowrs Nature Reserve (fresh as well as brackish water lagoons) for the protection of sea birds and fish.

Oman already has an impressive history of creating terrestrial and marine reserves. It is also a declared government policy to have more reserves in each governorate. **We therefore recommend the implementation of a new marine protected area (MPA) on the Musandam or a network of MPAs for the protection of this unique marine environment.** The Musandam is an ideal place for an MPA as impacts and population levels are still relatively low. In addition there is a strong military presence in the area already, due to its proximity to the Straight of Hormuz. Military exclusion zones could form part of a MPA and policing of protected areas could be done by the military with relatively little additional training.

The implementation of an MPA would reduce impacts on the marine environment and help to (a) conserve biological diversity and associated ecosystems that cannot survive intensively managed seascapes; (b) promote natural age structures in populations, increasing fish catches locally (by protecting critical spawning and nursery habitats) and in surrounding fishing grounds; (c) provide refuge for species that cannot survive in areas that continue to be fished; (d) provide alternative incomes for local communities and alleviate poverty; (e) protect sensitive habitats from disturbances and damage from fishing gear; (f) reduce “ghost fishing” by lost or discarded gear; (g) serve as point of reference of undisturbed control reference sites that can be used as baselines for scientific research and also to measure fishery effects in other areas and thereby help to improve fisheries management; and (h) act as focal points for public education and awareness on marine ecosystems and human impacts upon them (IUCN-WCPA 2008).

The Musandam peninsula could be established as a Biosphere Reserve under UNESCO’s Man and the Biosphere (MAB) Programme. Biosphere Reserves are areas of terrestrial, coastal and marine ecosystems established to promote and demonstrate harmonious and sustainable interactions between biodiversity conservation and socio-economic well-being of people, through research, education, monitoring, capacity-building and participatory management. By being protected under this classification, UNESCO can provide advice and occasionally source funds to start local efforts; it can also help broker projects or set up durable financial mechanisms. **Eventually this could also lead to the Musandam peninsula being declared a UNESCO World Heritage Site,** which is something that should be considered at government level.

Knowing that implementing an MPA and/or a UNESCO Biosphere Reserve can take several years to accomplish, it is necessary to take additional action until an MPA and/or a UNESCO Biosphere Reserve is in place.

Deployment and maintenance of standard mooring buoys in all known dive sites would help to decrease the impacts of anchor and boat damage.

Musandam is a well known place for divers. At the moment the numbers of divers are not a serious problem due to the lack of support platforms, as well as dive centers. **With future plans for the implementation of more dive centres in the region it is necessary to create, implement and police regulations for the diving industry, such as (1) regulating the number of boats and divers allowed per dive site, (2) not permitting anchoring and (3) placement and maintenance of anchoring buoys in all dive sites.**

2.7. References

Al-Cibahy, A., Al-Harthi, S., Al-Moati, A., Al-Mansoori, A., Foster, K.A., Launay, F., Al-Mubarak, R., Purkis, S., Riegl, B. & Tourenq, C. (2008) Conservation and Management Plan of Abu Dhabi and Eastern Qatar Coral Reefs (Qatar & Abu Dhabi: Supreme Council for the Environment and Natural Reserves (SCENR) of the State of Qatar, Environment Agency of Abu Dhabi Emirate (EAD), National Coral Reef Institute (NCRI), Emirates Wildlife Society in association with the World Wide Fund for Natures (EWS-WWF)

Anderson, D.M. (1997) Turning back the harmful red tide. Nature 388, 513-514.

Baker, A.C., Starger, C.J., R.McClanahan, T. & Glynn, P.W. (2004) Corals' adaptive response to climate change. Nature 430, 741.

Bernstein, L., Bosch, P., Canziani, O. et al. (2007) Climate Change 2007: Synthesis Report (pp. 73. Valencia, Spain: Intergovernmental Panel on Climate Change.

Buddemeier, R.W., Baker, A.C., Fautin, D.G. & Jacobs, J.R. (2004) The Adaptive Hypothesis of Bleaching. Paper presented at: Coral Health and to Disease Meeting, Israel.

Burt, J., Bartholomew, A. & Usseglio, P. (2008) Recovery of corals a decade after a bleaching event in Dubai, United Arab Emirates Marine Biology 154, 27-36.

Carpenter, K.E., Krupp, F., Jones, D.A. & Zajonz, U. (1997) The living marine resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates. In: FAO species identification guide for fishery purposes (pp. 293. Rome: FAO.

Coles, S.L. (2003) Coral species diversity and environmental factors in the Arabian Gulf and the Gulf of Oman: a comparison to the Indo-Pacific region. Atoll Research Bulletin 507, 1-19.

EWS-WWF (2008) Final report January 2005 - December 2007 In: Coral Reef Investigations in Abu Dhabi and Eastern Qatar (pp. 74. Dubai.

Fraser, F.C., Falcon, N.L., Falcon, M., Cornelius, P.F.S., Hugh-Jones, P., Bertram, G.C.L., Shearman, D.J., Glennie, K.W., Glennie, M., Shotton, F.W., Vita-Finzi, C., Roberts, D.G. & Robinson, G.P.G. (1973) The Musandam Expedition 1971-72 Scientific Results: Part I: Discussion. The Geographical Journal 139, 422-425.

Fritz, H.M., Blount, C.D., Albusaidi, F.B. & Al-Harthy, A.H.M. (2010) Cyclone Gonu storm surge in Oman. Estuarine, Coastal and Shelf Science 86, 102-106.

Goldberg, J. & Wilkinson, C. (2004) Global Threats to Coral Reefs: Coral bleaching, global climate change, disease, predator plagues, and invasive species In: Status of Coral Reefs of the World: 2004 (ed. C. Wilkinson), pp. 67-92.

Grandcourt, E.M., Abdessalaam, T.Z.A., Francis, F. & Shamsi, A.T.A. (2005) Population biology and assessment of the orange-spotted grouper, Epinephelus coioides (Hamilton, 1822), in the Southern Arabian Gulf. Fisheries Research 74, 55-68.

Grimsditch, G.D. & Salm, R.V. (2006) Coral Reef Resilience and Resistance to Bleaching (pp. 52. Gland, Switzerland: IUCN.

Harrison, P. (2008) UNEP Year Book 2008: An Overview of Our Changing Environment, UNEP Division of Early Warning and Assessment (DEWA)

Hinchley, D., Lipsett-Moore, G., Sheppard, S., Sengebau, F.U., Verheij, E. & Austin, S. (2007) Biodiversity Planning for Palau's Protected Areas Network: An Ecoregional Assessment. In: TNC Pacific Island Countries. Report No 1/07 (South Brisbane, Australia: The Nature Conservancy, Indo-Pacific Resource Centre.

Hodgson, G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., Shuman, C. & Torres, R. (2006) Reef Check Instruction Manual: A guide to REef Check Coral Reef Monitoring (pp. 86. California, USA: Reef Check Foundation.

Hodgson, G. & Liebeler, J. (2002) The Global Coral Reef Crisis: Trends and Solutions (pp. 78. Reef Check.

IUCN-WCPA (2008) Establishing Marine Protected Areas Networks - Making it Happen. IUCN-WCPA, National Oceanic and Atmospheric Administration and The Nature Conservancy, Washington, D.C.

Marshall, P. & Schuttenberg, H. (2006) A Reef Manager's Guide to Coral Bleaching (pp. 166. Townsville, Australia: Great Barrier Reef Marine Park Authority.

McClanahan, T.R., Sheppard, C.R. & Obura, D.O. (2000) Coral reefs of the Indian Ocean: theirs ecology and conservation, NY, Oxford University Press.

Mooney, C. (2008) Storm World: Hurricanes, Politics, and the Battler Over Global Warming, Houghton Mifflin Harcourt.

Pilcher, N.J., Wilson, S., Alhazeem, S.H. & Shokri, M.R. (2000) Status of coral reefs in the Arabian/Persian Gulf and Arabian Sea region (Middle East). In: Status of Coral Reefs of the World: 2000 (pp. 55-64. Australian Institute of Marine Science.

Pous, S.P., Carton, X. & Lazure, P. (2004) Hydrology and circulation in the Strait of Hormuz and the Gulf of Oman-Results from the GOGP99 Experiment: 2. Gulf of Oman. J. Geophys. Res. 109.

Randall, J.E. (1995) Coastal Fishes of Oman, Honolulu, University of Hawaii Press.

Rezai, H., Wilson, S., Claereboudt, M. & Riegl, B. (2004) Coral reef status in the ROPME sea area: Aranian/persian gulf, gulf of Oman and Arabian. In: Status of Coral Reef of the World 2004 (ed. C. Wilkinson), pp. 155-170.

Richlen, M.L., Morton, S.L., Jamali, E.A., Rajan, A. & Anderson, D.M. (2010) The catastrophic 2008-2009 red tide in the Arabian gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate Cochlodinium polykrikoides. Harmful Algae 9, 163-172.

Riegl, B. (1999) Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality. Coral Reefs 18, 63-73.

Riegl, B.M., Purkis, S.J., Kohler, K.E. & Dodge, R.E. (2006) Spatial patterns in Arabian Gulf coral assemblages (Jebel Ali, Dubai, U.A.E.) in response to temperature-forcing. Paper presented at: 10th International Coral Reef Symposium, Okinawa, Japan.

Sadovy, Y.J. & Vincent, A.C.J. (2002) Ecological Issues and the Trades in Live Reef Fishes. In: Coral Reef Fishes. Dynamics and diversity in a complex ecosystem (ed. P. F. Sale), pp. 391-420. San Diego: Elsevier Press.

Sheppard, C., Price, A. & Roberts, C. (1992) Marine Ecology of the Arabian Region. Patterns and Processes in Extreme Tropical Environments., London, Academic Press.

Siddeek, M.S.M. (1999) Marine fisheries resources, fisheries and marine environmental management, coral reefs and marine parks in the Northwest Indian Ocean In: Regional Workshop on Fisheries Monitoring, Control and Surveillance (pp. 101-115. Muscat.

SOMER (2003) State of the Marine Environment Report (pp. 217. Kuwait: Regional Organization for the Protection of the Marine Environment.

Spalding, M., Ravilious, C. & Green, E.P. (2001) World Atlas of Coral Reefs, University of California Press.

Subba-Rao, D.V. & Al-Yamani, F. (1998) Phytoplankton ecology in the waters between Shatt Al-Arab and Straits of Hormuz, Arabian Gulf: A review. Plakton Biology and Ecology 45, 101-116.
Wilkinson, C. (2004) Status of Coral Reef of the World 2004

Wilkinson, C.R. (2008) Status of coral reefs of the world : 2008, Townsville, Australia, Global Coral Reef Monitoring Network, Reef and Rainforest Research Centre.

Wilson, S., Fatemi, S.M.R., Shokri, M.R. & Claereboudt, M. (2002) Status of Coral Reefs of the Persian/Arabian Gulf and Arabian Sea region. In: Status of Coral Reefs of the World: 2002 (ed. C. Wilkinson), pp. 53-62. Australian Institute of Marine Sciences.

3. Expedition leaders' diary: Musandam 2009 by Matthias Hammer

4 October

Hello everyone and welcome to the first diary entry for Biosphere Expeditions' first ever Musandam expedition. I am Matthias Hammer, founder and Managing Director of Biosphere Expeditions, and I will also be your expedition leader for this project. Working with me will be the lovely Rita Bento from the Emirates Diving Association, a qualified Reef Check instructor and PADI AI. There will also be a divemaster from Khasab as well as the crew and cook of the MS Sindbad, our live-aboard dhow.

It's quite some time since I've led an expedition myself and I am very much looking forward to the experience and touching base again with what Biosphere Expeditions is all about.

At the moment I am still in Europe, preparing paperwork and equipment, but soon I will be flying to Dubai for more preparation work and some extreme shopping for the expedition (what better place to do this in than Dubai!). One of my paperwork jobs was to set the itinerary (attached). As you can see, it's a packed schedule, especially on the first three days with lots of training and some tests before we let you lose on the reef, collecting data and experiencing conservation in action. No doubt you'll need a holiday after the expedition ;), but please try to come rested and fresh in your minds, ready for the challenges ahead. Please also remember that we are all trailblazers and that this is the first Musandam diving expedition ever. The itinerary may look well-organised, but things are bound to change for a multitude of reasons, so please come with an open mind and lots of "Insha'Allah" attitude.

"Insha'Allah", by the way, is a phrase you are about to become very familiar with… It translates roughly as... 'If Allah wills it' and is a marvelously useful term of complete fatalism and one which has no direct English equivalent. The nearest thing would probably be '...but on the other hand I might get hit by a number 73 bus tomorrow' - uttered in tones of sodden dejection by a clinical depressive with a strong Solihull accent :))

But I digress. You won't be hearing from me for a while now and I'll probably be back in touch the week after next from Dubai with news of all the pairs of shoes I have bought for myself next to some expedition essentials such as aftersun lotion, duck tape, vinegar, a stapler and the all-important LAMINATOR! You'll see what I mean when you get to the dhow.

Make sure your PADI medical statements are in order (otherwise you ain't getting in the water!), that your dive gear is working and that your buoyancy skills are up to scratch.

Finally, my mobile phone number during the expedition will be +968 92380988. Remember that this is for emergency purposes only (such as being late for assembly, for example).

I'll see you all at the Ibis in Dubai in due course, Insha'Allah.

Best wishes

Matthias

P.S. This diary is now also on www.biosphere-expeditions.org/diaries, so you can pass this on to your families & friends for updates on what we are up to.

15 October

Too easy! I found most of the stuff we still needed in one big mall in Dubai. Only the GPS, some lead weights and THE LAMINATING SHEETS required a special trip.

The word from the peninsula is that MS Sindbad, our trusty live-aboard was seen afloat a couple of days ago, so that's also a good sign and I am hoping she is waiting for me in Khasab harbour as I write this sitting in a lobby in Dubai waiting to be picked up.

We're all packed, ready to go. The lovely Rita is sitting next to me, also ready to dazzle you all with coral disease, fish & invertebrate ID, substrate composition and other such exciting stuff.

Dubai is as ever mad, hot, dusty, sunny. It'll be great to get out of here and my next instalment should be from MS Sindbad with the wind in my bld head and the sun in my eyes ;)

See you all soon.

16 October

As promised, here's an entry from the Sindbad, all afloat and well in the middle of nowhere. We're pretty much ready for you, the sun is shining, it's hot and the visibility isn't too bad. The corals are still here, as are the skipper Ali, his deck hand Mohammed, our cook Polly and his helper Chandu, all from last year's reconnaissance trip.

We're back in Khasab tomorrow and then off to Dubai at some ungodly hour in the morning to meet trailblazing slot 1 in the Ibis at 09.00.

See you there soon.

19 October

Slot 1 has arrived safely. Within a few hours we had left the madness of Dubai behind and made our way to the mountains and the port of Khasab. As I write this our belies are full with another great dinner by our cook Polly and our heads are full with indicator fish, invertebrates, substrate, transecting lines and other such sciency stuff. Rita has taught as well and we're about to go into our Reef Check exam. Wish us luck!

Our classroom is surrounded by mountains, sits on a glassy sea and has the world's biggest swimming pool all around us. Oh, and diving is fun too. 31 C today!

More later…

22 October

We now have a fully trained Reef Check team and we are managing to get three survey dives in per day. Rita tells us that we are the best Reef Check team she's ever taught and we desperately want to believe her ☺.

Highlights of our diving so far include some interesting currents, a beautiful coral garden with 81% hard coral cover, a few eagle rays, a turtle, as well as two big lobsters, one of whom mysteriously disappeared, so we named that site "Lobster's Demise".

The weather is brilliant, the coastline stunning, the food great & the pace brisk. Hard life of a marine biologist ;).

24 October

Slot 1's passed in a flash. We managed to get 20 sets of Reef Check data, which is a brilliant result for a week including training. We've surveyed and named many new sites. Highlights included "Coral Garden" and "Snapper's Tragedy", where a snapper we freed from a hook in its mouth, was promptly eaten by a moray eel within seconds after we let it go. Some of the sites were spectacular above and below water. High mountains and sheer rock walls plunging into the water with coral gardens and fish galore below. But we also surveyed sites such as "Death Valley", where a combination of storm damage and last year's red tide algal bloom have turned the reef into a wasteland of death and destruction with very few living corals and fish.

Highlights included a shark, a huge ray, several turtles, a barracuda, 81% hard coral cover, and of course Polly's cooking.

As I write this, I am sitting in an internet café near Khasab port. Parts of the team have gone for a quick tour of Khasab and its souk and fort, others have stayed on the dhow for some snorkelling. Soon we'll be heading back to Dubai for the changeover. A big thank you to Conny, Adel, Michele, Steve, Pippa, Dörthe, Rob, Berit, Lars, Gordon, Wayne, Anke, Rita & the crew for their efforts. It's much appreciated and we hope to see you again sometime.

Safe travels and I'll see slot 2 tomorrow.

26th October

Slot 2 has arrived safely and I am writing this from the top deck as the team is getting ready for their first exam below. Other than studying hard, we went for a couple of training dives today and saw lots of firefish, a ray, huge hard corals, a barracuda and some interesting dive techniques :)

More exams and a mock survey dive tomorrow, before going for the real thing...

30 October

Apologies for the silence, but we have been out of range around the remoter parts of the peninsula for the last few days.

The wind has blown up, so some of the sites we wanted to survey, we could not because of the waves. The sites we did survey yielded cuttlefish mating, groupers being rescued from discarded nets, a monster moray eel and plenty of good fun whilst collecting data. Only one more dive to go until we are done for this year. It's passed in a flash and I want to thank everyone for their efforts and input - we could not do this without you.

Preliminary results and a last farewell in a few days. Until then, please don't forget to share your pictures via www.biosphere-expeditions.org/pictureshare.

1 November

The 2009 Musandam expedition has come to an end and I am in Dubai wrapping things up for a day with Rita, starting the report, storing equipment, giving interviews, etc. A first article about the expedition has appeared yesterday and you can see it at http://www.thenational.ae/apps/pbcs.dll/article?AID=/20091031/NATIONAL/710309823/1010.

The expedition has been a great success and I want to thank everyone for their efforts and contribution. I hope we have shown you that your input is essential in this little researched and important area. The Musandam peninsula is a unique place that deserves our attention. We have found that siltation (for example from construction) and bleaching are not a problem and that hard coral cover is slightly above the global average. This is good news. More worryingly, however, fish numbers and general biodiversity were low, probably due to overfishing and the recent red tide and category 5 cyclones such as Gonu in June 2007 add further stresses to the fragile reef ecosystem. Other stresses are coral damage due to boat anchors and the cyclone as well as trash and fish nets. Despite these stresses, you have all seen that the reef life of the Musandam is really quite amazing and definitely worth protecting.

These are preliminary results, of course, and the report will go into much more detail. For now, I think we can all be proud of what we have achieved.

I wish you safe travels home and hope to see you again some day on one of our expeditions.

Very best wishes

Matthias

P.S. Don't forget to share your pictures on www.biosphere-expeditions.org/pictureshare.