PROJECT REPORT

Expedition dates: 6 – 12 October 2013
Report published: April 2014

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

Cover image (c) Kelvin Aitken

First Choice Responsible Tourism Awards	The Independent on Sunday	responsibletravel.com	the guardian	ISLANDS	Umwelt-Online-Award	P.M.
BEST VOLUNTEERING ORGANISATION	BEST FOR GREEN-MINDED TRAVELLERS	TOP RESPONSIBLE HOLIDAY	BEST WILDLIFE VOLUNTEERING HOLIDAY	BEST IN SUSTAINABLE TRAVEL	ENVIRONMENT AWARD	TOP HOLIDAY FOR NATURE
UK	UK	UK	UK	USA	Germany	Germany

EXPEDITION REPORT

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

Expedition dates:
6 – 12 October 2013

Report published:
February 2014

Authors:
Jean-Luc Solandt
Marine Conservation Society

Matthias Hammer (editor)
Biosphere Expeditions

Abstract

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

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

Between 6 and 12 October 2013, Biosphere Expeditions conducted its fifth annual coral reef survey (2009 – 2013) using the Reef Check methodology in 8 different dive sites along the northern Musandam peninsula coastline. The main objectives of the 2013 expedition were to (1) monitor the health of and impacts on the Musandam peninsula's coral reefs, (2) train local scholars in the Reef Check methodology and involve these individuals in surveys, and (3) use and disseminate these findings for the purposes of management, education and conservation by local government and non-governmental organisations (NGOs).

This particular expedition saw coral cover of around 55% for most of the dives at shallow (<12 m) depths. Perhaps more significantly, there was little evidence of any coral disease, bleaching or predation. All corals were in a healthy climax state on many of the shallow reefs, with many sites hosting very large *Porites* colonies, indicating no significant damaging events to corals over the past 400 years.

The grouper populations were healthier this year than in previous years' expeditions; however, this does not necessarily indicate a recovery as the sites visited in 2013 are not necessarily exactly the same as those in previous years. However, the fact that the numbers are about double (of animals greater than 30 cm size) of previous expedition surveys (comparisons are made here with 2010 in particular, but also apply to surveys of 2011, 2012 and before) indicates that there may be something of a recovery in the population. Snapper populations are considerable at most shallow sites, and are joined deeper down by populations of medium to large emperor and bream. The latter two families were seen at almost every site.

Invertebrate populations (as recorded by Reef Check) were dominated by *Diadema* urchins – from the shallowest reef flats, within *Pocillopora* colony framework, and in the deeper waters where the more open water *Echinothrix diadema* feeds out on sand flats, particularly during nighttime foraging. Pencil urchins were common in shallow waters. Giant clam remain absent from the region. Large commercially important molluscs are dominated by *Murex* spp. that were observed during the expedition being harvested by fishermen using snorkeling gear. Commercially important lobsters were observed at low densities, with a total of 5 recorded on all surveys combined. However, this is a reasonably high density compared to many surveys from around the Indo-Pacific.

In 2013, the Omani government (Ministry of Agriculture and Fisheries) announced a Marine Protected Area (MPA) for the southeast of the Musandam peninsula in the area of two inlets (Khor Najd and Khor Hablain). The management measures introduced were to restrict fishing to handline only for the entirety of these areas. All net, longline and trap fishing were banned. This is a significant step for the conservation of the fisheries of the area, whilst allowing local artisanal fishing to persist – a sensible management measure given the need for local communities to fish.

The peninsula itself, with so many clear natural waypoints, bays, inlets and geological features, lends itself to very effective MPA conservation measures at a discrete scale. It is recommended that these natural features are used to their maximum potential to zone areas for different protection measures around the rest of the Musandam peninsula beyond the Khor Najd and Hablain inlets.

We therefore recommend that the following additional projects are instigated by local government and NGOs: (1) fisheries landings studies, (2) patrolling of and new legislation for the diving and fishing communities beyond the Khor Najd and Hablain inlets, (3) extension of Marine Protected Area (MPA) measures or a network of MPAs, including the installation and monitoring of fixed and marked mooring buoys, and (4) actions to declare the Musandam peninsula a UNESCO Biosphere Reserve and ultimately a UNESCO World Heritage Site.

ملخص

تعتبر الشعاب المرجانية من أحد أهم مكونات النظم البيئية الحيوية والتى تساهم بصورة إيجابية فى التنوع البيولوجى، ليس فقط بكونها الموئل الذي لا يمكن الإستغناء عنه للعديد من الكائنات الحية، ولكن لكونها مصدرا هاما للكثير من المكونات الغذائية ، ولدورها الحيوي في حماية السواحل . ولكن وبالرغم من تلك الأهمية القصوى للشعاب المرجانية ، فإن هذا الموئل الحساس يتعرض وباستمرار لشتى أنواع التهديدات بتأثير من الممارسات البشرية المباشرة أو غير المباشرة ، كتغير المناخ والتلوث البيئى والأستخدام الجائر للمصادر الشحيحة بالأضافة إلى التغير المناخى. إن الشعاب المرجانية في شبه جزيرة مسندم والتابعة لسلطنة عمان والتي تقع على مضيق هرمز في شبه الجزيرة العربية ، قد أصبحت بيئة محفوفة بالمخاطر كغيرها من الشعاب المرجانية في أجزاء أخرى من العالم ، حيث تعاني من ظروف قاسية للغاية تتمثل في ارتفاع نسبة الملوحة ودرجة الحرارة وبالرغم من ذلك فإن تلك الشعاب المرجانية مازالت موجودة ومزدهرة فى المنطقة بالرغم من التحديات والتهديدات المحيطة والتى تواجها العديد من مناطق الشعاب المرجانية حول العالم.

بالرغم من المرونة الشديدة والتأقلم على البيئة المحيطة والتى تظهرها الشعاب المرجانية بمنطقة شبه جزيرة مسندم فإن الدراسات الحديثة أعربت عن تخوفها وقلقها الزائد على مدى قدرة تلك الشعاب المرجانية على تحمل أى ضغوط ومؤثرات سلبية إضافية والتى قد تنتج عن طريق الكوارث الطبيعية المحتملة بالمنطقة أو عن طريق المؤثرات البشرية السلبية الواقعة على تلك البيئات الهشة والتى قد تعجل فى هلاك ودمار البيئة المرجانية بالمنطقة. على امتداد العقد الماضي ، تعرضت الشعاب المرجانية الرئيسية بمنطقة الخليج العربى للدمار من خلال مايعرف بإبيضاض الشعاب المرجانية ، و الطحالب الضارة ، والأعاصير ، بالإضافة إلى أعمال التطوير الساحلي والإنشاءات والتي تتم على نطاق واسع، وقد لوحظ أيضاً من خلال الدراسات التى تمت على بيئة تلك المنطقة انه هناك أنهيار فى أعداد الأسماك من خلال الصيد الجائر لأنواع محددة من الأسماك مثال أسماك الهامور مما أدى إلى تقلص سريع لأعداد أسماك القرش بالخليج.

في الفترة ما بين بين 6 و 12 أكتوبر 2013 ، أجرى فريق "بعثات بايوسفير الاستكشافية" مشروعه البحثي للسنة الخامسة على التوالى (2009 – 2013) وذلك على امتداد ساحل شبه جزيرة مسندم . تم خلال المشروع مسح الشعاب المرجانية باستخدام " منهجية مراقبة الشعاب المرجانية " و هو بروتوكول دولي لرصد الشعاب المرجانية ، تم تطبيقه في ثمانية مواقع للغوص. إن الأهداف الرئيسية للبعثة هى 1) متابعة الحالة الصحية للشعاب، 2) تعليم وتدريب شباب الباحثين المحليين على أحدث طرق رصد وتقييم الشعاب المرجانية، 3) إستخدام تلك النتائج لاتخاذ القرارات الإدارية والتعليمية ولغايات جمع بيانات علمية موثقة يمكن استخدامها من قبل المنظمات غير الحكومية والحكومات المحلية مستقبلاً .

فى تلك الدراسة تم ملاحظة وتسجيل تجمعات شعاب مرجانية بنسبة حوالى 55% فى معظم مناطق الدراسة وذلك فى المناطق الضحلة والتى يبلغ فيها العمق لحوالى 12 متر، لم يوجد أى دليل ظاهرى على وجود شعاب مرجانية مريضة أو مبيضة أو أى مظاهر لأفتراس تلك الشعاب المرجانية، كل التجمعات المرجانية كانت بحالة جيدة مما أعطى دليلاً على أنه لايوجد أضرار كبيرة تعرضت لها الشعاب المرجانية بالمنطقة لزمن يعود إلى 400 عام مضى.
لوحظ من خلال الدراسة الاخيرة أن أسماك الهامور أصبحت فى أفضل حالتها مقارنة بأعدادها فى السنوات السابقة. وبالرغم من ذلك، لا يعتبر هذا التقدم فى الأعداد فى سنة 2013 ومقارنته بالسنوات السابقة مقبولا بصورة نهائية لإختلاف مواقع الرصد فى كل سنة عن السنوات السابقة. ومع ذلك، فإن تضاعف أعداد الإسماك (التى حجمها أكبر من 30سم) مقارنة بالمواسم السابقة (حيث تمت مقارنة دراسة عام 2013 بعام 2010 تحديداً وإجمالاً مع عامى 2011 و 2012) أثبت أن هناك تحسناً ملحوظاً فى الثروة السمكية فى منطقة الدراسة حيث زادت أعداد أسماك النهاش بصورة مقبولة فى المناطق الضحلة وشارك أسماك النهاش فى المناطق العميقة من الدراسة أسماك الأمبراطور وأسماك الدنيس والتى تمت مشاهدتهما فى معظم المواقع التى تم دراستها.
وبالنسبة لحصر وتسجيل الأنواع اللافقارية فقد تم تسجيل نوع من أنواع قنافذ البحر الشوكية (Diadema urchins) وذلك فى المناطق الضحلة المستوية داخل مستعمرات المرجان البحرى الحجرى (Pocillopora colony)، وبدراسة المناطق العميقة تم تسجيل قنفذ البحر من نوع (Echinothrix diadema) ويتغذى فى المناطق الرملية المستوية فى قاع الخليج العربى وبالأخص فى فترات الليل، وكذلك تم تسجيل نوع (Pencil urchins) فى المناطق الضحلة مع غياب حيوان البطليموس فى تلك المناطق.
تعتبر الرخويات والمتمثلة فى القواقع البحرية هيا الأهم من الناحية الإقتصادية التجارية من نوع (.Murex spp) والتى تم تسجيلها وملاحظتها أثناء فترات الدراسة حيث يتم تجميعها بواسطة الصيادين بإستخدام عدة الطفو البسيطة، تم أيضاً ملاحظة وتسجيل حيوان سرطان البحر ولكن بإعداد قليلة جداً بإجمالى خمس أفراد فقط فى كل مناطق الدراسة وإجمالا لكل السنوات الماضية ولكن بالرغم من ذلك تعتبر تلك المشاهدات كبيرة مقارنة بالعديد من الدراسات الأخرى فى مناطق المحيطين الهادى والهندى.

قامت الحكومة العمانية فى العام 2013 والممثلة فى وزارة الزراعة والثروة السمكية بإعلان منطقة جنوب شرق شبه جزيرة مسندم كمنطقة محمية بحرية وتتكون من خور النجد وخور الحبلين، وتم تفعيل خطط إدارة للمنطقة بتقييد الصيد الجائر لكل المنطقة والسماح فقط بإستخدام السنارة البسيطة ومنع كافة أشكال الصيد الأخرى مثل الصيد بالشباك ووضع مصائد للأسماك حيث أعتبر هذا القرار كخطوة هامة فى مجال الصون والحفاظ على الثروة السمكية بالمنطقة مع إستمرار السماح للمجتمعات المحلية البسيطة والتى تقيم بتلك المنطقة بالصيد لسد إحتياجاتهم الغذائية من الموارد المتاحة.

تحتوى شبه جزيرة مسندم على العديد من المناطق الطبيعية الخلابة من الخلجان والخور وكذلك التشكيلات والتكوينات الجيولوجية المتنوعة والفريدة من نوعها، تم إقتراح ان يتم إدارة المنطقة عن طريق فرض نطاقات حماية محددة للحفاظ عليها وأن تشمل مستويات إدارة مختلفة لكل شبه جزيرة مسندم.

إجمالاً وتلخيصاً لما سبق فإننا نقترح البرامج والمشاريع التالية أن توضع فى الإعتبار بواسطة الحكومة المحلية ومنظمات المجتمع المدنى:

1) دراسات متخصصة عن مصائد الأسماك.
2) تنظيم عمليات التقييم والدوريات على أنشطة الغوص والصيد فى جميع مناطق شبه الجزيرة بخلاف خور النجد وخور الحبلين.
3) توسيع المحميات القائمة أو إنشاء محميات جديدة ويشمل ذلك إنشاء وتركيب ومتابعة عوامات المراسى الثابتة منها وكذلك المتحركة.
4) وضع خطة عمل فعالة لإعلان منطقة مسندم منطقة محمية من محميات المحيط الحيوى والتابعة لمنظمة اليونسكو وكذلك محاولة إعلانها منطقة تراث طبيعى عالمى.

Contents

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

1. Expedition Review

M. Hammer (editor)
Biosphere Expeditions

1.1. Background

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

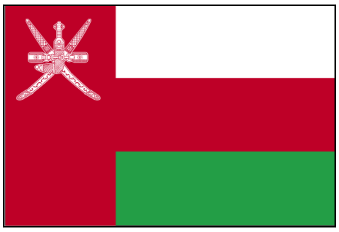
This project report deals with an expedition to the Musandam peninsula that ran from 6 to 12 October 2013 with the aim of monitoring the health of the Musandam peninsula's reefs, fish and invertebrate communities so that informed management, education and conservation decisions can be made by the government and NGOs. Data on the current biological status of the reefs and 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 Reef Check EcoDivers.

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

The 650-kilometre coastline of the Musandam peninsula is strewn with rocks and coves, gradual steps, steep rocky slopes and cliffs that plunge to great depths all over the fjord-like landscape. The coral reefs that grow along the margins of this stunning landscape are still relatively untouched as influences such as industrial-scale fishing, pearl or scallop extraction or large numbers of recreational divers have not wreaked their destructive influence there. The area is therefore a prime target for studying intact reef ecosystems, conserving them for future generations and using them 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 peninsula 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 one week, and was composed of a team of international research assistants, scientists and an expedition leader. Expedition dates were:

2013: 6 – 12 October

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

1.4. Local Conditions & Support

Expedition base

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

Weather & water temperature

The climate is tropical and maritime. The average day temperatures during the expedition were 30 – 35°C with sunshine and no clouds on all but a few rare days. Water temperature during the expedition ranged from 28 to 32°C.

Field communications

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

Transport, vehicles & research boats

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

Medical support and insurance

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

Diving

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

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

1.5. Local Scientist

Dr Jean-Luc Solandt is a Londoner with a degree in Marine Biology from the University of Liverpool. After graduating, he spent a year diving on the Great Barrier Reef assisting field scientists in studies on fisheries and the ecology of soft corals and damselfish. He returned to the UK and enrolled in a Ph.D. in sea urchin ecology in Jamaica, based both in London and Jamaica. He went on to be an expedition science coordinator for projects in Tanzania, the Philippines and Fiji, and is now undertaking campaign and policy work in planning and developing Marine Protected Areas in the UK. He has been the Reef Check coordinator for the Maldives since 2005 and has thus far led three expeditions to undertake surveys inside and outside Marine Protected Areas on the islands. Jean-Luc has 800 dives clocked up since he trained to be a marine biologist 20 years ago.

1.6. Expedition Leaders

The 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.

Catherine Edsell joined as assistant leader. Catherine was born in the UK into a family of mountaineers, skiers and adventurers. With wanderlust in her blood and a BA Hons in Creative Arts under her belt, she left her career as a choreographer, and set off to the jungles of Central America and Indonesia, lived in the Himalaya with locals, trekked through the Namib Desert in search of elusive elephants and dived the oceans. Her passion for conservation grew as she sought out and trained with expedition organisations who echoed her ecological beliefs, and for seven years straight, her feet barely touched British soil as she lived the expedition life in all sorts of terrains. Catherine joined Biosphere Expeditions in 2012 to realise her ambition to participate in true conservation work.

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):

6 – 12 October 2013

Amran AlKamzari (Oman, from the Ministry of Environment and Climate Affairs, placement courtesy of Biosphere Expeditions), Nasser Al-Khanjari (Oman, placement courtesy of Biosphere Expeditions), Elmar Blume (Germany), Hazel Christie (UK, placement courtesy of the Anglo-Omani Society), Michael Enders (Germany), Hideko Kawabata (USA), Monica Majors (Oman), Tim Polaszek (UK placement courtesy of the Anglo-Omani Society), Di (Steven) Song (China), Antonia Vegh (Oman, placement courtesy of Biosphere Expeditions).

1.8. Other Partners

On this project Biosphere Expeditions is working with the Marine Conservation Society, Reef Check, local dive centres, businesses & resorts, the local community, Sultan Qaboos University, the Oman Ministry of 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).

1.9. Expedition Budget

Each team member paid towards expedition costs a contribution of £1,280 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	5,270
Grants	6,000
Expenditure	
Research vessel includes all board & lodging, ship's crew, fuel & oils, other services	6,900
Transport includes transfers & visas	336
Equipment and hardware includes educational & research materials & gear purchased in UK & Middle East	162
Staff includes local and international salaries, travel and expenses	3,513
Administration includes registration and other admin fees	475
Team recruitment Musandam as estimated % of PR costs for Biosphere Expeditions	6,400
Income – Expenditure	**- 6,516**
Total percentage spent directly on project	**173%***

*This means that in 2013, the expedition ran at a loss and was supported by Biosphere Expeditions over and above the income from the expedition contributions and grants.

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 to 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, Swarovski Optik and BUFF® for their sponsorship. Biosphere Expeditions also gratefully acknowledges grant support from the Waterloo Foundation. The Anglo-Omani Society and the Friends of Biosphere Expeditions kindly supported the placements on this expedition.

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 via www.biosphere-expeditions.org.

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

2. Reef Check Survey

Jean-Luc Solandt
Marine Conservation Society

2.1. Introduction

Study site description

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

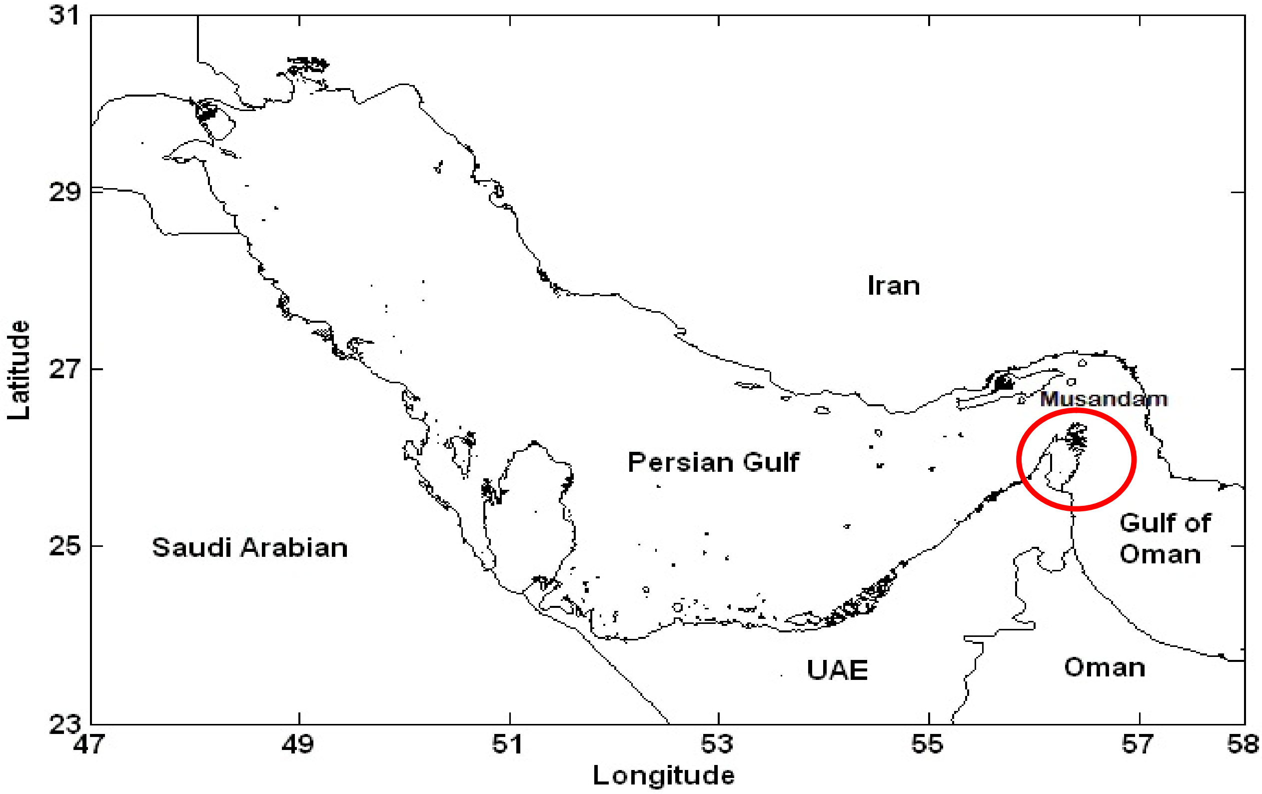


Figure 2.1a. Location of the Musandam peninsula in the Middle East.

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

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

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

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

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

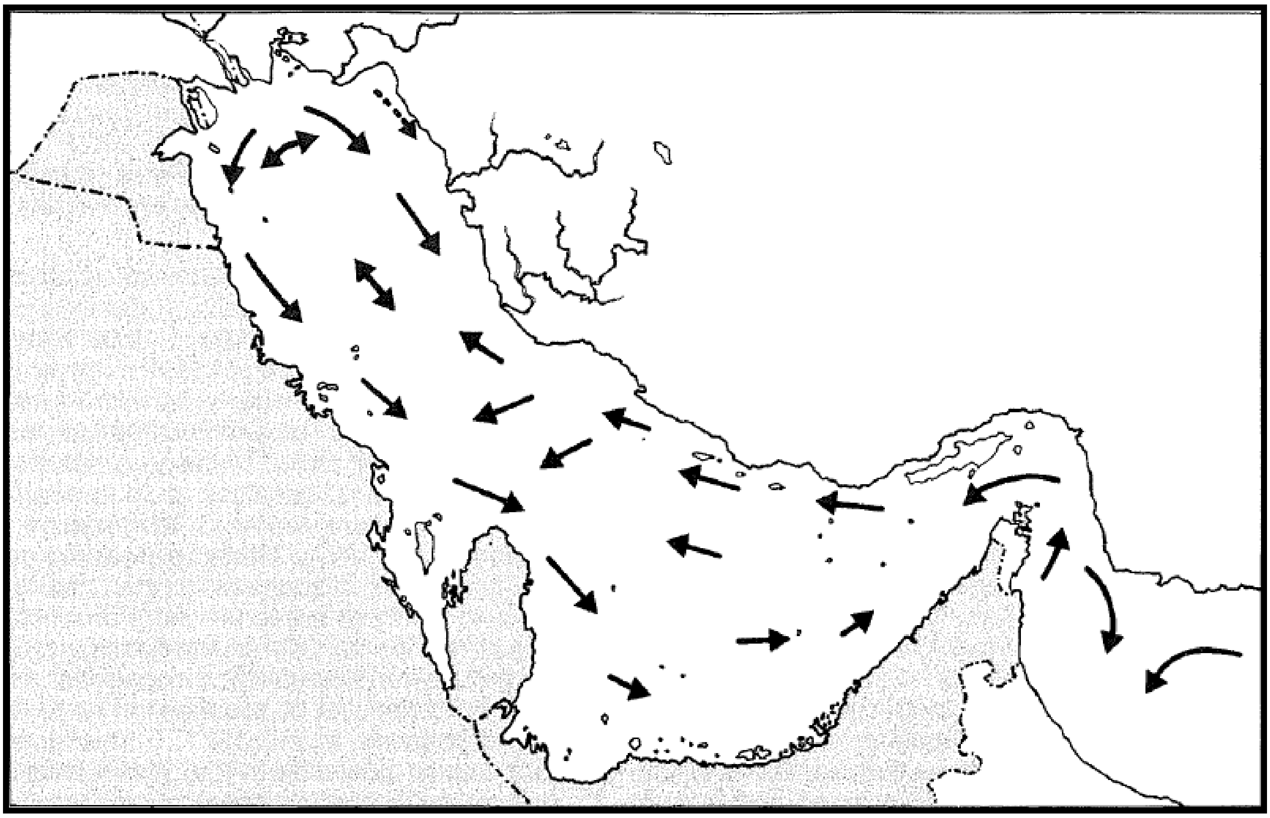


Figure 2.1b. Major current patterns of the Arabian Gulf and northern Arabian Sea (Reynolds 1993).

Tides in the Gulf of Oman and the Arabian Sea are oceanic in type where frictional effects are minimal. Tide heights can range from 1.5 metres in the Arabian Sea to 2.5 metres in the Gulf of Oman, being predominantly semi-diurnal and correlating closely with those of the Indian Ocean. 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 and 31°C (maximum recorded of 35°C), and can often cover this range within one day (Rezai et al. 2004). In the Arabian Sea the seasonally reversing winds induced by the monsoon create a strong upwelling, which causes the remarkable low sea temperatures off the southeast Arabian Peninsula in the hottest summer months (Sheppard et al. 1992; Carpenter et al. 1997). In the Gulf of Oman the cool water influences are less constant, although occasional upwellings occur and can replace surface waters very rapidly such that falls of up to 10°C over one or two days can happen. Such upwellings have a significant impact on the marine ecology, and therefore areas of reef development are few (Randall 1995; Spalding et al. 2001).

Salinity in the Gulf of Oman is generally at 36.5, but, due to the influence of the Arabian Gulf, 38.9 has been recorded in the surface waters of the Strait of Hormuz, in the Musandam peninsula, to Ra’s Al-Hadd at the entrance to the Gulf of Oman (Rezai et al. 2004). Salinity values experienced in the Arabian Gulf exceed the optimum range for coral reef in other tropical regions in the Atlantic and Pacific, which normally show a salinity interval of 35 to 37 and an upper tolerance range between 40 and 45 (Price et al. 1993; Coles 2003). The SST values observed in the Arabian Gulf are the highest encountered worldwide on reefs, varying by up to 25ºC annually (Sheppard and Loughland 2002; Coles 2003). In other tropical regions the range is normally only 19ºC, with the normal upper limits between 33ºC and 34ºC and the lower limits between 13 and 16ºC (Coles 2003). Species that establish populations in the area must therefore be capable of withstanding the stress of osmotic and temperature extremes. 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 species in different regions can live under quite different temperature regimes and thus have different thermal tolerances (Grimsditch and Salm 2006; Marshall and Schuttenberg 2006). Corals and reef communities in some areas (such as the Arabian Gulf and Gulf of Oman) tolerate salinity and temperature conditions that are lethal when imposed rapidly on the same species in less extreme environments (Baker et al. 2004; Buddemeier et al. 2004; Riegl et al. 2006).

Rezai et al. (2004) describe coral communities of the Gulf of Oman and Arabian Sea as 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 conditions (Coles 2003).

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

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

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

Additional external factors affecting the area

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

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

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

Reef Check

Reef Check’s survey method uses simple techniques to collect scientifically robust data. This methodology is specially designed for recreational divers that might not have a scientific background, so training has to be precise, rapid and understandable in order to guarantee that organism identification is accurate (Hodgson et al. 2006).

To understand the health of a coral reef, Reef Check bases its data collection on “indicator organisms” 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 is easy to identify. A Reef Check team collects four types of data (Hodgson et al. 2006):

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

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

Aims and objectives

The primary aim of this project was to continue to provide data on the health of the Musandam peninsula's coral reefs and current threats. With the beginning of this project in 2009 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 now useful for comparison with the survey conducted in 2009, as well as future surveys, and to provide data from Musandam for the global Reef Check database.

2.2. Methods

Site selection & sampling design

Between 6 and 12 October 2013, 8 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.

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 17 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.

Figure 2.2a. Location of the 8 dive survey sites around the Musandam peninsula in October 2013.

Table 2.2a. Dive sites visited during the 2013 expedition.

Site name	Date surveyed	GPS location
D1 – Lobsters Demise	6 Oct 2013 (practice)	26 17 48 N; 056 26 05E
D13 – Khayl Island	7 & 9 October 2013	26 21 55.7 N; 56 27 7.27E
D7 – Coral Gardens	7 & 10 October 2013	26 22 34.27 N; 56 24 56.78E
D9 – Eagle Bay	8 & 10 October 2013	26 22 56.45 N; 56 25 4.15E
D24 – Ballerina Cliffs	8 October 2013	26 19 46.21 N; 56 27 37.07E
D11 – Faq al Asad	9 October 2013	26 21 29.42 N; 56 29 53.03E
D12 – Faq Al Asad east	9 October 2013	26 21 20.55 N; 56 29 56.63E
D10 – Ras Tahur	11 October 2013	26 23 6.05 N; 56 25 14.7 E
D5 – Pipi Beach	11 October 2013	26 22 31.71 N; 56 23 7.36 E

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

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

The team also undertook a snorkel on 10 October 2013 in order to investigate the outside of the northernmost island of the archipelago (see site D10 Fig 2.2b above) that we were surveying, and on the current rich northwest side. Detailed survey notes of this survey are included in appendix I.

Belt transect surveys

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

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

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

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

Substrate line transect surveys

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

Coral Point Count

Photo transects were undertaken at six locations, from the exposed northwestern most site of the archipelago (in an area of high current – Ras Tahur) to the eastern area of the archipelago (Faq Al Asad). These photo transects capture images of the reef from vertical view at about 2m from the seabed. Post-hoc analysis occurs with the software CPCe (Coral Point Count with excel extensions) (Kohler and Gill, 2006). Various categories of substrate were then able to be recorded at greater resolution including coral lifeforms.

Data analysis

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

Analysis of 2013 data was compared to 2010 data first and foremost, but also to other years, to give a qualitative indication over time of the general attributes of the reefs, and of their health, impacts and commercially and ecologically important fish and invertebrates. All mean data from 2013 surveys are ± Standard Deviation (SD). All data from 2010 surveys are ± Standard Error (SE).

2.3. Results

General human use and surface observations

These observations were made using the ‘site description’ form. There was very little variation in surface temperature (29 – 30°C). Variation was also minimal at 3 m (28 – 29°C) and waters at 10 m (27 – 29°C). Visibility ranged from 5 to 20 m. The best visibility was at Ras Tahur, an area to the northwest of the archipelago with strong currents. All other areas had lower visibility that even differed in the same site between days. The range of the Coral Gardens site was from 5 m to 12 m. Khyal Island also ranged from 6 to 12 m visibility. Air temperatures ranged from 32 to 37°C.

The clearest observable impacts at many of the sites were the use of fish traps to catch reef-associated species, handlining for tuna, and gillnets set for reef and pelagic-associated species (Fig. 2.3a and b).

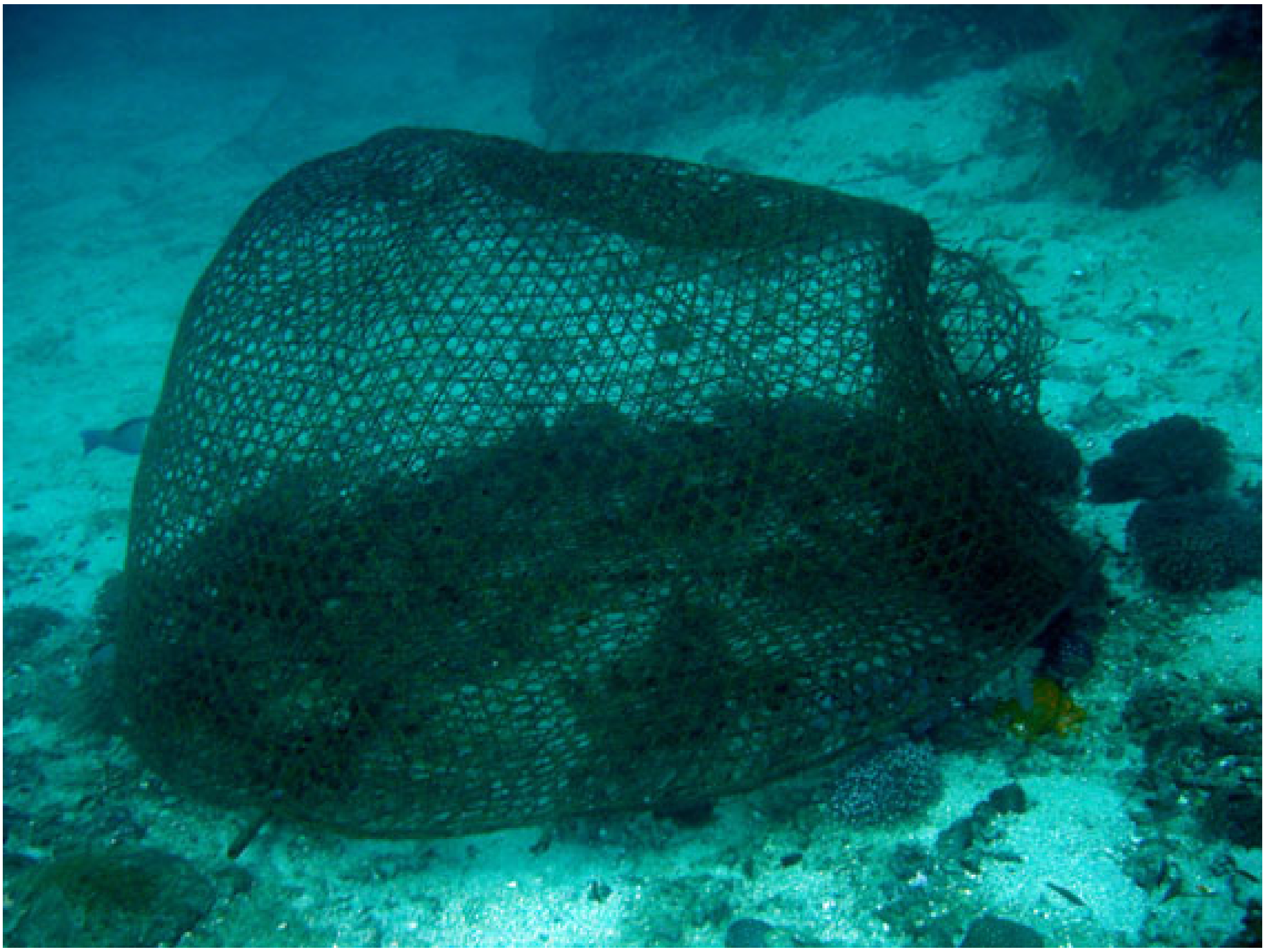


Figure 2.3a. Discarded fish trap commonly observed between 8 and 12 m on the seaward edge of fringing reefs.

Figure 2.3b. Wall net, typically used close to reefs and in areas where tuna 'baitballs' are observed. These will commonly catch reef fish, pelagic predators, and lobster.

Other impacts appeared to be at a minimal level. Evidence of impact from human activities appeared only to be fisheries-related. There were no overt occurrences of coral damage that may be derived from anthropogenic sources. Similarly, the corals appeared to be in good health, with very limited incidence of disease reported from the sites. It appears some form of ‘white syndrome’ or ‘white band disease’ was occurring on faviid colonies from one site in particular – Faq Al Asad. However, no *Acropora* colonies appeared to be suffering from any wasting or disease or syndrome. Previous reports of invertebrate harvesting for food have been reported by Rita Bento (previous expedition scientist for the Musandam expeditions, see previous expedition reports on www.biophere-expeditions.org/reports). We observed at least one incident of invertebrate harvesting during the 2013 expedition. It appeared that large molluscs such as *Murex* gastropods were being collected in this instance (Fig. 2.3c).

Figure 2.3c. *Murex* gastropod recorded at 4 m depth, well within the range of snorkel harvesting.

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

Fish community

Only three species of butterflyfish were observed during surveys: *Chaetodon melapterus* (Fig. 2.3d), *Chaetodon nigropunctatus* and *Heniochus diphreutes* (schooling bannerfish). Only a single snapper species was observed on the surveys, the widespread *Lutjanus ehrenbergii* (blackspot snapper).

Figure 2.3d. *Lutjanus ehrenbergii* (left) and *Chaetodon melapterus* (right) at Khyal Island.

In both the 2009 and 2010 expeditions, snappers and butterflyfish were the most abundant species seen on transects from the six categories of indicator fish counted in the Reef Check methodology for this expedition (19.8 ± 3.6 and 12.8 ±0.9 per 100 m^2, respectively, for 2010; 19.96 ± 22.3 and 10.97 ± 6.69 for 2013). The next most abundant in 2013 were, as in 2010, the parrotfish (4.5 ± 3.5 per 100 m^2), followed by groupers (2.4 ± 2.7 per 100 m^2) (Fig. 2.3e).

Grouper numbers were higher in 2013 (2.42 ± 2.7 per 100m^2) than in 2010 (1.15 per 100m^2) (Fig. 2.3f). Sweetlips (0 ± 0 per 100 m^2) and moray eels (0.26 ± 0.52 per 100 m^2), were the least abundant. Only one painted sweetlips (*Diagramma pictum*) was observed during the surveys across the whole week period – this was recorded off transect at the Ras Tahur site on 11 October 2013.

Other predatory fish species observed were mature (>30 cm) spangled emperor fish *Lethrinus nebulosus* and the doublebar bream *Acanthopagrus bifasciatus* that was common at most sites. Although these species are not on the Reef Check list, they are no doubt important contributors to the fisheries of the Musandam peninsula.

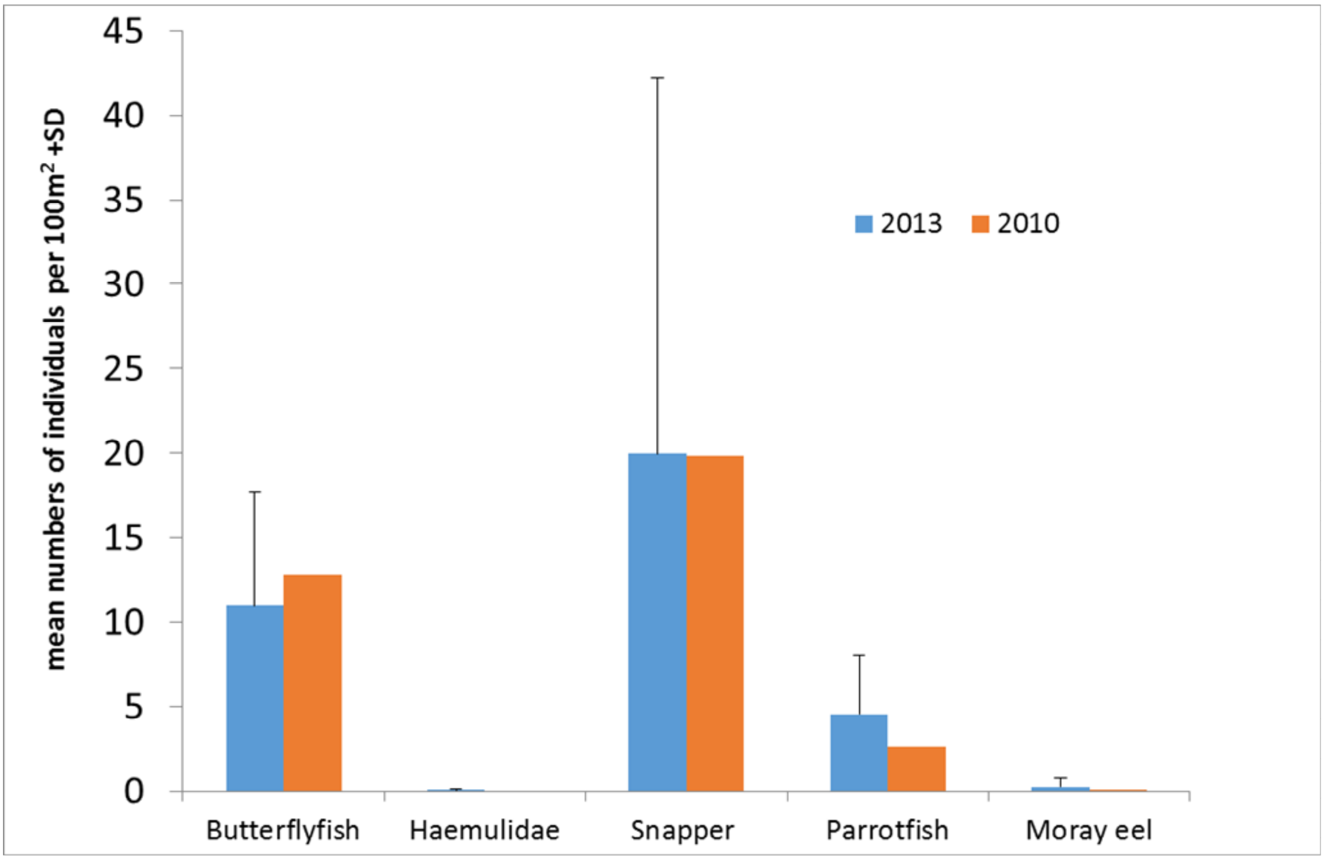


Figure 2.3e. Pooled average fish abundance from all sites at all depths for 2013 (n = 76 replicates from 19 surveys) and 2010 surveys for comparison.

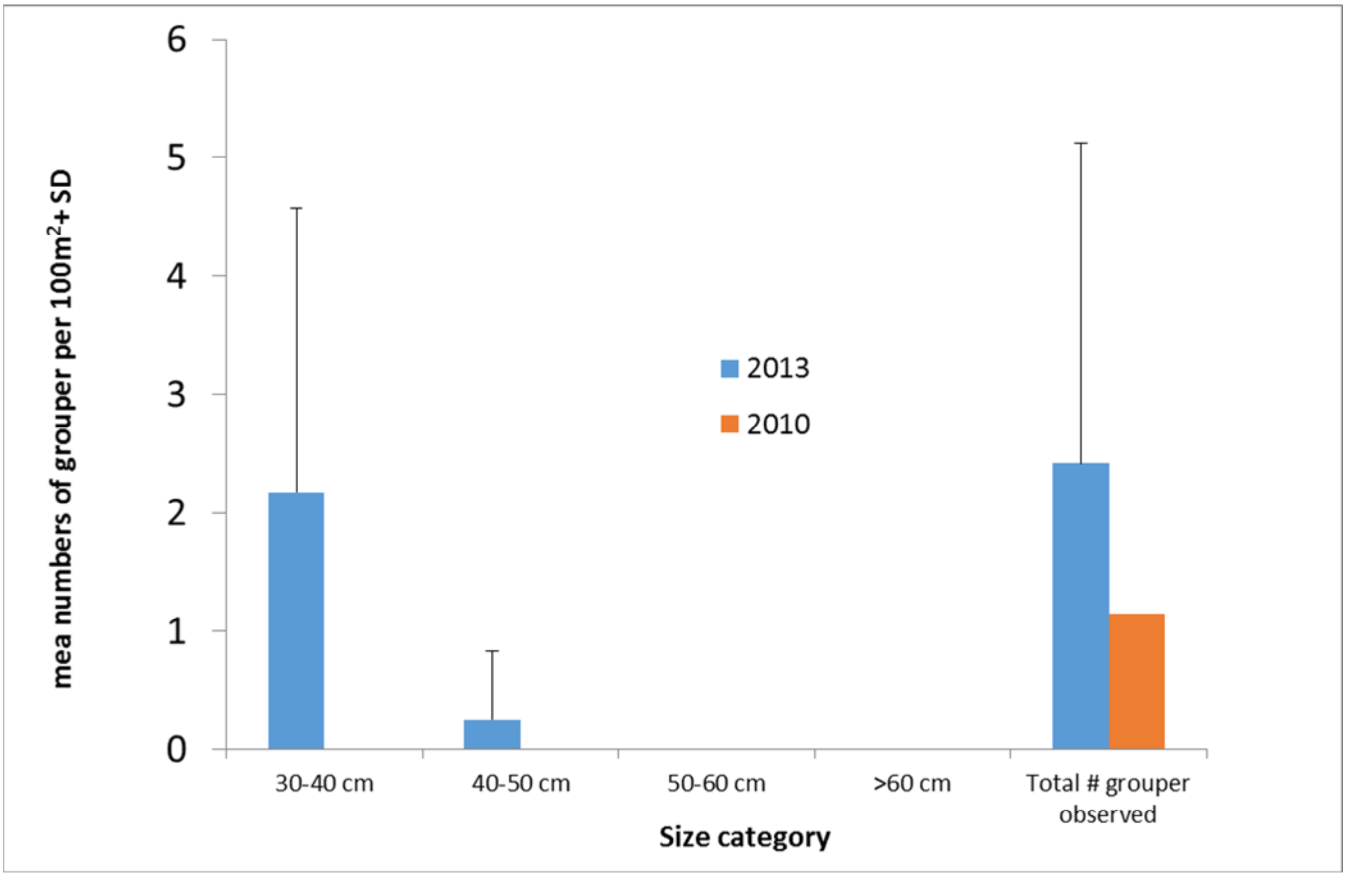


Figure 2.3f. Average numbers of groupers (and size distribution) per 100m^2 in 2010 and 2013.

Unusual sightings

Hawksbill *Eretmochelys imbricata* (Coral Gardens, Pipi Beach) and green turtles *Chelonia mydas* (Eagle Bay, Khyal Island) were observed quite often (Fig. 2.3g). Individual size was relatively small, with hawksbills being approximately 40 cm and greens about 60 cm long.

At one site, Pipi Beach, there was a very large school of yellowtail barracuda *Sphyraena flavicauda* (possibly in excess of 400 individuals). These individuals were schooling at the base of the coral heads at a depth of 12–14 m (Fig. 2.3h).

At Eagle Bay a 6m whale shark was observed at the surface, feeding close into the reef on 8 October 2013.

The only other shark species observed was the blacktip reef shark *Carcharhinus melanopterus*. Individuals were only seen off transect. Blacktip reef sharks were seen at Eagle Bay and Ras Tahur on two separate occasions. One reef shark was seen (on a snorkel) at the northern section of the Coral Gardens site.

An Indo-Pacific humpback dolphin *Sousa chinensis* was seen at the Faq Al Asad site on 9 October 2013.

Figure 2.3g. A subadult hawskbill recorded at Pipi Beach.
Green and hawksbill turtles were often observed off transect.
All appeared to be at a large juvenile stage.

Figure 2.3h. The yellowtail barracuda *Sphyraena flavicauda* at Pipi Beach.

Invertebrate community

The *Diadema* urchin *Diadema savignyi,* the most common *Diadema setosum*, and *Echinothrix diadema* (mostly found on flatter, deeper, sandier sediment dominated habitat) were again the most abundant invertebrates in Musandam, with an average (for all three species pooled) of 112 ± 74 per 100m^2, a little lower than in 2010 (186 per 100 m^2) (Fig. 2.3k). All the other invertebrates counted had an average number below 2 per 100 m^2, as was also observed in 2009 and 2010. Some shallow surveys had considerable numbers of pencil urchins (Fig. 2.3i and j). They appeared to be associated with *Pocillopora* monospecific stand colonies in the shallow sheltered bays (e.g. Eagle Bay). Here, they colonised underneath and between the live coral matrix, in densities of up to 0.06 per m^2.

Figure 2.3i. Monospecific stands (up to 50 metres length in places) in shallow (< 3 m) waters of many embayments in the peninsula often hosted large numbers of pencil urchins within the base of the coral colonies.

Figure 2.3j. Pencil urchin firmly wedged into coral rubble. These were only found on shallower transects, and usually in greatest densities amongst the lower matrix of living *Pocillopora* colonies.

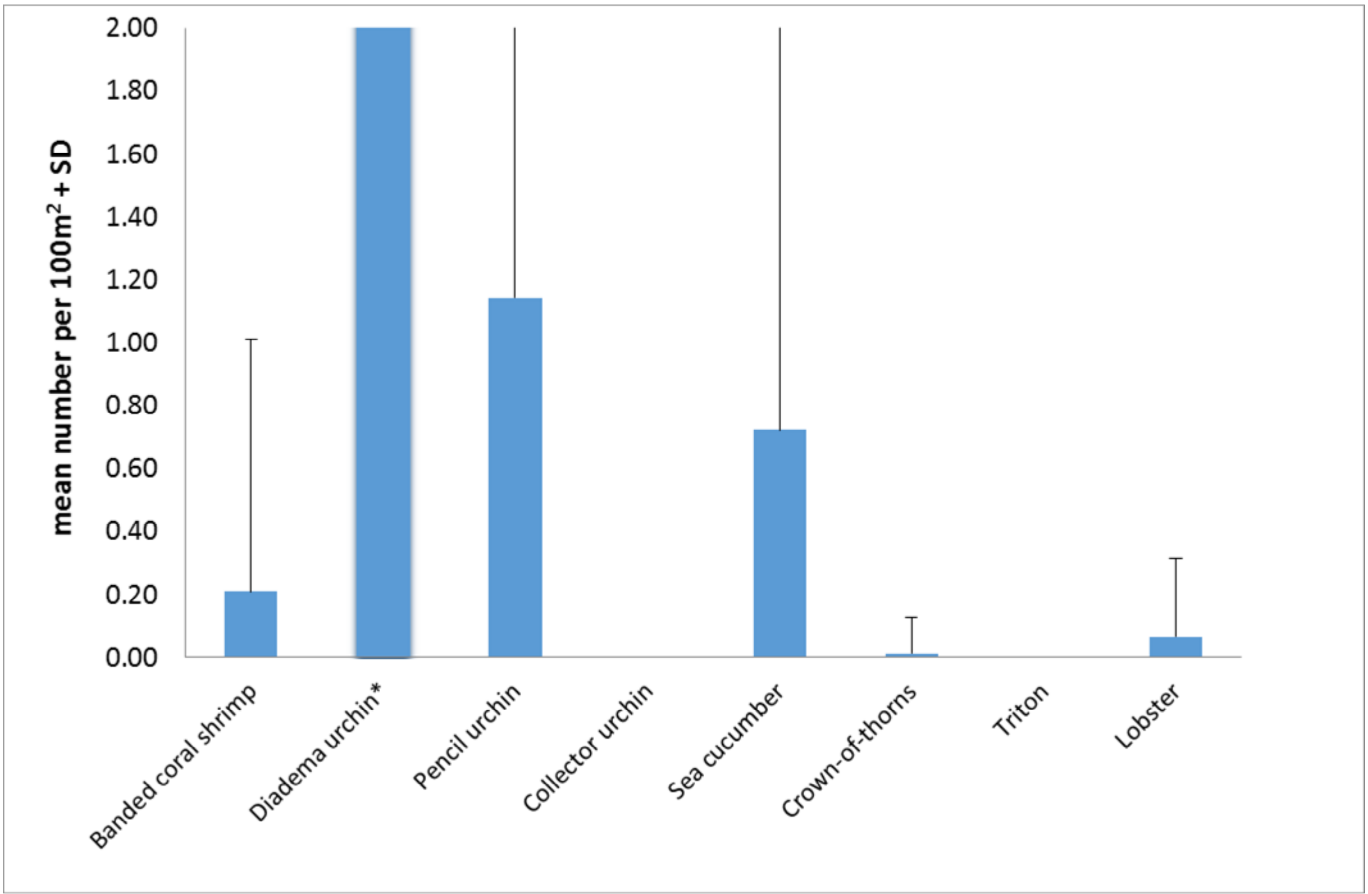


Figure 2.3k. Pooled mean numbers of invertebrate indicators per 100 m^2.

- *Diadema* urchins were at densities of 112 ± 74 per 100 m^2 (beyond the scale of this graph).

Toxopneustes pileolus sea urchin was observed foraging on sandy habitat away from the reef during night dives (Fig. 2.3l).

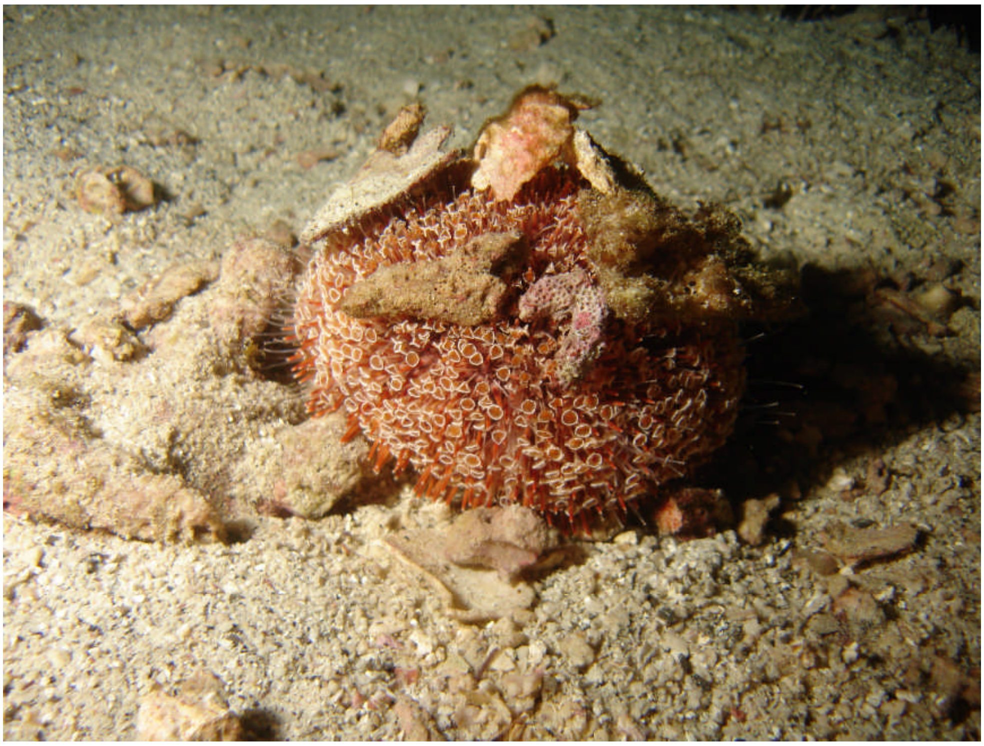


Figure 2.3l. *Toxopneustes pileolus*.

Lobsters were seen both on transect and off transect (Fig. 2.3m). The size of the individuals indicated that they were quite mature. One was found at Ras Tahur site, one at Pipi Beach, one at Faq Al Asad, and one at Coral Gardens. It appears that fishermen don't tend to use SCUBA when fishing. This perhaps allows individual lobsters to persist where they have been extracted from most other reefs around the world.

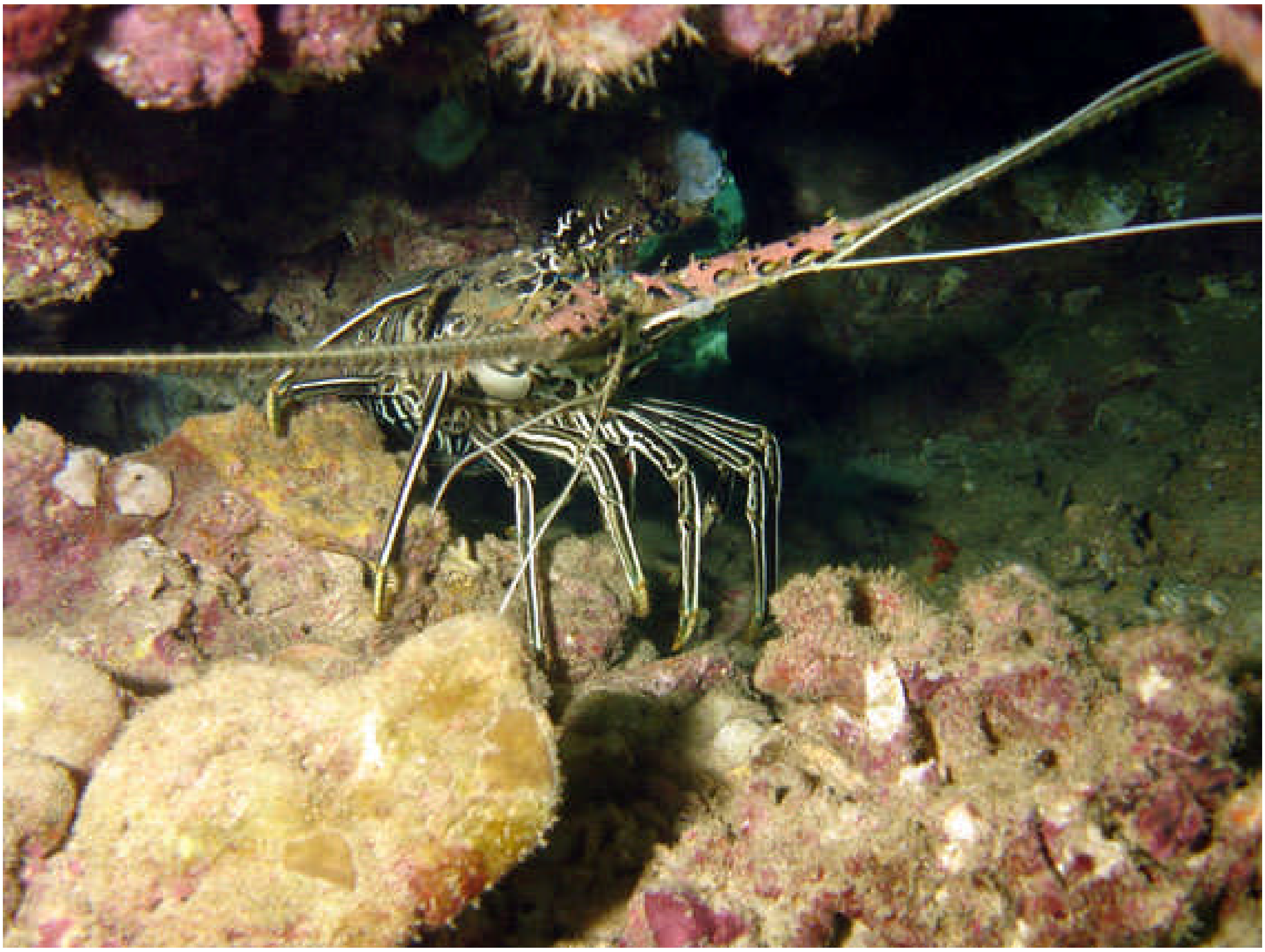


Figure 2.3m. The crayfish / reef lobster, *Panulirus versicolor* (photo from Pipi Beach, 11 October 2013).

Substratum / benthic community

Most sites offered almost the exact same subtidal geology – shallow embayments hosting populations of corals dominated by *Pocillopora* sp. (probably either *damicornis* or *verrucosa*) in waters of approximately 1 – 3 m depth (Fig. 2.3i). Deeper down, the complexity increased in coral species guild, with many sites hosting mature, large *Porites* mounds from 7 – 12 m depth (Fig. 2.3n). *Platygyra sinensis* or *Leptoria irregularis* (brain corals of the Faviid family) also appeared to grow in a shallow zone (Fig. 2.3o), only attached to the base rock of land (rather than appearing to start their life history in deeper waters as with *Porites*). As such, they were always recorded in shallow water (< 5 m depth). The largest of the *Porites* colonies were found at Pipi Beach, with some reaching 6 m in height and 8 m in basal diameter. This indicates that these colonies could be in excess of 400 years old (Sheppard et al. 2008 states that *Porites lobata* grows at a maximum rate of 1 cm per year). It was very rare to find corals of any kind below 12 m, with almost every site having a sediment plain at this depth. The coral cover of 54.4 ± 25.5 % is high for the Indo-Pacific region, and there was very little rubble, or dead coral, indicating a very healthy coral environment (Fig. 2.3p).

Figure 2.3n. Left: typical reef community at 4 – 6 m depth with foliose and branching coral growth forms. Right: Slightly deeper down, *Porites* colonies dominated the seascape for many sites. More exposed sites such as Ras Tahur had low-growing or smaller growth forms, and at areas of strong current, soft corals were recorded.

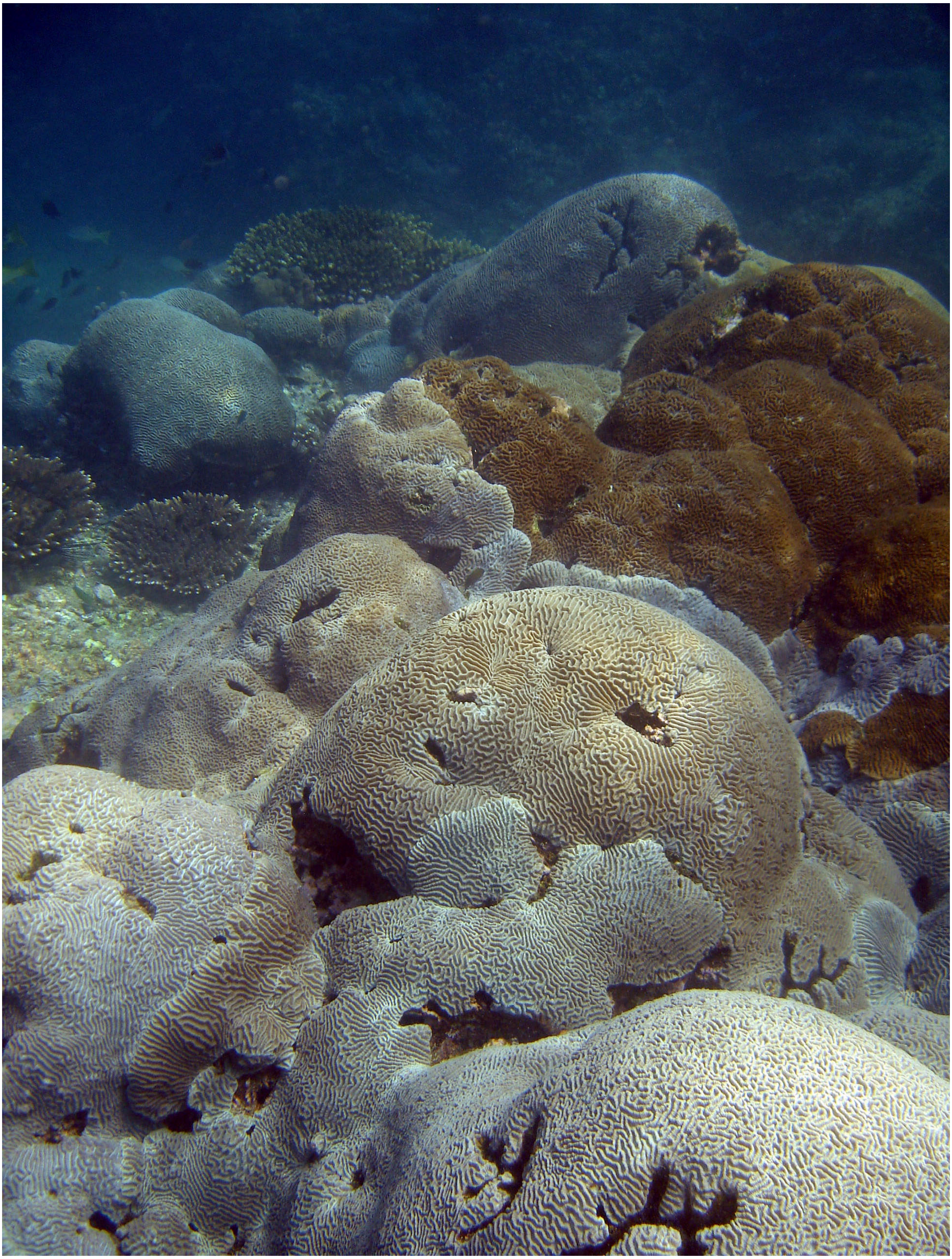


Figure 2.3o. Brain coral colonies (Faviid family) growing on subtidal rock.
They often formed monospecific stands up to 5 m across in this shallow (3m) depth zone.

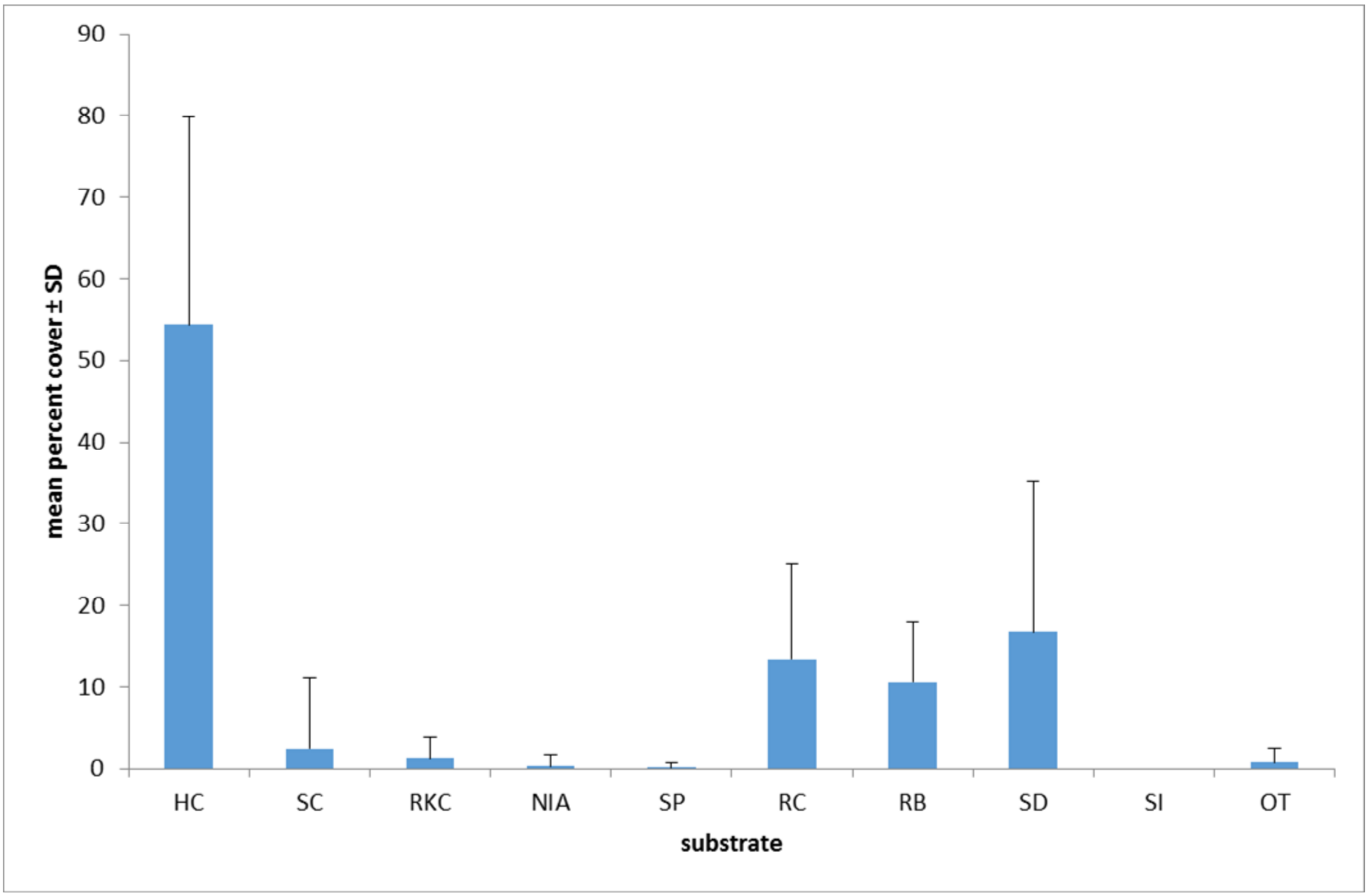


Figure 2.3p. Pooled average percentage cover (n=70 replicates from 17.5 transects recorded from 8 sites) of different substrates seen in Musandam (HC=hard coral; SC=soft coral; RKC=recent killed coral; NIA=nutrient indicator algae; SP=sponge; RC=Rock; RB=rubble; SD=sand; SI=silt; OT=others). Error bars are Standard Deviation. The average depth of the surveys was 5.8 ± 2.3 metres. Soft corals were only recorded at one site – Ras Tahur (a site with high current).

Coral Point Count (CPC) photo transect data

Surveys undertaken using the CPC photo transect methodology (Kohler and Gill 2006) revealed three different community types (Fig 2.3q&r). One of shallow reefs (<5 m) dominated by 'non-Acropora branching' lifeforms, most frequently dominated by *Pocillopora dammicornis* (Fig 2.3i). Deeper communities (5-12 m) were either dominated in more exposed areas by Faviids brain corals, generally in more exposed locations (such as southwest of Ras Tahur – Fig 2.3o), or, in sheltered deeper locations, by *Porites*, and, in some locations such as Pipi Beach, larger mounds (Fig. 2.3n).

The only site of the archipelago surveyed that had a dominance of other coral living seabed lifeforms was outer (deeper) Ras Tahur where soft corals were dominant on the flat current-scoured pavement seabed (Fig. 2.3s). Here currents were noticeably stronger, leading to difficult survey conditions nearer to the point of the island, as currents whip around this headland from east to west. The genus of coral dominant at this site was *Lobophyton*.

Figure 2.3q. See description for 2.3r below.

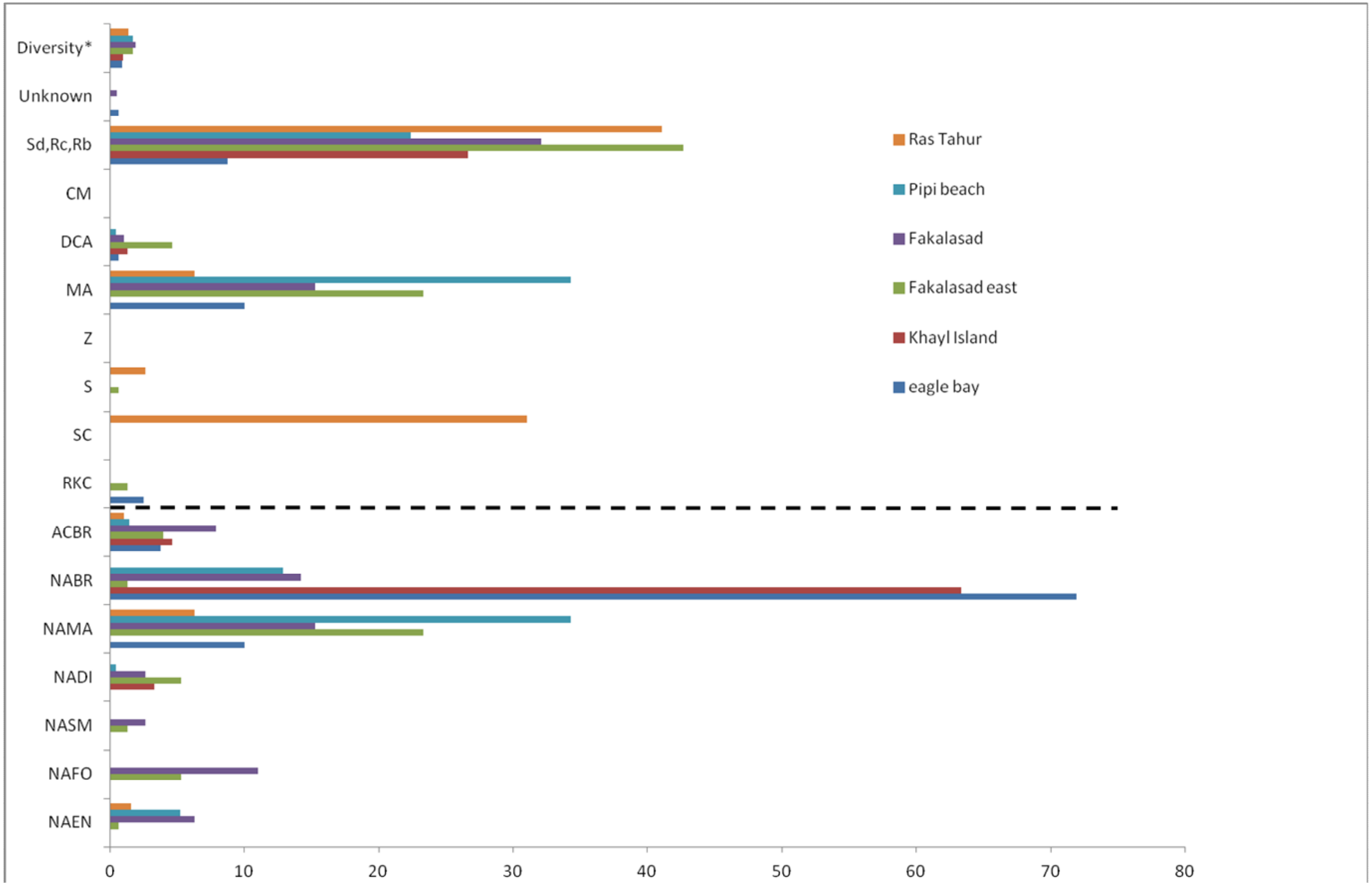


Figure 2.3r. Habitat profiles for six sites shown in Fig 2.3q above in the Musandam peninsula. Below the dotted black line are coral lifeforms. Above the line are other lifeforms such as corallimorphs, zooanthids and inanimate substrate (sand, rock and rubble). DCA is dead coral with algae, and MA is macroalgae, the equivalent of Reef Check's NIA. There are essentially three habitat types - Eagle Bay and Khayl Island are dominated by *Pocilliopora*; Fak Al Asad and Pipi Beach are dominated by lobed massive *Poritesi,* and finally, the current exposed point of Ras Tahur, dominated by soft corals, and small massive coral colonies.

Figure 2.3s. Soft coral colonies (*Lobophyton* sp.) growing on exposed current-scoured pavement at Ras Tahur northwest point (approximately 7 m depth).

Underwater impacts, coral damage and coral disease

The most significant regularly occurring impact on the reefs of Musandam was discarded fishing gear, including lines (of minimal impact), but more commonly fishing traps and gillnets (Figure 2.3t). However, compared to many other coral reef areas of the Indo-Pacific, there are no significant immediate anthropogenic threats to the reefs. Disease appears to be negligible, there is very little bleaching (Fig. 2.3u), and there is no dynamite fishing. Coral bleaching, due to the loss of the symbiotic algae known as zooxanthellae, was very low in the coral populations surveyed in Musandam in 2013, both in terms of the percentage of individual colony surface area affected (<6% on average), and the overall percentage of the living coral population (less than 0.3% on average across all sites visited).

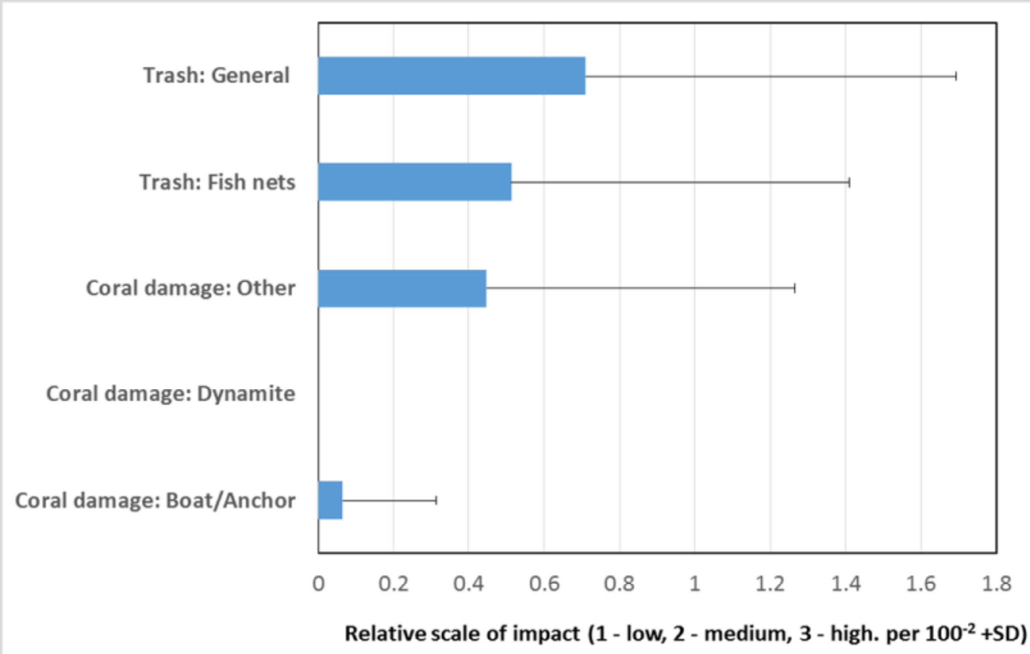


Figure 2.3t. Pooled average number of Reef Check impacts / trash categories (0=none; 1=low; 2=medium; 3=high). Coral damage (other) was often from *Drupella* feeding scars.

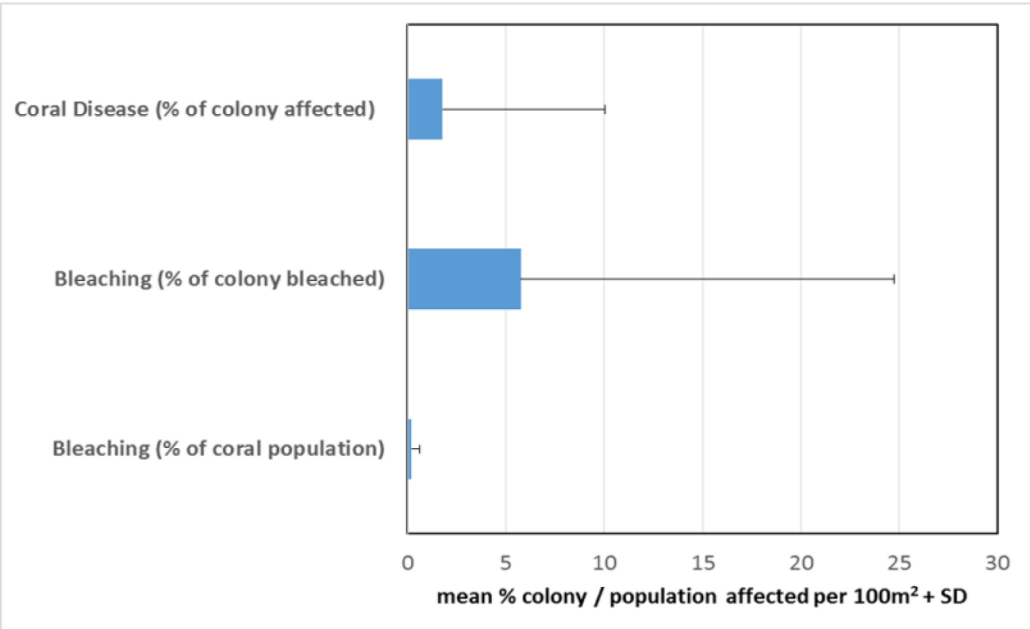


Figure 2.3u. Mean percentages of bleached and diseased coral colonies and populations per $100m^2$ in 2013.

2.4. Discussion & Conclusions

In the past decades there have not been many studies on the Musandam peninsula's coral reef biodiversity. The latest research in the region that collected data in the Musandam peninsula includes topics such as tropical harmful algal blooms (Bauman et al. 2010), kingfish fisheries (Claereboudt et al. 2004), shark fisheries (Henderson et al. 2007) and phytoplankton (Subba-Rao and Al-Yamani 1998). But the last published scientific study done exclusively in Musandam was conducted in 1971 and 1972 (Fraser et al. 1973). It is therefore still difficult to understand if the changes seen between the 2009 and 2010 expeditions are following a typical and already well established trend pattern or if they are changes that started recently.

One of the main objectives of this expedition, besides elucidating the possible impacts on the health of the Musandam coral reefs, is also to understand for the first time what characterises the marine life of the area. By comparing data collected in 2013 with data of previous years from the shallow reefs of Musandam, and also with future expeditions, it will be possible to apply these findings in management and conservation decisions as well as in local and international education.

Fish community

Fish populations of species and families other than grouper mirrored the numbers recorded in previous years. Diversity of the peninsula is low. Commonly only one bream species, one snapper and one lethrinid were seen on surveys. However, the numbers of these species were reasonably healthy.

Although an increase in the mean average number of groupers (hammour) was noticed in 2013, the average number is still relatively low, with 2.4 groupers over 30 cm recorded on average per 100m^2. However, this does represent a doubling of numbers compared to 2010 when only 1.15 individuals were recorded per 100m^2. Again in 2013, as in 2010, no groupers greater than 50 cm were seen. There is a targeted line and net fishery for groupers around the Musandam peninsula largely because of the high commercial value of this family for fishermen. Many groupers, such as *Epinephelus coioides*, are important commercially exploited species in the Arabian Gulf (Grandcourt et al. 2005; Siddeek 1999). The most abundant grouper size class is the smallest class, 30 – 40 cm. FishBase reports that the age of (female) sexual maturity of *E. coioides* is between 25 and 30 cm in the Arabian Gulf. It is likely that many of these individuals at this size are not attaining male sex (they are sequential hermaphrodites, with individuals starting as females, and later in life, turning into males). This is likely to be related to fishing pressure, which is not allowing this species to grow to anywhere near its maximum age or size. The larger the fish, the greater the reproductive output. This is particularly important with regard to female egg supply at spawning locations. We believe there is thus a strong need for conservation and management measures, as well as more research in this field from the Musandam area. This would clearly necessitate the establishment of grouper no-take zones (NTZs) as groupers are 'site attached' for much of their life, as well as the protection of spawning locations (if they are known) in order to enhance the fishery. Furthermore, we would recommend both minimum and maximum landing sizes for groupers (on a species basis) to ensure that a significant proportion of the population gets to female breeding age. We would suggest a minimum landing size of 30 cm for *E. coioides*. Furthermore, we would suggest a maximum landing size (38 cm) for species to ensure that enough males are generated within the population to spawn. Any *E coioides* caught over 38 cm in size should be released in order to ensure a significant portion of males remain within the population.

With these management measures in place, the population should recover within 5–10 years to be exponentially more productive (given studies from elsewhere) where even quite small sites have been protected (e.g. Hol Chan marine reserve in Belize).

Increased awareness of the life history requirements of the species amongst local fishermen (and fish buyers) would be necessary to tie in with management measures as discussed above. Otherwise, there will be little compliance.

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 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 with the possibility of reproductive failure (Sadovy and Vincent 2002).

New fisheries management measures

There has been a promising announcement of new Marine Protected Area management measures in the south-eastern section of the Musandam peninsula. The measures are to ban all fishing other than handlining in the inlets of Khor Najd and Khor Hablain to the southwest of the peninsula (Fig. 2.4a).

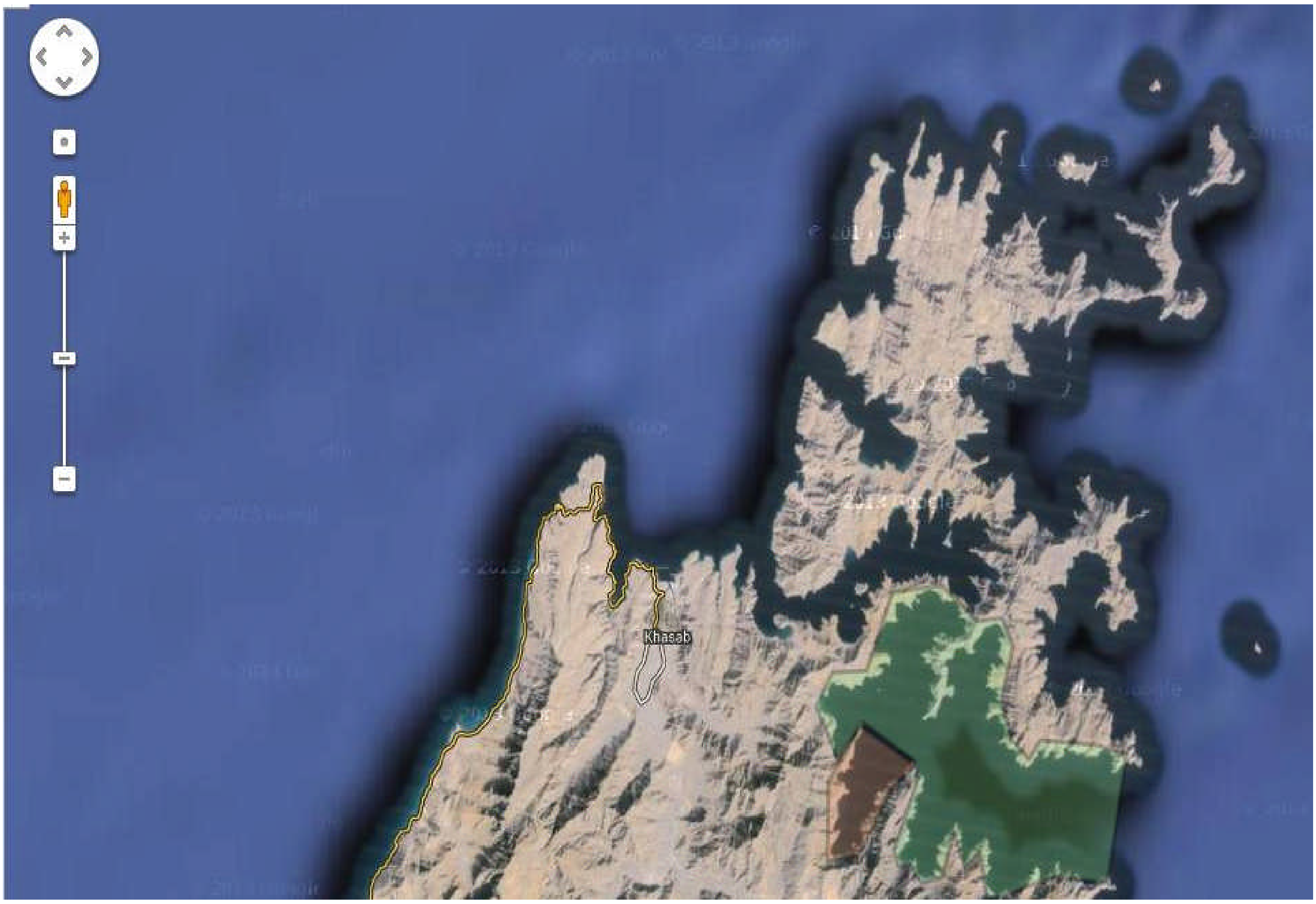


Figure 2.4a. The new Marine Protected Area measures in the Musandam peninsula. They are in the bays of Khor Najd (smaller inlet – brown), and Khor Hablain (green). Image courtesy of Google Earth.

Invertebrate community

The number of *Diadema* urchins was still high in 2013. More research needs to be conducted in the region regarding this species, because 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, making it difficult for new coral recruits to settle. An increase in numbers in different areas of the world's oceans is often indicative of overfishing of their predators, such as large emperor and triggerfish (Levitan 1992). Urchins can also graze around the bases of large coral colonies, destabilizing coral heads and increasing their susceptibility to getting knocked over by storm waves (Hodgson and Liebeler 2002).

Crown-of-thorns starfish (COTS; *Acanthaster planci*) numbers were very low, as in all other years. However, COTS abundance needs to be monitored carefully, firstly because coral mortality caused by the predatory COTS can be catastrophic or near-catastrophic in scale, and secondly, because no tritons (a COTS predator) were found during the expedition. The existence of tritons in the region is not confirmed and observations of such species have not been corroborated scientifically. Plagues of COTS are increasingly reported around areas of human activities, with two strong hypotheses for this advanced. The plagues may be initiated and certainly exacerbated by overfishing of key starfish predators; and/or increases in nutrient runoff from the land may favour the planktonic stages of the starfish (Goldberg and Wilkinson 2004). Excess nutrients are not a direct cause for concern in the straits of Hormuz, probably because of the considerable tidal flushing of the area.

The number of lobsters in Musandam is still low and serves as further evidence of fishing pressure (Hodgson and 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). Siddeek (1999) has also shown that lobster landings in the region have been dropping steadily, from a peak of 4,570 tons in 1991 to 2,032 tons in 1996. More fisheries landings studies need to be conducted in the region to understand if this number is still decreasing.

Substrate and benthic community

Knowing that many of the world's best reefs have a hard coral coverage of 32% (Hodgson and Liebeler 2002), the shallow reef coral cover of Musandam of 54% is very encouraging for coral reef conservationists, particularly given the unique stresses of the region (highly variable water temperature, salinity and visibility). There was little rubble observed on the reefs, although large damaged tracts of corals were periodically observed that appeared to have been caused by anchors (e.g. at Pipi Beach, Fig. 2.4b). Furthermore, individual colony health was outstanding, with very little observation of disease, mortality or epiphytisation (the growth of one organism on another). The size of *Porites* colonies at sites such as Pipi Beach suggests that there have been no serious wide-scale coral-damaging events in the past 400 years. Otherwise, these large (8 m basal diameter) colonies would not have appeared undamaged. If they had indeed been seriously impacted in the past 400 years, they have shown almost complete recovery in form and structure. These are likely to be some of the healthiest reefs of the entire Indo-Pacific, and particularly of the Arabian region, although species diversity is low (only 41 taxa were recorded 20 years ago by coral specialists (Salm 1993)). Salm (1993) reported the corals of the Musandam peninsula as not being as diverse as those from the Muscat area, but coral growth as being more abundant, and coral structure more substantial.

Impacts and coral damage

The highest general impact found in the region in both 2010 and 2013 was commercial fishing, albeit still at a low-medium level overall per site. Previous Biosphere Expeditions reports from Musandam have reported a heightened demand for diving in this popular area, mainly due to the current coastal development and increased number of hotels and dive centres in the Musandam region (Bento and Hammer 2010). Although general trash and destruction from boats and anchors are still below the low pressure level, these values are likely to increase in the future as a consequence of the increasing number of boats and divers in the region. However, because tourist trips currently appear to be short-term (day trips), most of the impact appears to be felt at Telegraph Island. Unfortunately, mooring buoys have only been installed at one dive site (not surveyed in 2013; Telegraph Island), and even these two buoys are not nearly enough for the number of boats that arrive during the weekends. When the expedition visited Telegraph Island in 2013, it appeared that these mooring buoys were actually absent. Including our own research vessel, a further three dhows carrying no fewer than 20 passengers on each vessel offloaded their clients in the waters of the island. It is clear from the brief snorkel undertaken by the author around this island that it is heavily impacted. It would appear that it is not naturally the best coral reef of the region, because of the enclosed nature of the bay, but coral cover appeared very low (<10%), and much of it was affected by anchor damage (Fig. 2.4c).

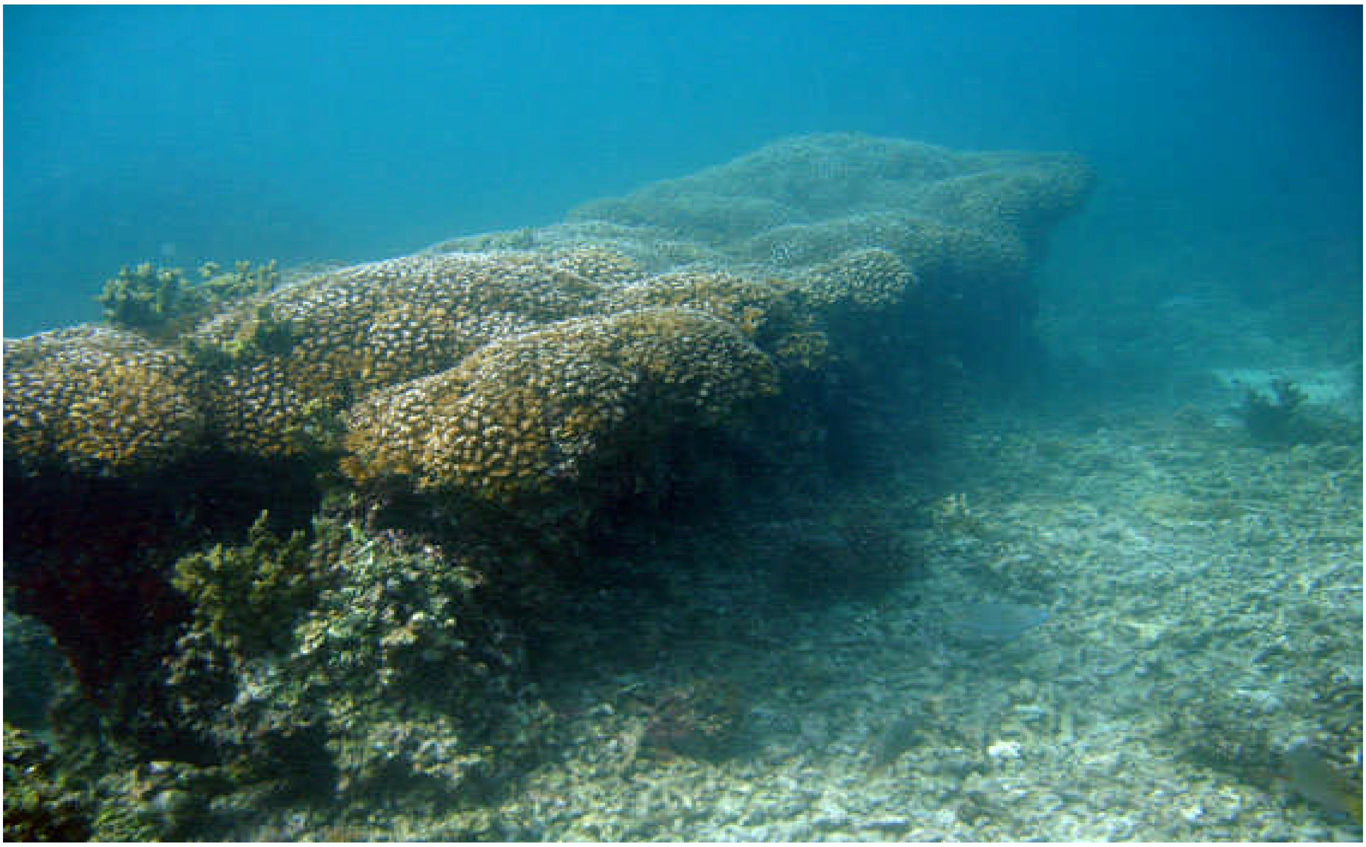


Figure 2.4b. A large *Pocillopora* stand adjacent to a rubble field at Pipi Beach. The direction of the rubble field (north-south) and the clear straight edge of the extant live coral reef suggests anchor damage from a large vessel.

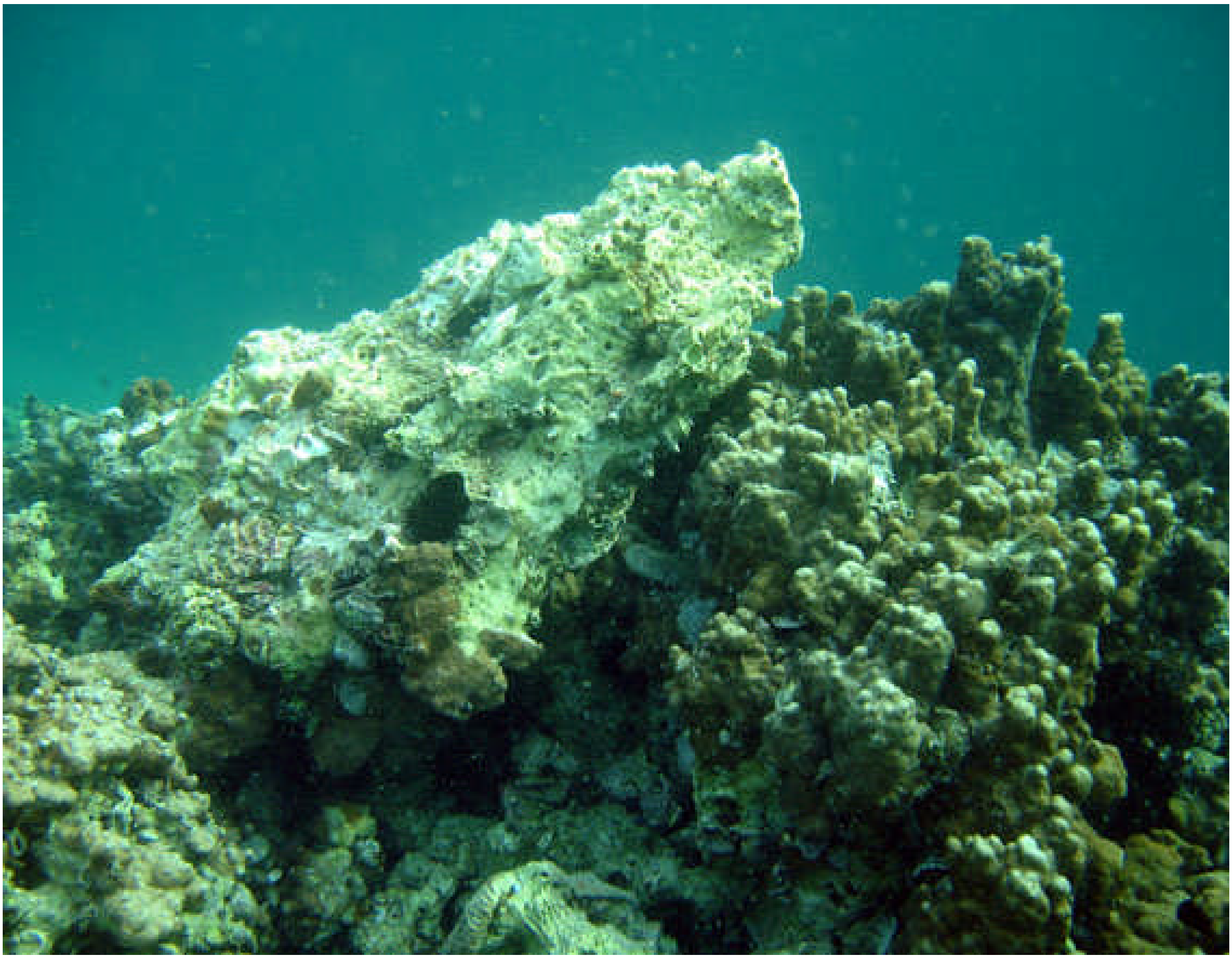


Figure 2.4c. Badly damaged coral at Telegraph Island. Anchors are routinely placed in living coral heads at the site.

There is an argument in conservation to heavily exploit (and potentially 'damage') certain reef areas, leaving the majority of other areas free of heavy use. This philosophy is used within the diving industries of the Great Barrier Reef Marine Park Authority (GBRMPA) to allow live-aboard and tourist snorkel / dive platforms to sustainably permanently moor at certain reefs. Strict rules apply to these licences in order to preserve surrounding coral reef habitats over the long-term. The phenomenon of 'sacrificial reefs' has also been illustrated in Bezaury Creel (1997) where Cancun's reefs are considered in certain locations to be 'sacrificial' where they are heavily exploited, thus preserving other reefs from heavy tourism impacts (usually pollution and physical abrasion from contact).

Besides human impacts, the most powerful determinants of coral reef health are temperature and salinity. Higher than normal sea surface temperature (SST) stresses corals and causes 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, a hypothesis exists saying that corals, via their symbiotic zooxanthellae, may evolve rapidly by acquiring more thermally tolerant symbionts within a few decades. This would make corals more thermally tolerant and allow them to 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 (Burt et al. 2008; Wilkinson 2008).

There might be a resistance of local coral communities in Musandam to wide temperature variation, since corals with higher SST variation exist in the region, as for example the Arabian Gulf and Eritrean corals, where 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's 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 as a result of natural and anthropogenic physical and chemical alterations in the environment. In the Arabian Gulf, several coral diseases occur that can be a factor in coral mortality. For example, black band disease (BBD) is a common disease on branching corals during summer, but tends to disappear in winter. Infection rates of 25% on *Acropora* species have been reported in some parts of the region. White band disease (WBD) is usually rare and not infectious, even in physical contact situations, but 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). In our surveys, the only corals that appeared to be affected by disease were faviid corals, but at an extremely low frequency.

2.5. Recommendations & Future Expedition Work

The work of the 2013 expedition shows clearly that Musandam probably hosts the most well-developed coral reefs of the region in a unique area of natural beauty as well as commercial importance.

However, there is a considerable demand and stress on them from the fishing community. The contrasting values of a high coral coverage of 54% and the low average numbers, small mean size and even absence of lobsters, moray eels, groupers and sweetlips show that this ecosystem holds potential, but that its finfish populations are below natural levels. This is inevitable in an area that relies predominantly on fishing and tourism, and mirrors the initial declines of most relatively isolated reefs around the world. However, there is the opportunity to recover these populations in sensitively managed areas that allow regeneration of fish communities, whilst allowing sustainable exploitation in different areas. This will necessarily require spatial management (a zoning system akin to the Great Barrier Reef would be effective) (Fig. 2.5a).

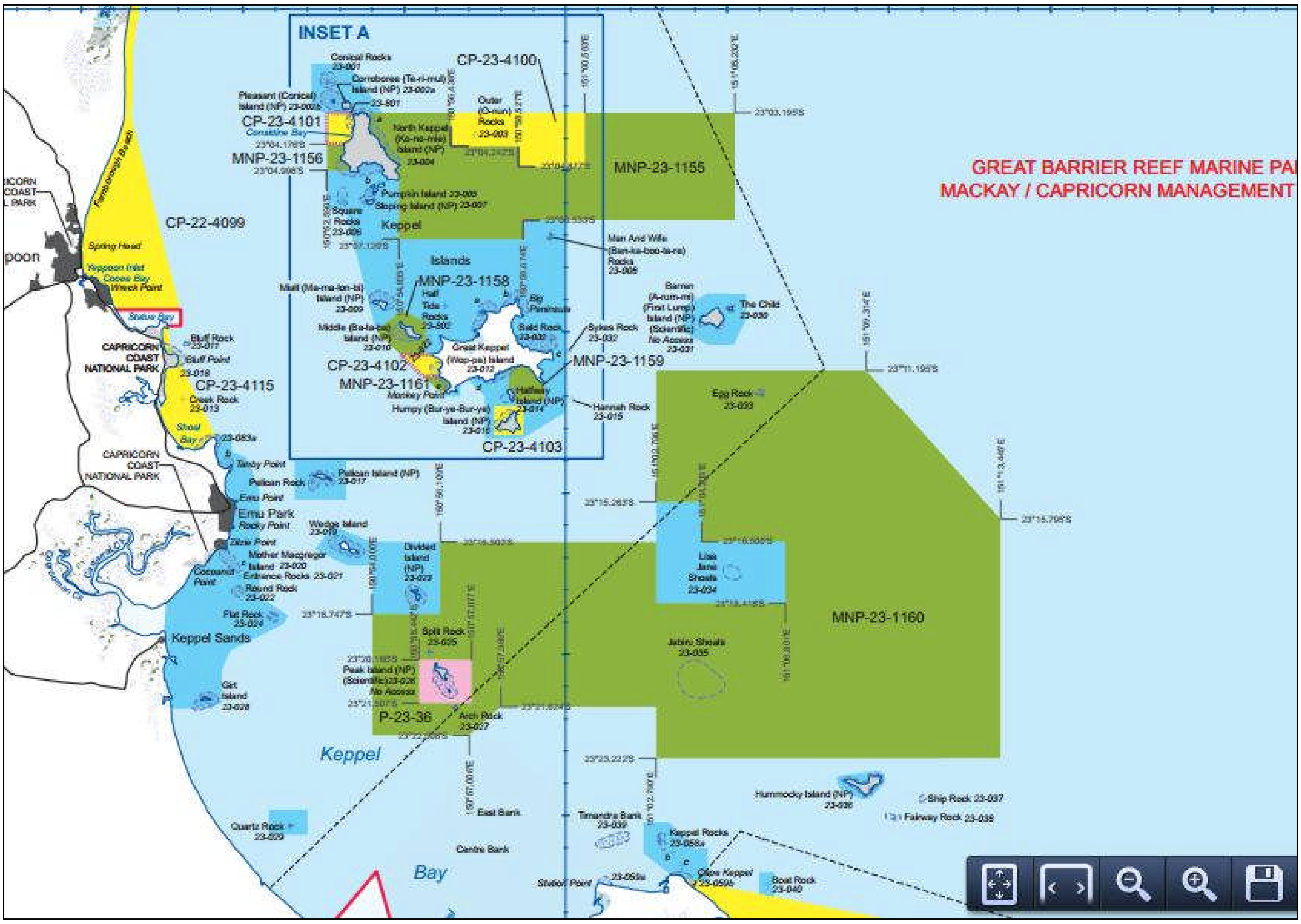


Figure 2.5a. A section of the zoning plan for the Great Barrier Reef Marine Park. A guide to the management of different areas (with different colours) is available from the Great Barrier Reef Marine Park Authority website[1].

Further surveys are needed as they will generate a better understanding of population sizes and trends, as well as the level of impacts and pressures for the area. And of course, it is now vital to record the trends in the two new managed areas to the southwest of the peninsula (Khor Najd and Hablain).

The continuing involvement of Omani citizens in the Biosphere Expeditions surveys and, in the case of the 2013 expedition, Omanis in Marine Protected Area management, is essential to provide a legacy to the project. Furthermore, it engenders a responsibility to the area, and will lead to better collaborative opportunities in the future. This is imperative in such a remote area, where governance arrangements associated with developing management measures will be difficult to introduce and enforce. The two scholars on this particular expedition were Nasser Al-Khanjary, who dives around the reefs of Muscat and the Dimaniyat Islands with the dive group 'Sea Legends'; and Amran Mohamed Al Kamzari from the Ministry of Environment and Climate affairs, who works as a part of the management group of the marine environment near to the central Omani coast.

All the studies, new policies and regulations that could be applied in Musandam have to take into account the need to improve social resilience by helping local communities to adapt to these changes. More strategies and approaches, done by management activities and planning for change, are needed to minimise impacts and build resilience. To achieve this resilience,

[1] http://www.gbrmpa.gov.au/zoning-permits-and-plans/zoning/zoning-guide-to-using-the-marine-park/interpreting-zones

focus should primarily exist on the management of land-based sources of pollution and of overfishing, whilst monitoring the indirect impacts of climate change (increased SST, bleaching impacts and acidification).

Musandam as a Marine Protected Network

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). There is 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, and Dhofar Khowrs Nature Reserve (fresh as well as brackish water lagoons) for the protection of seabirds and fish. All of these reserves are located outside Musandam Governorate and no protected area has been declared there yet. However, it is a stated government policy to have more reserves in each governorate. Hence it is welcome that the government announced the management measures around the Khor Najd and Khor Hablain inlets to the southwest of the peninsula.

We recommend a further progression of zoned area-based management measures throughout the peninsula that includes:

1. Minimum and maximum landing sizes for reef fish, particularly grouper, snapper, emperor and breams.
2. Minimum landing sizes for invertebrates (particularly molluscs).
3. Closed fishing during grouper spawning seasons, and at spawning points.
4. Closed seasons for fishing bait balls.
5. Entire closed areas for reef and pelagic-associated fisheries.
6. Reference areas where no extraction or deposition is allowed for preservation of all biodiversity (such as fish, motile invertebrates and coral populations).
7. Restrictions on longlining in the entire area, with potential full closures of this fishery in the area out to 3 nm from the nearest landmass.

The strong military presence in the area, due to its proximity to the Strait of Hormuz, is also significant for the implementation of a MPA, since 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 a wider MPA around the whole peninsula will help to mitigate the impacts of stresses found by the expedition, as well as create benefits such as (a) conserving biological diversity and associated ecosystems that cannot survive in most intensely managed seascapes; (b) promoting natural age structures in populations, increasing fish catches locally (by protecting critical spawning and nursery habitats) and in surrounding fishing grounds; (c) providing refuge for species that cannot survive in areas that continue to be fished; (d) providing alternative incomes for local communities and alleviating poverty; (e) protecting sensitive habitats from disturbances and damage from fishing gear; (f) eliminating "ghost fishing" by lost or discarded gear; (g) serving as a point of reference for 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) acting as focal points for public education and awareness on marine ecosystems and human impacts upon them (IUCN-WCPA 2008).

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

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

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

2.6. 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 for 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 Nature (EWS-WWF).

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

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

Bauman, A.G., Burt, J.A., Feary, D.A., Marquis, E. & Usseglio, P. (2010) Tropical harmful algal blooms: An emerging threat to coral reef communities? Marine Pollution Bulletin 60, 2117-2122.

Bento, R. & Hammer, M. (2010) Underwater pioneers: studying & protecting the unique coral reefs of the Musandam peninsula, Oman. In: Expedition Report (ed. M. Hammer), p. 51. Biosphere Expeditions.

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

Bezaury Creel, J.E. (1997) The reefs at Cancún: a social laboratory. In: Coral Reefs: Challenges and Opportunities for Sustainable Management (eds. M.E. Hatziolos, A.J. Hooten & M. Fodor). Washington: Proceedings of the 5th Annual World Bank Conference on Environmentally and Socially Sustainable Development.

Buddemeier, R.W., Baker, A.C., Fautin, D.G. & Jacobs, J.R. (2004) The Adaptive Hypothesis of Bleaching. Paper presented at: Coral Health and 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, p. 293. Rome: FAO.

Claereboudt, M.R.G., Al-Oufi, H.S., McIlwain, J. & Goddard, J.S. (2004) Relationships between fishing gear, size frequency and reproductive patterns for the kingfish (*Scomberomorus commerson* Lacépède) fishery in the Gulf of Oman. In: Management of Shared Fish Stocks (eds. A.I.L. Payne, C.M. O'Brien & S.I. Rogers), pp. 56-67. Oxford: Blackwell.

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, p. 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.

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. Australian Institute of Marine Science.

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.

Henderson, A.C., McIlwain, J.L., Al-Oufi, H.S. & Al-Sheili, S. (2007) The Sultanate of Oman shark fishery: Species composition, seasonality and diversity. Fisheries Research 86, 159-168.

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 (p. 86). California, USA: Reef Check Foundation.

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

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

Kohler, KE., and Gill, SM (2006). Coral Point Count with excel extensions (CPCe): A visual basic program for determination of coral and substrate coverage using random point count methodology. Computers and geosciences. 32 (9): 1259-1269.

Marshall, P. & Schuttenberg, H. (2006) A Reef Manager's Guide to Coral Bleaching (p. 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: Their Ecology and Conservation. NY: Oxford University Press.

Mooney, C. (2007) Storm World: Hurricanes, Politics, and the Battle Over Global Warming. Boston: Houghton Mifflin Harcourt.

Pilcher, N.J., Wilson, S., Alhazeem, S.H. & Shokri, M.R. (2000) Status of coral reefs in the Arabian/Arabian Gulf and Arabian Sea region (Middle East). In: Status of Coral Reefs of the World: 2000 (ed. C. Wilkinson), 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, C12038.

Price, A.R.G., Sheppard, C.R.C. & Roberts, C.M. (1993) The Gulf: Its biological setting. Marine Pollution Bulletin 27, 9-15.

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

Reynolds, R.M. (1993) Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman—Results from the *Mt Mitchell* expedition. Marine Pollution Bulletin 27, 35-59.

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 Sea. In: Status of Coral Reefs of the World: 2004 (ed. C. Wilkinson), pp. 155-170. Australian Institute of Marine Science.

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. (2001) Inhibition of reef framework by frequent disturbance: examples from the Arabian Gulf, South Africa, and the Cayman Islands. Palaeogeography, Palaeoclimatology and Palaeoecology 175, 79-101.

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.

Salm, R.V. (1993) Coral reefs of the Sultanate of Oman. Atoll Research Bulletin 380, 1-85.

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

Sheppard, C.R.C. & Loughland, R. (2002) Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf. Aquatic Ecosystem Health and Management 5, 395-402.

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 (p. 217). Kuwait: Regional Organization for the Protection of the Marine Environment.

Spalding, M., Ravilious, C. & Green, E.P. (2001) World Atlas of Coral Reefs. Berkeley, California: 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. Plankton Biology and Ecology 45, 101-116.

Wilkinson, C.R. (2004) Status of Coral Reefs of the World: 2004. Townsville, Australia: Australian Institute of Marine Science.

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 Arabian/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 Science.

Appendix I: Snorkel Field Notes

Field notes from the expedition of a snorkel (10 October 2013) around the north-western island from Ras Tahur to Coral Gardens.

Eagle Bay to Coral Gardens
The survey snorkel from EB to CG was conducted on 10/10/13. Two blacktip reef sharks, Picasso triggerfish.

26 23 07.4 ; 56 25 09.1 (10.45) **POINT 1**
Boulders to sand slope. Flat coral growth forms (no *Porites*). Corals and life adapted to wave action. Initial depth greater than sheltered conditions (straight to 4–6m). visibility much better (12m?). Abundant emperors and surgeonfish. No *Diadema*. Brain corals abundant. Starry puffers at three sections of the dive. No urchins, no *Porites*, and no *Pocillopora*. Coral cover 30%.

26 23 06.7; 56 25 04.8 (10.55) **POINT 2**
Corals absent on wave exposed rock. Oysters and clams on intertidal and shallow subtidal. Some parrotfish and surgeonfish. Flat sand and boulder field with far less life (exposed to wave action). Sand is very coarse. No urchins, no *Porites* and no *Pocillopora*. Coral cover 2–5%.

26 23 04.6; 56 24 59.6 (11.05) **POINT 3**
Sparse flat and encrusting corals on large boulders fallen from island. (>3m). Corals more abundant on deep boulders. Turf algae on rocks <3m. Blacktip reef shark (4 ft). Coral cover 20%.

26 23 01.4 ; 56 24 56.6 (11.14) **POINT 4**
20 rabbitfish. Corals more foliose and branching. *Acropora* dominant. *Montipora* starts where surge is less (in lee of boulders). Tops of boulders host *Symphilia*. Viz is less (but still good). Dive ends with blacktip reef sharks. 20 streaked rabbitfish, 20–30 trevally. Coral cover 35%.

26 22 55.1; 56 24 53.9 (11.25). **POINT 5**

26 22 52.1 ; 56 24 51.1 (11.35) another blacktip. Numerous 2 bar bream. **POINT 6**

Geology and taphonomy
Geological distribution of reefs and sedimentary deposits (from land rather than corals) results in shallow waters near to embayments and headlands, and the distribution of hard corals only less than 12m for most sites. Light is perhaps a limiting factor, with viz decreasing considerably >3m at both sites. The cliffs are highly erosional. There are often streaks of sediments at the surface. Perhaps these sands are rich in limited minerals such as iron oxides that provide nutrients for plankton blooms?

Appendix II: Expedition diary and reports

A multimedia expedition diary is available on http://biosphereexpeditions.wordpress.com/category/expedition-blogs/musandam-2013/

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