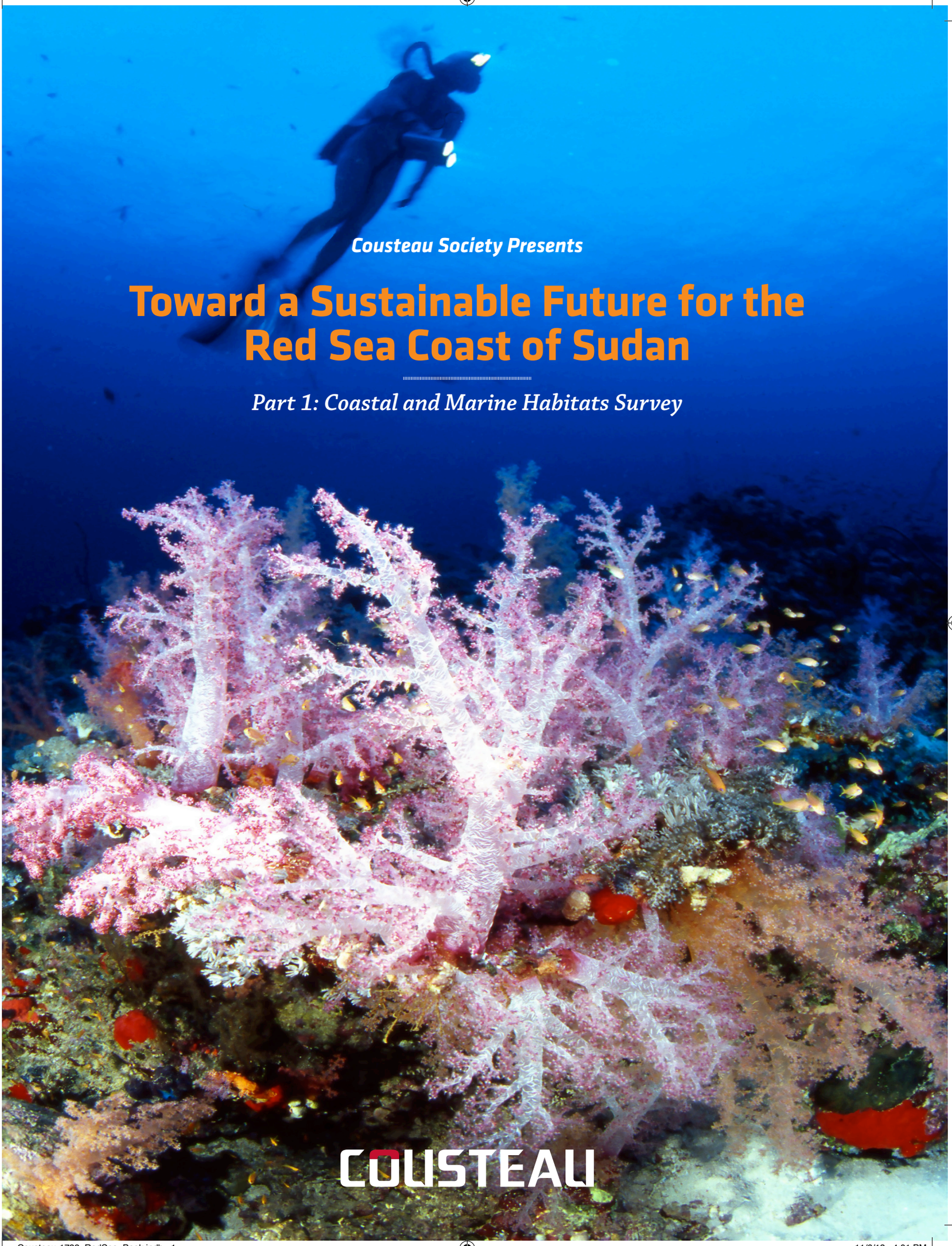


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Toward a Sustainable Future for the Red Sea Coast of Sudan

Part 1: Coastal and Marine Habitats Survey

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Cousteau Society Presents

Toward a Sustainable Future for the Red Sea Coast of North Sudan

Part 1: Coastal and Marine Habitats Survey

This program would have not be possible without the generous financial support of the European Commission and IWC Schaffhausen.

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Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA)

The United Nations Educational Scientific and Cultural Organisation (UNESCO)

Afrikan Parks Conservation (APC)

Coastal Oceans Research and Development in the Indian Ocean (CORDIO)

The Centre for Environment and Development for the Arab Region and Europe (CEDARE)

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The following people have also provided important information and advice, and their assistance is also acknowledged:

Dr. Taha Bedawi, *former Director of the ICZM Office, Port Sudan, Sudan*

Mr. Claudio Scarpellini, *owner and skipper of the MSY Elegante, WildSea Expedition*

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Pagoulatos family, *owners and managers of the Acropole Hotel, Khartoum, Sudan*

Layout & design:

Faircom New York

Photographic material by courtesy:

The Cousteau Society

Dr. Rebecca Klaus

Dr. Jeremy Kemp

African Parks Foundation

PROGRAM DEVELOPED BY EQUIPE COUSTEAU / THE COUSTEAU SOCIETY (EDS. T. CHEKCHAK AND R. KLAUS) (2013) TOWARD A SUSTAINABLE FUTURE FOR THE RED SEA COAST OF SUDAN. PART 1: COASTAL AND MARINE HABITATS SURVEY. PUBLISHED BY THE COUSTEAU SOCIETY, CUSTODIANS OF THE SEA • 4 EAST 27TH STREET • P.O. BOX 20321 • NEW YORK, NY 10001.

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ACKNOWLEDGEMENTS

Equipe Cousteau would like to thank the National and Red Sea State government organisations of Sudan, especially the Governor of the Red Sea State of Sudan, The Honourable Mohammed Tahir Aila and the members of its Government and other Red Sea institutions involved in this project. They shared with us the vision that Integrated Coastal Zone Management is a necessity for the future sustainable development of the magnificent coast of the Red Sea State of Sudan.

This programme would not have been possible without the support of the European Commission and we wish to especially thank Mr Paul Symonds (former Food Security Coordinator, Delegation of The European Commission To Sudan) who was a very responsive and supportive officer in charge of the follow-up of this programme, with a clear vision of environmental issues and opportunities for Sudan. We are grateful for the support given by PERSGA (The Regional Organization for the Conservation of the Environment of the Red Sea & Gulf of Aden) and want to especially thank Ms Khulood Tubaishat (former Advisor for Policy and Coastal Governance, PERSGA). Without her continuous involvement and commitment to the project, and the high level advisory and political support she provided, in Sudan and internationally, much less would have been achieved.

We would like to highlight the role of Dr Taha Bedawi, former Director of the ICZM Office in Port Sudan in coordinating locally the project. We are also grateful to Mr Mohammed Younis, formerly of the Wildlife Conservation General Administration, Dr Jeremy Kemp and Dr Rebecca Klaus for their continued commitment to the creation and sustainable management of the Marine Protected Areas of Sudan. We will never forget the commitment and support provided during the boat based survey by Mr Claudio Scarpellini, owner and skipper of the MSY Elegante.

We are grateful for the support given by Mr Mustafa El Taïeb, former Director of the Division of Science Analysis and Policies (UNESCO, Natural Sciences Sector), Mr Natarajan Ishwaran, Director of the Division of Ecological and Earth Sciences, Mr Peter Dogse, Man and the Biosphere Programme (UNESCO, Division of Ecological Sciences) and Mr Ibrahim Sidibé, former Head of Office, UNESCO Sudan. We also want to thank Mr Abubaker Mustafa Mohammed Khair, founder and chairman of the Board of Trustees of The Future University, and the former Governor of the Red Sea State His Excellency Mr Hatem El-Wassila, for their early-stage support of this work and for helping to get the support of the highest political authorities in Sudan.

Tarik Chekchak
Director for Sciences & Environment

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Jacques Cousteau



Foreword

by Francine Cousteau

IN THE FOOTSTEPS OF JACQUES COUSTEAU...

Fifty years ago Jacques Cousteau's Calypso dropped anchor on the coral reef Sha'ab Rumi off the coast of Sudan.

It was there that Cousteau designed and built the first underwater village as a place to test the inventions he created that would enable people to live and work under the sea. The brave pioneers on his crew spent a month under water, brilliantly demonstrating the vision of Captain Cousteau.

Their experiences and subsequent contributions to science – including invaluable achievements in training astronauts to work in a weightless environment – have been the subject of numerous scientific publications.

In 2003/2004 the Cousteau Society revisited the Captain's trail with Aquanaut Claude Wesly, who in 1963 at Sha'ab Rumi had lived and slept in the village immersed under the sea, and later had seen images of it in the Captain's "The World Without Sun" feature, which won an Oscar in 1964. This was a hugely emotional moment not only for Claude and the entire team, but also for some local Sudanese who recalled childhood memories of the Calypso and its Captain.

Cousteau was always looking to the future and, as I thought of him and of the permanent residents of Sha'ab Rumi, I decided to use the occasion of our return to Sudan to establish a long-term goal of providing these men and women with highly-skilled work that will help them build their future.

We have had boots on the ground since 2003, with dozens of top scientists from around the world producing a highly-detailed study on the Sudanese coast. As part of this effort, we created the UNESCO Cousteau University Chair in Khartoum. Since 2010, we have been developing a system of acoustic and satellite monitoring of sting rays and sharks in the Red Sea manned by Sudanese teams. Scientific discoveries already have been made on how coral adapts to extreme conditions, and on the hybridization of the species.

The two volumes presented here are available to scientists and policy makers who need to take better care of generations to come. I express my deep gratitude to all those who have helped us achieve this work that extends the path defined by Jacques Cousteau.



Francine Cousteau
President
Team Cousteau
The Cousteau Society

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LIST OF ACRONYMS

ACORD	Agency for Cooperation in Research and Development
AGRRA	Atlantic Gulf Rapid Reef Assessment
AIG	Alternative Income-Generating Activities
APF	African Parks Foundation
CBD	Convention on Biological Diversity
CBO	Community-Based Organisation
CBS	Central Bureau of Statistics
CEDARE	Centre for Environment and Development in the Arab Region and Europe
CLA	Coastal Livelihoods Assessment
CORDIO	Coastal Oceans Research and Development in the Indian Ocean
CPA	Comprehensive Peace Agreement
CPCe	Coral Point Count with Excel Extensions
DMNP	Dungonab Bay – Mukkawar Island National Park
EC	European Commission
EIA	Environmental Impact Assessment
EIA-WG	Environmental Impact Assessment Working Group
EFA	Education for All (UN)
EPSSim	Education Policy and Strategy Simulation Model
ESC	Environmental School Club
ESPA	Eastern Sudan Peace Agreement
ESSP	Education Sector Strategic Plan
EWG	Education Working Group
FAD	Fish Aggregating Devices
FAO	Food and Agriculture Organisation of the United Nations
FMoGE	Federal Ministry of General Education
FTI	Fast Track Initiative (UN)
GAM	Global Acute Malnutrition
GDP	Gross Domestic Product
GER	Gross Enrolment Ratio
GIS	Geographic Information System
GMP	General Management Plan
GONU	Government of National Unity
GoS	Government of Sudan
GPI	Gender Parity Index
HCENR	Higher Council for Environment and Natural Resources
HQ	Headquarters
ICZM	Integrated Coastal Zone Management
ICZMO	Integrated Coastal Zone Management Office
IDPs	Internally Displaced People
IMO	International Maritime Organisation
INC	Interim National Constitution
IOC	International Oceanographic Commission
ISO	International Organisation for Standardisation
JAM	Joint Assessment Mission
LBS	Land-Based Survey
LPG	Liquid Petroleum Gas
M&E	Monitoring and Evaluation
MAD	Maritime Administration Directorate
MDGs	Millennium Development Goals
MDTF	Multi-Donor Trust Fund

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MEAs	Multilateral Environmental Agreements
M&E Manual	Monitoring and Evaluation Manual
MEPA	Marine Environment Protection Administration
MoAAWNR	Ministry of Agriculture, Animal Welfare and Natural Resources
MoET	Ministry of Environment and Tourism
MPA	Marine Protected Area
MRI	Marine Research Institute
NBSAP	National Biodiversity Strategy and Action Plan
NER	Net Enrolment Ratio
NGO	Non-Governmental Organisation
NOAA	National Oceanographic and Atmospheric Administration
NOSCP	National Oil Spill Contingency Plan
NRT	Net Registered Ton
PAP/RAC	Priority Actions Programme – The Coastal Management Centre
PASED	Port Sudan Association for Entrepreneur Development
PEMSEA	Partnerships in Environmental Management for the Seas of East Asia
PERSGA	The Regional Organisation for the Conservation of the Environment in the Red Sea and Gulf of Aden
PHC	Public Health Centres
PIT	Point Intercept Transect
PRIMER	Plymouth Routines In Multivariate Ecological Research
REA	Rapid Ecological Assessment
RRP	Rehabilitation and Recovery Programme
RSGA	Red Sea and Gulf of Aden Region
RSS	Red Sea State
RSSMH	Red Sea State Ministry of Health
RSU	Red Sea University
SC	Stakeholder Consultation
SDD	Sudanese Dinars
SECS-RSS	Sudan Environment Conservation Society – Red Sea State
SEPC	Socioeconomic Programme Coordinator
SIA	Social Impact Assessment
SMNP	Sanganeb Atoll Marine National Park
SMoE	State Ministry of Education
SocMon	Socioeconomic Monitoring Programme
SPC	Sea Ports Corporation
SPLM/A	Sudan People's Liberation Movement/Army
SWG	Socioeconomic Working Group
ToR	Terms of Reference
UBE	Universal Basic Education
UNDP	United Nations Development Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation
UNICEF	United Nations International Children's Fund
UNIDO	United Nations Industrial Development Organisation
UPE	Universal Primary Education
UVC	Underwater Visual Census
VECs	Valued Environmental Components
VEMP	Village Environmental Management Plan
WB	World Bank
WCGA	Wildlife Conservation General Administration
WHC	World Heritage Centre
WHO	World Health Organisation
WSSD	World Summit on Sustainable Development

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GLOSSARY

Bahari silif	Marine customary law
Beja	Dominant ethnic group in RSS
Birish	Woven matting over wooden frames used for building shelters
Dangiet, lahagen, togwan	Gifts and loans governed by the silif and administered through the patriarchal leadership to diwab members needing support in times of sickness, famine, homelessness, travel, marriage and death (a form of social security in a sense).
Dewali	State Governor
Dh'ufra	Opercula of Lambis and Strombus mollusc species, used for making perfume (khumbra)
Diwab	Kinship groups
Khor	Freshwater river
Khumbra	Traditional perfume made by using the opercula of Lambis and Strombus molluscs
Kurai	Terrestrial territories
Mahallia	Locality
Nazir	Tribal leader in Beja communities
Omda	Below the Nazir in the leadership hierarchy
Sakanab	Ritualised greetings in the Beja custom
Sanduk	Traditional wooden fishing boat
Sheik	Person providing the institutional framework for Beja communities and leading large extended families (positioned below the Omdas in the Beja leadership hierarchy)
Silif	Beja customary law governing economic, social and environmental aspects of Beja life, including resource and land management
TuBedawye	Traditional Beja language
Wadi	Dry riverbed
Wilaya	State
Wali	Governor

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EXECUTIVE SUMMARY

In 2007, more than 50 years after Jacques Cousteau filmed the reefs of Sudan, during the making of the movies *The Silent World* and *The World without Sun,* Equipe Cousteau gathered a network of partners and a multidisciplinary team to carry out the most comprehensive survey of the Sudanese Red Sea coastal and marine environment ever attempted. This document reports the findings from these surveys, and provides baseline information intended to assist Sudan in establishing Integrated Coastal Zone Management (ICZM) of its unique and valuable coastal and marine resources.

Sudan has a long history of instability and during the 48 years since independence there have been 37 years of war, and this provides the backdrop to the ICZM survey. The successful Eastern Peace Agreement in 2006 provided an opportunity to begin to address some of the development needs of the Red Sea State by working to conserve Sudan's rich natural heritage and to ensure that the coastal communities would benefit in a sustainable way. South Sudan became an independent state following a referendum on 09th July 2011. Much of both countries, including the Red Sea State, are still in a state of social, economic, political and environmental disorder. The ICZM Project was designed to help decision makers, coastal entrepreneurs and managers to mitigate future conflicts that may arise over natural resource use, distribution and over-exploitation.

The ICZM survey report is divided into two volumes: the first volume focuses on the marine and coastal habitats and biodiversity and the second volume focuses on the socio-economic situation and governance of the Red Sea State. The current volume reports the main results of a month long boat-based survey of the Sudanese marine environment completed by the Equipe Cousteau team in December 2007, and the results of a coastal survey completed by partners from the Red Sea University in early 2008. The Equipe Cousteau team who participated in these surveys adopted a combination of methods that included: (i) subtidal diving surveys to assess the status and diversity of benthic communities on the reefs of Sudan and their associated fish and macro-invertebrate communities; (ii) a rapid fishery survey to identify the commercially fished stocks, the status of these stocks and key environmental issues linked to the exploitation of living resources; (iii) surveys of shark populations and the establishment of a monitoring programme in association with the local dive operators; (iv) a rapid assessment method to collect ground-truthing data for use in mapping the spatial distribution of marine habitats; (v) coastal vegetation surveys and; (vi) ground truthing and rapid assessments of coastal habitats. The marine and coastal ground-truthing data were used in combination with satellite-based remote sensing data to create habitat maps illustrating the distribution of coastal and marine biotopes. The current management status and situation within the Marine Protected Areas of Sudan are presented, and recommendations for improved management of coastal and marine resources are provided.

For completeness, the Executive Summary, introductory materials and the ***analysis and recommendations for key environmental issues and future interventions*** that could lead to an efficient integrated approach to the complex coastal systems are presented within both Volumes.

Tarik Chekchak
Director for Sciences & Environment

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SUMMARY OF KEY FINDINGS FOR THE ICZM SURVEY

Coastal and Marine Habitats and Biodiversity

1. Fifty years after Cousteau first dived in the Sudanese Red Sea there has been relatively little development along the Red Sea coast. Much of the coastal and marine habitats remain relatively undisturbed.

2. Sudan hosts an extensive and complex network of coral reefs, seagrass beds, mangroves and other shallow marine habitats that support a diversity of marine fauna and flora.

3. The coral reefs exhibit evidence of both resistance and resilience to coral bleaching events in areas around Dungonab Bay and further south around Suakin.

4. Only low numbers of commercially important finfish and invertebrates were observed, indicating severe overfishing of specific groups, including illegal fishing.

5. There are serious concerns about the health of the shark populations in Sudan.

6. Urgent regulation and enforcement are needed in all fisheries.

Socio-economic development

7. Much of the coastal region of Sudan has remained unaffected by the changes taking place in many other countries bordering the Red Sea over the past 50 years.

8. Coastal development is currently limited to a 70 km strip, extending from Port Sudan south to Suakin; damage due to construction within this strip is already quite extensive.

9. The offshore environment and reef complexes remain relatively undisturbed by human pressures other than fishing.

10. Following the peace agreement and the recent discovery of oil and gas reserves, economic transformation may result in a rapid surge in coastal development and associated risks.

11. While the centre for industrial development is likely to remain in Port Sudan and the Suakin area, tourism development activities may extend northwards from Port Sudan and the Dungonab Bay MPA, as well as southwards to the Suakin area.

12. The new coastal road from Port Sudan to Egypt is nearing completion, which increases the accessibility of vast stretches of hitherto relatively undisturbed coast, creating opportunities for development to the north of Port Sudan, with all the associated risks.

13. The Red Sea State has a significant natural resource base but it has yet to benefit fully from these natural and strategic assets and remains one of the poorest regions in Sudan.

14. The root cause of conflict in Sudan's eastern region is linked to natural resource issues, such as access to natural resources, equity in resource distribution and livelihoods.

15. The Dungonab Bay National Park and Suakin areas are potential pilot sites for livelihood intervention testing. Six sectors have been identified that could be developed for livelihood intervention:

a. offshore fishing;

b. aquaculture;

c. pearl oyster farming;

d. animal husbandry;

e. trading centres; and,

f. sustainable tourism.

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Governance and Planning

16. There is potential for enhanced environmental governance in RSS, as exhibited by the willingness of the local government and the community.

17. The promulgation of the environmental law in 2007 and the establishment of the Ministry of Environment and Tourism and the ICZM Office illustrate the significant efforts by the RSS that have been made to establish viable environmental institutions and framework.

18. Environmental issues have not yet been mainstreamed into the planning process within the Red Sea State and there is an urgent need to support this effort.

19. Local authorities have a role to play in environmental management in general, and in Environmental Impact Assessments (EIAs) in particular.

20. Local and international NGOs in RSS have made significant contributions to the protection of the environment, and there is a need to strengthen their participation in all relevant activities.

21. With regard to EIAs, it was evident that MoET currently lacks the necessary and the appropriate institutional framework for establishing an "EIA" system in RSS.

22. Mass tourism has not yet started in Sudan, the relevant authorities will need to regulate the growth of this sector, and focus on promoting "ecotourism" and local community participation.

23. Since the departure of the African Park Foundation, the two Marine Protected Areas (MPA)are no longer managed. This is a major setback, not only for their proper management in general that includes the development of these areas, but also for the ongoing process of UNESCO World Marine Heritage sites nomination.

24. Education levels in the RSS are low (illiteracy averaged 50%) due to inadequate educational infrastructure, the legacy of traditionally discouraging women from pursuing education and the lack of adequate training and remuneration for teachers.

25. Complete educational data compilation is needed so as to build an appropriate RSS education development strategy with the support of UNESCO.

26. The Environmental School Clubsprovide a good basis to further developing environmental awareness amongst young people.

27. The possible piloting of UNESCO-MAB's Teaching Resource Kit for Dryland Countries in selected RSS schools could benefit environmental education efforts in the State.

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SUMMARY OF RECOMMENDATIONS FROM THE SUDAN ICZM PROJECT (PHASE I)

Code	Description of the action recommended
Coastal and Marine Habitats and Biodiversity of Red Sea State	
Hab	**HABITAT AND BIODIVERSITY**
R-Hab-1	Complete geographically comprehensive baseline habitat and biodiversity studies in the following areas: • From Dungonab Bay (at approximately 21°15'N), northwards to the Egyptian border; • From Shubuk (19°N), southwards, as far as possible, in the direction of the Eritrean border; • Remote outer reefs, in the Suakin Archipelago, particularly those within the eastern and southern parts (also see recommendation R- HAB-4).
R-Hab-2	Develop and implement a National Strategy for the Management of Marine and Coastal Flagship Species.
R-Hab-3	Establish a baseline water quality monitoring programme with sampling stations situated along the coast.
R-Hab-4	Implement a detailed, specifically management-oriented, survey programme of the Suakin area and Shubuk.
R-Hab-5	Implement fisheries management for sustainability.
R-Hab-6	Urgently incorporate basic considerations of sustainable development into coastal development and infrastructure projects and initiatives at both the national and State levels.
R-Hab-7	Support the development of local collaborative management schemes for traditional fisheries, fully involving resource users in decision making (MFA), as well as monitoring and surveillance tasks.
R-Hab-8	Adequately fund the marine Fisheries inspection and data collection services operating out of the Red Sea ports to enable monitoring of catches and offshore fisheries, including foreign vessels.
R-Hab-9	Implement and enforce management restrictions to control the sea cucumber fishery.
GIS	**GEOGRAPHICAL INFORMATION SYSTEM (GIS): A TOOL FOR ICZM DECISION MAKING**
R-GIS-1	Continue to support the development of a GIS to provide the basis for Marine Spatial Planning for the Red Sea State.
R-GIS-2	Establish and train a regional team of GIS specialists.
R-GIS-3	Conduct an assessment of GIS capacity needs and identify appropriate institutional arrangements.
R-GIS-4	Develop a GIS Website and use it for awareness raising.
R-GIS-5	Expand the applied use of remote sensing and GIS to improve decision making in RSS.

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MPA	**INTERNATIONAL SIGNIFICANCE OF SUDAN'S MARINE PROTECTED AREAS**
R-MPA-1	Implement effective management of the two existing globally and nationally important MPAs at Sanganeb and Dungonab.
R-MPA-2	Expand the existing MPA network to meet the recommended 10% protection of all coastal and marine areas by 2020.
R-MPA-3	Implement Next Steps and Way-Forward for World Heritage Status of DMNP and SMNP.
Governance and planning in Red Sea State	
Gov	**IMPROVING COASTAL AND OCEAN GOVERNANCE**
R-Gov-1	Strengthening institutional capacity: in particular, by allocating human and financial resources in order effectively to support government efforts to incorporate basic considerations of ICZM into pertinent sectoral policies and guidelines, related to coastal development and infrastructure projects and initiatives at the national and State levels.
R-Gov-2	Establish and develop mechanisms to monitor and evaluate environmental management and the extent to which the objectives of environmental priorities are efficiently met.
R- Gov-3	Facilitate private sector participation in environmental management functions.
R-Gov-4	Strengthen the established GIS unit in the ICZM office, where data collection and analysis should be organised, to ensure the free flow of information between all involved actors on the governmental and non-governmental levels.
R-Gov-5	Pursue the links between Sudan and its neighbouring countries, as they will be essential. PERSGA and CEDARE will play a key role in ensuring coordination and knowledge transfer with other countries of the Red Sea.
R-Gov-6	Strengthening Institutional Capacity and Participation to conduct rigid ElA (including SIA components).
R-Gov-7	Strengthening the EIA Legal Framework.
R-Gov-8	Promote Environmental Best Practice for Development Projects.
Edu	**EDUCATION AND SUSTAINABILITY**
R-Edu1	Establish collaboration with the other education projects being conducted in RSS (inter alia, the WB-UNICEF and EC initiatives) in order to determine division of responsibilities so as to avoid duplication of efforts and to utilise available resources efficiently.
R-Edu2	UNESCO should be approached to provide the SMoE, EWG and ICZM Office with a methodology model for partnership mapping, as well as to help coordinate with the EC and UNICEF to explore funding opportunities for future education planning work.
R-Edu3	Establish a longer-term official partnership agreement between RSS SMoE and UNESCO in order to continue capacity-transfer for all stages of the education policy planning process and strategy development phases.
R-Edu4	Participants of the UNESCO workshop conducted as part of the ICZM Survey agreed that more State actors should receive UNESCO training: more training should be conducted and should span a longer time period.
R-Edu5	Complete education data compilation is needed so as to build an appropriate RSS education sector development strategy.

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R-Edu6	Data gathering should feed a brief education sector analysis which should be drafted for assessing the emerging needs of the RSS educational system, and which provides both qualitative and quantitative analysis, as well as consideration for environmental education.
R-Edu7	Pursue working with an existing Beja Education Fund for the Red Sea State to integrate efforts in strengthening the educational system for marginalised and nomadic communities in RSS, and ensuring that the needs of these under-served groups are adequately considered in the RSS Education Strategy.
R-Edu8	Identification of priority needs and development of a project proposal for the strengthening of environmental school clubs in RSS. Such considerations as the installation of solar energy devices in schools should be included.
R-Edu9	Continue discussions with the UNESCO ESD programme to explore the feasibility for harnessing UNESCO resources and expertise in expanding RSS's environmental education approach. Similarly, the possible piloting of UNESCO-MAB's Teaching Resource Kit for Dryland Countries in select RSS schools could benefit environmental education efforts in the State.
R-Edu10	The legal foundations for building a concrete environmental education programme in RSS should be further explored, especially given that the Federal Government acknowledges the need for ESD and environmental education and several avenues exist for application in the education system.
Socio Economic development in the Red Sea State	
Liv	**LIVELIHOOD OPPORTUNITIES AND SUSTAINABLE DEVELOPMENT**
R-Liv-1	Sustainable Fisheries: develop traditional regulation system, zoning, specific protection for overfished species, new opportunities and stronger control.
R-Liv-2	Sustainable Tourism: conduct an urgent assessment and develop investors' profile.
R-Liv-3	Develop Tools for Livelihoods Intervention: Community fund, technical support and equipment provision.
R-Liv-4	Develop six sectors for livelihood intervention: Offshore fishing, Aquaculture, Pearl Oyster Farming, Animal Husbandry, Trading Centres and Tourism.
R-Liv-5	Strengthen Partnerships for Livelihood Alternatives.
R-Liv-6	Improve Livelihoods in Inland RSS (Sinkat-Arkawit area).
Risk	**COASTAL DEVELOPMENT AND RISK MANAGEMENT**
R-Risk-1	Issue, ratify and enforce the necessary bylaws and regulations, special attention and priority to be given to the monitoring and inspection bylaws, fisheries, EIA, marine environment and coastal protection, air and water protection, etc.
R-Risk-2	Harmonise the international, regional and national legal framework and ensure incorporation of international environmental obligations into national laws and instruments.
Socio	**DESIGNING A SOCIO-ECONOMIC MONITORING PROGRAMME FOR RSS**
R-Socio-1	Implement the follow-up Socio-economic Monitoring work programme designed during the survey.

(continued)

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Gen	GENERAL RECCOMENDATIONS FOR NEXT PHASE
R-Gen-1	Next phase of the ICZM project should include the establishment of a committee that works to select a comprehensive set of special indicators from the IOC handbook and the European Working Group on indicators and data, to be used for the future, and which helps to monitor any changes on a regular basis.
R-Gen-2	Awareness of the potential risks and long-term environmental cost of unsustainable Development should be prioritised in all key government offices.
R-Gen-3	Urgently develop conflict resolution skills in Red Sea State decision makers and major stakeholders through workshops and case studies.

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1 Introduction

1.1 PROJECT BACKGROUND

1.1.1 An Integrated Coastal Zone Management Project in Sudan

Equipe Cousteau undertook a commemorative expedition to The Red Sea, known as "Back to Silent World", in 2004. Following this mission Equipe Cousteau formed a consortium of partner organisations for the development of an Integrated Coastal and Ocean Management (ICZM) Project in Sudan.

The goal of the ICZM Project was to bridge the need for conservation management of the coastal and marine ecosystems and biodiversity of the Sudanese Red Sea, on one hand, and the needs of the people of the Red Sea State for sustainable development, on the other hand.

Box 1: What is ICZM?

The European Commission defines Integrated Coastal Zone Management as: *"A continuous process of administration, the general aim of which is to put into practice sustainable development and conservation in coastal zones and to maintain their biodiversity. To this end, ICZM seeks, through more efficient management, to establish and maintain the best use and sustainable levels of development and activity (use) in the coastal zone, and, over time, to improve the physical status of the coastal environment."*

Coastal zones are among the most productive regions on the planet, as well as supporting a wealth of biodiversity and providing essential ecosystem services for people living near the coast. Coastal zones harbour complex and diverse ecosystems that provide essential feeding habitats, as well as breeding and nursery grounds for many different marine animals. Coastal zones also provide a wide range of ecosystem goods and services, and commercially important fish, a source of protein and livelihood for coastal communities. Many of the goods and services provided by the coastal zone are naturally renewable if they are managed equitably and if the integrity of the ecosystems is preserved.

Coastlines across the world are subject to increasing pressure due to the expansion of urban areas and coastal development. Beyond the acute problems resulting from the physical removal of coastal habitats and the fragmentation of these ecosystems, are more chronic stressors such as nutrient enrichment, sedimentation, and contamination from ship- and land-based sources that can lead to degradation of the habitats over longer time scales. As coastal populations expand, the pressure on resources increases, which can lead to over-exploitation and a cascade of other impacts on biodiversity and food-webs. Different stakeholder groups may compete for access to and use of resources, resulting in conflicts and inequity.

There is a need to plan and manage coastal development, in order both to protect the biodiversity and the integrity of ecosystems, and to help maintain equitable access to resources. Historically, the management of the marine environment has taken many forms, often focused on individual sectors, with little consideration of either potential cross-sectoral conflicts, or the cumulative impact of human activities on the marine environment. The failure of these sectoral approaches has resulted in recognition of the need to shift towards a more holistic integrated *ecosystem based approach* to managing marine and coastal areas that considers ecological, social, economic, and institutional dimensions.

Box 2: Ecosystem Approach

The Convention on Biological Diversity (CBD) defines the ecosystem approach as *"a strategy for integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way."*

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In the 1990s, the Earth Summit at the United Nations Conference on Environment and Development (UNCED) (Rio de Janeiro, 3-14 June 1992) identified Integrated Coastal Zone Management (ICZM) as a way to solve some of the issues arising in the coastal environment with the aim of achieving sustainable development. Chapter 17 of Agenda 21 and the Jakarta Mandate on Marine and Coastal Biological Diversity of the Convention on Biological Diversity call on countries to implement national plans to protect coastal resources.

The World Summit on Sustainable Development (Johannesburg, South Africa, 26 August-4 September, 2002), subsequently highlighted the failure to achieve sustainable development. The WSSD Plan of Implementation (PoI) identified the need to continue to promote Chapter 17 of Agenda 21 and the Jakarta Mandate and the integrated management and sustainable development of coastal areas, including exclusive economic zones. The recognition of the importance of ICZM is backed up by other international instruments including the Convention on Biological Diversity, the Global Programme of Action for the Protection of the Marine Environment from Land-Based Sources (GPA) and the FAO Code of Conduct for Responsible Fishing, which also now all call for signatories to adopt an integrated ecosystem-based approach to the management of coastal and marine resources.

The implementation of ICZM should, in theory, contribute to the conservation of biodiversity and the protection of resources for future generations, both concepts that are fundamental to sustainable development. The development of an ecosystem-based approach to ICZM requires an understanding of the interactions between all aspects of the ecological, social, economic and institutional environment. Ecosystem based approaches take into consideration the biological organisation of a system and the essential processes, functions and interactions between organisms and their environment. Ecosystem based approaches also recognise that the human communities living in that environment, and their organisational arrangements and resource use patterns, are integral components of the ecosystem.

1.1.2 The Red Sea State

Sudan has a long history of instability, and during the 48 years since independence there have been 37 years of war that led to the recent independence of Southern Sudan. Much of North Sudan, including the Red Sea State, is still in a state of social, economic, political and environmental disorder, and this provides the backdrop to the ICZM Project.

After 10 years of insurgency, the rebels of East Sudan signed an agreement on 14 October 2006 in which the Federal Sudanese Government offered a power-sharing agreement. This agreement, the Eastern Sudan Peace Agreement (ESPA), was developed as part of the 2005 Comprehensive Peace Agreement (CPA) and is incorporated in Sudan's 2005 Interim National Constitution (INC). Both these documents currently provide guidance for national governance, and constitute an important step towards achieving civil peace. The peace negotiations presented a unique opportunity to address both human development needs and environmental issues. Of relevance to ICZM is the following ESPA stipulation:

> *The people of Sudan, including the people of Eastern Sudan, shall have the right to a clean and diverse environment. The State shall not pursue any policy or take any action which may adversely affect the existence of any species or animal or vegetative life, their natural or adopted habitat. Best known practices in efficient utilization of natural resources and environmental management shall be adopted' (ESPA, 2006: Article 19, point 50).*

Over the last three decades, the Red Sea hills have been subject to frequent droughts, causing famine, and this has resulted in impacts on the natural environment in both rural and coastal areas as the demand for scarce resources has increased (e.g. firewood and charcoal, livestock and fishing).

Conflicts can arise from competing uses of natural resources, and planning, cooperation and carefully monitored use can help prevent tension. The ICZM Project represents a flagship initiative that was designed to address the root causes of both poverty and ecological degradation and, accordingly, to link the conservation of Sudan's marine and coastal environment with improving the quality of life for RSS communities.

The ICZM Project also aims to assist North Sudan in fulfilling its obligations under the multilateral environmental agreements to which the country is party, including the Convention on Biological Diversity (CBD), the

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Millennium Development Goals (MDGs) and the World Summit on Sustainable Development Plan of Implementation (WSSD), as well as International Maritime Organisation (IMO) Conventions, RAMSAR, United Nations Convention on Climate Change, among others. It also aims to provide a framework for achieving food security, sustainable livelihoods, poverty alleviation, improvement of sanitation conditions and reduction of vulnerability to natural hazards, whilst preserving ecological integrity and associated long-term human and environmental health. Addressing these international commitments while establishing the new governance structures will require political will, sustained resources, and collective engagement among all stakeholders: not only by the authorities but also by civil society, the international community and the private sector.

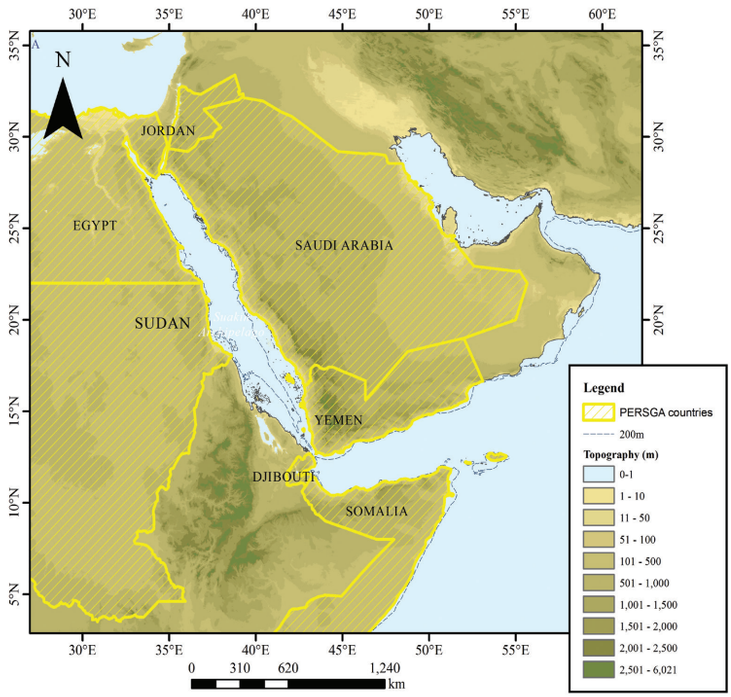


Figure 1: *Parties to the Jeddah Convention before the division of Sudan in North and South Sudan*

1.1.3 The Jeddah Convention & Related Protocols

The Red Sea and Gulf of Aden Region is internationally recognised for the variety and value of its coastal and marine environments, as well as its strategic, economic, and social value to the region. The most significant threats to the long-term stability of the marine ecosystem stem from the increasing human population in the coastal zone, and the rapid rise in economic growth, are placing considerable pressure on the environment.

Threats such as marine pollution, depletion of marine resources and overfishing are of a trans-boundary nature that necessitates regional cooperation to define their causes, effects and management actions. Hence, The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA) was established in 1974 in collaboration with the Arab League Educational, Cultural and Scientific Organisation (ALECSO) and with the support of the United Nations Environment Programme (UNEP), as part of the Regional Seas Programmes.

In 1982 PERSGA was underpinned by a legal framework in the form of the Jeddah Convention, formally entitled "*Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment*". The Jeddah Convention expresses the commitment and political will of the governments in the region jointly to tackle issues linked to the marine and coastal environments of the Red Sea and Gulf Aden through coordinated activities. The provisions of the Jeddah Convention are complemented by those of MARPOL and the Basel Conventions, the Articles of the United Nations Convention on the Law of Seas (1982), whose Article 123 calls for cooperation between coastal countries of an enclosed or a semi-enclosed sea, and coordination regarding the rights and duties concerning marine environmental protection and pollution prevention.

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In addition to the Convention, the Conference also produced and signed another important legally binding agreement: the "*Action Plan for the Conservation of the Marine Environment and Coastal Areas in the Red Sea and Gulf of Aden*".

While the Jeddah Convention is a legally binding agreement, it does not include specific control measures and actions. Hence, the region has adopted the mechanism of developing protocols to allow countries such as Sudan the opportunity to agree upon a wide range of actions to address specific problems. As marine pollution by oil and other harmful substances is an urgent and important issue in the region, the "*Protocol Concerning Regional Cooperation in Combating Pollution by Oil and Other Harmful Substances in Cases of Emergency*" was signed along with Jeddah Convention in February 1982.

The Jeddah Convention, the Action Plan and the Protocol entered into force in August 1985. The following countries are the parties to the Jeddah Convention: Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan and Yemen.

Until recently, the region remained comparatively unaffected by the changes taking place elsewhere. Rapid development, particularly from oil exploration and extraction, shipping, tourism and industry, have driven an unprecedented economic transformation that has resulted in a surge in coastal development and introduced a range of new threats to the natural environment. Thus, in accordance with Article III of the Jeddah Convention, PERSGA formulated two additional protocols (declared in September 1995): *Protocol Concerning the Conservation of Biological Diversity and the Establishment of Network of Protected Areas in the Red Sea and Gulf of Aden*, and *Protocol Concerning the Protection of the Marine Environment from Land-Based Activities in the Red Sea and Gulf of Aden*. The two Protocols were signed by the plenipotentiaries during 2005.

1.1.4 Cousteau in Sudan

> *The greatest resource of the ocean is not material but the boundless spring of inspiration and well-being we gain from her. Yet we risk poisoning the sea forever just when we are learning her science, art, and philosophy and how to live in her embrace.*
>
> – Jacques Yves Cousteau: from *"The World Without Sun"*

In 1963, during the filming of "*The World Without Sun*", Cousteau launched the Conshelf II experiment off the coast of Sudan (Plate 1), which aimed to test whether or not humans could live underwater for extended periods of time. This famous experiment sent five men to live ten metres underwater for one month in a pressurised submersible, named '*Starfish House*' because of its radiating legs. The 'oceannauts' lived in this air-conditioned base station which provided sleeping quarters for eight people, kitchen, dining room, laboratory and dark room. Two oceannauts lived for a week at 26 m underwater in a smaller '*Deep Cabin*', which had a dry living space cabin above and a wet cabin below. The remains of this 'small village under the sea' can still be found at Chab Rumi in the Sudanese Red Sea, located near Sanganeb Atoll.

In late 2003-2004, Equipe Cousteau undertook an expedition in the Red Sea supported by UNESCO. The expedition in Sudan provided the opportunity to revisit sites where, 50 years earlier, Cousteau had filmed "*The Silent World*" (Palme d'Or at the Cannes Film Festival; Oscar in Hollywood) and "*World without Sun*", in the Cousteau village at Chab Rumi near Port Sudan.

During the 2004 Cousteau Expedition the team was impressed by the rich marine biodiversity and the quality of the Sudanese coral reefs. They were also appreciative of the Sudanese inhabitants of the Red Sea State and their willingness to find a way to achieve a better future.

The conclusion of this mission was as follows:

> *The marine ecosystems were seemingly in good overall condition and they also represent a major potential source of income for local population if only this treasure is sustainably managed. If we are to achieve our common goals of sustainable development, political stability and peace, it is now imperative that greater emphasis is placed on the increasing of local population welfare and poverty reduction, linked with the conservation of biodiversity. Such objectives can only be attained if sustainable development trajectories are offered to the Red Sea State of Sudan.*
>
> – Tarik Chekchak, Cousteau's Director for Sciences & Environment.

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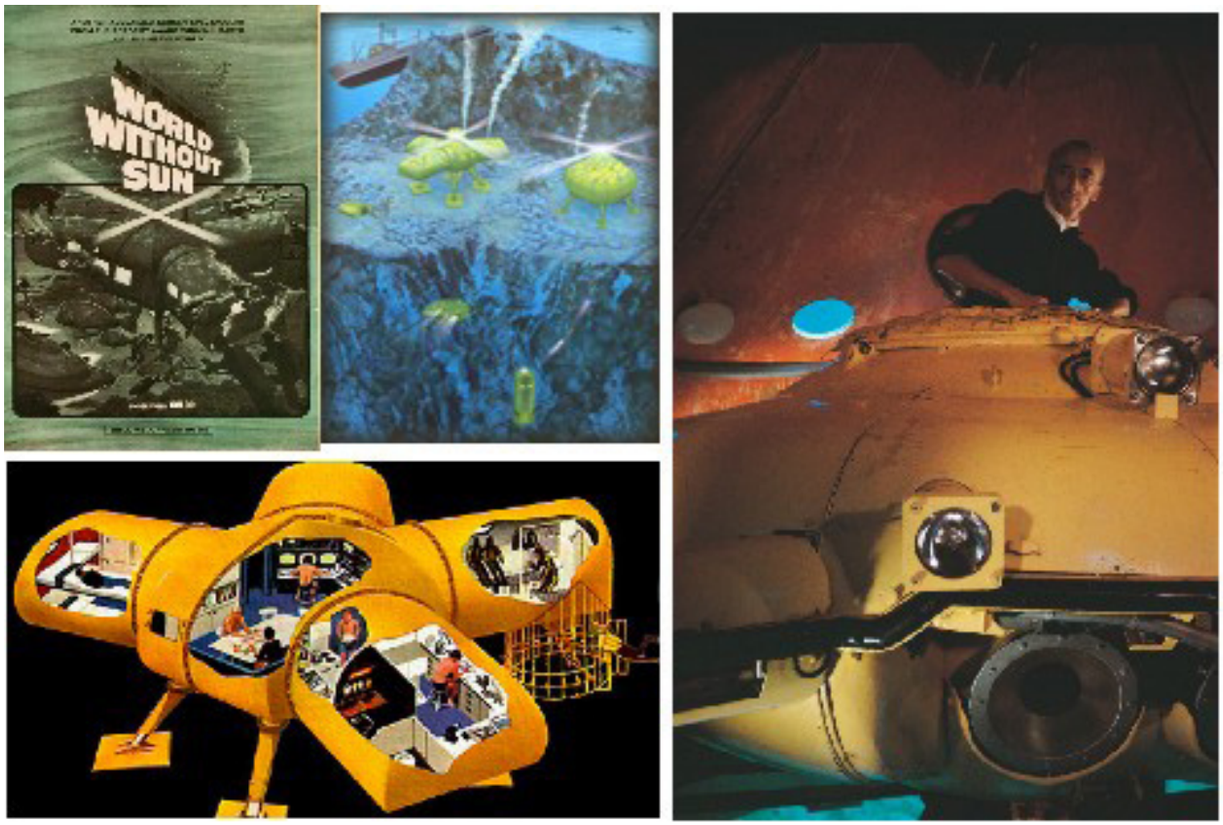


Plate 1: *Conshelf II experiment in Chab Rumi near Port Sudan, with J.Y Cousteau in the submarine "Denise". Conshelf II consisted of four main buildings and eight ancillary structures. "Starfish House", the air-conditioned central base. The Deep Cabin was a large yellow diving bell anchored 26 metres underwater.*

1.1.5 Linking biodiversity Conservation & Poverty reduction

An agreement was signed in 2004 between Equipe Cousteau and the Governor of the Red Sea State, which was later approved by the Sudanese Minister of Foreign Affairs. In this agreement, Sudan agreed to implement the fundamental principles of sustainable development and ICZM on the whole coast of the Red Sea State allowing for the development of human activities that are carefully controlled and sustainably managed.

Faithful to the principles set forth by Captain Cousteau upon the creation of l'Equipe Cousteau, we accord the highest priority to the development of a more harmonious relationship between man and his environment. The sustainable development of these ecosystems is necessarily related to the improvement of the well-being of the coastal populations, sometimes extremely poor, like those in Sudan. We have as a constant concern to preserve the great ecological cycles and to ensure that future, and present, generations have access to a planet whose integrity is maintained, even restored. Witnesses to the state of our environment through our documentaries, we are equally active participants through our work in the field and the lobbying we undertake. The philosophy expressed by Jacques-Yves Cousteau drives us to toil wherever things can be improved, including in the most troubled zones. Armed with the leverage of the Cousteau name and our vigilance, we engage with all the decision makers desirous of applying concrete measures in the right direction.

Based on this agreement and the support of the new Red Sea State Governor, Equipe Cousteau submitted a project proposal concerning the development of an ICZM Plan for the Red Sea State of Sudanto Mr Louis Michel, European Commissioner for Development and Humanitarian Aid. A positive response led to financial support for the proposal from the European Commission (EC).

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Plate 2: *A Cousteau diver in Sudan with a soft coral (Alcyonarian).*

1.2 PROJECT GOAL AND OBJECTIVES

The main goal for the ICZM Project is the development of an ICZM plan for RSS, to establish a multi-sectoral, transparent and effective decision-making framework, which outlines the processes to guide the long-term sustainable use of RSS's invaluable coastal and marine areas and resources.

The ICZM planning process offers a platform for the coordinated implementation in the RSS of national and international legislation pertaining to marine management, navigation, fisheries, natural resource use and environmental protection.

Recognising that effective environmental management cannot operate in isolation, the ICZM Project places the improvement of community livelihoods and the reduction of poverty at the heart of its action plan. Each general objective outlined in the ICZM Project Document has been linked with specific activities that were pursued as part of this initial Phase, the *Survey for the Integrated Coastal and Ocean Management of the Red Sea Coast of Sudan,* hereafter referred to as the ICZM Survey.



Plate 3: *A young Sudanese fisherman beach seine fishing in the mangroves south of Port Sudan.*

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The ICZM Survey (Phase I) of the ICZM Project, financed mainly by the European Commission, aimed to achieve ground-breaking activities in RSS. There were 9 main objectives for Phase I, as follows:

1. Assess the status and condition of the coastal and marine habitats and biodiversity within selected parts of the coastal zone (650 km, the two marine national parks of Sanganeb and Dungonab)
2. Identify threats to the coastal zone and their current and needed levels of management.
3. Review existing environment and sustainable development legislation, and propose recommendations for the improvement of governance of the Red Sea State coast and the implementation of Integrated Coastal Zone Management;
4. Enhance the capacity of the Red Sea State for sustainable environmental management through establishing an official RSS GIS to help inform future management decision making, and providing training in EIA-SIA and risk management assessment of navigation, ports, maritime issues and the oil industry;
5. Increase understanding of the socio-economic situation, through the preparation of a socio-economic monitoring programme for the Red Sea State, collection and analysis of data; and to recommend opportunities for local populations;
6. Make recommendations for the management of cultural resources, with a specific focus on the protection and rehabilitation of Suakin;
7. Identify the potential for ecotourism along the Red Sea State coastline and improve understanding of cultural assets, through association with a project to rehabiliate the historical coral town of Suakin;
8. Raise awareness, and provide training for reform of the RSS education sector on reef and coastal zone conservation; and
9. Produce a cross-disciplinary assessment of potential coastal resource use, conflicts and conflict resolution.

Furthermore, the ICZM Project has enabled local capacity-building in data collection and programme development, forged key local and international partnerships to help achieve ICZM goals, and contributed to the general (and much-needed) strengthening of scientific literature on the Sudanese coastal zone.

1.2.1 Project Process and Phases

As stated above, the ICZM Project aims to establish sustainable and integrated coastal and marine management of the Red Sea coast of Sudan, being entirely included within the Red Sea State of North Sudan. The ICZM Survey (Phase I), was designed to be the first of a three-phase ICZM Project (see Figure 2).

The structure of the work packages and expected outputs of Phase I are set out in Section 1.2.2 below. The main findings from each output (Volumes 1 and 2) are summarised in the recommendations. The recommendations were designed to be as practical as possible, so that they can be used as the basis to guide the development of actions to be implemented in the subsequent Phases. To further facilitate this, each recommendations is assigned to one of three categories, according to how and when they can be implemented (Figure 3).

The three classes of recommendations thus provide the initial outline framework for Phases II and III, even which can be built upon and expanded during the next two Phases. Details of these two Phases are summarised in Figure 4.

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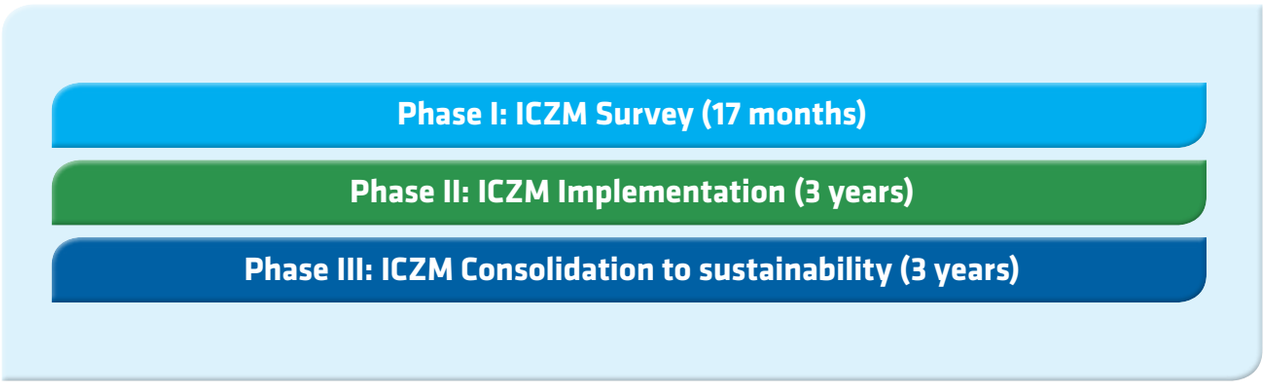


Figure 2: *The three Phases of the ICZM Project in the Red Sea State of Sudan.*

Recommendations for actions

(All recommendations and classes below assume immediate availability of funds and full political endorsement.)

Class I – Immediate

These recommendations can be immediately implemented, without the need for another step, and completed in a relatively short period (maximum of a few months). Examples : purchase of specialised equipment, amending a specific law.

Class II – To Launch

These recommendations can be immediately launched, without the need for another step, but will take a longer period to be completed (6 months to 3 years). Examples: new studies needed in the field, partnership to develop, governance process to establish.

Class III – Future

These recommendations cannot be immediately launched, because they need another step to be completed first, or because basic requirements for implementation are not there yet.

Figure 3: *The recommendations for action issued by the ICZM Survey.*

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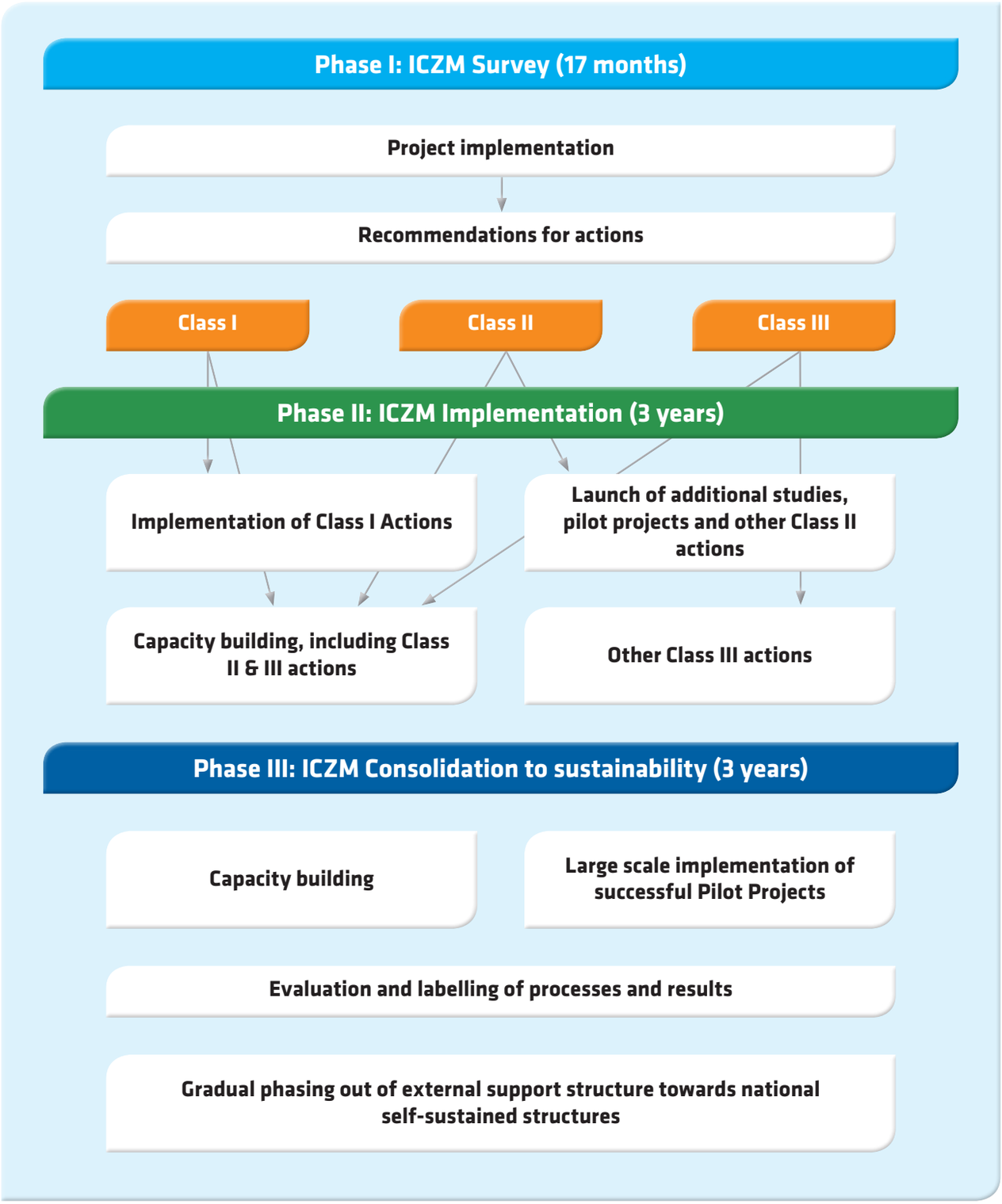


Figure 4: *Details of the three Phases of the global ICZM project in the Red Sea State of Sudan.*

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1.2.2 Work packages & Organisational Arrangements

Phase I of the ICZM Project was divided into 7 work packages (excluding project management) (see Figure 5). Each work package was designed to cover aspects essential to the ICZM approach, and to provide the foundations for the implementation of ICZM during Phase II. These work packages were undertaken by a group of experts within a consortium of partner organisations, as outlined in section 1.2.3 below.

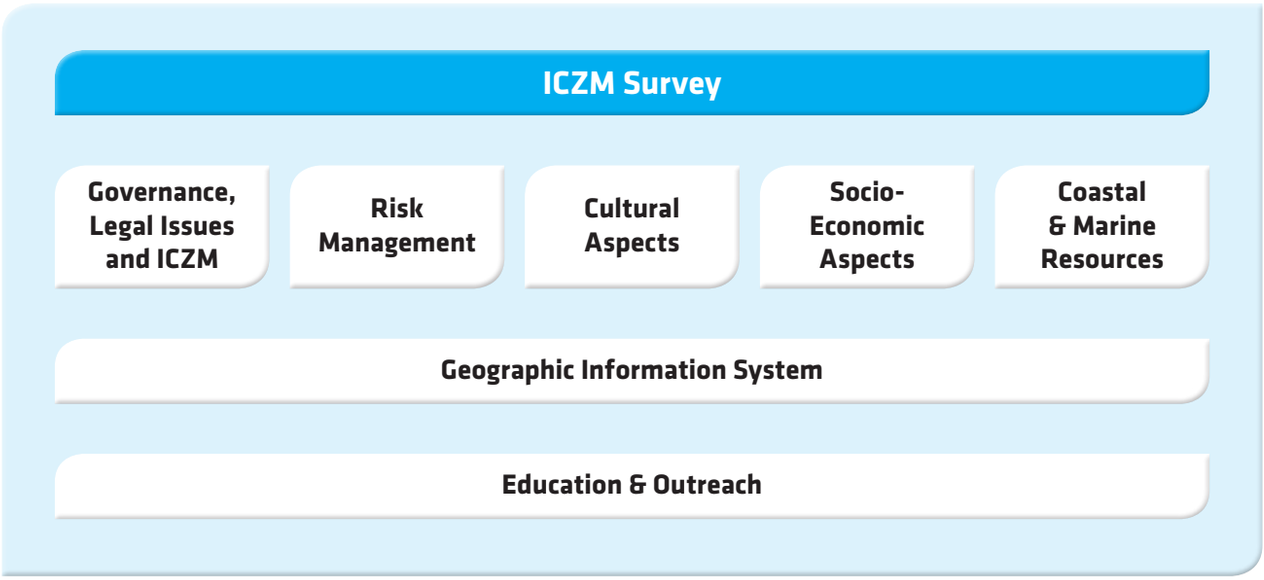


Figure 5: *Details of the work packages of the ICZM Survey in the Red Sea State of Sudan*

1.2.3 Consortium of Partners

Phase I of the ICZM Project was supported by a direct grant from the European Commission (EC), which contracted Equipe Cousteau as the sole beneficiary responsible for carrying out the action. Equipe Cousteau gathered a network of partners before initiating the survey, some of which committed further co-financing to the action. The implementation of the project was only possible through the collaborative work of all the partners.

The Higher Council for Environment and Natural Resources (HCENR)

Until 2007 no single Ministry was responsible for the environment in RSS. Instead, a council with a recognisable identity, known as the "Higher Council for Environment and Natural Resources", was the authority responsible for protecting the environment in the state.

The Higher Council for Environment and Natural Resources (HCENR) was first established in1995 as an umbrella entity with a major mandate to conserve the environmental resources in RSS. The council was re-established according to the environment law of 2006 by a decree made by the governor of RSS.

HCENR should continue to perform the key functions, which are assigned to it by the 2006 environment law, until the newly established Ministry of Environment and Tourism (MoET) becomes institutionally and technically able to fulfil its responsibility to protect the environment of the RSS.

HCENR has been the channel of communication with the Government of the Red Sea State throughout the project, mostly through the General Secretary of HCENR, who is also the director of the ICZM office established as part of the project.

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Programme for the Environment of the Red Sea and the Gulf of Aden (PERSGA)



PERSGA, the Regional Organisation for the Conservation of the Environment of the Red Sea and Gulf of Aden, is an intergovernmental body dedicated to the conservation of the coastal and marine environments found in the: Red Sea, Gulf of Aqaba, Gulf of Suez, Suez Canal, and Gulf of Aden surrounding the Socotra Archipelago as well as nearby waters. PERSGA's member states include: Djibouti, Egypt, Jordan, the Kingdom of Saudi Arabia, Somalia, Sudan and Yemen.

PERSGA was the main international partner of Equipe Cousteau during the Survey, and focused its assistance and work on ICZM policies and governance, as well as on socio-economic aspects, in accordance with the regional Strategic Action Programme for the Red Sea (SAP) which PERSGA implements throughout the whole region.

Website: www.persga.org/

African Parks Foundation (APF)



African Parks Foundation (formerly known as African Parks Conservation) is a private not-for-profit organisation set up to assist in the protection and development of national parks in Africa. It is the first private park management institution in Africa that takes on the actual long-term management responsibility of parks, in public-private partnerships with governments, by combining world class conservation practice with business expertise. Emphasis is placed on the stimulation of responsible tourism and associated private enterprise as a mechanism for achieving financial sustainability of the parks, as well as providing a foundation for sustainable economic development and poverty reduction.

In partnership with the Sudan Wildlife General Conservation Administration, APF aims to restore and protect the two Marine National Parks, Dungonab and Sanganeb National Parks, for the long-term benefit of biodiversity and the people living in and around them.

Partnership between Equipe Cousteau and APF began before the Survey was initiated. This association resulted in increasing the geographic coverage of the survey, as the same surveys and studies were pursued inside the parks as in the area covered by the boat-based survey led by Equipe Cousteau. It also enriched socio-economic surveys, as a result of the work pursued by African Parks on alternative livelihoods and village environmental management plans.

APF entered into renegotiations of the agreement with Sudan during the implementation phase of the Survey. The new agreement sought was for a longer term (25 years), which is one of the key bases of the African Parks model in Africa. Negotiations were conducted by African Parks at both the regional (Red Sea State) and the national levels of government. However, the negotiation ran into problems due to differences in interpretation of the new constitution, relating to authority over and administration of national parks, by the Red Sea State government on one hand and by the national Wildlife Conservation General Administration on the other. The second point of issue was the core matter of what was seen as a request to release sovereignty over a Sudanese territory, to a private business, for a period of 25 years. These and probably other issues resulted in the failure of the negotiations, and the official announcement of the withdrawal of African Parks from Sudan, with complete cessation of activities on 11 August 2008.

While the cessation of APF's involvement in Sudan did not affect the survey, as it happened too late to be even considered during the implementation period (which ended on 31 May 2008) it is, of course, a major setback in several main areas to which the ICZM Project is closely linked. This report provides recommendations on these issues which were designed in anticipation of continuing involvement by African Parks in managing Sudan's two marine parks. A new management structure is needed to replace African Parks in this endeavour, and the recommendations should thus be considered as addressing this new structure.

Website: www.african-parks.org/

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The United Nations Educational Scientific and Cultural Organisation (UNESCO)



UNESCO was involved in the project, with experts from the Man and Biosphere programme (MAB) and from the Division of Education Strategies and Capacity Building from UNESCO's Paris headquarters, as well as experts from the Sudan UNESCO office in Khartoum.

UNESCO participated in and helped organise workshops on education strategy and on strategy for the ICZM. UNESCO was also involved in the project through collaboration with the UNESCO Cousteau Ecotechnie Program (UCEP). UCEP is a university-level programme that applies integrated multidisciplinary approaches to education, research and policy-making, taking into account ecology, economy, the social sciences and technology. The UCEP chair at the Computer Man College in Khartoum was intended to be closely involved in the development of the Geographic Information System component of the Survey. Part of the GIS system was to be set up in Khartoum, and the Computer Man College was to be involved in training ICZM stakeholders of the Red Sea State (in the ICZM office and elsewhere) in using and integrating GIS for ICZM implementation strategies. This collaboration required a strong partnership between the Red Sea State, the Computer Man College and the Red Sea University. The project management stressed this, and met with all stakeholders at the outset, but it was not possible to establish such a partnership between the Sudanese entities. The GIS component was thus implemented in the Red Sea State without further development of the collaboration with the Ecotechnie Chair at Computer Man College in Khartoum. It is hoped that this situation will be temporary, and recommendations are made to achieve this very important collaboration in the near future.

Website: www.unesco.org/mab/

Coastal Oceans Research and Development in the Indian Ocean (CORDIO)



CORDIO is a not-for-profit organisation based in Kenya and working in countries of the Indian Ocean, covering Eastern Africa (Kenya, Tanzania, Mozambique, South Africa), South Asia (India, Sri Lanka, Maldives), Southeast Asia (Thailand, Indonesia) and the Indian Ocean islands (Seychelles, Mauritius, Madagascar, Comoros, Reunion).

CORDIO supports monitoring and research on coral reefs, participatory monitoring of artisanal fisheries (biological, resource and socio-economic), education and awareness-raising, and policy development. Its primary goal is to conserve biodiversity in the context of improved livelihoods and sustainable development of people directly dependent on coastal and marine resources.

CORDIO-East Africa was registered to implement the CORDIO programmes in East Africa, focusing on coral reef health and recovery following mass mortality of corals in 1998, and addressing artisanal fishermen on coral reefs, being the human population group that is most vulnerable to reef degradation.

CORDIO was involved in the project through a CORDIO expert being hired for the project.

Website: www.cordioea.org/

The Centre for Environment and Development for the Arab Region and Europe (CEDARE)



CEDARE was established in 1992 as an international inter-governmental organisation with diplomatic status, based in Cairo, Egypt. CEDARE addresses current and emerging environmental issues in the areas of c1imate change, coastal zone management, waste management, genetically modified organisms, etc. The programme also focuses on cross-cutting themes, such as public participation (with a focus on women and youth), peace and environment, environmental education, environmental impact assessment, and the socio-economics of sustainable development.

CEDARE has a wide experience in implementing and using Geographic Information Systems in all the countries of the Red Sea area (among others) and was thus added as a partner to the project following devel-

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opment of the GIS component between Sudanese partners (see UNESCO-Cousteau Ecotechnie Programme Chair at Computer Man College, in the UNESCO section above). CEDARE experts were contracted to assist with the analysis of satellite images, and to manage the implementation of the GIS component of the project, including training the Sudanese stakeholders.

Website: www.cedare.int/

Mallinson Architects

The British architectural company run by Mr Michael Mallinson is the main international partner of the Ministry of Culture of the Red Sea State and has a long history of involvement in the study, preservation and rehabilitation of the old coral town of Suakin, the historic port town of Sudan which dates back to the 10th century and is on the tentative list of UNESCO's World Heritage Centre.

Michael Mallinson has been involved in the cultural aspects of the project, focusing on the Suakin cultural management plan, future development, and links with the marine area and marine issues in the vicinity (Ferries, Suakin archipelago, etc.)

1.2.4 Monitoring the ICZM Process

During the last 10 years there have been two major iniatives that have attempted to establish monitoring and evaluation programmes to track ICZM's progress in a quantifiable way.

- *European ICZM Indicators and Data Working Group* (WG-ID) : The working group was established in 2003 by the European Topic Centre Land Use and Spatial Information (ETC_LUSI). The WG-ID developed two sets of of indicators for Member States and candidate countries:
  - *Progress Indicators*, to measure the progress of implementation of ICZM; and
  - *Sustainability Indicators,* a core set of 27 indicators (composed of 44 measures) to measure sustainable development of the coastal zone.
- *IOC-UNESCO :* A pilot project was established under the auspices of IOC-UNESCO in 2003 to promote the development and use of indicators for coastal and ocean management in collaboration with the Canadian Department of Fisheries and Oceans, the US National Oceanographic and Atmospheric Administration (NOAA), and the University of Delaware. The aim of the pilot project was to promote an outcome-oriented approach to guide the selection and application of indicators to measure the progress and effectiveness of integrated coastal and ocean management interventions.

The IOC-UNESCO pilot project resulted in a handbook for the monitoring and evaluation of ICZM (UNESCO 2006)[1] and an associated suite of indicators (Table 1, Table 2 and Table 3). The IOC Handbook is part of a comprehensive toolkit intended for use by coastal and ocean managers, practitioners, evaluators and researchers. The handbook aims to promote an outcome-orientated, accountable and adaptive approach to ICZM and provides a step-by-step guide to help users develop, select and apply common governance, with ecological and socio-economic indicators to measure, evaluate and report on the progress and outcomes of ICZM interventions. It further proposes analytical frameworks and includes processes and lessons learned from previous case studies around the world.

Both sets of indicators were considered for use within the context of this ICZM Project. To assess the initial state of ICZM in RSS, the first set of EU WG-ID Progress Indicators was used to compare ICZM governance of the Red Sea State between 2003, when PERSGA started to implement activities in the Red Sea State, and Phase I of the ICZM Project. A summary of the findings is presented in the concluding section (Gap Analysis).

[1] *IOC Handbook for Measuring the Progress and Outcomes of Integrated Costal and Ocean Management*. IOC Manuals and Guides, 46: ICAM Dossier, 2 Parts UNESCO (2006).

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Box 3: What is monitoring?

Monitoring is the process of repeated observation for specified purposes, according to prearranged schedules in space and time and using comparable data collection methods (after Meijers, 1986). Monitoring can be used to:

- Assess the ecological state of ecosystems;
- Assess whether regulated performance criteria have been exceeded;
- Detect and assess impacts of human-generated disturbance(s);
- Assess responses to restoration efforts.

In conducting this analysis, it was observed that all 27 indicators recommended by the EU WG-ID are directly or indirectly included in the IOC indicators tables (Table 1, Table 2 and Table 3). In addition, it was found that the IOC-UNESCO Handbook indicators are better adapted to measuring the initial state of ICZM initiatives in developing countries. The indicators presented in the IOC Handbook have been used throughout Volumes 1 and 2. The relevant IOC indicators are indicated in this report following the titles of the specific chapters and sections.

Box 4: What are Indicators?

An indicator as a measure (quantitative or qualitative) of how close we are to acheiving what we set out to acheive (i.e. our objectives). Indicators are quantitative/qualitative statements or measured/observed parameters that can be used to describe existing situations and measure changes or trends over time. Indicators serve 3 main functions: simplification, quantification and communication (Belfiore *et al.* 2006).

- Indicators must reflect changes at spatial and temporal scales of relevance to management and what needs to be measured ;
- Differing indicators should be used for site level and system level ;
- As well as more obvious environmental indicators, social and governance indicators should also be developed;
- Ecological goals and socio-economic goals are not mutually exclusive; however, but they do need different evaluation crietria/indicators.

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Table 1: *Ecological Indicators from the IOC Handbook*

Goals	Objectives	Indicators and parameters
Organisation: Conserve the ecosystem structure – at all levels of biological organization – so as to maintain the biodiversity and natural resilience of the ecosystem	Maintaining biodiversity	**E1 Biological diversity** Diversity of communities Diversity of populations Diversity of species Genetic diversity
	Maintaining species distribution	**E2 Distribution of species** Horizontal distribution (patchiness, aggregation) Vertical distribution (food web/trophic structure)
	Maintaining abundance	**E3 Abundance** Biomass (key populations) Number of individuals (marine mammals) Density (plants, benthic organisms)
Vigour: Conserve the function of each component of the ecosystem so that its role in the food web and its contribution to overall productivity are maintained	Maintaining primary production and reproduction	**E4 Production and reproduction** Primary productivity : quantity (biomass) and quality Secondary productivity Life history stages Reproductive parameters Spawning survival rates Mean generation time (longevity)
	Maintaining trophic interactions	**E5 Trophic interactions** Complexity of food web Key predator/prey interactions Keystone species Size spectra
	Maintaining mortalities below thresholds	**E6 Mortality** Fishing mortality Incidental mortalities (by-catch) Natural mortality (predation, diseases)
Quality: Conserve the geological, physical and chemical properties of the ecosystem so as to maintain the overall environmental quality	Maintaining species health	**E7 Species health** Species at risk of instinction (Bio)accumulation of toxic componounds Diseases and abnormalities Seafood quality
	Maintaining water and sediment quality	**E8 Water quality** Water column properties Oceanographic processes and variability (and regime shifts) Sedimentation (e.g. Transport of suspended sediments) Pollutants and contaminants Eutrophication parameters
	Maintaining habitat quality	**E9 Habitat quality** Habitat types Habitat alteration Sea level change Landscape and bottomscape integrity Sediment quality (nature/properties of sediments)

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Table 2: *Governance indicators from the IOC Handbook.*

Goals	Objectives	Indicators and parameters
Ensuring adequate institutional, policy and legal arrangements	Ensuring the coordination and coherence of administrative actors and policies	**G1 Existence and functioning of a representative coordinating mechanisme for ICZM** Existence of a coordination mechanism Functioning of the coordinating mechanism Outcomes and influence of the coordinating mechanism
	Supporting integrated management through adequate legislation and regulations	**G2 Existing and adequacy of legislation enabling ICZM** Existence of legislation on coastal and marine resources Adequacy of the ICZM legislation
	Assessing the environmental impacts of policies, plans, programmes and projects	**G3 EIA, SEA and CCA procedures for plans, programmes and projects affecting coastal zones** Use of EIA and SEA procedures and modifications to coastal projects Use of CCA procedures in coastal tourism development
	Resolving conflicts over coastal space and resources	**G4 Existence and functioning of a conflict resolution mechanism** stakeholders and issues at stake Agreed procedures and mechanisms for conflict resolution changes in the proportion of conflicts that are mitigated, resolved, or prevented Overall changes in the number of conflicts
Ensuring adequate management processes and implementation	Managing the coastline through integrated plans	**G5 Existence, status and coverage of ICZM plans** Existence and statut of ICZM plans Characteristics of ICZM plans Extent (percentage) of coastline covered by ICZM plans
	Implementing and enforcing ICZM plans and actions	**G6 Active management in areas covered by ICZM plans** Level of implementation of ICZM plans, actions and projects, including infrastructure building Procedures, legal tools and monitoring and sanctioning applied for enforcement of ICZM plans/actions Level of compliance with ICZM plans
	Routinely monitoring, evaluating and adjusting ICZM efforts	**G7 Routine monitoring, evaluation and adjustment of ICZM initiatives** Existence of an operational monitoring and evaluation system with related indicators Consideration of results into ICZM initiatives Adjustments made to ICZM initiatives
	Supporting ICZM through sustained administrative structures	**G8 Sustained availability and allocation of human, technical and financial ressources for ICZM, including the leverage of additional resources** Staff Budget Facilities

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Enhancing information, knowledge, awarness and participation	Ensuring that management decisions are better informed from science	**G9 Existence, dissemination and application of ICZM-related scientific research and information** Existence of research studies and scientific publications Completion of a diagnostic assesment that identifies root causes of coastal and marine degradation and establishes priority for interventions Existence and dissemination of a state of the coast report Existence and functioning of a science advisory body Existence and operation of a routine monitoring of the marine environment Inputs from scientific research and diagnostic assesment into ICZM
	Ensuring sustained support from engaged stakeholders	**G10 Level of stakeholder participation in, and satisfaction with, ICZM decision making processes** Level of stakeholder participation Level of stakeholder satisfaction with the participation and with ICZM outcomes
	Ensuring NGOs and Community-based Organization involvement	**G11 Existence and activity level of NGOs and CBOs supportive of ICZM** Educational and training programmes incorporating ICZM People having completed educational and training programmes in ICZM Employment of people with education and training in ICZM
	Ensuring adequate levels of higher eductaion and professional preparation for ICZM	**G12 Incorporation of ICZM into educational and training curricula and formation of ICZM cadres** Educational and training programmes incorporating ICZM People having completed educational and training programmes in ICZM Employment of people with eduction and training in ICZM
Mainstreaming ICZM into sustainbale development; Economic instruments mainstreaming	Enabling and supporting ICZM through technology, including environmentally-friendly technology	**G13 Use of technology, including environmentally friendly technology, to enable and support ICZM** Availability of ICZM-enabling and supporting technology at an acceptable cost Level of use of ICZM-enabling and supporting technology in substitution of counter-ICZM technology Level of coordination of ICZM-enabling and supporting technology
	Incorporating economic instruments into coastl management policies	**G14 Use of economic instruments in support to ICZM** Availability of economic instruments, including environmental quality certifications, in conjunction with regulatory instruments Level of implementation and enforcement of economic instruments
	Mainstreaming coastal and ocean management into sustainable development	**G15 Incorporation of ICZM into sustainable development strategy** Existence of sustainable development strategy or Agenda 21 incorporating ICZM chapter Level of implementation of ICZM chapter on sustainable development strategy or Agenda 21

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Table 3: *Socio-economic indic ators from the IOC Handbook.*

Goals	Objectives	Indicators and parameters
A healthy and productive economy	Maximize economic development	**SE 1 Total economic value** Value of living resources Value of non-living ressources Value of non-consumptive uses Economic value-added Value of exports Management and administration costs
		SE 2 Direct investment Investment by government Private sectore investement Foreign direct investment
	Increase employment	**SE 3 Total employment** Number employed Employment payroll value Same sub-categories as total economic value
	Foster economic diversification	**SE 4 Sectoral diversification** Land based activities dependent on the marine environment Activities in the ICZM area out to the boundary of the EEZ or the continental shelf Non-living resource exploitation Non-consumptive use
A healthy and productive environment	Minimize habitat destruction and alteration from human pressures	**SE 5 Human pressures on habitats** Land use/land cover patterns and composition Population density Extend of hard-surface areas High-impact fishing gear/practices Dumped and dredged material
	Reduce the volume of introduction of all types of pollutants	**SE 6 Pollutants and introductions** Population served by wastwater treatment Volume, number, and type of point-source discharges Non-point-source nutrient loading Discharged sediments and nutrients Volume of ballast and bilge discharge Litter and debris
Public health and safety	Protect human life and public private property	**SE 7 Disease and illness** Fecal coliform counts Days of beach closure Extent of contaminated species Extent of contaminated water Seafood-transmitted illnesses
		SE 8 Weather and disaster Economic value of loss from marine weather-related events Lives lost from weather and marine disasters

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Social cohesion	Maintain equitable population dynamics	**SE 9 Population dynamics** Degree of public access Resident and total (seasonal) population
		SE 10 Marine dependency Economic dependency social dependency
		SE 11 Public access Physical access Economic access
Cultural integrity	Maintain cultural integrity	**SE 12 Traditional knowledge, innovations and practices/ cultural integrity** Linguistic diversity traditional land and water tenure Lands and waters managed or co-managed by indigenous and local communities Movement away of indigenous and local communities Establishment and implementation of favourable government policies and programmes Access to traditional coastl and marine ressource rights Manifestation of traditional knowledge
		SE 13 Protection of coastal heritage resources Number and type of coastal heritage resources identified and assessed Percentage of coastal heritage resources that are protected Percentage of coastal heritage resources that are vulnerable or being damaged because of natural and human factors Use of cultural heritage resources and most visited sites

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2 Sudan's Red Sea Environment

2.1 INTRODUCTION

This chapter summarises the physical and chemical characteristics of the Red Sea and, based upon the reviews by Edwards and Head (1987) and Sheppard *et al*. (1992), it introduces the marine and coastal environments of Sudan's Red Sea region.

2.2 PHYSICO-CHEMICAL CHARACTERISTICS OF THE REGION

2.2.1 Geographical and Geological Setting

2.2.1.1 GEOGRAPHICAL LOCATION

North Sudan is bordered on its north-eastern side by the Red Sea. The Sudanese coast lies in the central-northern Red Sea, and extends for 750km, from 18°00'N to 22°55'N. It is bordered by the coasts of Egypt to the north and Eritrea to the south (Figure 6).

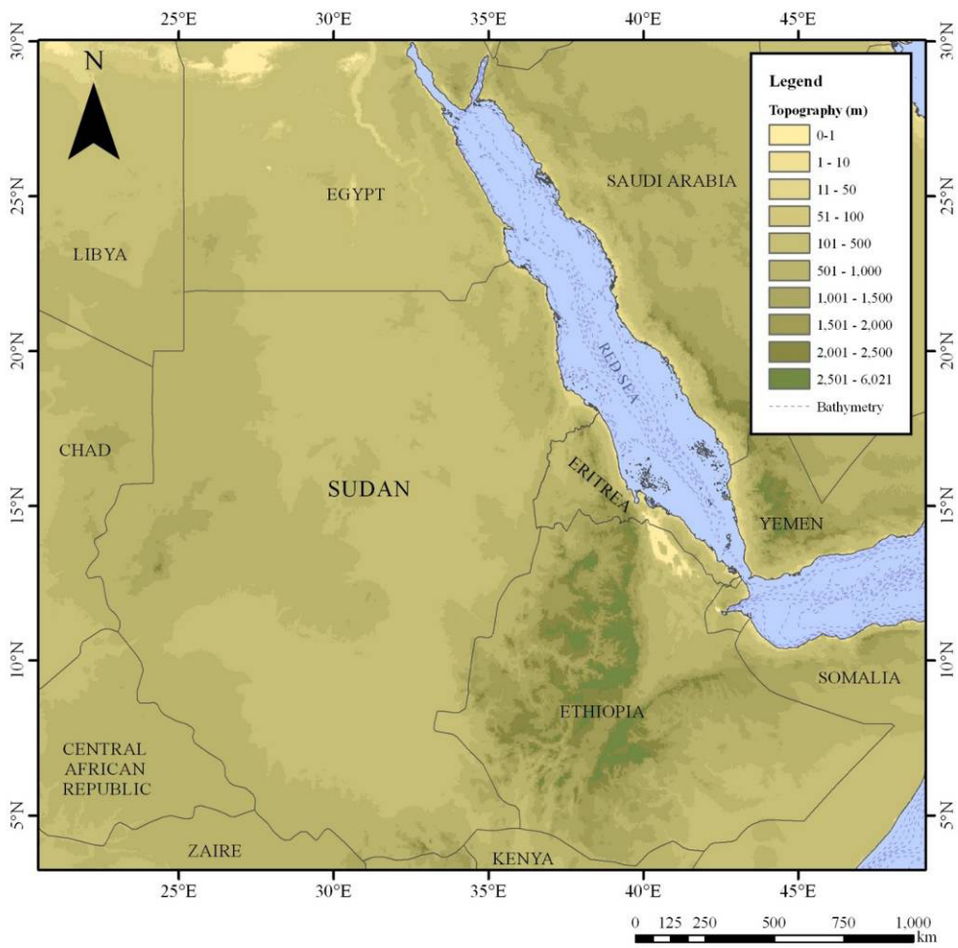


Figure 6: *Map showing the location of Sudan on the Red Sea, between Egypt to the north and Eritrea to the south.*

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2.2.1.2 GEOLOGICAL SETTING

The Red Sea is 2,100km long, extending from NNW to SSE, between the latitudes of 30°N to 12°30'N, from the Suez in the north-west to the Bab el Mandeb in the south-east (Chiffings, 1995). The average width is 280km with a maximum of 306km near Massawa and a minimum of 26km at the Bab el Mandab (Chiffings, 1995).

In geological terms, the Red Sea is an ocean, with a spreading and rifted sea floor created as a result of the gradually increasing separation between the African and Arabian tectonic plates, a process which began approximately 70 million years ago (Sheppard et al. 1992). Rifting has not been continuous. During the first part of the Tertiary, there were episodes of volcanic activity which led to the extrusion of volcanic islands within the Red Sea. Rifting recommenced between 2 and 5 million years ago at a rate of 2cm per year. Only 10,000 years ago the Straits of the Bab el Mandab were closed and this led to increased salinity and the build up of salt deposits.

2.2.1.3 BATHYMETRY

The geological process of rifting has created a stepped profile to the continental margins either side of the Red Sea. The maximum depth of the Red Sea is over 2000m, but the shallowest of the rift valley steps lies less than 50m below modern day sea level and, throughout much of the Red Sea including Sudan, supports numerous coral reefs.

The Red Sea is deep and steep-sided throughout its northern and central area (where the shelf extends less than 20 km from the shore, and in many places is almost non-existent). South of about 20oN, however, the continental shelf becomes wide (Figure 7) giving rise to different conditions and ecological communities. In Sudan the continental shelf extends over 50km offshore in the area of the Suakin Archipelago, south of Port Sudan.

The bottom relief of the Red Sea can be divided into six regions:

- Coral reef zone: In the Red Sea coral reefs with depths of less than 50m are particularly well developed along the northern and central section, although there are also extensive coral reef ecosystems in the southern Red Sea.
- Coastal shelves: The shelves extend from the shore to a depth of 300-600m. From the coral reef zone, the sea bottom descends abruptly, then there are a series of shallow steps.
- Main trough: The trough extends in depth from 600m to 1100m, which is absent in some places.
- Axial trough: The axial trough varies from 1100m to over 2000m deep and is up to 20km wide. The shelves are narrower in the north and wider in the south.
- Hot brines: The central part of the axial trough is over 2000m deep and contains depressions with temperatures of over 60°C, and salinity of more than 300ppt, with rich deposits of trace metals.
- Straits of Bab el Mandab: The narrowing at the entrance to the Red Sea between Ras Bab el Mandab and Ras Siyan, separated by Miyurn Island.

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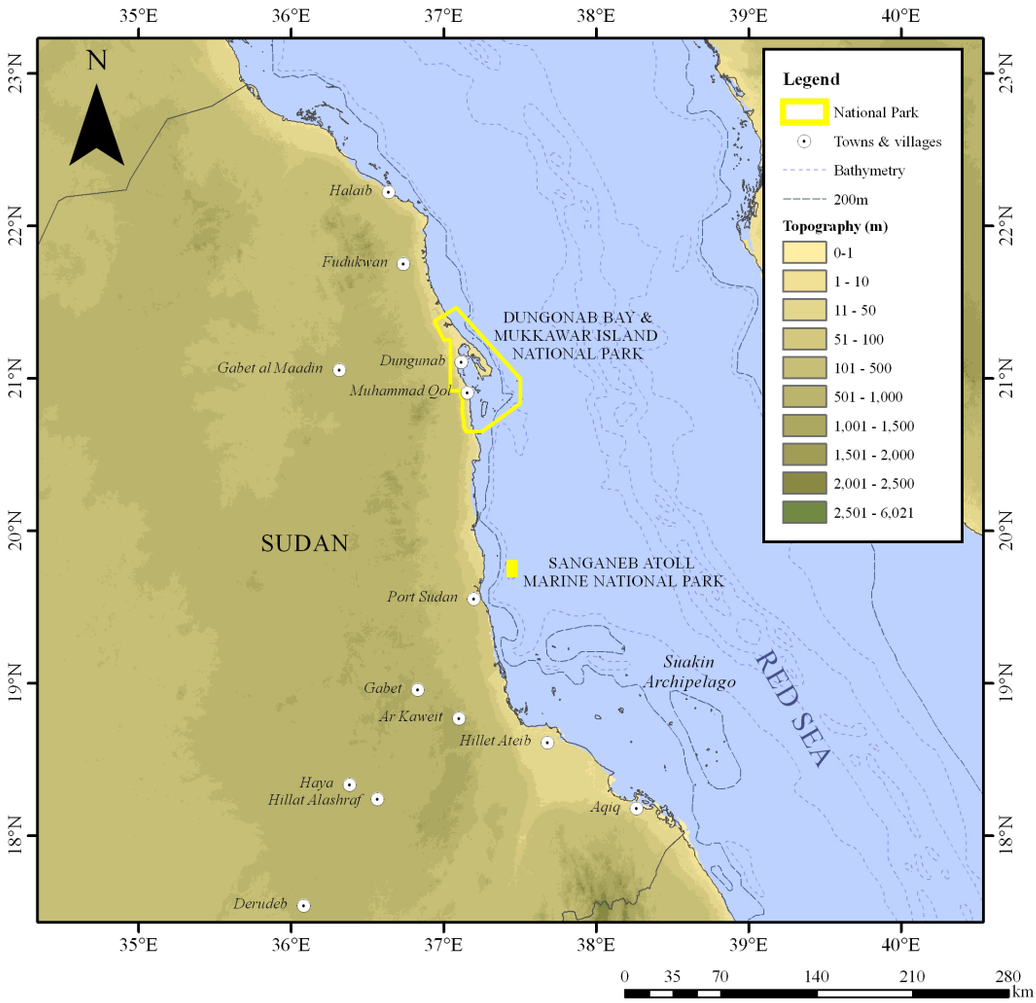


Figure 7: *Map showing the pronounced change in the width of the continental shelf between latitudes 19°N and 20°N. The areas outlined in yellow are the two existing marine and coastal sustainable management / conservation initiatives at Dungonab Bay and Sanganeb Atoll.*

2.2.2 Climate

2.2.2.1 AIR TEMPERATURES

The climate of the Red Sea region is hot and arid. During the winter, air temperatures may fall as low as 15°C, but summer temperatures can reach 40°C or higher (Farah, 1982; Sheppard *et al.*, 1992).

2.2.2.2 SEAWATER TEMPERATURES

Sea water temperatures range from 26°C to 31°C, but in semi-enclosed and shallow waters may range from a low of 19°C in winter to a high of 35°C in summer (Farah, 1982).

2.2.2.3 RAINFALL

Rainfall in coastal regions adjacent to the Red Sea is generally low and variable, ranging from 193mm per year at Massawa (193mm) to 3mm in Hurghada. Annual precipitation along the Sudanese coast is low (111mmyr^{-1}) and hugely variable, with most rains occuring between October and March.

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2.2.2.4 WINDS

The Red Sea climate and circulation pattern are governed by the seasonal reversal of the monsoon winds. During the summer months, from June to August, a strong SW monsoon wind blows over Arabia. From September to early October there is a transitional period. Then in the winter, from November to March, the system reverses and the NE monsoon prevails, followed by another transitional period in April and early May. This gives rise to a seasonal reversal of prevailing wind directions in the southern Red Sea. South of latitude 19°N (a position approximating to the south-central part of the Sudanese Red Sea coast), NW winds prevail in summer, while in winter winds blow from SE over the southern Red Sea. North of 19°N there is a fairly constant NW wind throughout the year (Currie et al., 1973).

2.2.2.5 EVAPORATION

The low rainfall, combined with a lack of perennial freshwater inputs from land and high rates of evaporation (2,000mm yr^{-1}) mean that the entire Red Sea is effectively an evaporating basin, only maintained by net inflow of water from the Gulf of Aden via the Bab al Mandab. Average evaporation in the Red Sea has been estimated to range from 183cm yr^{-1} to 230cm yr^{-1}, with an average of 210cm yr^{-1}. Evaporation in the Red Sea is generally considered to be higher at the northern and southern extents of the basin and lower in the central region (between 16°N to 19°N), due mainly to the wind speed variations between these regions.

2.2.3 Hydrography

The Red Sea is partially isolated from the rest of the global ocean, connected to the Indian Ocean at its southern end by the Bab el Mandeb (Figure 6), a strait 29km wide and a maximum of 130m deep. At its northern end it is connected to the Mediterranean Sea by the Suez Canal.

2.2.3.1 SEA LEVEL

Sea levels in the Red Sea are driven by a combination of winds; atmospheric pressure and circulation patterns, and the sea level varies with the influence of these factors from north to south. The highest range of mean sea level fluctuation is observed at Port Sudan (35cm) while the lowest range (24cm) is at Miyurn Island in the Bab el Mandab.

2.2.3.2 TIDES

The tides within the Red Sea are essentially oscillatory and mainly semi-diurnal. The time of high water in the north is six hours behind that in the south. Tidal range is generally small, varying between 25cm and 75cm, with the greatest ranges occurring in the northern (60cm) and southern Red Sea (90cm) and the lowest range in the central Red Sea and in enclosed areas (Edwards, 1987). The tidal range throughout the Sudanese Red Sea is in the region of 55cm, although this is significantly reduced in semi-enclosed areas and basins such as Dungonab Bay (Farah 1982). At Port Sudan and Jeddah there is virtually no tide, due to an anticyclonic system.

2.2.3.3 TIDAL CURRENTS

Tidal streams are present at the two extremities of the Red Sea: the Gulf of Suez and the Bab Al Mandab; the intensity of the currents decreases towards the central region. Tidal streams passing through restrictions caused by reefs, current-formed sand bars, and low islands, commonly exceed 1-2msec^{-1} (Sheppard *et al.* 1992). Tidal currents are important mechanisms of water and nutrient movement and influence the vigour of benthic communities. In general, tidal currents in the Red Sea flow north when the tide is ebbing and south when it is flooding.

2.2.3.4 SEA WATER TEMPERATURE

Sea water temperature ranges in the Red Sea increase from north to south and then decrease towards Bab el Mandab. Sea surface water temperatures range from 21°C to 28°C in the north and from 26°C to 32°C in the south (Edwards, 1987; Gladstone, 2000). Temperatures reach a minimum in February; maximum temperatures occur in August (north of 20°N) and in September (south of 20°N). Maximum sea water temperatures range from over 25°C in winter (December-February) to over 31°C in summer (June-September). During the

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summer months the area of maximum temperature spreads with the NW winds, whereas in winter the area contracts as winds blow towards the central region. Temperatures tend to be higher on the African side during the summer months due to circulation patterns that pile warm waters onto the African coast in summer under the influence of NNW winds.

There is a thermocline in the Red Sea from 50m to 200m which is stronger than in the north or the south, and weaker in winter than in summer. Below the thermocline the temperature decreases gradually to a minimum of 21.6°C at about 600m and then increases to more than 21.8°C.

2.2.3.5 SALINITY

The waters of the Red Sea are the most saline of any oceanic body of water. The high net evaporation in the Red Sea basin, and limited water exchange through the Bab al Mandab, give rise to high salinity, ranging from 37‰.near the Bab al Mandab in the south to 42‰.in the north. The northwards increase in salinity is due to the combination of evaporation and mixing of low saline Gulf of Aden waters with the more saline deep water, as the latitudinal salinity gradient is accompanied by an increase in salinity with depth. The vertical salinity gradient is strongest in the south and decreases gradually towards the north. In the south the upper 200m show the influence of low salinity water of the Gulf of Aden. In the north the vertical gradients of temperature and salinity are much smaller in winter and deep water appears to be better mixed than in the summer. Below 200m there are high salinity waters of about 40.6 ‰.

2.2.3.6 DISSOLVED OXYGEN

The concentration of dissolved oxygen in the Red Sea varies with: circulation patterns (horizontal and vertical), water temperature and salinity. Oxygen is near saturation in the surface water and ranges from 4.4 to 4.9ml l^{-1} during the cooler winter season and from 3.8 to 4.6 ml l^{-1} during the summer season. The northern and southern ends of the Red Sea are better oxygenated that its central area (19°N-20°N) where the minimum oxygen concentration coincides with the zone of maximum sea surface temperature. While oxygen content is well mixed to about 180m, there is a sharp decline in dissolved oxygen in intermediate waters to a minimum of 1.5 to 1.75 ml l^{-1} at a depth of 500m, beneath which oxygen levels increase.

2.2.3.7 NUTRIENTS

There is little nutrient input into the Red Sea from land based sources; waters are generally nutrient poor (nitrate, phosphate, ammonium and silicate) particularly in open waters. Nutrient concentrations are generally higher in the southern Red Sea due to the influx of enriched intermediate water from the Gulf of Aden during late summer. This can increase nutrient concentration by up to 25% above the level of the central Red Sea, and stimulate primary production by 300%.

- Inorganic Phosphate: Dissolved inorganic phosphate ranges between 0.1 and 0.4µg P-PO4kg, with lower values towards the north. Phosphate concentration increases with depth from 0.5µg P-PO4/kg at the surface to 1.0µg P-PO4/kg in deeper layers, which may be due to phosphate mining in Egypt.
- Inorganic Nitrate: Concentration ranges from 0.15 to 0.5µg N-NO3/kg, with lower concentrations towards the north. Nitrate concentration increases with depth to 200-500m. Maximum concentrations are encountered in shallower water in the south.
- Silicate: Concentrations range between 0.1 and 0.8µg at Si-SiO2/kg and increase with depth to a maximum of about 25µg Si-SiO2/kg in the southern Red Sea at a depth of between 80 and 200m.

2.2.3.8 PRODUCTIVITY

Pelagic primary productivity is relatively low in the clear waters of the northern and central Red Sea, and higher in the southern Red Sea, where waters with elevated nutrient content penetrate through the Bab el Mandeb from the Gulf of Aden (Sheppard et al., 1992). Pelagic productivity is low due to the thermocline and halocline which prevent the recycling of nutrients from deeper waters to the euphotic zone, but increases from north to south. In the central Red Sea, primary productivity is close to 170mgC m^{-2} d^{-1} whereas it can exceed 500mgC m^{-2} d^{-1} in the south.

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2.2.3.9 TURBIDITY

A lack of terrestrial fresh water runoff, combined with relatively low productivity, give rise to low levels of turbidity in the central and northern Red Sea, including most Sudanese coastal waters. Sea water clarity is particularly high in deeper water areas and around offshore reefs, where visibility typically ranges between 20 and 30m, but may reach 70m (PERSGA, 2001). This is in marked contrast to the situation in the biogeographically and ecologically very different southern Red Sea, south of approximately 20°N.

2.2.3.10 CURRENTS AND CIRCULATION

Surface currents in the Red Sea vary seasonally, driven mainly by the monsoon winds and by changes in water density caused by temperature and salinity differences. At more local scales, inshore currents tend to follow the prevailing local wind pattern. During the SW monsoon (May to October) a south and south-east current predominates, and surface waters from the southern Red Sea flow out into the Gulf of Aden and the Arabian Sea. During the NE monsoon (November to April) currents are reversed and surface water flows northwards. North of 20°N the current is typically north-westerly, against the wind, creating a convergence which facilitates the formation of deep water in the north in winter. This simple pattern of surface currents is complicated by mesoscale variability in the form of gyres and eddies.

The mean residence times of water masses in the Red Sea is quite long, ranging from 5 years for water in the upper 150m to 200 years for the entire water mass (Sheppard *et al., 1992*). Water balance is generally negative given the low levels of precipitation and high evaporation. The balance of water is compensated for by the inflow of water through the Bab el Mandab, but this process is complex, and influenced by the presence of the sill, seasonal wind patterns, and a pressure gradient over the sill.

A key feature of the Red Sea circulation is that it is driven by lower water temperatures and higher salinity in the north, which causes surface water in the north to sink and flow southwards along the sea bed, to be replaced by surface waters from further south. This sinking, dense, salty and cool water in the north, together with winds that drive shallower water into the Red Sea from the Gulf of Aden in winter, creates a circulation pattern throughout the entire Red Sea: a double contra-flow with surface waters flowing into the Red Sea at the Bab al Mandab, above a counter outflow of colder and more salty water. In the summer a three layer system exists which includes: a warm and high saline surface out-flow following the winds over the southern Red Sea and the strong upwelling, then a cool, low salinity and low oxygen (0.6ml l^{-1}) inflowing intermediate layer (40 and 80m deep) from the Gulf of Aden and a deep outflow (over 80m).

2.3 BIOLOGICAL CHARACTERISTICS OF THE REGION

The seas of the Arabian region contain some of the world's most diverse tropical marine habitats and communities. They have complex biogeography, high levels of biodiversity, and high levels of endemism. They also include some of the most northerly coral reef and mangrove communities in the world, subject to unusually extreme seasonal variations in temperature. These characteristics make the region globally important for marine biodiversity conservation (Sheppard & Wells, 1988; Sheppard et al., 1992; Chiffings, 1995, Spalding et al., 2001, PERSGA 2001).

The Red Sea itself is one of the more biologically diverse tropical seas in the world outside the Indo-Pacific centre of marine biodiversity in the Indo-malay region (Spalding et al., 2001). There are more than 200 species of corals recorded from the Red Sea, of which about 6% are endemic, and 170 species of echinoderms, of which 5.3% are endemic (Sheppard et al., 1992). About 500 species of benthic algae have been recorded (Chiffings, 1995) and over 1,000 species of fish (Sheppard et al 1992, Goren & Dor 1994). The level of endemism amongst Red Sea fish is about 17%; however, this is an average value and numbers vary greatly between families. For example, amongst small territorial families, such as dottybacks (Pseudochromidae) about 90% of species are endemic, whilst amongst pelagic (open water) families there are few or no endemic species.

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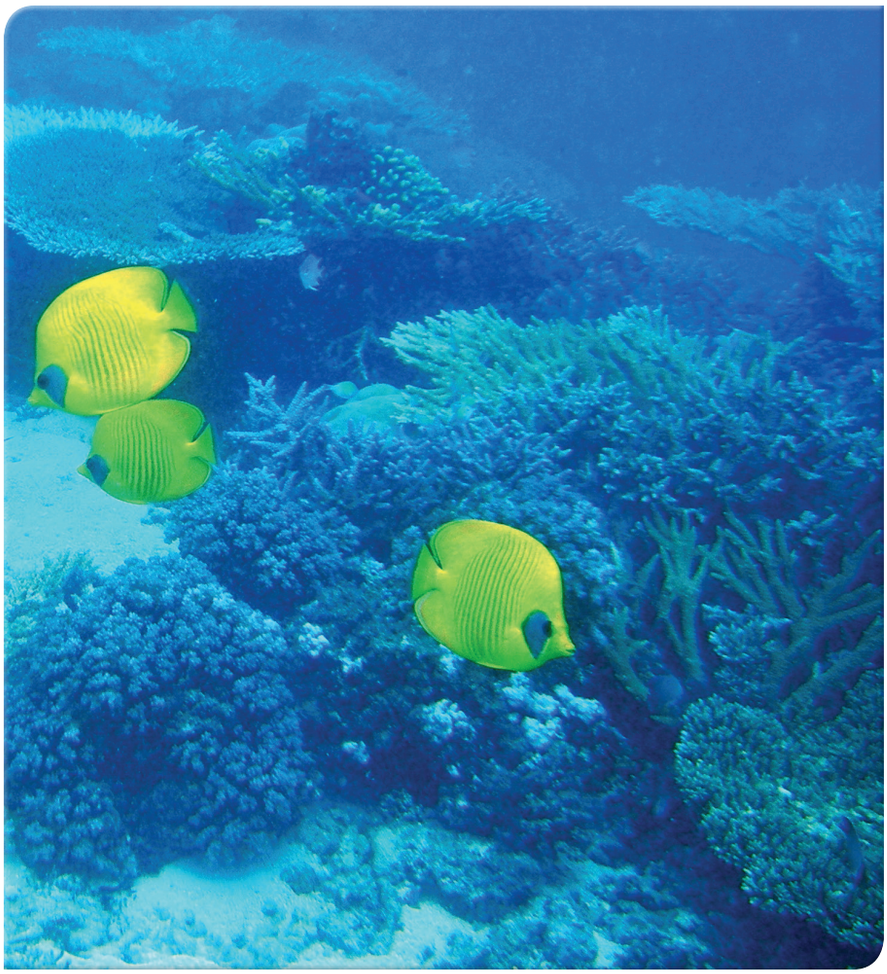


Plate 4: *The Red Sea is home to many endemic species, found only in this region, such as this pair of blue-cheeked butterflyfish* (Chaetodon semilarvatus) *photographed on a Sudanese reef near Suakin.*

As with most of the tropical Indo-West Pacific, scleractinian corals are a dominant feature of hard substrates in the shallow sublittoral of the Red Sea. The deep oligotrophic waters of the northern and central Red Sea, including the Sudanese coast, are fringed by almost continuous well developed biogenic coral reefs (Plate 5). In many areas a well developed offshore barrier reef complex exists, between 1km and 20km offshore, with a steep drop-off to several hundred metres on the seaward side of this reef. Water depths between the mainland and the barrier reefs are typically between 100m and 400m.

Within the Red Sea, complex patterns of species distribution occur. This means that areas of the Red Sea separated by relatively short distances of 100-200 kilometres can be home to markedly different species assemblages, and this is well illustrated by the fish communities found there (Roberts et al., 1992; Sheppard et al 1992; Kemp, 1998). Distinct species assemblages occur in: the Gulf of Suez; the Gulf of Aqaba; the central and northern Red Sea; and the southern Red Sea (Kemp, 1998). There is a major discontinuity at approximately 20°N (coinciding with the widening of the continental shelf) separating the group of species assemblages characteristic of the north-central Red Sea from those of the southern Red Sea (Winterbottom, 1985; Blum, 1989; Roberts et al., 1992).

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Plate 5: *The clear oligotrophic waters of the central and northern Red Sea, combined with the steep edges of the rift valley, create conditions in which well developed coral reefs thrive on the edges of steep drops-offs into deep water.*

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3 Coastal & Marine Habitats & Biodiversity

Linked to following IOC Ecological indicators (Table 1):

- ✓ **E1 : Biological diversity**
- ✓ **E2 : Distribution of species**
- ✓ **E3: Abundance**
- ✓ **E5 : Trophic interaction,**
- ✓ **E7 : Species health**
- ✓ **E9 : Habitat quality**

Linked to the following IOC Socio-economic indicator (Table 3):

- ✓ **SE 5 : Human pressure on habitats**

3.1 AIMS AND OBJECTIVES

The overall aim of the Coastal and Marine Habitats and Biodiversity Survey was to assess the characteristics and status of the marine and coastal environment found in the Sudanese Red Sea. Given the size of the area to be surveyed, the aim was to provide a synoptic overview, by assessing representative sites distributed throughout the area. Given the limited time available, the team focused on key groups that are fundamentally important to the ecosystem functioning, including the benthic communities, macroinvertebrate fauna, and fishes. The specific objectives of the survey were to:

- Assess the broad distribution (IOC indicator E2) and characteristics (ICO indicator E9) of benthic habitats and community types, fishes, key macroinvertebrates, and key conservation flagship species (IOC indicator E2);
- Assess the status (population health, IOC indicator E7) and diversity (IOC indicator E1) of key groups, particularly including corals and fisheries species (in both fish and invertebrates);
- Identify areas of special conservation significance; and
- Provide recommendations with regard to future management.

3.2 METHODOLOGY

Four principal survey methodologies were utilised for the broad scale surveys, with the addition of a fifth rapid fishery assessment method and a sixth set of survey methods for sharks and rays. The methods employed for the broad-scale habitat and biodiversity surveys were designed to be both compatible and comparable with surveys carried out in Dungonab Bay and Mukawwar Island National Park (DMNP) and Sanganeb Atoll Marine National Park (SMNP) in 2002 and 2006, and included:

- ***Detailed Site Surveys***. Providing baseline data on corals and benthic communities, fishes, key mobile invertebrates, and overall site status/health.
- ***Monitoring Site Surveys***. Providing data on corals and benthic communities, fishes, key mobile invertebrates, and overall site status/health. The survey at monitoring sites included additional coral/benthos data collection methods, and the position of the transect at these sites, unlike that in the Detailed Survey Sites, was permanently marked with steel stakes positioned on the reef.
- ***Quick Site Surveys***. Specifically for satellite image ground truthing. Designed to be carried out very rapidly (in less than 15 minutes per site) in order to allow the large number of sites necessary for ground truthing to be completed.

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- ***Rapid Ecological Assessment Surveys***. Designed for use at coastal and island sites, and based upon methods developed and widely used in the Red Sea and Arabian Gulf. Provides a rapid assessment of the distribution of key habitat types, and human uses and impacts, over large areas of coast.

Each of these methods is further described below.

3.2.1 Study Area and Survey Site Selection

Field surveys were conducted in October and November 2007, from the MSY *Elegante* (Plate 6). The survey covered approximately 195km of coast north to south, and approximately 75km west to east, across 2° of latitude (between 20°28'N and 18°45'N) and 1° of longitude (between 37°11'E and 38°10'E).

In order to capture the characteristics of the reefs within Sudanese waters, survey sites were selected to be representative of the range of reef types observed inshore and offshore. The coast was sub-divided into three large sections, and sites were then selected semi-randomly from within these sub-sections (Figure 8) based on reference to previous work, topographic and hydrographic maps, and Landsat 7 ETM+ satellite images. The criteria used for site selection included reef structure, coverage of habitat types, areas likely to be of particular interest or uniqueness, areas of potential impact from industrial, urban or tourism development activities and potential special management areas.

Site selection was in part constrained by both security and safety issues. Security issues restricted access to parts of the mainland coast, particularly the area north of Dungonab Bay towards the Egyptian border, a section of mainland coast immediately south of Port Sudan, and the coast and islands south of Shubuk. Safety issues were given due regard, particularly within the Suakin Archipelago, as the area is poorly charted and some of the more remote parts have limited safe anchorages for a vessel like the *Elegante*.



Plate 6: *MSY Elegante, a fully equipped diving vessel well suited for survey work, with a crew experienced in working with survey expeditions.*

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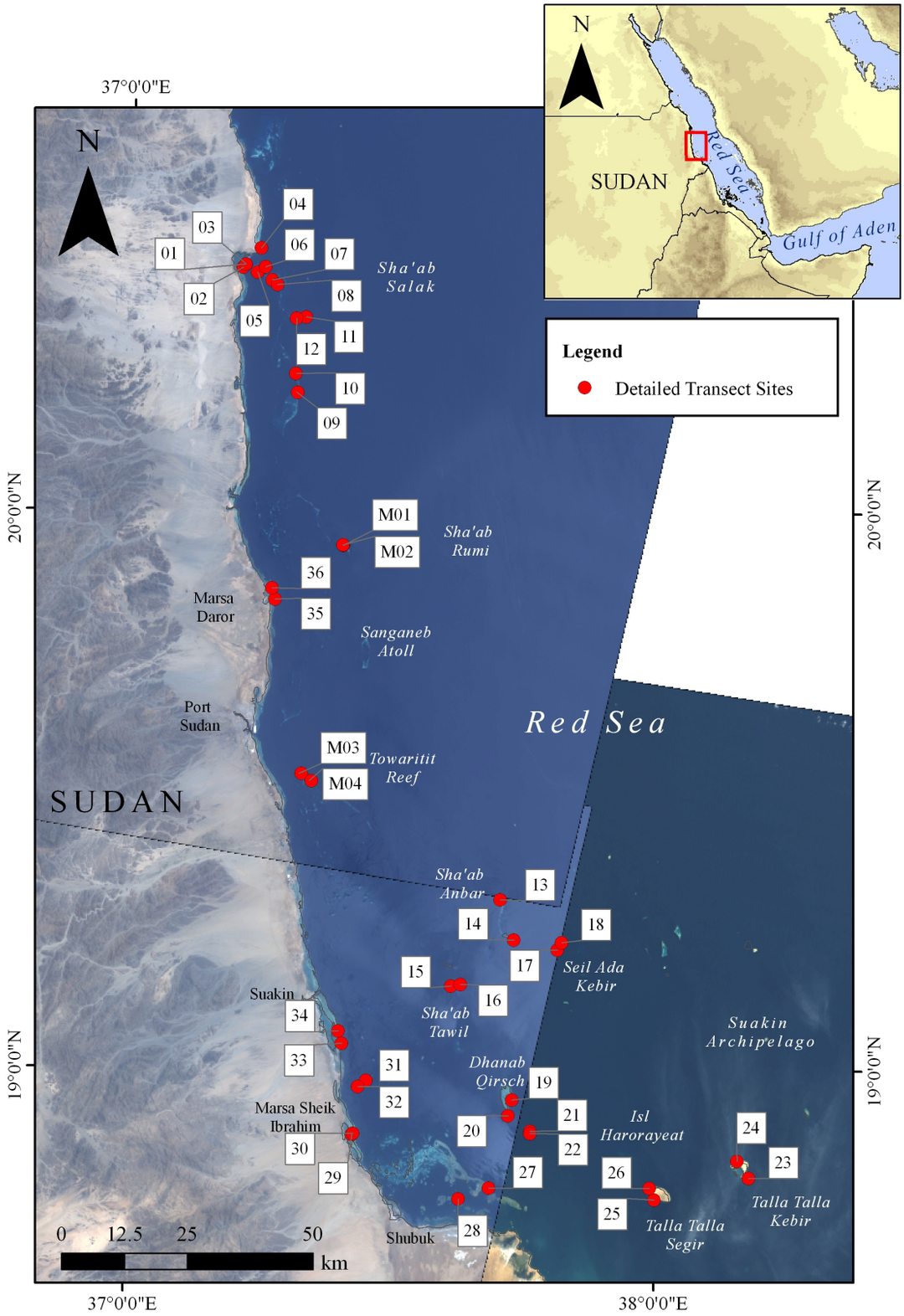


Figure 8: *Map showing the distribution of Detailed Sites surveyed in October-November 2007.*

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3.2.2 Detailed Survey Methods

3.2.2.1 BENTHIC COMMUNITIES

By Rebecca Klaus

The specific sub-objectives of the benthic surveys were as follows:

- Assess the distribution of coral habitats and amount of reef development;
- Assess the benthic cover and extent of live coral cover;
- Assess the species richness and zoogeography, and identify community types;
- Assess coral health and identify potential threats or specific impacts;
- Identify reefs and larger areas of special conservation status; and
- Provide recommendations with regard to future management.

In order to achieve these sub-objectives a combination of survey methods were used at each of the sites, as follows.

Benthic video transects

A digital video camera in an underwater housing was used to record the benthic cover along the transects at each survey site. Video survey methods are faster to implement in the field and provide an archival dataset that can be re-analysed. The video survey method used during these surveys is a modification of global standard protocol (English et al. 1997) that has been adapted for use in the region (Kemp & Klaus 2001; Klaus & Turner 2001a, b; Klaus & Turner 2004; APF 2006).

One diver swam slowly at a speed of approximately 4-5m per minute along the each of the four 20m transects while recording a 0.25m wide belt from 0.3m height above the substrate (English et al. 1997 pp 363-376). The videographer stopped at the beginning of each transect and captured 360° images of the general habitat before continuing along each transect (Plate 7).



Plate 7: *A survey diver carrying out a benthic video survey on a transect site.*

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Video transects were analysed using the standard point count methods (English et al. 1997) using the Coral Point Count (CPCe v.3.5) software. CPCe is a Windows-based programme that allows for the determination of benthic cover from digital stills images or captured stills from video data (Kohler & Gill 2006). The user predefines the substrate and biological cover categories to be used in the analysis. The software then allows the user to specify the number of random points to be used in the analysis. The randomly generated points are then distributed on the screen overlaid on top of the image. The user then identifies the cover type lying beneath each point and records this in the programme. Once all the points have been assigned to an individual cover type, the user moves onto the next image and repeats the process. Once all images have been processed the data can then be exported to Excel to allow for analysis.

In the analysis of the video data from the 2007 survey, digital still images were captured from the video footage to a computer using Adobe Premier software. A total of 25 screen grabs were captured per 20m transect resulting in a total of 100 still images per site. A total of 124 categories of biological or substrate were defined within 20 category type for use in the CPCe software (Table 4). The biological cover types used were typically at the level of genera, and growth form for corals (e.g. *Acropora* staghorn, *Porites* massive). The substrate and biological cover within each of the captured images was then analysed. The composition of benthos under 25 randomly distributed points per image were recorded, resulting in a total of 625 points per 20m transect and a total of 2,500 points per site.

Table 4: *Biological and substrate cover types and the number of categories per type as used in the analysis of the benthic video data.*

Biological Cover Types	No.	Substrate Cover Types	No.
Coral	64	Recently Dead Coral	2
Soft coral	17	Dead Standing Coral	1
Hydrozoan	3	Coral rock	1
Macroalgae	10	Rubble	1
Coralline algae	1	Rock	1
Turf algae	5	Sand	1
Sponge	6	Silt	1
Tunicate	2	Other	1
Actinia	1	Tape/shadow	1
Zooanthids	2		
Other live	3		
Total	**114**		**10**

Benthic Point Intercept Transects (PIT)

The Benthic Point Intercept (PIT) transect method was used to quantify the percent cover of different substrate types at the Monitoring Sites along with the Benthic video transects. The benthic cover directly beneath the transect tape was recorded at 50cm intervals along each of the four 20m sub-transects of the 100m transect. Living and non-living benthic cover were recorded. Living cover is recorded to genera or species where possible. This survey method was only used at Monitoring Sites.

The Benthic Point Intercept Transect data were entered into an Excel spreadsheet and the total cover per category was calculated per transect. Mean percent cover per site was then calculated by averaging the total cover for each cover category over the four 20m transects. The mean percent cover data from the Monitoring Sites were then combined with the data from the Benthic Video Transects.

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Coral Colony Health

A basic Coral Health survey was carried out to capture information on the size, distribution and condition of specific coral genera at the individual coral colony level. The method is derived from the Atlantic Gulf Rapid Reef Assessment (AGRRA) protocol (www.agrra.org). Individual coral colonies that intersect the transect were counted, and the genus/growth form, size class and current condition in terms of partial mortality of the colony recorded. Evidence of other impacts, such as bleaching, sediment damage, disease or corallivores was also recorded. These data can be used to provide information on the demographics (size distribution) of the coral community, the condition of individual coral genera and the prevalence of particular impacts.

Taxonomic inventories

At the end of the video transect the surveyor swam for an additional 20 to 30 minutes across the transect area and across the slope to record species of sessile benthic taxa and record other observations about the reef structure and development (Done 1982; Sheppard & Sheppard 1985, 1991; DeVantier et al. 1998). Taxa were identified in situ to the following levels:

- Stony corals: Species level wherever possible (Scheer & Pillai 1983; Hoeksama 1989, 1993; Sheppard & Sheppard 1991; Wallace 1999; Veron 2000) otherwise genus level and growth-form.
- Soft corals (Plate 8), zoanthids, corallimorpharians, anemones and some macroalgae: Genus or family level (Reinicke 1997; Fabricus & Alderslade 2001).
- Other sessile macrobenthos, such as sponges, ascidians and most algae: Higher taxonomic level, usually phylum plus growth-form (Allen & Steene 1994; Richmond 1999).

At the end of the swim the inventory was reviewed. Corals that could not be easily identified in the field were photographed and, very rarely, representative samples of the colonies were collected. Specimens collected were bleached, rinsed in freshwater and then allowed to dry. Provisional identification of corals that remained unidentified will be referred to taxonomic experts for further appraisals.



Plate 8: *An example of the soft corals found in Sudan.*

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Analysis of Benthic Data

A number of statistical methods and multivariate analytical techniques were used to explore the benthic cover, coral species and coral health datasets, as follows.

- ***Benthic Cover**:* The benthic cover data recorded at each site using the PIT or video records were grouped into a simplified set of 19 basic benthic cover types (e.g. hard coral, soft coral, macroalgae, etc.) Standard statistical techniques were used to explore trends in the relative abundance of different cover types, and the relationship between the different cover types and various environmental variables. The data were tested for normality and, if non-normal distributions were detected, the percent cover data were transformed using an arcsine transformation and tested again for normality. In cases where the data were non-normal, non-parametric methods were adopted.
- ***Benthic Composition:*** Multivariate techniques were used to explore the composition of the substratum at the reefs surveyed in 2007 and to identify site groups. Groups of sites with similar characteristics were identified using hierarchical cluster analysis. Cluster analysis of the basic benthic cover types (19 categories), using Bray Curtis similarity, identified 6 groups with 70% similarity. The cover types that best characterised each of these groups were then determined using SIMPER analysis and the variation between these groups was tested using a non-parametric analysis of variance (Kruskall-Wallis).
- ***Coral Species Diversity:*** The coral species list recorded from this survey was compared at the site level (alpha diversity), at the national level (beta diversity), and within the region (gamma diversity). Comparisons in the species list were made using records from previous surveys in Sudan (Head 1980) and elsewhere in the region (DeVantier et al., 2000; Turak et al., 2007; Veron 2000). The zoogeography of the species recorded was also considered as were the occurrence and distribution of Red Sea endemics.
- ***Coral Community Structure:*** A second multivariate cluster analysis was used to explore coral community composition at each of the sites and to identify site groups on the basis of similarities in the abundance of coral genera. The detailed benthic cover dataset recorded from the video and line intercept transects, which includes 76 cover types, mostly at the genera level, was used in this analysis. The cluster analysis identified 8 groups; the similarities were further explored to identify characteristics of each of these groups using SIMPER analysis.
- ***Coral Health, Impacts and Threats:*** The size class distribution of the corals present on a reef can provide an indication of the health of the coral population, in terms of the age of coral colonies, evidence of recent disturbance events and the level of new recruitment. The coral health dataset was used to explore the colony size class distribution and relative amount of damage among colonies of different growth forms. The relative occurrence of various impacts observed to be affecting the corals at each site was compared.

3.2.2.2 MACRO-INVERTEBRATES

By Melita Samoilys

Key species of macro-invertebrates were quantitatively surveyed to provide a baseline of presence/absence of species on the Sudanese coast and to quantify specific key taxa.

Belt transects

The surveys used a modified version of the Reef Check belt transect method. The presence and abundance of key macroinvertebrates species were recorded within a 5m-wide belt along each of the four 20m sub-transects of the 100m transect.

Surveys focused on indicators of reef health (e.g. sea urchins and corallivorous snails) and selected molluscs and echinoderms that are exploited or potentially exploited in the coastal reef fisheries to try and assess the state of these species' populations and hence the impacts of the fisheries (as shown inTable 5).

Sea urchin abundance surveys focused on *Diadema* and *Echinometra,* the two dominant genera on reefs which probably have the largest impact ecologically in terms of grazing of turf algae (*Diadema*) and bio-erosion of reefs (*Echinometra*). They therefore serve as important indicators of reef health. Starfish species were counted and identified, to species level whenever possible.

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Table 5: *Molluscs and other echinoderms surveyed by UVC at the detailed sites. Arabic names in inverted commas where known. These taxa serve as indicators for Sudan's invertebrate coastal fisheries.*

Latin Name	Common Name	Use/Value
Molluscs (shells)		
Trochus	Trochus ("kokkian")	Mother of pearl buttons (export)
Lambis	Spider shell	Perfume (dh'ufra) and meat
Strombus	Conch	Perfume (dh'ufra) and meat
Murex		Meat
Tridacna	Clam	Meat and medicinal
Sea cucumbers		
Holothuria scabra	Sand fish ("abushutur")	High commercial value Export to Asia (tend to be large, fat, short, and smooth skinned)
H. nobilis	Black teat fish ("abushutur")	
H. fuscogilva	white teat fish	
Holothuria atra	("abusonoun")	Low commercial value Export to Asia (tend to be longer, slimmer and rougher skinned)
H. edulis	("abusonoun" or "abudam")	
H. parva	("abukaboub")	
Actinopyga mauritania	surf red fish ("abushereira")	
A. echinites	Deep water red fish	
A. miliaris	Black fish ("abukaboub")	
Thelenota ananas	prickly red fish ("abushok")	
Pearsonothuria graeffei		No commercial value
All other species		

Surveys also quantified crown of thorn starfish and their feeding scars, the small corallivore gastropod *Drupella*, and lobster.

The molluscs selected for survey (Table 5) are those which have traditionally been fished along this coast, either for their meat or for use as a base for perfumes or medicines.

It was clear that the fishery for sea cucumbers is significant in Sudan, and that species differ in value in the export market. Consequently, sea cucumbers were surveyed by species and allocated a category: high commercial value, low commercial value, or no commercial value, based on information from the fishery in Sudan and East Africa. The groups are shown in Table 5.

The Arabic names and the categorising by value in the fishery are not definitive and require further research. In particular, it transpired that the low value sea cucumbers could probably be split into two groups: medium value (*abushereira* and *abushok)* and low value (*abusonoun* and *abudam).*

Analysis of Macro-invertebrate Data

The notably low numbers of macro-invertebrates throughout the survey, particularly of the exploited molluscs and sea cucumbers, limited the number of statistical analyses that could be undertaken. Most statistical tests were applied to the sea urchin data.

Pair-wise correlations were used to test whether sea urchin density varied with algal cover and with latitudinal gradient. Sea urchin and starfish abundances were compared to test the hypothesis that both have similar life history strategies and should therefore show similar patterns. Sea urchins respond to reef degradation and colonise degraded reefs and, therefore, where there are differences in their densities this may reflect reef degradation. The relationship between sea urchins and fish taxa that prey on sea urchins, such as snappers, emperors and sweetlips, was also examined using correlation analysis.

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The influence of environmental parameters, such as depth on the distribution of *Lambis* shells and clams, was also investigated. Depth values were changed into classes and a one-way ANOVA and a Chi Square test of association were performed to test whether the depth classes differed in *Lambis* and clam abundance; or whether *Lambis* or clams were significantly associated with depth classes.

3.2.2.3 FISH

By Jeremy Kemp and Melita Samoilys

The detailed fish surveys aimed to collate a representative assessment of the fish communities associated with the coral reef. The surveys were designed to enable site characterisation on a site-by-site basis and to provide baseline information about the distribution and abundance of key species groups and fish community types.

Underwater Visual Census

Quantitative surveys of selected families of reef associated fish, including groups that are exploited or potentially exploited in Sudan's coastal reef fisheries, were carried out using a modified form of Reef Check's underwater visual census (UVC) method to estimate abundance (number per $100m^2$) and/or species presence/absence data at 40 sites along the Sudanese coast.

A surveyor, experienced in Indo-Pacific reef fish identification to the species level, swam slowly along the survey transect line directly above the transect tape, recording fish abundances within the 5m-wide belt transect of fish of a number of indicator groups, on pre-printed survey sheets. The surveys recorded the abundance of both general ecological/biodiversity indicators and fisheries groups.

At the start of the transects, and then at each 5m gap between 20m sub transects, the observer used a second survey record sheet to record the presence of fish from nine indicator families, and whether these were observed inside or outside the area of the belt transect. The indicator families were identified to species, and included general ecological/biodiversity indicator groups (butterflyfish, angelfish, damselfish, wrasse, triggerfish, surgeonfish) and fisheries families (snappers, emperors, groupers). After finishing each transect the observer spent a further ten minutes carrying out a timed search for additional species in these indicator families.

Ecological/biodiversity indicator groups

The survey focused on six indicator families of fishes, in addition to fisheries groups (see following section) that provide an indication of the nature of the overall fish community at a coral reef site. These families were: butterflyfishes (*Chaetodontidae*), angelfishes (*Pomacanthidae*), damselfishes (*Pomacentridae*), wrasse (*Labriade*) triggerfish (*Balistidae*) and surgeonfish (*Acanthuridae*). Data collected using this method include:

- Abundance of butterflyfishes and angelfishes within the four replicate 20m x 5m belt transects at each site (all individuals identified to species level).
- Species richness of surgeonfish, triggerfish, damselfish and wrasse.
- Additional observations of the presence and abundance of sharks, rays and moray eels.

Exploited Fin-Fishes

The survey focused on the following families that comprise key fisheries species: Sweetlips (*Haemulidae*), Snapper (*Lutjanidae*), Emperors (*Lethrinidae*), Groupers (*Serranidae – Epinephelinae*), Parrotfish (*Scaridae*) including the large bump headed parrot fish (*Bolbometapon muricatum*) and the Napolean or Maori wrasse (*Cheilinus undulatus*). Population abundance was quantified at species/genera levels in these families, as shown in Table 6, which was based on their probable value in the local fisheries.

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Table 6: *Finfish groups surveyed by UVC at the detailed sites.*

Latin name	Common name	Fishery
Haemulidae	Sweetlip	Some species taken
Lutjanidae • small *Lutjanus* species • *Macolor niger* • large *Lutjanus* species	Snapper	Some species taken Not taken Highly valued in local fishery
Lethrinidae – *Lethrinus* spp. *Monotaxis grandoculis*	Emperors Big eye emperor	Highly valued in local fishery Not taken
Serranidae • *Cephalopoholis spp.* • *Aetheloperca rogaa* • *Epinephelus spp.* • *Plectropomus* (2 spp.)	Groupers small coral species small black grouper larger groupers coral trout – "najil"	Generally not taken Taken in local fishery Highly valued in local fishery Highly valued and exported
Scaridae • large species • small species • *Bolbometapon muricatum*	Parrot fish Bump head parrot fish	 Not taken Not taken Taken in local fishery
Cheilinus undulates	Napoleon wrasse (also called maori wrasse)	Not taken

Data collected using this method include:

- Abundance of groupers, snappers, emperors, parrotfish within the four replicate 20m x 5m belt transects at each site; and
- Abundance of Napoleon wrasse within the four replicate 20m x 5m belt transects at each site. These are high value target species in fisheries in many parts of the Indo-Pacific region, and have high conservation and tourism value and, as such, are included in all ReefCheck-based surveys.

Analysis of Fish Data

A number of statistical methods and multivariate analyses were carried out to examine the fish survey data and the distribution patterns of both ecological indicator groups and exploited finfish and macro-invertebrates. Data were tested for normal distribution before tests were carried out. If non-normal distributions were detected, non-parametric methods were adopted.

The spatial distribution of fish communities and their affinities were investigated utilising the PRIMER (Plymouth Routines In Multivariate Ecological Research) statistical package. Where appropriate, data were tested for normality before tests were carried out. If non-normal distributions were detected, non-parametric methods were adopted.

Cluster analyses were used to reveal national and regional biogeographic relationships, permitting the inclusion of data from surveys carried out elsewhere in the region for comparative purposes.

The following were considered important indicators in assessing the reef fisheries of Sudan, and therefore the data analyses revolved around these taxa:

- The grouper *Pletropomus* spp. (najil), which is a valuable export fishery to Saudi Arabia, though this market has been closed by Saudi Arabia for the present;

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- The large snapper group, because it includes *Lutjanus bohar* (named after its Arabic name, bohar), an important component of Sudan's coastal hand line fishery. It is also widespread and commonly occurring throughout the Indo-Pacific and Arabian region and therefore serves as an indicator species for population status of Sudan's reef fisheries;
- The small colourful snappers that are common on coral reefs (*L. fulviflamma*, *kasmira, ehrenbergi*) and the black snapper (*Macolor niger*) are not targeted significantly in reef fisheries and therefore their population densities may reflect reef type and reef health. This may serve as a useful proxy control against fishing pressure;
- Four species of *Lethrinus* emperor are listed as targeted in Sudan's coastal hand line fishery;
- Parrot fish are not taken in Sudan's fisheries but as herbivores they are significant in the recovery of coral reef to bleaching and as such are a key group to monitor; and
- The Napoleon Wrasse (*C. undulatus*) is listed on Appendix II and has high conservation and tourism value.

Stepwise multiple regression with substrate types was used as the regressors with fish taxa as the response variable in an attempt to generate a 'good' set of regressors/predictors for each fisheries taxon. In stepwise multiple regression, the exploration of alternatives frequently assumes a 'stepwise' format, in which regressors are successively added to or deleted from the initial formulation, generally in a hierarchical fashion, i.e. once a regressor is introduced it remains in the model, or alternatively, once deleted, it remains out of the model. All substrates types were added to the stepwise model and variables that significantly influenced the distribution of response fish taxa were noted. Within this analysis we tested the general hypothesis that parrotfishes are key herbivores on the reef and important grazers of algae which in turn helps coral recolonisation and reef recovery after bleaching.

Large and small snapper abundances were compared across sites using matched pairs analysis to test the theory that small snapper species are not targeted in fisheries and may therefore reflect "normal" patterns of density, whereas the large ones will reflect fishing pressure. Matched pair analysis compares means between two response columns with a t-test and a plot of the difference of the two responses on the ***y***-axis, and the mean of the two responses on the ***x***-axis. The mean difference is shown as the horizontal line, with the 95% confidence interval above and below.

3.2.2.4 RAPID FISHERY ASSESSMENT

By Melita Samoilys

The fisheries of Sudan range from locally exploited food fisheries to high value export fisheries which have been exploited over the last 100 years or so. During the biodiversity survey a qualitative assessment of the coastal fisheries was made through interviews with fishermen at sea, through direct observations of fishing activities and through informal discussions with various Sudanese colleagues. This information, together with the analyses of the biodiversity survey data on exploited species above, provides a preliminary assessment of the current status of Sudan's coastal fisheries, but should not be considered as definitive or quantitative.

Methods

Information on Sudan's coastal fisheries was obtained through: (a) a visit to the main fish market in Port Sudan; (b) semi-structured interviews with fishers *in situ*, together with direct observations of these fishers. The interviews were conducted on islands where fishers were camped or on the mainland where fishers were found fishing. They had to be conducted quickly and opportunistically in between the dives for the biodiversity survey. The interviews were conducted in Arabic by Sheik el Din and were structured as shown in Table 7.

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Table 7: *Questions posed to fishers during the biodiversity survey to obtain qualitative information on current fisheries observed during the survey (October-November 2007).*

Questions	Information obtained
1) Who is fishing?	Describes the fishers – from local communities to foreign fishers
2) What are they catching? What species ? Where are the fishing grounds ? When do they fish species x ?	Describes the catch Describes the main fishing areas of Sudan's coast Describes any seasonality in fishing
3) Where does the catch go? Who buys it ? What is the market chain ? Who are the buyers ? What quantities and value are involved ?	Describes the market chain and the value of the fishery

3.2.2.5 SHARKS AND RAYS

By Nigel Hussey and Steve Kessel

Methods

A number of field survey approaches were adopted in the shark and ray survey, including in-water dive surveys, tagging, nursery area surveys and dive operator interviews.

Diving Surveys

At each site the species of sharks present were documented and, where possible, information on sex and size class were recorded. Size class of expected sharks/rays (juvenile/sub-adult and adult) were derived from the literature (FAO 2005). Abundance estimates of sharks and rays were undertaken through coarse counts by two surveyors in the water, and comparisons of observations were made after each survey.

A bait drum containing fish carcases was suspended at a predetermined depth using floats and anchored to the sea bed. Where possible the bait drum was left in place for several hours to attract animals to the site. In most cases this approach was unsuccessful, due to both the time constraints of the survey programme and the time of year, as it is known that sharks either inhabit much deeper cooler water at this time of year or move to different locations (along unknown migration routes).

Tagging

The tagging programme involved the application of placard ID tags, consisting of a large plate tag with a clearly embossed, unique number or name connected by monofilament line to a dart anchor (Plate 9). This tag type was used for both manta rays (*Manta* spp.) and shark species (of over 1m in length).

Data for each tagged animal were recorded during the tagging process (species, location, date etc.) The tags are specifically designed for in-water identification of animals, coordinated with the recreational diving industry. The modern expansion of the recreational diving industry provides an opportunity to coordinate 'in water' reporting of tags with the industry, on a long-term basis (Plate 10).

Nursery Area Surveys

Regulated gill netting (checks every 10 minutes) was undertaken to identify whether nursery areas existed in likely areas, both by night and by day, at 4 sites.

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Size (pre-caudal length, fork length and total length) and sex measurements were recorded for juveniles caught. Caught juveniles were then released. Genetic samples were taken as the first steps in the establishment of a Red Sea shark genetic database.



Plate 9: *A tag being prepared for application at a survey site.*

Divers Aware of Sharks
Equipe Cousteau

African Parks Conservation

Equipe Cousteau
Cousteau Society

Dive boat: *Don Questo*
Divemaster: *Marco*
Weather conditions: *Sunny, clear and flaw calm*

Date: *18th November 2007*	Dive Location: *Sha'ab Rumi, South plateau*	
Dive Start Time: *7.14 am*	Dive Finish Time: *8.10 am*	Video/photos (file name): *181107Jsmith*
Current: *SW/medium*	Visibility: *20 m*	

Type / Species	Number of animals	Size/s (m)	Sex	Depth of animal/s (m)	Water Temp (°C)	NOTES (placard tag sighting/behaviour/presence of scars – fishing hooks etc)
Grey Reef	*10*	*7 (1.8)* *3 (1.3)*	*8 (F)* *2 (M)*	*20*	*29*	*Tag number 11 on east edge of the plateau walls*
Hammerhead	*25*	*10 (1.3)* *10 (1.5)* *5 (2.3)*	*8 (M)* *3 (F)* *18 (?)*	*30*	*27*	*Seen initially in deeper water (around 35m). Small sharks came on first and seemed curious*
Tiger						
Whitetip Reef						
Manta Ray						
Eagle Ray						
Other:	*1*	*2.1*	*F*	*14*	*29*	*Came from east, circled group and then descended off west wall to deeper water*

Plate 10: *Re-sighting of a tagged grey reef shark* (Carcharhinus amblyrhynchos).

Site selection for future research

Sites deemed to be of particular interest, for example sites with known dense aggregations and cleaning stations, were documented for future research. This included identifying possible sites for the positioning of fixed monitoring devices that could gather information about movements of tagged sharks and rays. Species particularly amenable to this approach are the scalloped hammerhead (*Sphyrna lewini*), the silvertip shark (*Carcharhinus albimarginatus*), the grey reef shark (*Carcharhinus amblyrhynchos*), the silky shark (*Carcharhinus falciformis*) and the Manta ray (*Manta birostris*).

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Dive Operator interviews

Interviews were conducted with key dive operators working in the region. It was apparent from the onset that regional dive operators possess extensive knowledge regarding the elasmobranch species present, as well as their abundance on a seasonal basis. The main sites that key species frequent were identified and, where possible, seasonal patterns in abundance were recorded.

Sudan is a prized international destination for diving with sharks and rays. Coupled with the extensive knowledge and commitment of dive operators, a 'Diver network reporting programme' was initiated. Seven dive boats are involved in this programme to date. This programme will record basic data on species present, abundance, size, sex, the depth and temperature of sighting and current conditions throughout the diving season and will be achieved by dive operators, in conjunction with clients, logging their dives on a specially designed survey form.

Materials developed for the Diver network reporting programme were as follows.

1. A diver information pack, detailing what the project aims to achieve, why it is needed and what is involved, was produced and a laminated version deposited on each dive boat.
2. Survey forms for reporting basic data on shark and ray species present were produced in conjunction with dive operators and multiple copies supplied to each boat.
3. 500GB hard drives were placed on each boat for dive clients to download shark and ray video and photographs in an organised format.
4. An access data entry programme is currently being developed to enable direct entry of the survey data on dive boats. Files can then be emailed to the main database.
5. A project-dive industry coordinator was elected by the dive operators to liaise directly with Equipe Cousteau (Claudio Scarpellini, of the Elegante).
6. Data from the Diver programme will be collated throughout the diving season and analysed using basic statistics to identify the abundance and seasonal distribution of shark and ray species. Long term archived image material may be used to compile a database of individual animals sighted and used for future population assessments at sites.

For each dive, data recorded by divers on the designed survey forms include:

1. Species observed;
2. Number of individuals of each species observed;
3. Estimated length of the individuals;
4. Sex of individuals: Male/Female/Unknown;
5. Depth of the sighting;
6. Temperature of the water;
7. Visibility;
8. Strength and direction of the current; and
9. Weather conditions.

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3.2.3 Quick Survey Sites

By Rebecca Klaus

The ground-truthing surveys were intended to collect broad scale information on the spatial distribution and variability of subtidal benthic biotope types for use in creating maps. The ground-truthing surveys employed the "Quick Site" survey method, which provides an initial comparative dataset on the physical structure and composition of the biological community.

The "Quick Site" method was previously adapted from DeVantier et al. (1998) and has successfully been used in mapping other parts of Sudan (PERSGA 2004a and b), the Red Sea, and wider Indian Ocean region (Klaus & Turner 1999; Klaus & Turner 2001a, b; Klaus *et al.* 2008). As the method is quick it allows a survey team to cover a large number of sites over a broad area (Figure 9) in a relatively short period of time and thereby provides a more geographically comprehensive overview of an area than would be achievable using more detailed survey methods alone. This facilitates the identification of: (i) Broad groups of biotopes for mapping (Biotope Complexes), (ii) Suitable survey sites for more Detailed Surveys, and (iii) New or previously undescribed biotopes, which may also require more detailed surveys.

At the start of the "Quick Site" survey the centre of the area was marked using a GPS, and the depth and surface water temperature were recorded using a Norcross handheld depth sounder. Team members then randomly snorkelled over an area of roughly 100m x 100m for 10-15 minutes and recorded information on the composition of the substratum and percent biological cover (Table 8) to provide a visual semi-quantitative estimate of the characteristics of the site. The categories used in these surveys have been shown to be relatively insensitive to biases among different observers (Miller and De'ath 1996; Vogt *et al.* 1997; Miller and Muller 1999). They have also been shown to be useful in distinguishing between contrasting benthic assemblages (Done 1982; De Vantier *et al.* 1998). Team members also recorded the presence/absence of key invertebrate macrofauna (urchins, sea cucumbers, starfish, clams and anemones) and species of algae, corals, fishes and other larger benthic invertebrates found in the area.

At the end of the survey, team members rapidly compiled their observations for each site. The percentages recorded for the structure and the biological cover, total 100 percent independently. The species lists recorded are not intended to be exhaustive, but should provide basic information on the most common and characteristic species found in each habitat. Finally, a brief description of the site including any particularly distinguishing features or ecological characteristics is recorded before progressing onto the next site.

Table 8: *The information collected at the subtidal ground-truthing "Quick Sites".*

General	Habitat Structure %	Biological Cover %	Presence	Common species
GPS waypoint	Large blocks >1m	Hard coral	Urchins	Algae
Date	Small blocks <1m	Dead coral	Sea cucumber	Corals
Transect number	Cobbles	Soft coral	Starfish	Fishes
Site name	Hard substratum	Turf algae	Clams	Invertebrates
Reef type	Rubble	Macroalgae	Anemones	
Reef Development	Sand	Coralline algae		
Depth, Min.	Silt	Seagrass		
Depth, Max.		Sponges		
Slope		Bare		
		Other		

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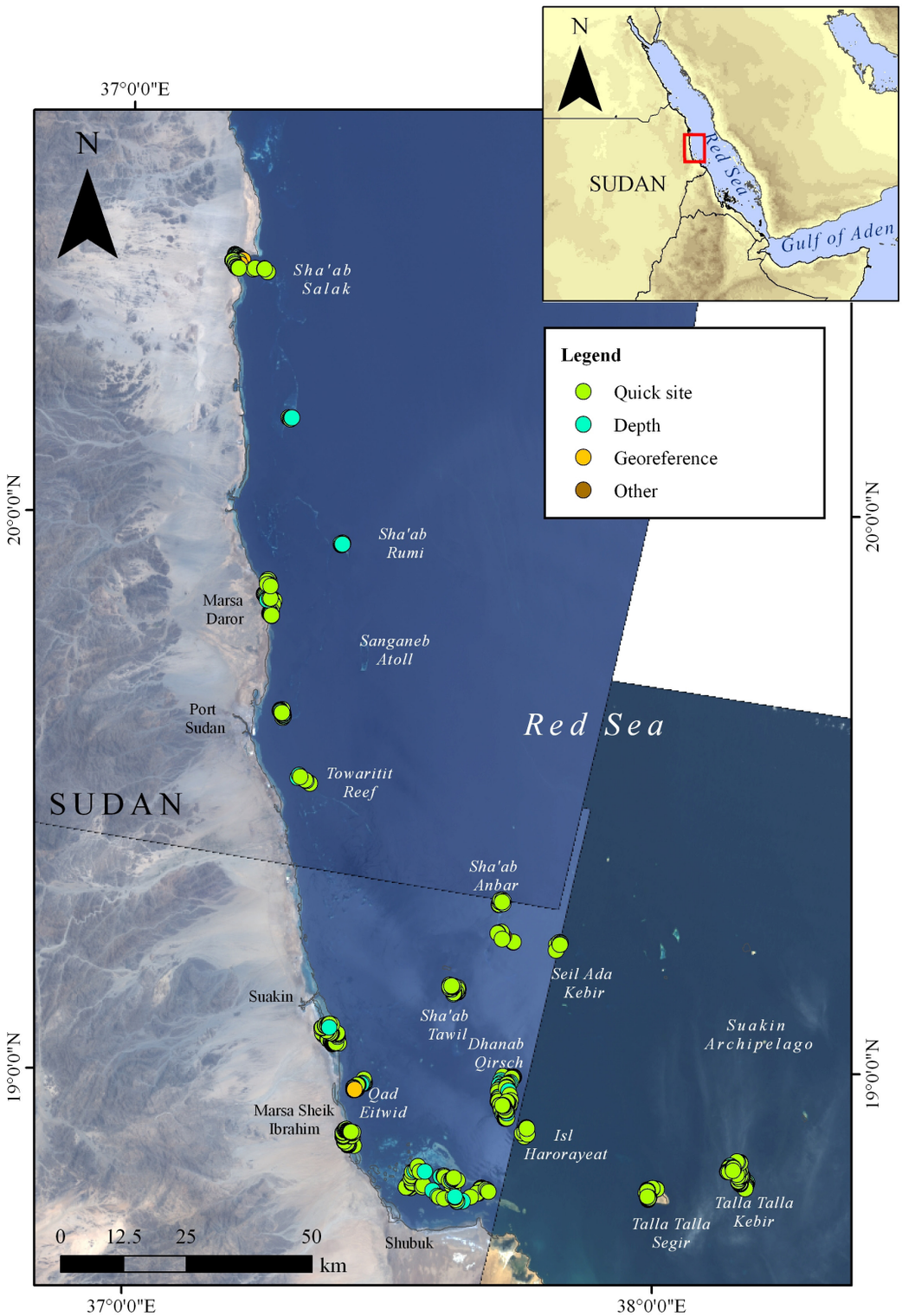


Figure 9: *Map showing the distribution of "Quick Sites" surveyed for ground-truthing in October-November 2007. Also illustrated are the depth records and ground control points for checking the geo-referencing of the satellite images.*

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3.2.4 Rapid Ecological Assessments (REAs)

By Jeremy Kemp and Rebecca Klaus

Rapid Ecological Assessment (REA) sites (Figure 10) comprise a quadrat 500m x 500m in extent, extending 250m up the shore and 250m into the subtidal zone (*Survey Sheet 7*). The intertidal/land component of the quadrat (500m x 250m) is determined from observations while walking. The subtidal component (500m x 250m) is examined while snorkelling. Within each quadrat, the abundance of biotopes and species groups and magnitude of human uses and impacts are estimated (Table 9). Observations at one site take about an hour. A logarithmic scale, using a 0–6 ranking system, is used to estimate the extent and abundance of ecosystems and species. In the case of flora and corals/reefs, scores are based on estimates of areal extent (m^2).

Table 9: *Logarithmic scale used for abundance estimates of coastal ecosystems (flora and reefs), species groups (fauna), and human uses/pressures (impacts).*

Ranked abundance/ Score (log scale)	Areal extent (m2) of flora and reefs or number of individuals of other fauna (equivalent arithmetic range)
0	0
1	1 – 9
2	10 – 99
3	100 – 999
4	1,000 – 9,999
5	10,000 – 99,999
6	100,000 +

For mobile fauna the same 0-6 scale is used to record the estimated number of individuals within the quadrat. The same 0-6 scale is also used to assess the relative magnitude of fishing, construction or developments (e.g. ports, jetties) as well as oil pollution, other impacts, and driftwood. Where any attributes cannot be quantified, a binary scale is used: - (absent) or + (present). The same +/- scale is used for assessing important attributes (e.g. construction, presence of mangroves, etc.) close to but outside the quadrat.

Coastal Vegetation and Ground Truthing

The Land Based Survey (LBS) was carried out by staff of the Institute of Marine Research of the Red Sea University in Port Sudan. The Survey Area for the Land Based Survey (LBS) covered the central coastal area of Sudan (Figure 10 & Figure 11) extending approximately 200km from north to south. The northern boundary of the survey area was the southern edge of the Dungonab Bay and Mukkawar Island Marine National Park (DBNP), and the southern boundary was 10km south of the port of Suakin. Two principal survey methods were used during the survey:

- REA surveys (see above) and
- "Quick Site" surveys, for satellite ground-truthing.

The objective of the ground truthing "Quick Site" Surveys is to collect rapid "spot-check" data on the coastal habitat types for use in calibrating and validating the satellite images, in order to produce habitat maps. The method results in a description of the physical structure (the substrate type) and the biological cover (in this case vegetation type) for each of the habitat types observed within the coastal zone.

Each "Quick Site" consists of a quadrat approximately 100m x 100m in size, with the waypoint taken at the centre of the quadrat. A photograph was taken at or near the centre of each site to capture the characteristics of the cover type. The characteristics of the site were then described according to their physical and biological cover.

- ***Substrate Type*:** The physical structure of the site was described by estimating the percent cover of different substrate types. The relative abundance of each substrate cover type were recorded as a percent cover, totalling up to 100 percent for each site. The different categories of substrate type that might be

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encountered are listed below. For example, the substrate may be composed entirely of sand (recorded as 100% sand), or a combination of sand and rubble (recorded as 60% sand and 40% rubble) or entirely rock (recorded as 100% hard substrate).

- ***Biological Cover:*** The biological cover observed at each ground truthing "Quick Site" were described by estimating the percent cover of vegetation types and dominant plant species. The relative abundance of each biological cover type and the amount of bare substrate without any biological cover were recorded as percent cover, totalling up to 100 percent for each site. The different categories of vegetation cover encountered are listed below. For example, the vegetation cover may be composed of 20% mangrove (recorded as 20% mangrove and 80% bare substrate), or a combination of 30% mangrove trees and 20% other halophytes (recorded as 30% mangrove, 20% halophytes and 50% bare substrate).

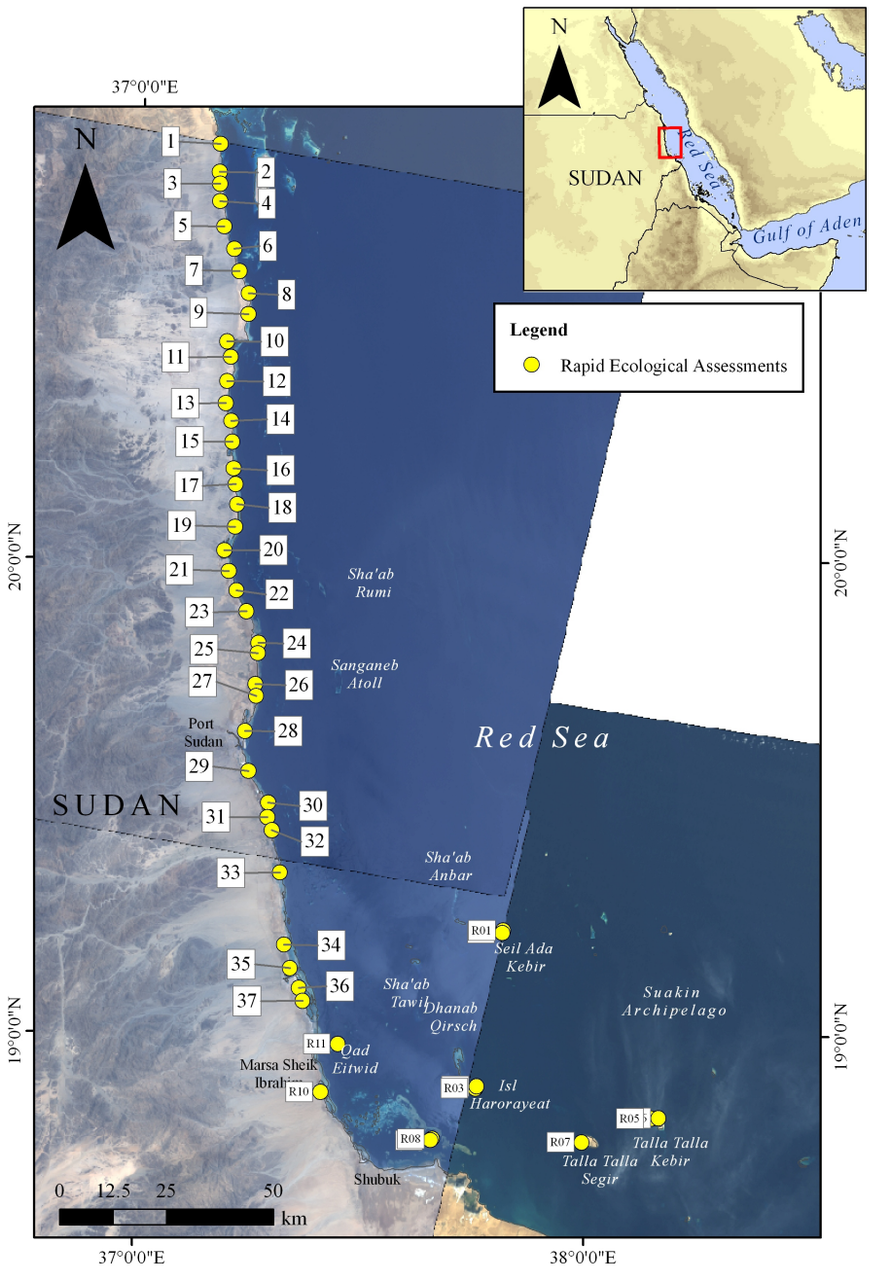


Figure 10: *Map showing the distribution of Rapid Ecological Assessment sites surveyed at offshore locations in October-November 2007 and along the mainland coast in 2008 by the Red Sea University.*

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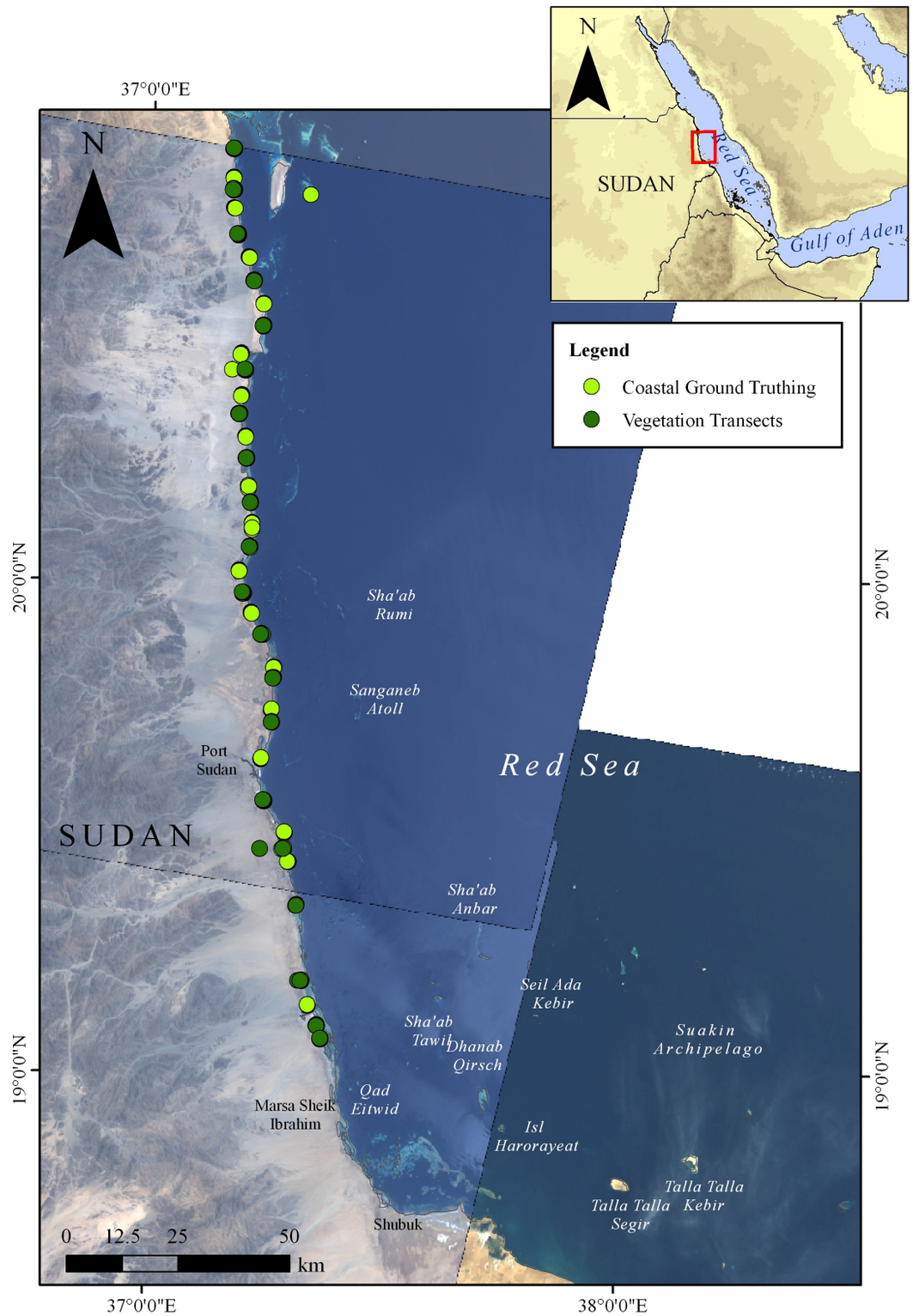


Figure 11: *Map showing the distribution of Coastal Vegetation Transects and ground truthing sites surveyed in 2008 by the Red Sea University.*

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3.3 RESULTS AND DISCUSSION

This section summarises the findings of the Marine and Coastal Habitats and Biodiversity Survey carried out in October and November 2007.

A total of 40 Detailed Sites were surveyed, including four permanent monitoring transects. At each of these sites data on fishes, invertebrates and corals were gathered that provide a useful snapshot of the status of the survey area in late 2007. Video transect data were also collected, and these form the basis of a permanent visual record of these sites.

Overall, the results of the survey presented in this report reveal a highly variable situation: coral communities were generally in good condition, but in some areas impacts on corals have been high in the recent past, probably as a result of coral bleaching events. Fish communities show pronounced geographical patterns that are consistent with wider biogeographic trends in the region and, although diversity and abundance of non-fisheries groups is generally good, there are serious causes for concern over fisheries groups.

The remote location of substantial parts of the survey area, and in many cases the presently low level of development along the coast, mean that (with the exception of reef fisheries) shore-based activities currently have little impact outside the immediate vicinity of Port Sudan (e.g. domestic or industrial pollution, landfill).

3.3.1 Benthic Biodiversity and Community Types

Related to IOC Handbook Indicators E1, E2 and E9 (Table 1)

By Rebecca Klaus

3.3.1.1 INTRODUCTION

The reefs of the Red Sea are known for their diversity and they have been the focus of detailed studies for many years. Early explorers (e.g. Forskal 1775) conducted taxonomic studies in the Red Sea and some of the earliest coral collections include specimens from the Red Sea (e.g. Linneaus 1767; Forskal 1775; Ellis & Solander 1788-1830; Lamarck 1816; Ehrenberg 1834; Edwards & Haime 1860; Klunzinger 1879). At the turn of the nineteenth century taxonomic studies continued (Marenzeller 1907; Gravier 1911) and studies also began to explore the ecological characteristics of the reef habitats. In the 1950s studies in the Red Sea continued (Hass 1952; Roghi & Baschieri 1956) most of which focused on the northern reefs and the southern reefs around the Dhalak Archipelago.

A resurgent interest in coral taxonomy in the 1980s resulted in the production of the first modern systematic account of reef-building corals in the Red Sea (Scheer & Pillai 1983) and wider Arabian region (Sheppard & Sheppard 1991). These studies identified a total of approximately 180 species in 68 genera from 16 families recorded from the Red Sea, including 9 endemic species in 8 genera within 6 families (Sheppard & Sheppard 1991; Sheppard 1997). These figures have been revised following more recent surveys, particularly on the Arabian side of the Red Sea (e.g. Saudi Arabia, by DeVantier *et al.*, 2000; and Yemen, by Turak *et al., 2007*) which contributed to the most recent major revision of the taxonomy of scleractinian corals, produced by Veron (2000).

While there have been extensive surveys in many part of the Red Sea there have only been a limited number of studies on the Sudanese reefs and these studies have, typically, been geographically limited to the reefs around Port Sudan (Head 1980; Edwards & Head 1987) and the Sanganeb atoll (Mergner & Schumacher 1985; Reinicke *et al., 2003*). More recent surveys in 2000 and 2006, associated with the establishment of marine parks in Dungonab Bay and the Mukkawar Island region in the northern part of Sudan, extended the understanding of the benthic communities found along these coasts (Kemp & Klaus 2001; PERSGA 2004a, b; APF 2006). The present study provides one of the first opportunities to study the species diversity and community structure on other more remote reefs within Sudanese water.

3.3.1.2 PHYSICO-CHEMICAL SETTING

During the survey period in October 2007 there was substantial variability in both the water clarity and sea surface temperature. Visibility ranged from 4m to 30m. Surface water temperatures ranged from 29°C to

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33°C and bottom water temperatures ranged from 29°C to 32.5°C. The highest visibility was recorded around Marsa Salak, Ras Salak and Sha'ab Salak (up to 30 m) and the lowest visibility was recorded in the southern part in Shubuk (4m inside the barrier reef complex and 5m just outside). Some of this variability was due to changes in the weather conditions during the survey, which were particularly windy during the latter part. However, some of the southern reefs, particularly those around shallower inshore regions near Shubuk, are likely to be exposed to naturally higher levels of turbidity for much of the year.

3.3.1.3 REEF DISTRIBUTION AND DEVELOPMENT

Related to IOC Handbook Indicators E9 (Table 1)

The coastal waters of Sudan support extensive coral growth and host a diversity of reef formations, most of which have not previously been surveyed or described. These reefs can be classified into five broad types: (i) mainland fringing reefs, (ii) nearshore barrier reef systems, composed of platform reefs, patch reefs and reticulated patch reef, (iii) offshore barrier reef systems, composed of ridge reefs (*sensu* GUILCHER 1988), linear or 'ribbon' reefs, platform reefs, pinnacles and patch reefs, (iv) island fringing reefs and (v) a combination of other isolated reef types including atolls, pseudo-atolls and tower reefs. Only 40 sites were surveyed during 2007 and these covered a relatively small number of the different types of reef. The following account thereby provides an introductory overview to the reef development observed on some of the reef types found within Sudanese waters.

Mainland Fringing Reefs

The mainland coast of Sudan is edged by a well developed near-continuous fringing reef that spans almost the entire length of the coast. The fringing reef extends north of Port to Sudan to the Egyptian border and south as far as Shubuk. Surveys were not carried out south of the Shubuk area due to security issues, although it is apparent from the satellite images that the fringing reef is absent between 18° 41'N to 18° 31'N, where the coast is more sedimentary. The breaks in the fringing reef along the mainland coast are usually situated at the entrance to ancient river beds ('khors') or embayments ('marsa'). These channels may be reef lined, and provide a habitat distinct from that of the outer fringing reefs, which often host a different biological community.

The extent of fringing reef development along the coast is variable and probably reflects differences in the local environmental conditions, proximity to deep water and degree of exposure. The fore reef slopes typically extend from a reef flat. The slopes are often terraced, and typically shelve gently near embayments and more steeply around headlands and promontories. The extent of reef development and the distance between the shore and the reef slope may vary from less than 200m to more than 2,500m, being greater where there are embayments. Extensive lagoon systems occur and provide a sheltered habitat for macroalgae, seagrass beds and patch reefs. The depth of these lagoons varies (provide depth range here or add below) and some may contain deep pools. Surveys in 2007 were carried out on mainland fringing reef in five areas: (from north to south) Ras Salak, Marsa Salak, Marsa Daror, Suakin and Marsa Sheik Ibrahim (Figure 12 a-d). The variation in the structure of the fringing reefs at these locations is as follows.

The reef around the headland at Ras Salak (Figure 12 a) is relatively close to the shore, backed by a narrow lagoon (~200m). The reef slope drops steeply from a submerged reef flat to over 15m depth at an angle of 80°. The reefs in front of Marsa Salak (Figure 12 a) and Marsa Daror (Figure 12b) are further from the shore and both enclose large soft, sediment filled lagoons, with channel reefs lining the passes into the lagoons.

At Marsa Salak (Figure 12 a) the reef slopes from the reef flat at an angle of 40-60 degrees. The reef then shelves more gently between 10-15m depth, before dropping vertically to 18m, then levelling out at a slope of 20° on a sandy base. The reef is composed of broad spurs, approximately 2-4m wide and elevated by 4-6m, orientated perpendicular to the shore separated by channels about 2-3m wide, filled with rubble and sand. Behind the reef, within the 2,800m wide lagoon, is a sequence of deep pools, separated by rocky platforms, before the water depth shallows towards the shore.

The reef slope to the north of Marsa Daror (Figure 12 b) drops more steeply at an angle of about 80° from the reef flat onto a rocky rubble covered substrate at about 15m with large coral heads (bommies) that continues to about 20m depth. The near-vertical fore-reef slope is rugged and has numerous well developed ledges, projecting overhangs and cracks, and the base of the reef is undercut.

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The reef near Suakin (Figure 12 c) is over 2,000m from the shore, separated by a large lagoon which hosts patch reefs, and macroalgal and seagrass beds. The outer reef is dissected and folds inwards, creating inlets with an outer and an inner reef slope. The outer fore reef slope is terraced and drops from the reef flat onto a gently shelving rock platform to about 8-9m depth. The reef then drops more steeply and levels off at about 15m before dropping off again to 30m. To the south of this entrance the reef floor was almost level, with a slope of less than 5 degrees.

Further south, at Marsa Sheik Ibrahim, (Figure 12 d) the fringing reef is situated at a distance of about 1,500m offshore, sheltering a broad shallow lagoon. Near the mouth of the Marsa the reef dips inwards and lines the entrance to the various channels and inlets and the edge of the main channel almost the entire width of the Marsa. To the north of the entrance the reef extends across a wide platform that extends from the reef crest to about 14m depth, shelves gently from the reef crest at 30°, to about 8m depth before dropping off more steeply at an angle of 50° and ending on sandy substrate.

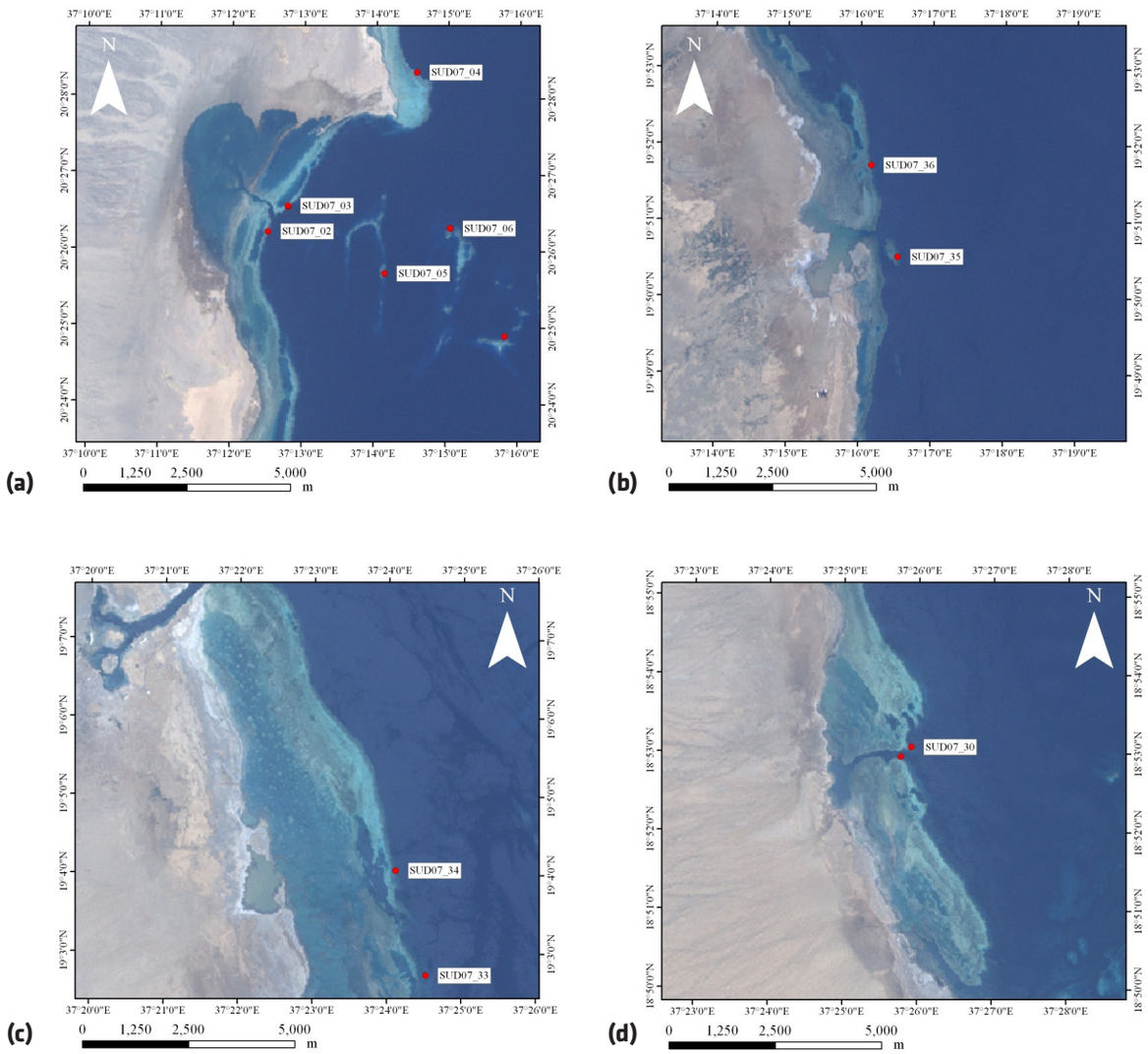


Figure 12: *Maps illustrating the diversity of fringing reef types found along the mainland coast of Sudan, and the location of sites surveyed on these reefs in October 2007 (red circular marker):* **(a)** *The reef in front of the wide sediment filled lagoon at Marsa Salak, and the narrow fringing reef around the headland at Ras Salak;* **(b)** *The fringing reef in front of Marsa Daror;* **(c)** *The broad fringing reef and lagoon south of Suakin (in the north-west corner of the map); and* **(d)** *The dissected fringing reef at Marsa Sheik Ibrahim. The maps are all derived from Landsat 7ETM+ satellite images, the details of which are provided in Section 3.4.*

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Inshore Barrier Reef

In the Shubuk region is a nearshore barrier reef system (Figure 13). This unusual structure has three main components: (i) a barrier reef orientated northwest to southeast, which forms the main barrier structure, (ii) reticulated low level patch reefs, orientated northeast to southwest, forming the north western edge of the structure, and (iii) an inner barrier reef composed of shallow patch reefs, platform and small fringing reefs around islets, which form an arc between the outer barrier reef and the shore.

The outer barrier reef structure is composed of a chain of large platform reefs, situated 15km from the shore, separated by reef lined channels. The largest individual section of the reef is more than 13km long and 3.6km wide at its widest point. The reef flats support some small corals and brown macroalgal communities. Steep sided pools occur on the dissected reef flat. Both the inner and outer reef slopes are colonised by corals. The inner reef slope is short and shelves relatively steeply onto a sandy floor. The outer reef slopes at approximately ~45° and ends on a sand bottom at 10-12m, where there are large tabular corals.

On the north-western border of the Shubuk barrier reef is an interlocking maze of low level patch reefs. The edges of these reefs are constructed from massive hard corals, typically *Porites* spp.and *Goniastrea* spp. The tops of these colonies are dead and heavily eroded where they reached the surface. Growing in between these colonies are large frondose brown algae (*Sargassum* spp. and *Turbinaria* spp.) and other coral communities, composed of *Montipora* spp.and *Pavona* spp.

Within the barrier reef complex are more patch reefs that form an arc closer to the shore. The reef surveyed on the eastern side of one of the islands (Site 28) shelved steeply at 70° from 0.5m to approximately 8m depth, where the seabed levelled out and was composed of fine silt and sand. Although these reefs exist in a highly sheltered environment, with naturally low levels of light due to the turbidity of the water, they still support high levels of coral cover.

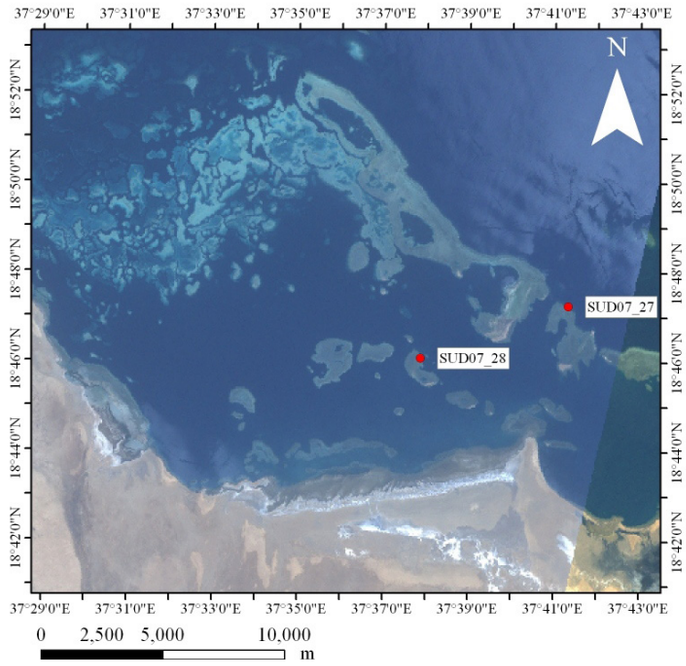


Figure 13: *Map showing the barrier reef complex at Shubuk.*

Offshore Barrier Reef

Off from the mainland coast is a second series of reefs, orientated NNW to SSE, that form a barrier reef complex extending almost the entire length of the coast, separated from the mainland reef formations by a deep water channel. The offshore barrier reef complex is composed of a string of interconnected reefs, which have been variously termed 'ridge' reefs, 'linear' reefs and 'ribbon' reefs, as well as platform reefs, pinnacles, patch reefs and tower reefs, of varying dimensions and separated by narrow channels. Many of these struc-

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tures are fully submerged, although some small sandy islets (cays) occur where they break the surface. The whole complex appears to be sitting on a platform of varying width at the top of the 'continental slope', where water depths increase from less than 50m to more than 200m. Surveys in 2007 were carried out within the offshore barrier reef in four areas: (from north to south) Sha'ab Salak, Gorna, Sudi, and Towaritit (Figure 14). These structures are described below.

Sha'ab Salak is a complex of patch reefs, linear reefs and pinnacles (Figure 14 a). Four transect sites were surveyed in this area (Sites 5 to 8). Site 5 is located on the eastern edge of a reef where the fore reef slopes from the reef flat at ~30° to 45°; there are some small terraces before the slope descends onto sand at ~8 m depth. Site 6 is located on the eastern edge of a channel between two patch reefs, where the reef slopes from 0.5m to over 15m depth at an angle of ~50°. The base of the channel is composed of sand with coral patches. Site 7 is located on the north face of a patch reef, where the reef slopes at an angle of 45° to 80° to over 15m depth and ends on sand. Site 8 is situated on a shallow back reef which shelves off steeply to about 8m depth and is composed mostly of rugose coral rock and dead standing corals at 2-3m with coral bommies at 5-10m, scattered on a shallow sand plain.

At ***Gorna*** two sites were surveyed (Sites 11 and 12) on the north and the east coast respectively (Figure 14 b). The reef on the east coast is terraced and slopes between 30° and 60° to a sandy ledge that extends to approximately 12m, before shelving off into deeper water. On the north coast, the reef is steeper and shelves off at an angle of approximately 80°. There are some vertical and overhanging walls and large pinnacles. The reef on the north coast is in relatively poor condition and there are many dead standing coral colonies covered in coralline algae and areas of more eroded dissected hard substrate.

Sudi is a larger complex structure, south of Gorna. Two sites were surveyed, both of which were situated on the outer reef on the eastern side of the structure (Sites 9 and 10) (Figure 14 c). The reef flat is healthy and composed of mainly small blocks of hard coral and soft corals. The reef slope is steep (85–90°). It extends to over 20m depth and supports a high level of coral cover.

At ***Towaritit reef*** two further monitoring sites (Sites M03 and M04) were established on the north-eastern end of the reef (Sites M03 and M04) (Figure 14 d). The reefs here are broad and of a relatively high and irregular relief, composed of large interlocking mounds of coral, some of which are composed entirely of acroporiids. Between these are patches of hard substrate colonised by encrusting and massive corals and soft corals.

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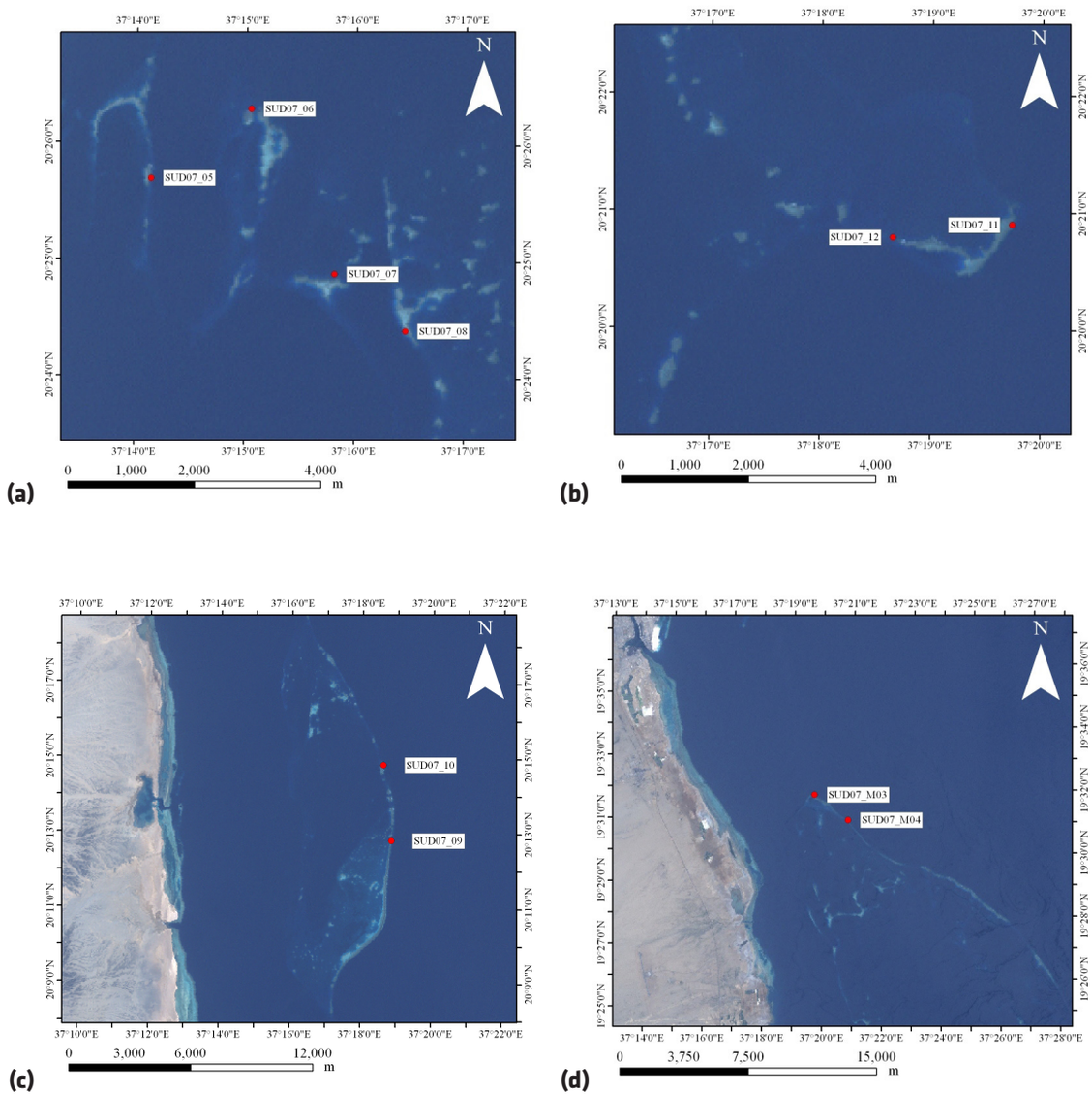


Figure 14: *Maps illustrating the diversity of reef types found within the barrier reef complex off the coast of Sudan. At* **(a)** *Sha'ab Salak,* **(b)** *Gorna,* **(c)** *Sudi and* **(d)** *the northern end of Towaritit, and the location of sites surveyed on these reefs in 2007 (red circular marker).*

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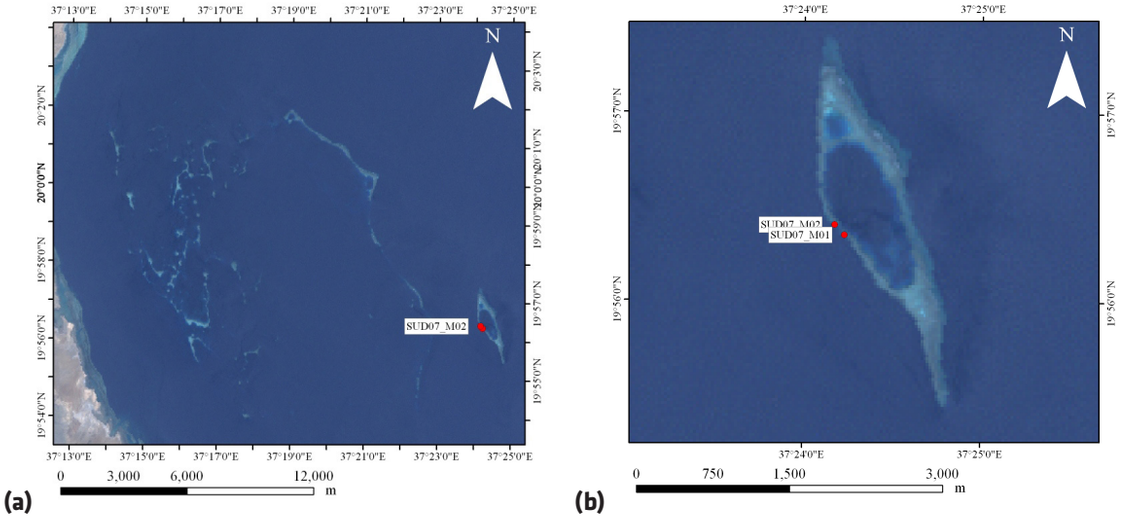


Figure 15: *Maps illustrating* **(a)** *the diversity of reef types found within the barrier reef complex off the coast of Sudan, and* **(b)** *the appearance of Chab Rumi, and the location of sites surveyed on these reefs in 2007 (red circular marker).*

Island Fringing Reefs

The ***Suakin Archipelago*** is situated in the south where the continental shelf extends further offshore. The archipelago contains a scattering of islands with independent fringing reefs, interspersed with other submerged reef structures. The structure of these island fringing reefs is different to those found edging the mainland. Typically the reefs are narrower and are backed by smaller lagoons, and the fore-reef slopes can be steeper. Surveys in 2007 were carried out on a selection of island fringing reefs (from north to south) at Seil Ada Kebir, Ilse Harorayeat, Talla Talla Kebir, and Talla Talla Segir (Figure 16a-d). The variation in the structure of these reefs is described below.

The island of ***Seil Ada Kebir*** (Figure 16 a) is the most northerly island visited in the Suakin Archipelago. This low lying, tear-drop shaped island is surrounded by a lagoon and fringing reef. To the south of the island the reef is narrow and there is virtually no lagoon, whereas in the north there is more extensive development. The reef flat on the south-eastern end was ~1m in depth, and the reef-edge started sloping at 30-45°. At ~3m depth, the reef drops near vertically at ~70-80° to ~15m where the slope becomes more gradual at 50-60°. On the north-eastern coast the fore-reef slope shelves relatively gradually from reef crest to about 5m, where it forms an uneven terrace at about 8m depth, before shelving very steeply to >40m. There are occasional channels down the reef slope.

Isle Harorayeat consists of a pair of small, low lying, vegetated islets, both of which are surrounded by fringing reefs and separated by a reef lined channel (Figure 16 b). The reef flat to the south-east of the island was wide (~100m) and the reef slopes at an angle of 25-45°. By comparison, the reef lining, the inner edge of channel between the islets, shelves gently eastward at an angle of about 20° onto a level sandy floor at about 8-10m, with occasional large coral patches and scattered rubble.

Talla Talla Segir (Figure 16 c) is a low level, oval shaped island, situated approximately 25km off the mainland coast. This was the most southerly island visited during this survey. The reef surrounding the island is narrow and ranges in width from 30 to 200m. On the north of the island the coast consists of a low lying, undercut rock platform, indicative of a high level of exposure. Extending almost directly from the shore is a narrow lagoon, with coarse gravely sand, a rocky reef flat composed of a near flat, continuous rock platform with some small coral colonies. The reef widens on the north-western corner, and here the slope drops onto a broad, very gently shelving, plateau at about 8-10m. To the south of the island was an exposed, narrow reef-flat to the island of ~50m. The reef slope was gentle at less than 30°.

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Talla Talla Kebir (Figure 16 d) is situated 13km northwest of Talla Talla Seghir and is the most westerly of the sites and the islands visited during this survey. The island is half-moon shaped and encircled by an independent fringing reef, with a perforated reef enclosing the embayment to the south. The reef on the north coast starts at about 3-4m depth, drops off steeply at about 60° and ends on a sand and rubble floor at about 20m depth. There is a spur and groove formation on the slope, with relatively deep grooves and broad spurs. On the south coast the reef slopes gently to around 4-5m and then drops at ~60-80° slope, dominated by *Acropora* corals.

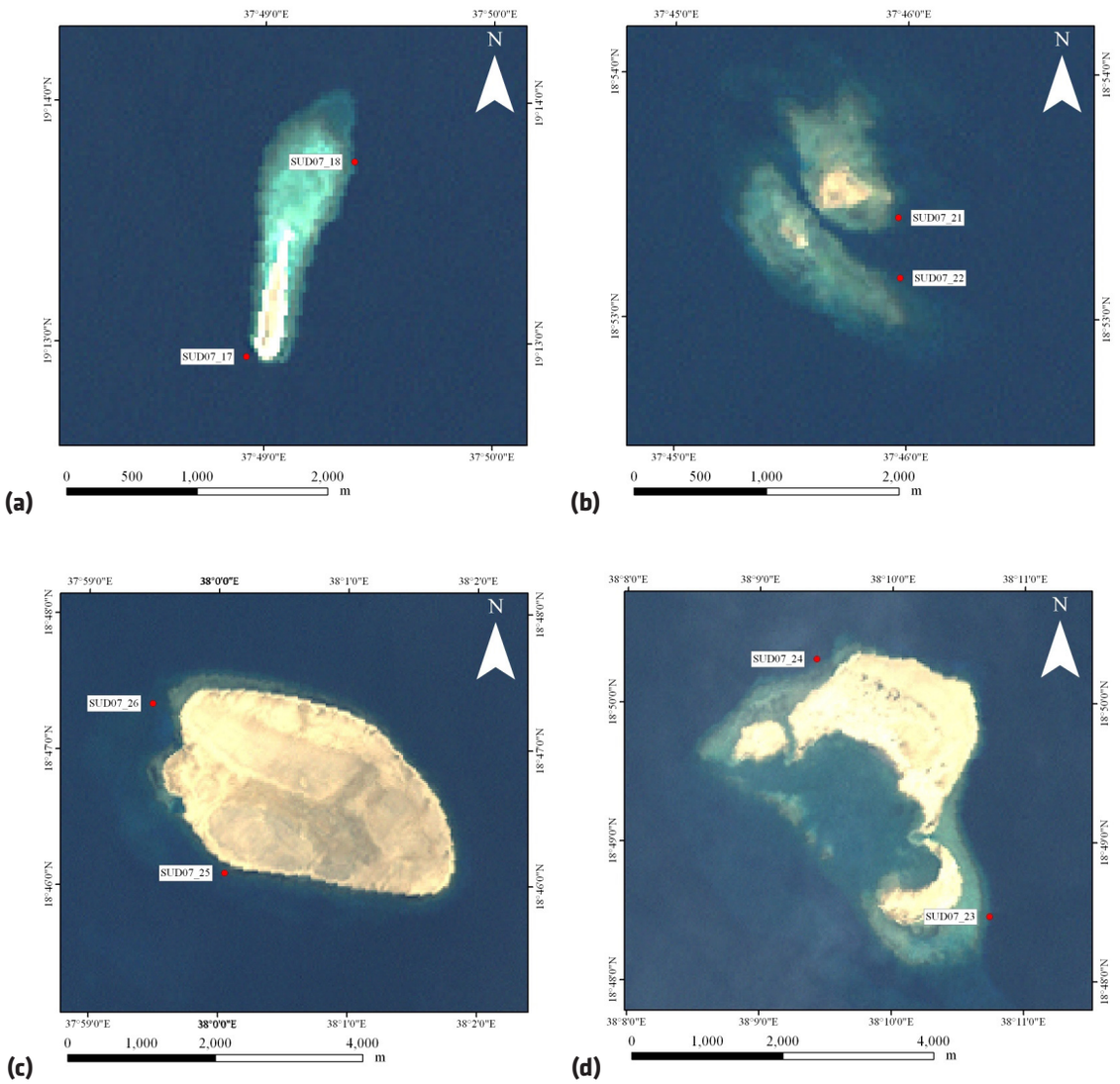


Figure 16: *Maps illustrating the variety of island fringing reefs, all of which are located in the Suakin Archipelago:* **(a)** *Seil Ada Kebir, the most northerly island surveyed, with more extensive reef development to the north of the island;* **(b)** *Isle Hararayeat, composed of two islands both with fringing reefs, separated by a reef lined channel;* **(c)** *Talla Talla Segir, a flat island with a narrow fringing reef, that widens slightly to the west;* **(d)** *Talla Talla Kebir, the most westerly island surveyed, is actually three islands, separated by narrow channels, encompassed by a fringing reef, with a narrow reef around the northern coast and broad bay to the south. The maps are all derived from Landsat 7ETM+ satellite images, the details of which are provided in Section 3.4.*

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Other Reef Types

There is a range of other independent reefs that are typically widely spaced and set within deep water, particularly within the southern waters of Sudan. Each of these reefs has its own unusual structure. Surveys were carried out on a selection of these reefs (from north to south) at Chab Rumi (Figure 15 b), Sha'ab Anbar, Sha'ab Tawil, Dhanab Qirsh and Qad Eitwid (Figure 17 a-d). The variation in the structure of these reefs is described below.

Chab Rumi is a pseudo-atoll situated offshore from the barrier reef complex north of Port Sudan. The reef is an elongated oval with a submerged, broad reef flat encompassing a deep lagoon. Two sites (Sites M01 and M02) were surveyed on the western side of the outer reef slope between 8-15m depth (Figure 15 b). The reef slope on this side of Chab Rumi has a broad and almost level sandy shelf at a depth of 8-12m, varying between 5m and 20m wide, backed by a very heavily dissected and undercut reef edge rising to within one metre of the surface. The shelf is covered in small blocks of coral interspersed with areas of hard substrate, although there are occasional large structures rising to 6m above the substrate. The edge of the shelf drops at between 45° and 60°, from approximately 12m to almost 30m where a second shelf is located. The reef slope at about 12m is composed of moderately sized blocks (less than1m) interspersed with some sand and an abundance of soft corals.

Sha'ab Anbar (Figure 17 a) is a large half-crescent shaped reef at the northern edge of the Suakin Archipelago. The reef is more than 8.5km long with a broad, submerged reef flat surrounding a narrow central lagoon. Two sites were surveyed on the western side of the reef in the north (Site 13) and the south (Site 14). In the north the reef is exposed to surge and swell, and slopes down to 3-4m at 30-45°, then drops off at ~ 85° into deeper water. At the southern end is a plateau at 3-4m depth and the reef slope is a near vertical wall. The reef slope has a well developed spur and groove formation and continues into water to more than 30m depth. At about 7m depth the reef is composed of heavily indented reef rock with deep crevices, densely colonised by large encrusting and massive coral colonies and soft corals. These structures formed a partial terrace that shelves more gently and forms overhangs. The reef is dissected at irregular intervals by deep grooves that extend at a steeper angle from the plateau down the slope.

Sha'ab Tawil (Figure 17 b) is a platform reef within the Suakin Archipelago. The reef consists of a shallow, oblong structure that extends east to west, creating a sheltered lagoon on the southern side, with a submerged tail-like extension that extends southwards. Two sites were surveyed on the outer reef of the main structure, on the west (Site 15) and on the east (Site 16). On the west the reef slopes at an angle of 45-85° onto sand with colonies of tabular *Acropora*. On the east the reef slope is composed of short spur and grooves, between 6m and 10m depth. These are interspersed with an interlocking series of patch reefs of variable height that are separated from the main reef by wide channels of flat sand. Some of these patch reefs break the surface while others have a much lower topographic relief.

Dhanab Qirsh (Figure 17 c) is orientated north-south with a deep lagoon inset into the northern end and two well developed promontories that extend southwards, with an outer reef slope on both the east and west side. The northern end of the reef shelves onto a broad deep platform. This platform and the outer reef slopes are colonised by mixed *Acropora* communities that are remarkably healthy. Two sites were surveyed, one towards the southern end of the eastern 'promontory' (Site 19) and the other on the inner reef slope of the western promontory (Site 20). On the east is an extensive plateau at 7-10m, with a shallow fringing reef dominated by large tabulate and branching *Acropora* and large *Porites*. The reef slopes at 20-45°, with a steeper section and terraces formed by large table *Acropora* ending on sand at ~9m with mounds of hard substrate. At the southern tip of the western promontory the inner reef slopes gently eastwards at an angle of approximately 10°. The reef is composed mainly of large *Porites lobata* colonies, and dense beds of *Acropora*, consisting of staghorn, tabular and corymbose growth forms.

Qad Eitwid (Figure 17 d) is a small low lying islet surrounded by a fringing reef. The fore-reef slope to the south east of this islet is a gently sloping sheltered reef, with a very slight incline of less than 5°, extending onto sand 10–20m wide, beyond which is a steep (near-vertical) drop off. Some small pinnacles of old (dead) coral rise above the reef level. *Porites* bommies (mostly *Porites solida*) of ~1m diameter and some *Acropora* tables of ~2m diameter, together with patchy staghorn and branching *Acropora,* are characteristic of this site. Sand occurred in patches. To the south-west of Qad Eitwid is a small sand cay (Figure 17 d) surrounded by a roughly triangular fringing reef that widens to the north-east. Behind the reef is a sandy lagoon, about

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250m wide, edged by a relatively narrow, reef flat composed of small *Porites* blocks on eroded hard substrate. The reef slope shelves away on all sides and is deceptively well developed, extending to over 25m depth over a relatively gradual slope. The reef on the south-eastern edge (Site 32) slopes over a broad, gently shelving platform to about 10m depth, at an angle of about 30°, before dropping off steeply to over 20m depth. The reef structure is rugose and composed of pinnacles and elevated mounds of some very large coral colonies, between which are large sand patches with some rubble. At the base of this platform, where the reef drops off, are encrusting, foliose and plating corals covering the substrate, and occasionally near-vertical walls.

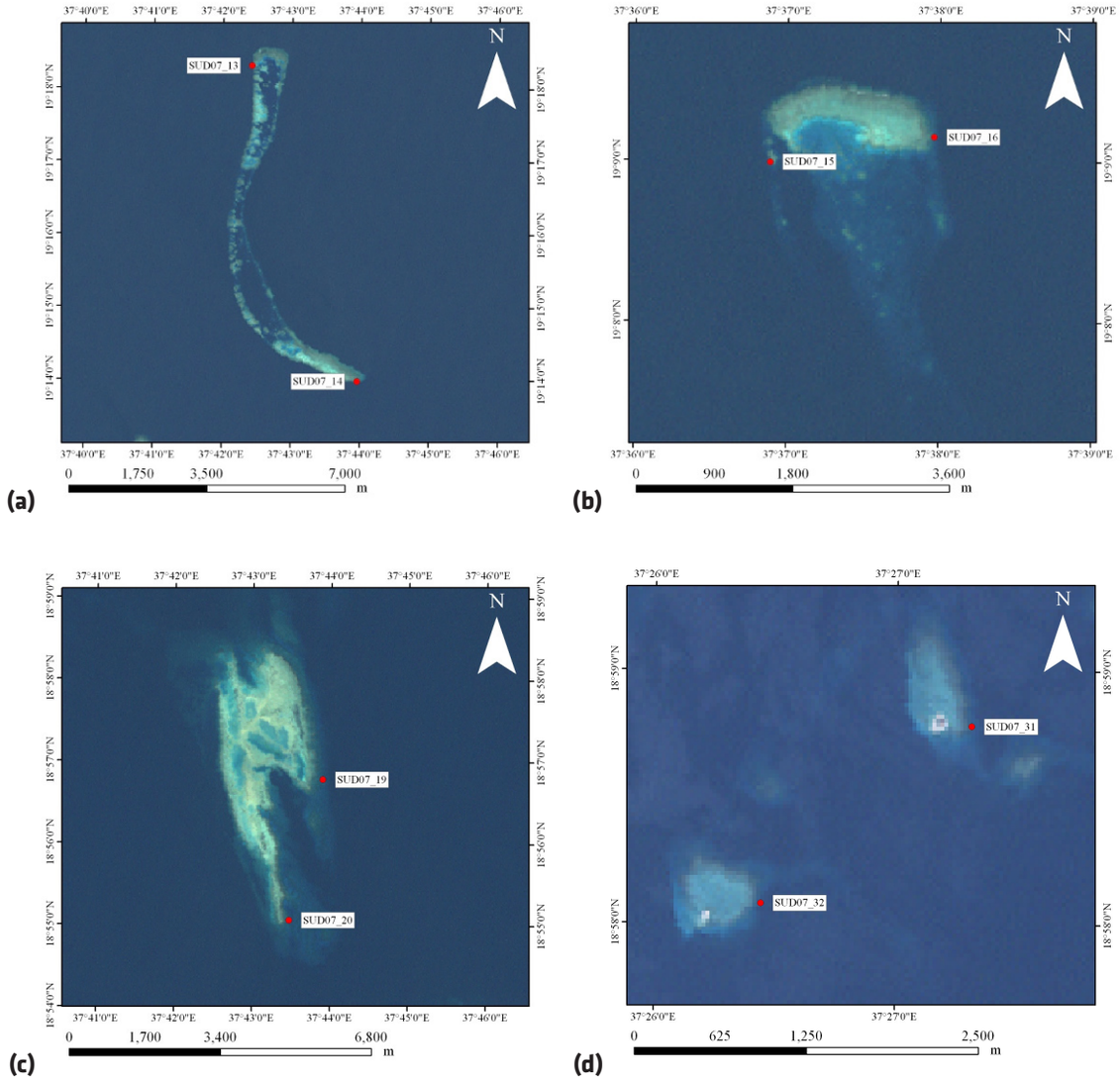


Figure 17: *Other varieties of reef formations from the Suakin Archipelago including:* **(a)** *Sha'ab Anbar,* **(b)** *Sha'ab Tawil,* **(b)** *Dhanab Qirsh and* **(d)** *Qad Eitwid and Qad Eitwid Cay, and the locations of sites surveyed on these reefs in 2007 (red circular marker).*

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3.3.1.4 BENTHIC COVER AND COMPOSITION

Related to IOC Handbook Ecological Indicators E1, E2, E3 and E9 (Table 1)

The composition of the benthic cover on the reefs of Sudan exhibits considerable variability that reflects the variation in geomorphological structures, environmental conditions and past disturbance. The following sections describe the general variation in benthic cover found on these reefs, and the results of a multivariate analysis of the broad benthic cover types.

Benthic Cover

Table 10 shows the mean cover of the main broad benthic cover types, and Table 11 shows the correlation coefficients for these main benthic cover types with some of the key environmental variables.

Living hard coral cover (excluding the hydrozoan fire coral *Millepora* spp.) ranges from 11% to 65%, with an average cover of 36% (Table 10 and Figure 19). Of the sites surveyed, only 12% had coral cover of more than 50%, a further 30% of sites had moderately high cover (30-40%), 20% had moderately low cover (20-30%), and 15% of sites had low cover of less than 20%.

Only one of the sites with the highest hard coral cover (over 50%) is situated to the north of Port Sudan (Site 35). All other sites are situated to the south of Port Sudan. The site with the highest overall hard coral cover (Site 28) is situated inside the barrier reef at Shubuck in the south and is dominated by *Montipora* spp. Of the other high coral cover reefs, three sites (Site 35, 30 and 22) are dominated by *Acropora* spp., while another (Site 27) is dominated by massive *Porites* spp.

By comparison, all of the sites with the lowest live coral cover (less than 20%) are situated to the north of Port Sudan, particularly in the vicinity of Ras Salak (Marsa Salak and Sha'ab Salak). The two sites with the lowest cover were either side of the entrance to Marsa Salak (Sites 01 and 02). The other sites were all situated within the complex of reefs on the barrier reef system around Sha'ab Salak.

The increase in live, hard coral cover southwards and offshore (Figure 20) is reflected in the significantly negative correlation of coral cover with latitude ($p<0.001$), and the positive correlation of coral cover with longitude ($p<0.05$) (Table 11). There is also a negative correlation of hard coral cover with visibility (Table 11).

The hydrozoan fire coral (*Millepora* spp.) contributed between 0% and 14% of benthic cover, although it was particularly common at some of the offshore reefs. This observation is supported by a significant correlation between fire coral coverage with longitude ($p<0.05$) (Table 11). Soft corals are also an important component of the communities at some sites, and cover ranges from less than 1% to over 28% with an average cover of 7%. Soft coral cover is positively correlated with depth ($p<0.05$) (Table 11). The sites with the highest soft coral cover included Chab Rumi (Sites M01 and M02), Sha'ab Anbar (Sites 13 and 14), Seil Ada Kebir (Sites 17 and 18), Sha'ab Tawil (Sites 16) and Marsa Sheik Ibrahim (Sites 29 and 30).

Algal cover was highly variable (Table 10). Coralline algae ranged from less than 1% to 37%, with an average cover of 13%. Turf algae was found growing on eroded coral rock, dead standing coral skeletons and coralline rubble, and cover ranged from 0% to 31%, with an average of 14%. There is a negative correlation between turf algae cover and the angle of reef slope and depth ($p<0.05$). Macro-algae were less common on these reefs with an average cover of 3%. Macro-algae showed no significant correlation with depth, but were negatively correlated with the slope and latitude, and positively correlated with longitude.

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Dead standing coral (where the coral skeleton has not yet been eroded) was found at most sites and there is a significant positive relationship with latitude ($p<0.05$) and a negative relationship with longitude ($p<0.05$). Whereas dead standing coral with turf algae shows a significantly negative relationship with latitude, as well as depth, visibility ($p<0.05$) and slope ($p<0.001$). Old eroded coral rock and coral rock with algae are significantly and positively correlated with latitude, visibility ($p<0.001$) and slope ($p<0.05$), and negatively correlated with longitude ($p<0.001$). Rubble with turf algae is higher at shallow depths than on deeper reef slopes. In addition, recently dead coral is negatively correlated with depth.

Table 10: *Substrate cover (%) at the sites surveyed along the coast of Sudan (N=40 including the monitoring sites M01 to M04).*

	Mean Cover (%)	SE	Minimum (%)	Maximum (%)
Hard coral	35.71	2.15	11.34	64.84
Soft coral	6.80	1.12	0.30	28.46
Hydrozoan	1.28	0.40	0.00	13.82
Macro-algae	3.17	0.54	0.00	14.25
Coralline algae	13.31	1.58	0.20	37.40
Turf algae	14.00	1.39	0.00	31.29
Sponge	1.03	0.21	0.00	6.38
Tunicate	0.21	0.08	0.00	2.44
Actinia	0.01	0.01	0.00	0.21
Zooanthids	0.37	0.13	0.00	4.19
Other live	0.10	0.03	0.00	1.08
Recently dead coral	0.21	0.10	0.00	3.93
Dead standing coral	1.43	0.33	0.00	10.57
Coral rock	12.27	1.74	1.01	41.64
Rubble	2.90	0.46	0.00	11.67
Rock	0.23	0.21	0.00	8.53
Sand	6.46	1.23	0.00	27.02
Silt	0.47	0.34	0.00	11.58
Other	0.05	0.02	0.00	0.81

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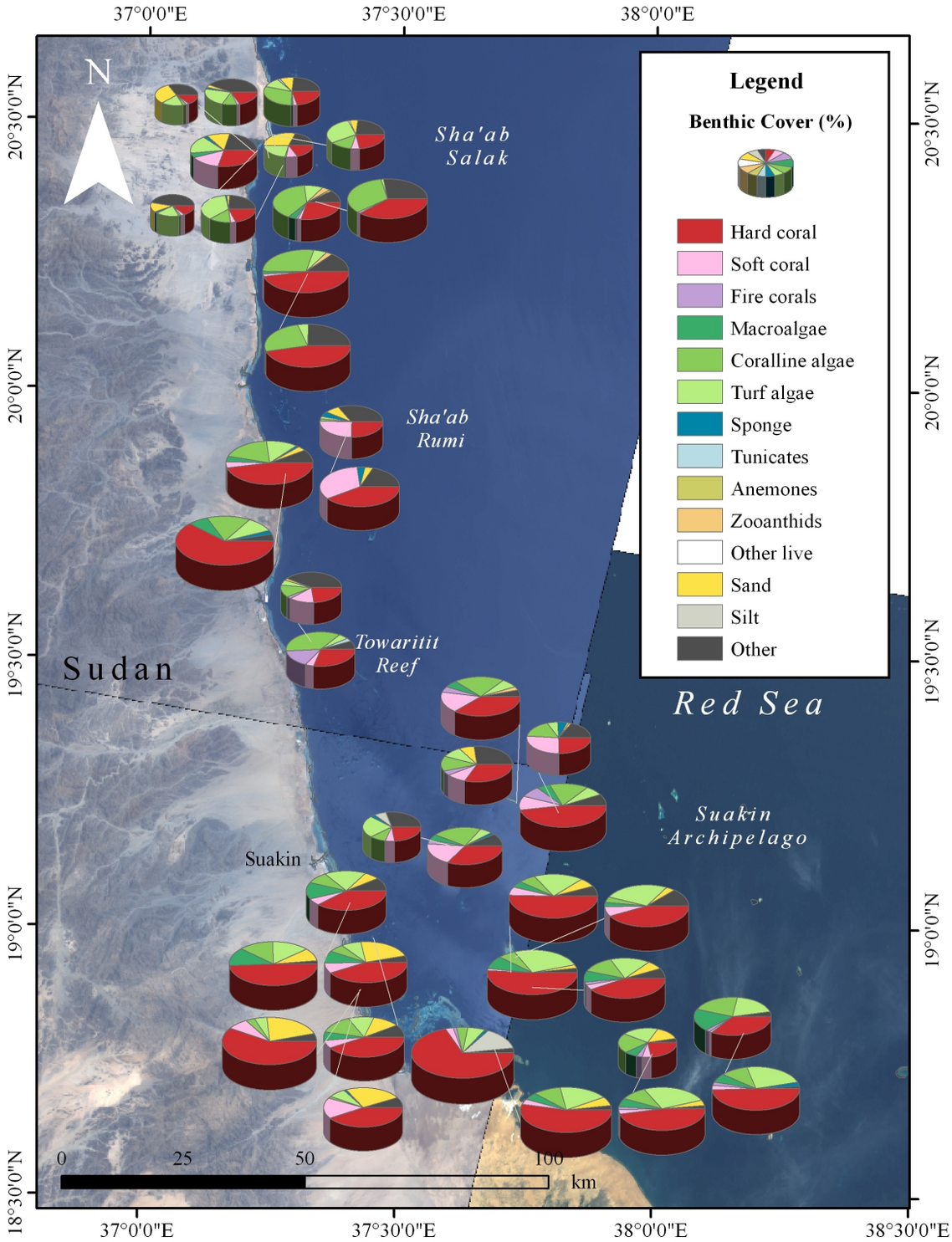


Figure 18: *Map showing the benthic cover at the detailed transect sites surveyed along the coast of Sudan (October-November 2007) (n=40 sites). Pie charts illustrate the relative abundance of a simplified set of the basic benthic cover categories, and charts are scaled relative to amount of live hard coral cover. The class 'Other' represents the cover types: coral rock, dead standing coral, rubble and rock.*

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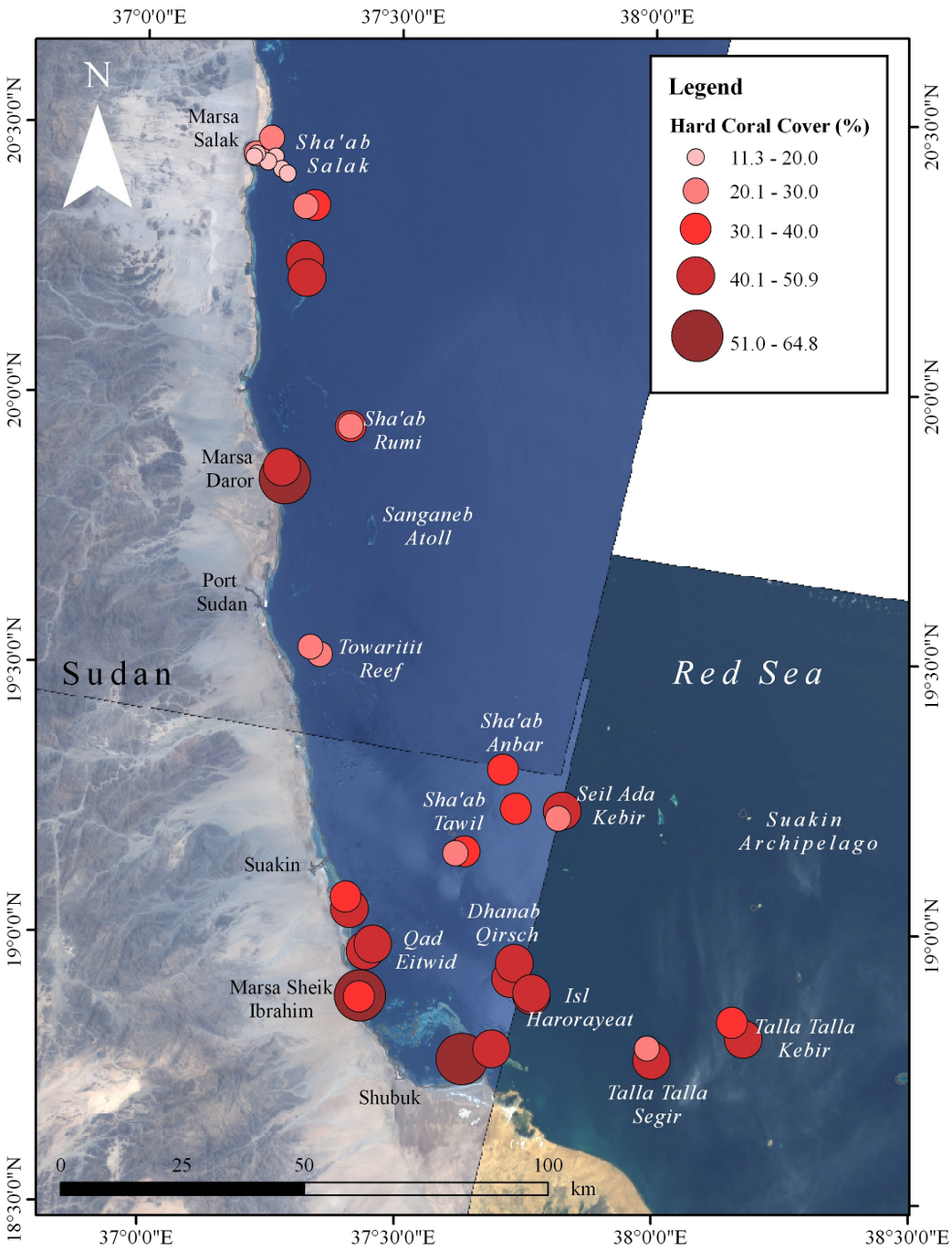


Figure 19: *Map showing the relative abundance of scleractinian hard coral cover at the detailed transect sites surveyed along the coast of Sudan (October-November 2007) (n=40 sites).*

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Table 11: *Pairwise correlations showing the Pearson product-moment correlations and significance probabilities for each pair of variables, showing only significant relationships (where * indicates p=<0.05, and ** indicates p<=0.001).*

Benthic Cover Type	By Variable	Correlation	p- value
Hard coral	Latitude	-0.580	0.000**
Hard coral	Longitude	0.348	0.028*
Hard coral	Visibility	-0.331	0.037*
Soft coral	Depth	0.375	0.017*
Hydrozoan	Longitude	0.388	0.013*
Macro-algae	Latitude	-0.499	0.001**
Macro-algae	Longitude	0.485	0.002*
Macro-algae	Slope	-0.387	0.014*
Turf algae	Slope	-0.372	0.018*
Turf algae	Depth	-0.465	0.003*
Tunicate	Slope	0.353	0.026*
Zooanthids	Slope	0.575	0.000**
Dead standing coral	Latitude	0.390	0.013*
Dead standing coral	Longitude	-0.312	0.050*
Dead standing coral (with turf algae)	Latitude	-0.488	0.002*
Dead standing coral (with turf algae)	Depth	-0.391	0.014*
Dead standing coral (with turf algae)	Slope	-0.690	0.000**
Dead standing coral (with turf algae)	Visibility	-0.395	0.013*
Coral rock	Latitude	0.731	0.000**
Coral rock	Longitude	-0.578	0.000**
Coral rock	Visibility	0.644	0.000**
Coral rock	Slope	0.353	0.025*
Coral rock (with turf algae)	Slope	0.348	0.030*
Coral rock (with turf algae)	Latitude	0.737	0.000**
Coral rock (with turf algae)	Longitude	-0.511	0.001**
Coral rock (with turf algae)	Visibility	0.505	0.001**
Rubble (with turf algae)	Depth	-0.417	0.008*
Recently dead coral	Depth	-0.368	0.019*

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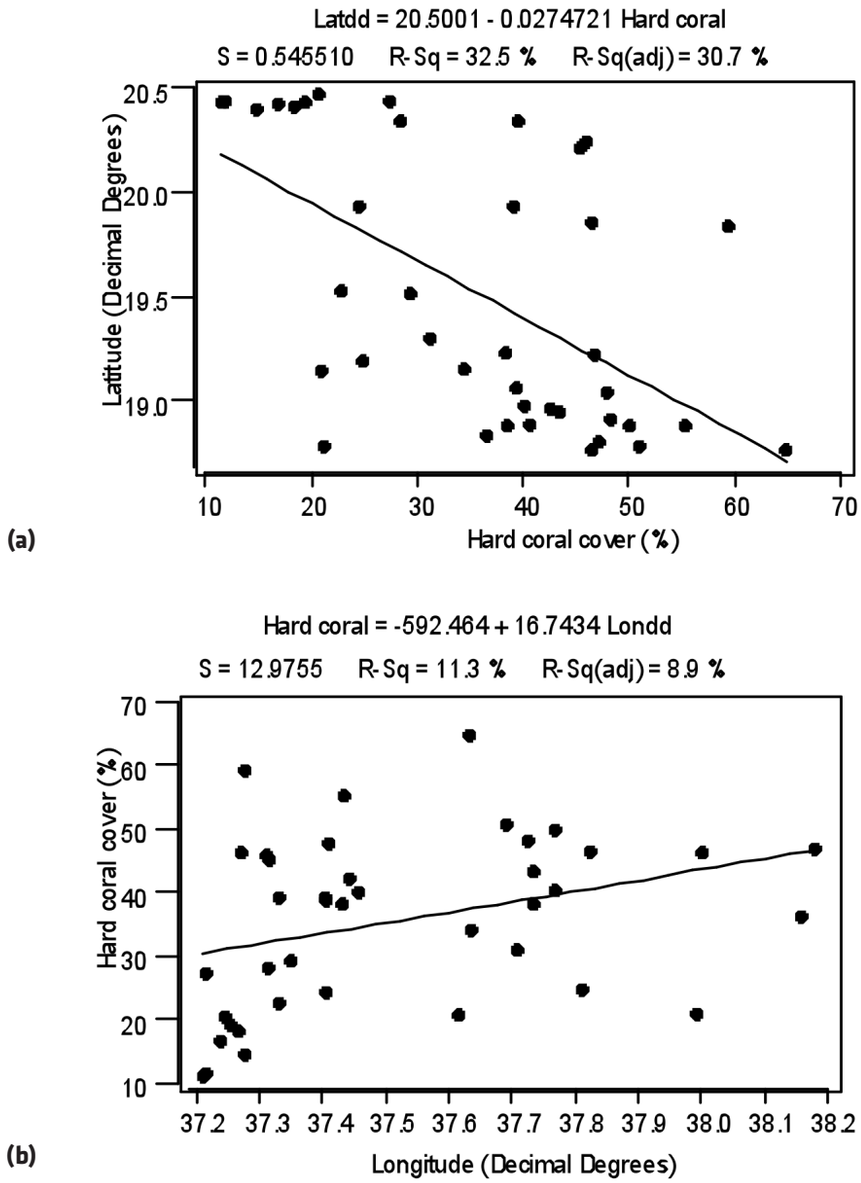


Figure 20: *Graphs illustrating:* **(a)** *the negative relationship between live hard coral cover and latitude, showing how coral cover increases southwards and* **(b)** *the positive relationship between live hard coral cover and longitude, showing the increase in live coral cover eastwards.*

Benthic Composition

Related to the IOC Handbook Ecological Indicators E7 & E9 (Table 1)

Multivariate analysis of the broad benthic cover categories (19 categories) revealed five clusters (Groups A-G) (Figure 21) with an average similarity of 70% or more, and one outlier (Site 28). The characteristics of these groups are described below: the mean biological coverage per group is illustrated in Figure 22 the mean substratum characteristics per group is shown in Figure 23, and variation in some of the key environmental variables between these groups is illustrated in Figure 12.

- **Group A** (Average similarity = 74.35%). The sites in this group support the lowest cover of live hard coral (<14%). The benthos is instead covered by turf algae, growing on rubble and dead standing coral and coral rock. Sand and rubble are common and comprise ~15% and 8% of the substrate cover respectively. The

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reefs in this group are typically shallow, with a moderately steep slope and high visibility. All these sites are situated to the north of Port Sudan.

- **Group B** (Average similarity = 69.88%). These sites support mixed communities with some live hard coral (<23%), soft coral (7%), turf algae (18%) and coralline algae (13%). There are some bare areas of coral rock (18%) and some sand (8%). The reefs in this group are not particularly steep and are moderately exposed, with average visibility of 15m. The sites in this group are mostly situated to the north of Port Sudan, with the exception of Sites 13, 15 and 26.
- **Group C** (Average similarity = 71.86%). The sites in this group support the highest abundance of soft corals (24%), mixed with a moderate hard coral coverage (28%). The sites also have the lowest cover of macro-algae and turf algae, although coralline algae are moderately common (7%). The remainder of the substrate is composed of coral rock (23%). The communities in this group are typically found deeper and on westward facing reefs, both north (two sites sampled) and south (two sites sampled) of Port Sudan.
- **Group D** (Average similarity = 74.30%). The sites in this group all support a moderately high abundance of hard corals (>40%) and the highest abundance of coralline algae (26%). These sites also have a moderately high abundance of macro-algae, and turf algae and soft corals are also present. The reef slopes are typically fairly steep (>60°) with very little silt, sand or rubble.
- **Group E** (Average similarity = 77.26%). Hard coral cover is high at these sites (>45%), combined with a moderate cover of turf algae (19%), coralline algae (8%) and macro-algae (5%). There is some recently dead coral and some remnant dead standing coral. The exposure of these sites is moderately high, the angle of slope generally low and the corals are often interspersed with sand patches (9%). The vertical visibility at these sites was low at the time of the survey. All of the sites in this group are situated to the south of Port Sudan.
- **Group F:** This is an individual site (Site 28) and has the highest coral cover (65%), composed mainly of *Montipora,* on a silty substrate and a relatively low cover of all other benthic cover categories. This site is situated in a very sheltered location behind the barrier reef system at Shubuk.

There are significant differences between the community types in terms of the benthic cover of hard and soft corals, macro-algae, coralline algae, turf algae, tunicates, recently dead coral, dead standing coral, coral rock, rubble, rock, sand and silt (Table 12).

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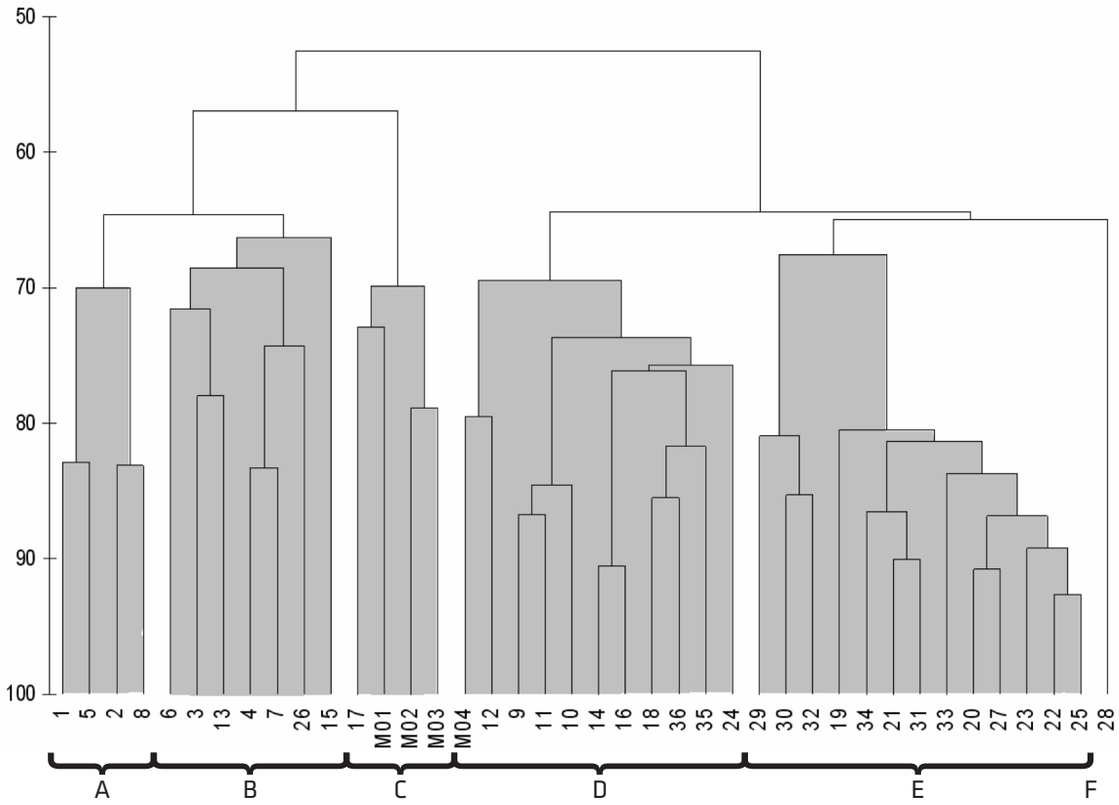


Figure 21: *Cluster analysis of basic benthic cover data (19 categories, Bray-Curtis Similarity, Group linkage). All the sites within Clusters A are north of Port Sudan and sites within Clusters E and F are south of Port Sudan. Sites within Clusters B are mostly north (with the exception of sites 13, 15 and 26) whereas Clusters C and D are mixed.*

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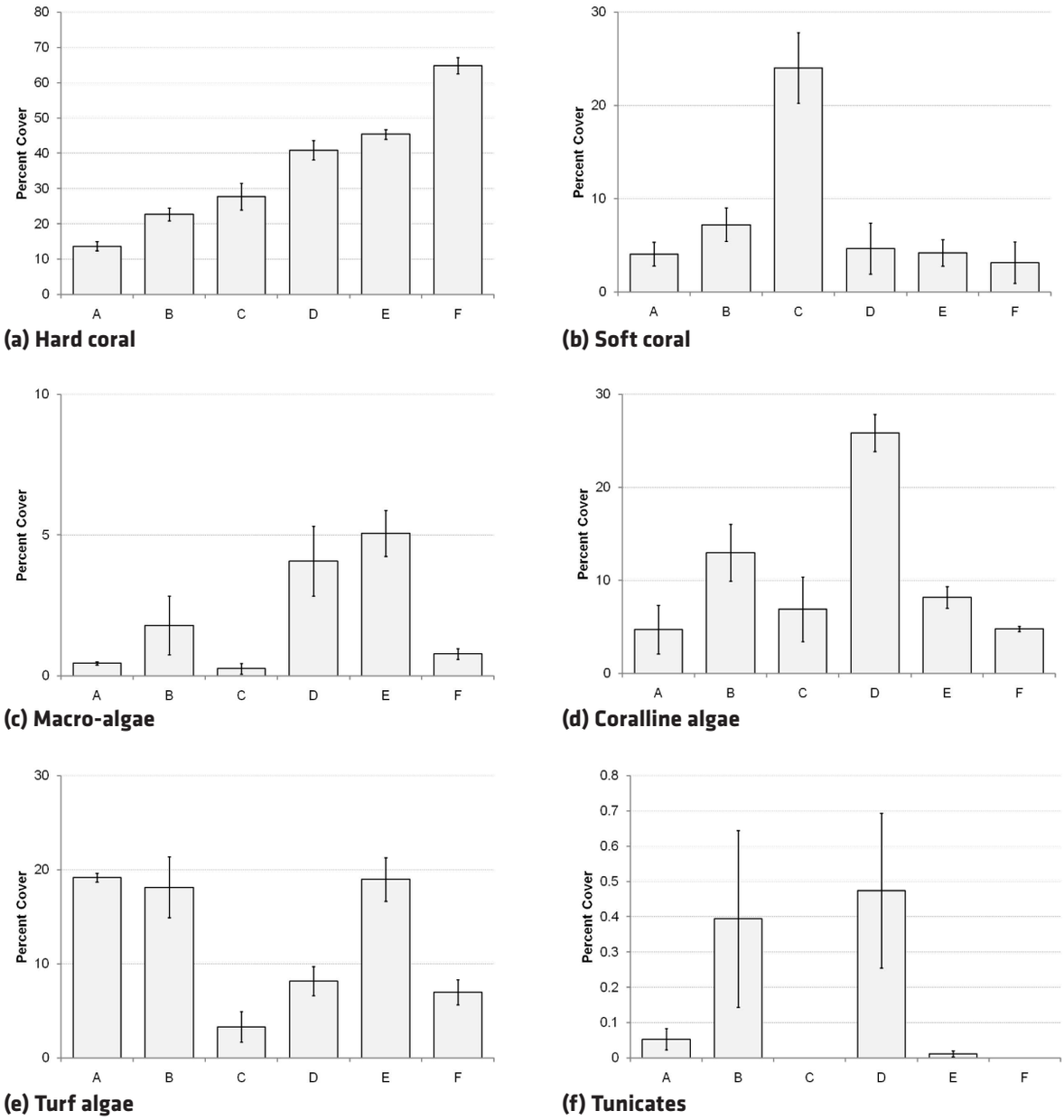


Figure 22: *Bar graphs showing the differences between the six community types (A to G) for the main benthic cover variables for which there was a significant difference of p<0.005 or p<0.001; error bars show standard error of the mean (+SE).*

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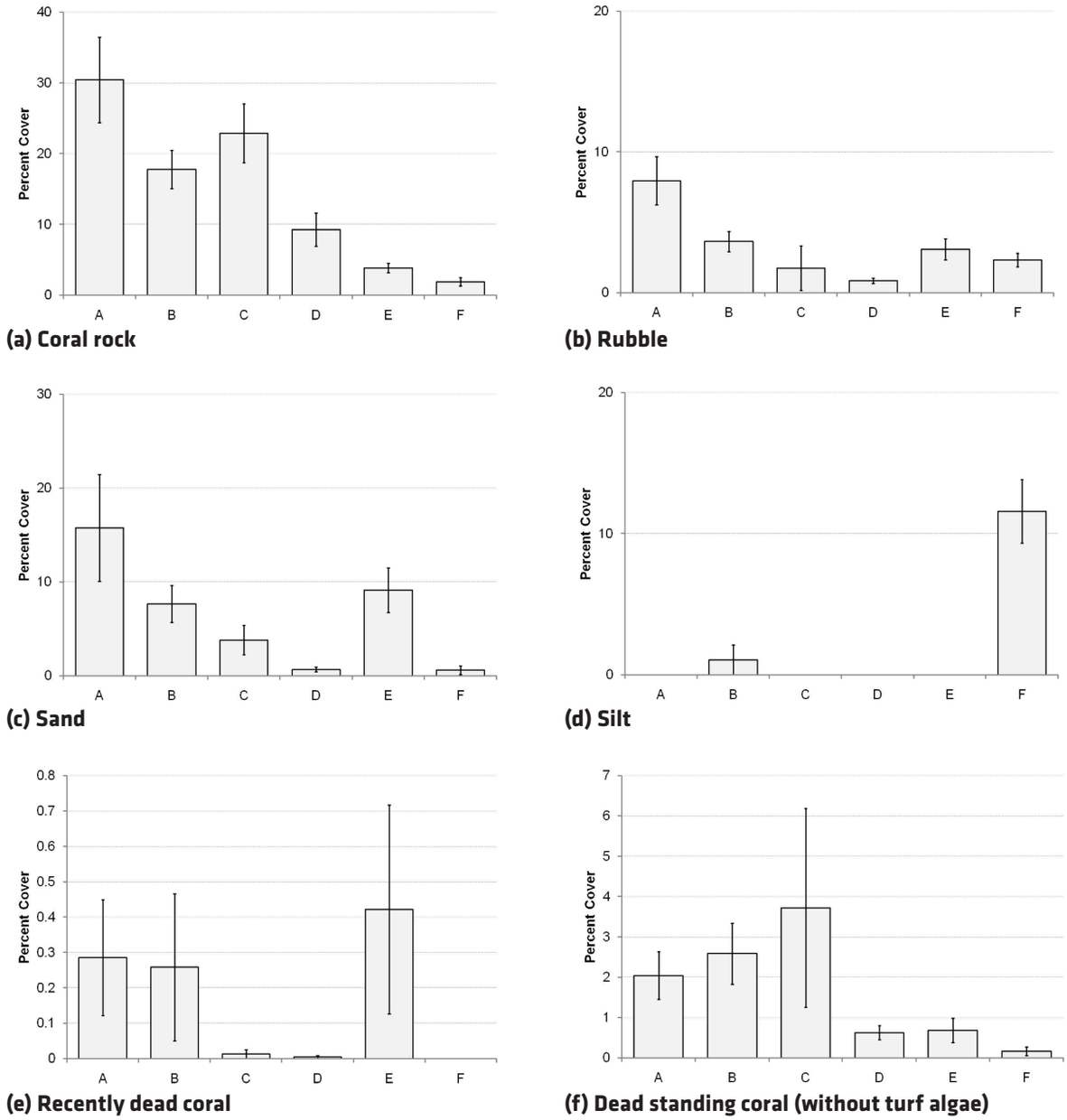


Figure 23: *Bar graphs showing the differences between the six community types (A to G) for the main substrate cover variables for which there was a significant difference of p<0.05 or p<0.001. Error bars show standard error of the mean (+SE).*

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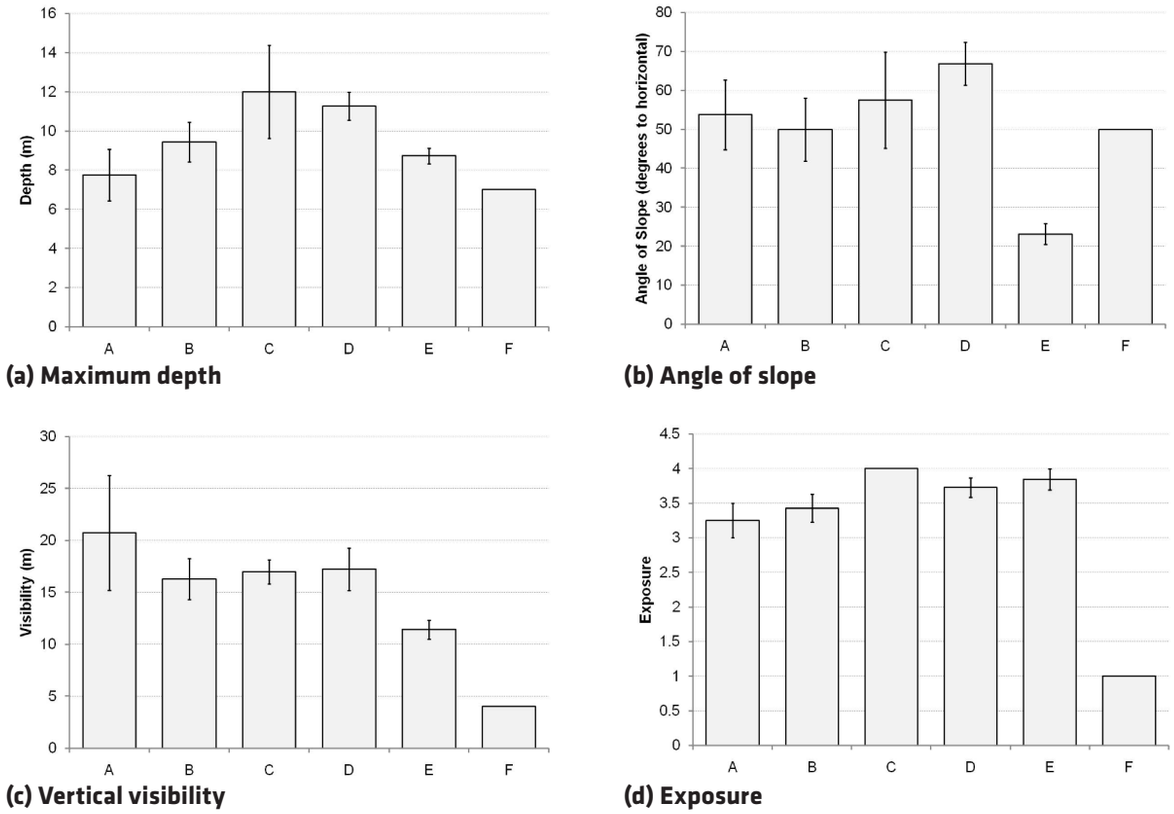


Figure 24: *Bar graphs showing the differences between the six community types (A-G) for the main environmental variables. Not all of these showed significant differences between these groups, although the trends are noticeable. Error bars show standard error of the mean (+SE).*

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Table 12: *Analysis of the differences among the six clusters (Groups A-G) in terms of benthic cover categories, environmental variables (Kruskall-Wallis test statistic H, df = degrees of freedom and p-values, where NS= not significant).*

Benthic Cover Category	H	df	p-values
Hard coral	29.50	5	<0.0001
Soft coral	14.5	5	<0.05
Hydrozoan	8.23	5	NS
Macro-algae	14.74	5	<0.05
Coralline algae	24.27	5	<0.0001
Turf algae	19.87	5	<0.001
Sponge	10.32	5	NS
Tunicate	15.42	5	<0.05
Actinia	4.67	5	NS
Zooanthids	7.29	5	NS
Other live	7.85	5	NS
Recently dead coral	16.13	5	<0.01
Dead standing coral	9.53	5	NS
Coral rock	23.40	5	<0.0001
Rubble	18.14	5	<0.05
Rock	14.88	5	<0.05
Sand	19.93	5	<0.001
Silt	22.29	5	<0.0001
Environmental Variables			
Depth	16.24	5	<0.01
Exposure	10.82	5	NS
Reef development	4.37	5	NS
Visibility	11.00	5	NS

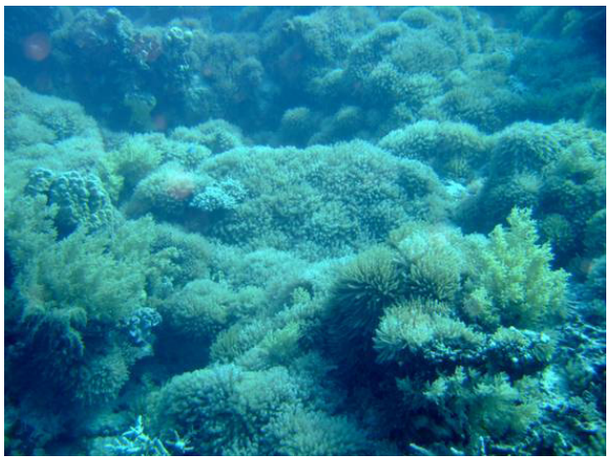
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(a)



(b)



(c)



(d)



(e)



(f)

Plate 11: *Photographs illustrating the broad benthic cover classes in (a) Group A (Site 2) showing an area of bare eroded coral reef rock, with some small remnant coral colonies; (b) Group B (Site 26), showing massive* Porites *corals, with a high abundance of turf algae and coralline algae; (c) Group C (Site M01) showing a carpet of soft corals (*Paralemnalia *spp.); (d) Group D (Site 10), where there is a moderate cover of small coral colonies and an abundance of coralline algae; (e) Group E (Site 25), with a particularly high abundance of live hard corals; (f) Group F (Site 28) where there is the highest cover of hard coral within the Shubuk barrier reef system.*

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3.3.1.5 Coral Species Diversity

Related to IOC Handbook Indicator E5

Coral species diversity on Sudanese reefs is considered below in terms of the number of species present at the site level (alpha diversity), the national level (beta diversity) and the regional level (gamma diversity). The zoogeography and occurrence and distribution of Red Sea endemics are also discussed.

Site (Alpha) Diversity

Species richness per site ranged from a minimum of 25 to a maximum of 119 species, with an average of 72 species per site. Species richness for each of the survey localities (paired sites) ranged from a minimum of 69 species on the offshore reefs around Sha'ab Salak (Sites 07 and 08) to a maximum of 136 at the island of Seil Ada Kebir (Sites 17 and 18), with an average of 110 species per survey locality (Figure 25). Other particularly species-rich localities with over 120 species included: Sha'ab Anbar (Sites 13 and 14), Shubuk (Sites 27 and 28) and Marsa Daror (Sites 35 and 36) in the north. The total number of stony coral species recorded per site shows only a weak positive correlation with hard coral cover and depth ($p<0.05$). Although there is no correlation of species richness per site with latitude or longitude, the sites with more than 100 coral species were all situated in the south, with the exception of Chab Rumi (M01).

Local (Beta) Diversity

A total of 291 species of scleractinian hard coral were recorded from 59 genera, and 15 families. There were also 3 species of the fire coral *Millepora* spp., and a further 27 taxa of other hydrozoans, soft corals and zoanthids were also recorded. There are still some taxonomic uncertainties at the species level for some of the stony corals, particularly the soft corals, which were only recorded at genera level. So this should be considered a preliminary list since further taxonomic studies and sampling of both hard and soft corals on deeper reefs, and in the southern region of Sudanese waters, will invariably reveal more species.

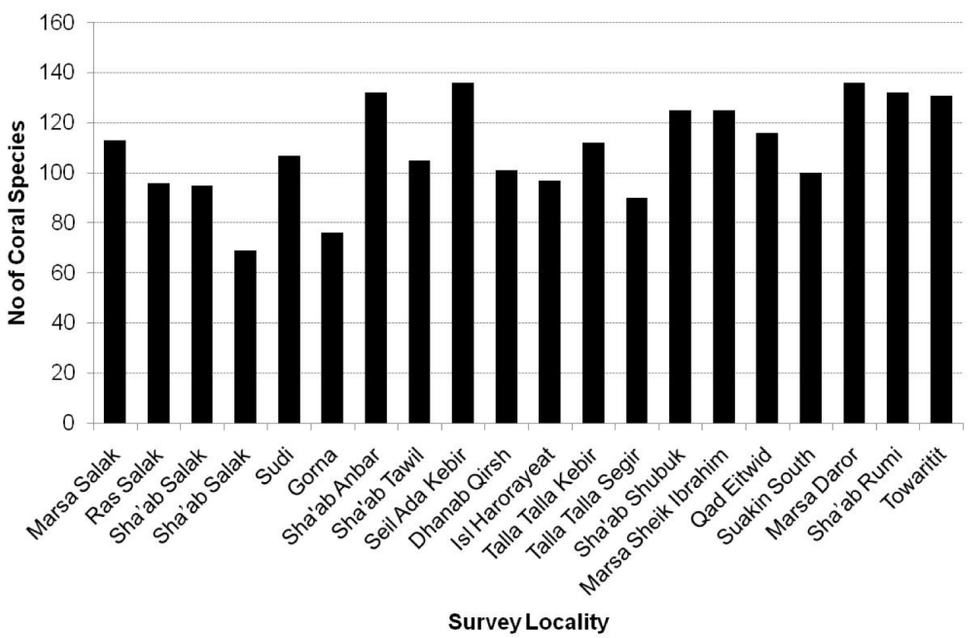


Figure 25: *Graph showing the total number of coral species recorded at each locality (site pairs).*

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Regional (Gamma) Diversity

Comparison with other studies within the Red Sea revealed that the coral species richness of 291 recorded in this survey in Sudanese waters is high. The number of species found in Sudan compares favourably with: the total of 340 species reported by Veron (2000) to occur within the whole Red Sea; the 260 species reported for the central and northern Red Sea coast of Saudi Arabia (DeVantier *et al.* 2000); the 219 species reported from the southern Red Sea coast of Yemen (Turak *et al.* 2007); and the combined total of 372 species from both these recent studies. The preliminary species list suggests that the reefs of Sudan support almost 80% of the species previously reported in the Red Sea.

Coral Zoogeography

The species recorded during this survey exhibit different distribution patterns. For example, some species are widespread across the entire Indo-Pacific (e.g. *Pocillopora damicornis, Porites lutea, Pocillopora damicornis*), the Indo-West Pacific (e.g. *Stylophora pistillata, Acropora muricata*), the Indian Ocean (e.g. *Coscinerea monile, Siderastrea savignyana*), or the Western Indian Ocean (e.g. *Acropora hemprichii, Acropora forskali*). Others are restricted to the Arabian region (e.g. *Acropora downigni*) or are endemic to the Red Sea (e.g. *Merulina scheeri, Montipora pachytuberculata*), or thought to occur only in the northern Red Sea (e.g. *Cantharellus doederleini*).

Of the total species recorded during this survey, 192 species were "Rare" and were found at fewer than 25% of sites, 61 species were "Uncommon" and found at 25-50% of sites, 33 species were "Common" and found at more than 50% and fewer than 75% of sites, and only 8 species were "Abundant" and found at more than 75% of sites. The most abundant species included those that are widely distributed throughout the Arabian region and Red Sea (*Acropora pharaonis, Echinopora forskaliana)* and the Indo-Pacific (*Pocillopora verrucosa, Coscinaraea monile, Pavona varians, Goniastrea edwardsi, Goniastrea retiformis, Porites lobata*). Rare species included 11 *Montipora* spp., 11 *Goniopora* spp., 9 *Acropora* spp., 4 *Alveopora* spp., 3 *Fungia* spp., 2 *Porites* spp. and a further 19 genera.

Red Sea Endemics

Corals that are considered to be endemic to the Red Sea were well represented and widely distributed across the Sudanese reefs (Table 13). However, some species known to occur within the central-northern Red Sea were not found during this survey. Indeed a further 8 families that are known to occur elsewhere in the Red Sea, the majority of which contain only a single species, were not found (*Madracis kirbyi, Euphyllia glabrescens, Physogyra lichtensteini, Caulastrea connata, Caulastrea tumida, Erythrastrea flabellata, Parasimplastrea sheppardi,* and *Heteropsammia cochlea*). The absence of some of these genera/species from the sites surveyed may be due to their habitat preferences (e.g. species only found in deep water) or to their limited distribution within the Red Sea. It is anticipated that, with future surveys on deeper reefs, some of these species will be found within Sudanese waters.

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Table 13: *The occurrence of Red Sea endemic coral species found on Sudanese reefs. Also shown are species with a limited range extension beyond the Red Sea, where NIO = Northern Indian Ocean, WIO = Western Indian Ocean, and AG= Arabian Gulf.*

Family	Species	Occurrence (% of Sites)	Red Sea and?
Acroporidae	*Montipora cryptus* (Veron 2000)	15	
	Montipora circumvallata (Ehrenberg, 1834)	2.5	
	Montipora echinata (Veron, DeVantier and Turak 2000)	2.5	
	Montipora hemispherica (Veron 2000)	2.5	
	Montipora meandrina (Ehrenberg 1834)	20	
	Montipora niugini (Veron 2000)	2.5	
	Montipora pachytuberculata (Veron, DeVantier and Turak 2000)	2.5	
	Montipora saudii (Turak, DeVantier and Veron 2000)	7.5	
	Montipora stilosa (Ehrenberg 1834)	65	NIO
	Acropora downingi (Wallace 1999)	12.5	AG
	Acropora haimei (Milne, Edwards and Haime 1860)	10	
	Acropora maryae (Veron 2000)	7.5	
	Acropora massawensis (Marenzeller 1906)	17.5	
	Acropora parapharaonis (Veron 2000)	27.5	
	Acropora rufus (Veron 2000)	5	
	Acropora variolosa (Klunzinger 1879)	45	
	Anacropora spumosa (Veron, Turak and DeVantier 2000)	2.5	
Pocilloporidae	*Stylophora danae* (Milne Edwards and Haime 1860)	35	
	Stylophora khuelmanni (Scheer and Pillai 1983)	32.5	
	Stylophora mamillata (Scheer and Pillai 1983)	0	
	Stylophora wellsi (Scheer 1964)	30	
Faviidae	*Cyphastrea hexasepta* (Veron, Turak and DeVantier 2000)	5	
	Echinopora forskaliana (Milne, Edwards and Haime 1860)	80	WIO
	Echinopora fructilosa (Ehrenberg 1834)	47.5	WIO
	Echinopora irregularis (Veron, Turak and DeVantier 2000)	20	
	Echinopora tiranensis (Veron, Turak and DeVantier 2000)	12.5	
	Favia albidus (Veron 2000)	32.5	
	Favia lacuna (Veron, Turak and DeVantier 2000)	22.5	
	Favites spinosa (Klunzinger 1879)	25	WIO
	Favites vasta (Klunzinger 1879)	37.5	WIO
	Goniastrea thecata (Veron, Turak and DeVantier 2000)	15	
Poritidae	*Porites columaris* (Klunzinger 1879)	15	
	Porites echinulata (Klunzinger 1879)	2.5	
	Porites harrisoni (Veron 2000)	0	AG
	Porites nodifera (Klunzinger 1879)	30	AG
	Sandolitha africana (Veron 2000)	0	
	Goniopora ciliatus (Veron 2000)	5	
	Goniopora pearsoni (Veron 2000)	5	
	Goniopora sauvignyi (Dana 1846)	2.5	
	Goniopora cf sultani (Veron, DeVantier and Turak 2000)	5	
	Gyrosmilia interupta (Ehrenberg 1834)	10	
Mussidae	*Symphyllia eythraea* (Klunzinger 1879)	32.5	
Merulinidae	*Merulina scheeri* (Head 1983)	37.5	
Pectiniidae	*Mycedium umbra* (Veron 2000)	15	
	Oxypora convoluta (Veron 2000)	2.5	
	Oxypora egyptensis (Veron 2000)	7.5	
	Pavona diffluens (Lamarck 1816)	22.5	AG
	Platygyra crosslandi (Matthai 1928)	42.5	WIO
Fungiidae	*Cantharellus doederleini* (Marenzeller 1907)	12.5	
	Podabacia sinai (Veron 2000)	10	

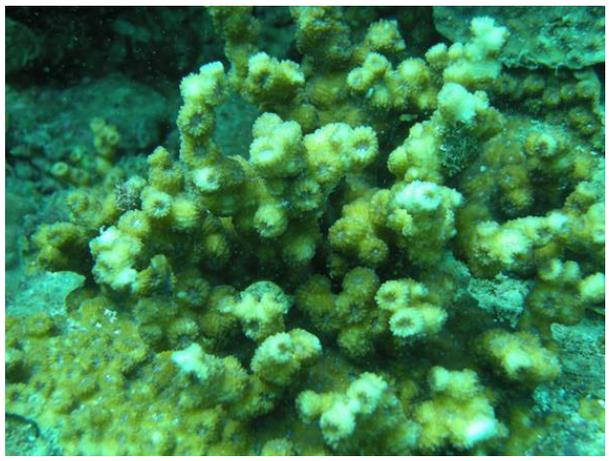
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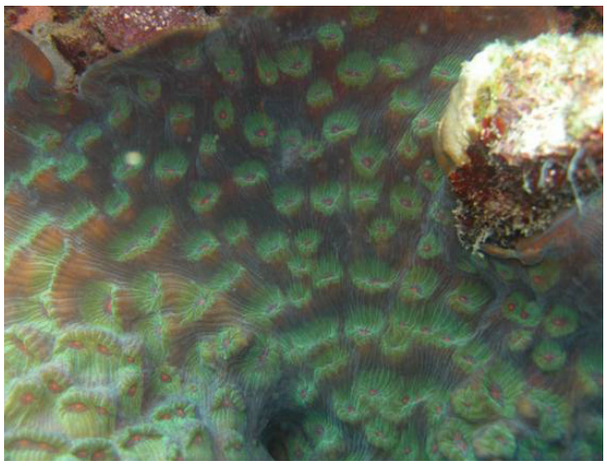
(a)



(b)



(c)



(d)



(e)



(f)

Plate 12: *Photographs showing some of the Red Sea endemic corals including:* **(a)** Acropora maryae, **(b)** Stylophora wellsi, **(c)** Echinopora fructilosa, **(d)** Mycedium umbra, **(e)** Symphyllia erythrea *and* **(f)** Favia lacuna.

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3.3.1.6 CORAL COMMUNITY STRUCTURE

Related to the IOC Handbook Ecological Indicators E1, E2 & E9 (Table 1)

Multivariate analysis of the detailed benthic cover data (76 categories) revealed 7 main clusters (Figure 26) with an average similarity of more than 60%, and one outlier (Group 2, Site 28). The analysis identified communities dominated by soft corals (Group 1), *Montipora* dominated communities (Group 2), tabular *Acropora* dominated communities, algal dominated communities (Group 4), *Porites* dominated communities (Group 5), mixed *Porites* and *Pocillopora* dominated communities (Group 6), communities dominated by coralline algae (Group 7) and mixed *Acropora* dominated communities (Group 8).
The results of the SIMPER analysis to characterise these groups is presented below.

- **Group 1:** These sites are soft coral dominated, and there are two sub-groups:
    - Group 1a (Average similarity = 69.40%) supports an average cover of 26.8% soft corals (*Lemnalia, Paralemnalia, Litophyton* spp.) mixed with hard corals including *Porites mayeri* (12%), branching acroporids (2.1%), the finer branching *Seriatopora* spp. and the agaricid *Pavona* (1.5%) and *Merulina scheeri,* as well as sponges (4%) Coralline algae (1.2 %) are also common. The sites in this group are on the west of Chab Rumi.
    - Group 1b (Average similarity = 61.60%) supports a lower abundance of soft corals (17.2%), dominated by xeniids, and a higher abundance of both coralline algae (12%) and turf algae (7%) on reef rock. Common hard corals include massive *Porites* (12%), and branching acroporids (3%), *Pocillopora* spp. (4.5%), and *Pavona* (3 %) are more abundant than in Group 1a. Also present are *Echinopora* spp. (1.4%*), Milleporadichotoma* (1.9%) and *Goniastrea* spp. (<1%). The sites in this group are on the west of Sha'ab Anbar, at Seil Ada Kebir and north of Towaritit.
- **Group 2:** This site is dominated by the hard coral *Montipora,* and is found on the very sheltered patch reefs in the barrier reef system at Shubuk (Site 28 only). Only one such site was surveyed, although similar sites were observed within Shubuk. This community is typically comprised of large encrusting and sub-massive colonies of various *Montipora* species (~17%). Other common species included mussids, such as *Lobophyllia hemprichii* and *L. corymbosa* (8.6%)*,* massive *Porites mayeri* (7 %), *Porites rus* and *P. nodifera* (4%), encrusting and foliose faviids such as *Echinopora* spp. (3.6%) (*E. forskaliana, E. irregularis*), pectinids (*Mycedium umbra*) merulinids (*Hydnophora* spp. and *Merulinascheeri*) and others known to be able to withstand low light conditions (e.g. *Galaxea* spp., *Goniopora* spp. and *Pavona* spp.).The Red Sea endemic acroporiid *Acropora maryae* (4.5%) was also quite common.
- **Group 3:** (Average similarity= 60.21%). These sites are dominated by tabular acroporids (24.2%), with carpets of soft corals (9%), massive poritids (5.8%), and staghorn *Acropora* corals (4.4%). The canopy provided by the tabular often shelters a diversity of other genera such as *Montipora, Echinopora*, and *Pavona*. Turf and coralline algae are also present, although do not form a particularly significant part of the community (6% and 2.4% respectively).
- **Group 4** (Average similarity = 64.86%). The dominant cover at these sites is turf algae (22.4%) and coralline algae (7.5%) and soft corals (4.8%) which are typically growing on old eroded reef rock and dead standing coral skeletons or rubble. This group includes sites that were impacted by the previous mass bleaching event, coral cover is variable. There is generally a moderate abundance of hard corals, and often those found include massive *Porites* (3.4%)*, Pocillopora* (2.4%)*,* branching (2.2%) and tabular *Acropora* spp. (3.5%)*, Montipora* (~1%) and *Echinopora* spp.
- **Group 5** (Average similarity = 59.60%). The coral community at this group of sites is dominated by massive *Porites* colonies, which provide 15% of the cover, and turf algae (14%). These communities typically include laminar or foliose *Echinopora* spp. (5%) and some tabular *Acropora* (5%), less frequent patches of staghorn *Acropora* (2%), and large *Lobophyllia* (2.4%) colonies. Other common coral genera include *Galaxea* spp. (1.5%), *Platygyra* spp. (1.4%), *Montipora* spp. (1.3%), pocilloporids and other massive faviids such as *Goniastrea* spp. (~1%).
- **Group 6** These sites are dominated by algal communities growing on the reef rock, old dead coral skeletons or rubble, with coral communities composed mainly of massive *Porites* and *Pocillopora*. There are two sub-groups.

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- Group 6a (Average similarity = 66.7%) includes sites where the cover is dominated by turf algae (18.6%), with some coralline (13%) and macro-algae (8%). *Porites* (11.6%) and *Pocillopora* (8.5%) are the most common hard corals, mixed with some digitate, tabular and staghorn *Acropora* (<5%).
- Group 6b (Average similarity = 65.55%) includes sites where the cover is dominated more by coralline algae (22.4%), with some turf (10.5%) and macro-algae (6.3%). *Porites* (8%) and *Pocillopora* (7%), are again the most common hard corals, although soft corals are also present (8.1%). Other common corals include *Echinopora* (5.7%) and other faviids (*Favia* spp., *Goniastrea* spp., *Favites* spp.) acroporids (*Montipora* spp. and *Acropora* spp.) and the hydrozoan fire coral *Millepora*.

- **Group 7** (Average similarity = 64.13%) The benthic cover at these sites is dominated by a high cover of coralline algae (30%) growing over old reef rock, dead standing coral skeletons and in some places rubble. The most common corals at these sites include *Pocillopora* spp. (9%), although massive *Porites* (7.6%), branching acroporiids(3%), typically *Acropora gemmifera,* and *Millepora* (2.3%) are also quite common, as are soft corals (2.3%). Other commonly found corals include *Echinopora* spp. (1.6%), tabular *Acropora* (1.5%), *Favia* spp. (1.5%), *Goniastrea* spp. (1.4%), *Pavona* spp. (1.4%) and *Montipora* (1.1%). These sites are almost all situated to the north of Port Sudan. These sites are typically shallow, and turf algae (6.3%) and macro-algae (1.3%) are also present.
- **Group 8** (Average similarity = 75.75%) The benthic communities at these sites are dominated by mixed *Acropora* communities, composed of thickets of the staghorn acroporids (15.3%), the most abundant growth form, which occurs with tabular (9.2%), branching acroporids (3.8%) and digitate (1.5%) growth forms. Other common hard corals are *Pocillopora* spp. (5.3%), massive *Porites* spp. (5.1%), *Echinopora* (2.2%), *Goniastrea* spp. (1.5%),*Seriatopora* spp. (~1%) and *Millepora* spp. (1%). The mushroom corals, including *Fungia* spp. and *Ctenactis* spp., are usually present. Turf algae (24.9%) is abundant ,and coralline algae (9.3%) and macro-algae (5.3%) are also quite common. Soft corals are present (2.6%) although not particularly abundant. All the sites in this group are situated in moderately exposed locations around the southern islands of Ilse Harorayeat, Talla Talla Segir, Talla Talla Kebir and the platform reef Dhanab Qirsch (with the exception of Site 35, which does not form part of the main group).

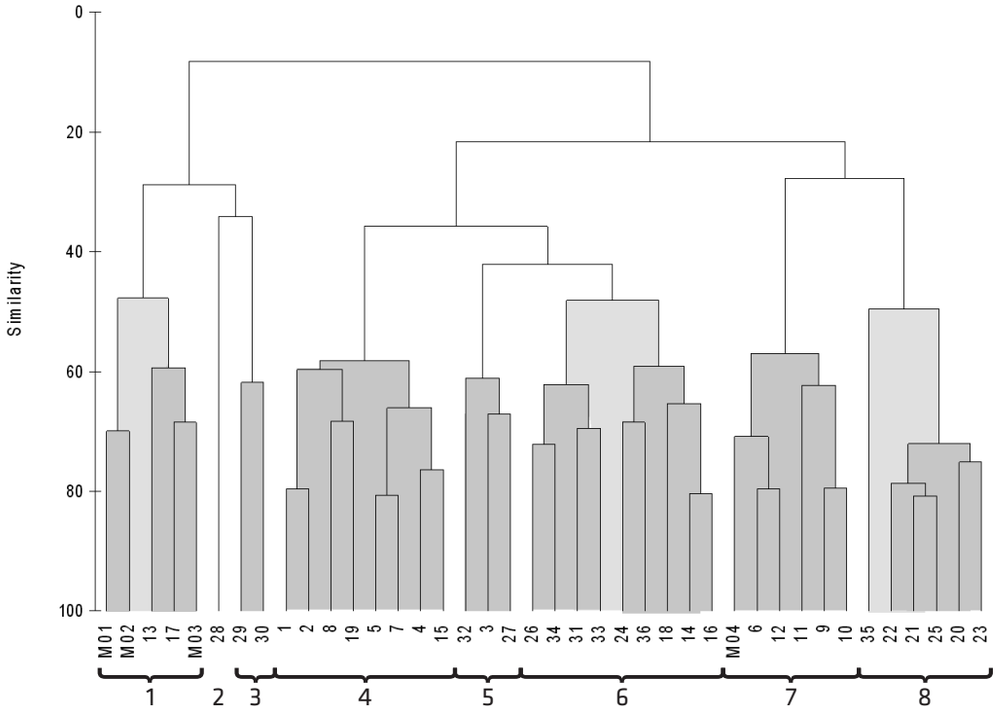
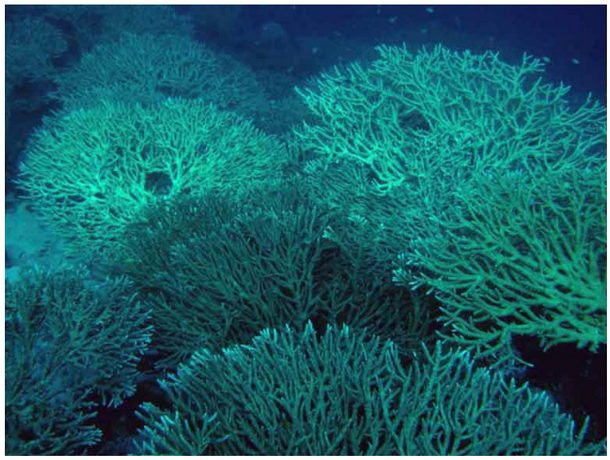


Figure 26: *Cluster analysis of detailed benthic cover data (76 categories, Bray-Curtis Similarity, Complete linkage). Dark grey shaded areas outline the groups identified at >60% similarity, including one outlier (Site 28), which fall within 8 groups at >45% similarity.*

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(a)



(b)



(c)



(d)



(e)



(f)

Plate 13: *Photographs to illustrate the characteristics of the 8 coral community types identified using the cluster analysis of the detailed benthic cover data (76 categories).* **(a)** *Group 3 (Site 30), where the coral community is almost entirely dominated by tabular acroporids;* **(b)** *Group 4 (Site 8) showing the turf algae growing on the reef rock, small colony of* Porites *and a faviid;* **(c)** *Group 5 (Site 32), which hosts a combination of* Porites *and tabular* Acropora; **(d)** *Group 6 (Site 34);* **(e)** *Group 7 (Site 11), where there is a high abundance of coralline algae and* **(f)** *Group 8 (Site 23) composed of branching and staghorn acroporids. Group 1 and Group 2 are illustrated above.*

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3.3.1.7 Coral Health, Threats and Impacts

Related to the IOC Handbook Ecological Indicators E7 & E9 (Table 1)

Coral Size Class Distribution

The size class distribution of the corals present on a reef can indicate the health of the coral population, in terms of the age of coral colonies, evidence of recent disturbance events and the level of new recruitment. Of all the corals observed[1] only 3.5% were less than 5cm, whereas nearly half (48%) of all the colonies were within the 6-20cm size class, 28% were 21-50cm, 9.8% were 51-75cm and 11% were over 76cm.

Comparison of the size class distributions for each of the coral growth forms (Figure 27), revealed a similar pattern, and the most commonly encountered size class for each of the growth-forms was 6-20cm. The only exception to this pattern was the tabular *Acropora* that were mostly commonly found with colonies over 76cm. Massive and foliose corals also regularly had colonies of over 76cm (19% and 17% respectively). Small colonies of less than 5 cm were common amongst the encrusting corals, massive and submassive corals as well as the branching *Acropora* and other branching corals.

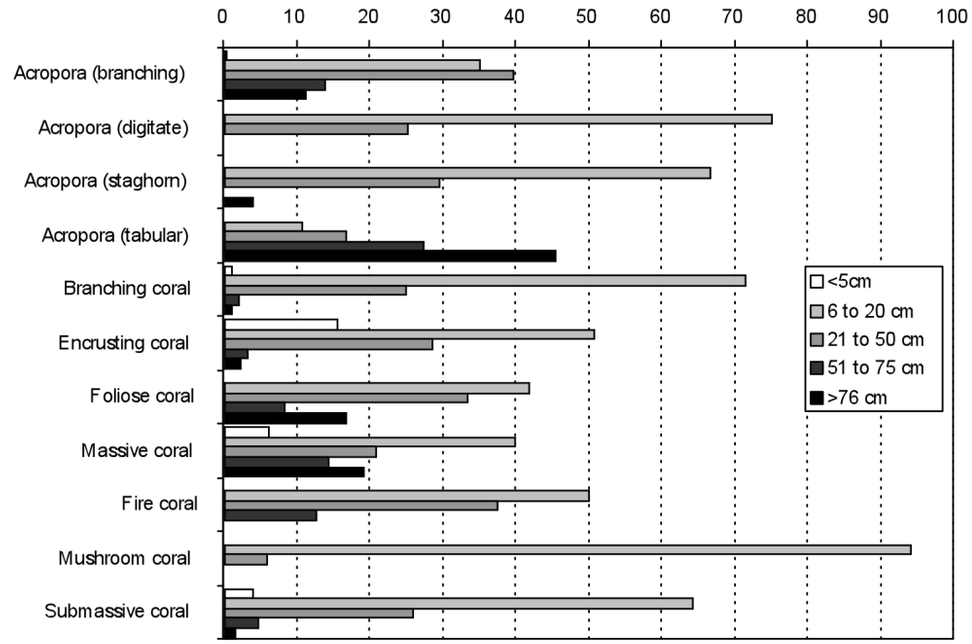


Figure 27: *Size class distribution for the various coral growth forms showing the relative abundance of the size classes for each growth form.*

Coral Colony Damage

Coral colony damage amongst the colonies sampled was low. While the percentage of damage to individual coral colonies ranged from 0% to 90%, the average damage observed amongst all the colonies sampled was less than 7.9%. Of all the colonies sampled, 66% exhibited no damage and 16.5% exhibited between 1-10% damage, whereas only 1.7% exhibited more than 75% damage (Figure 28). Indeed, only 3 colonies had 90% damage (massive coral, branching *Acropora* and sub-massive coral) and all of these were observed at sites in the north (Site 2, Site 7 and Site 8).

[1] Due to the limited number of surveyors at each site it was only possible to sample 25 coral colonies per site, and there was no within site replication, so these data need to be treated with caution.

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Coral colony damage varied significantly amongst the different growth forms (Kruskall-Wallis H = 87.09, df = 10, p = 0.000) (Figure 29). Massive growth forms exhibited the highest level of damage per colony, followed by foliose and branching corals. Pairwise comparisons of the amount of damage between the growth-forms revealed significant differences between the percent damage to all of the *Acropora* growth-forms and massive corals, as well as between massive corals and sub-massive, encrusting and mushroom corals ($p<0.001$) (Table 14).

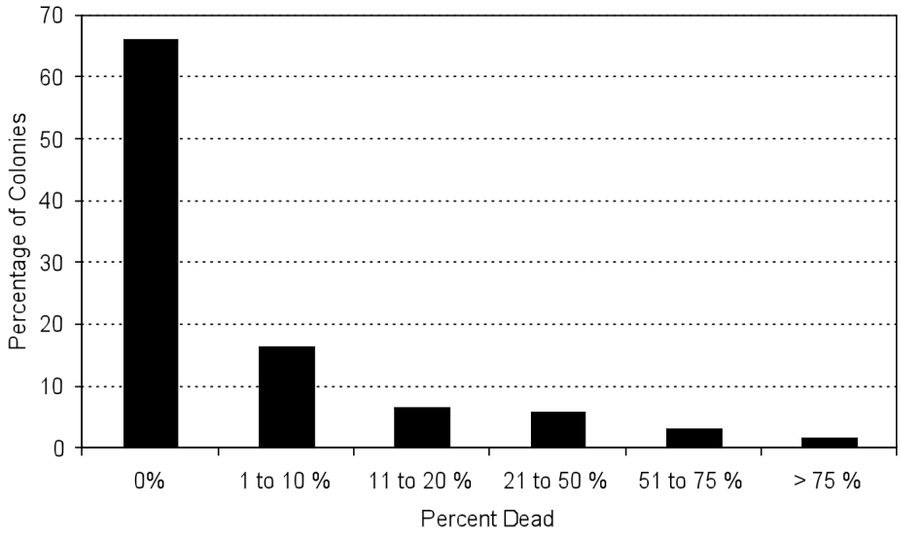


Figure 28: *Percentage of coral colonies sampled exhibiting damage.*

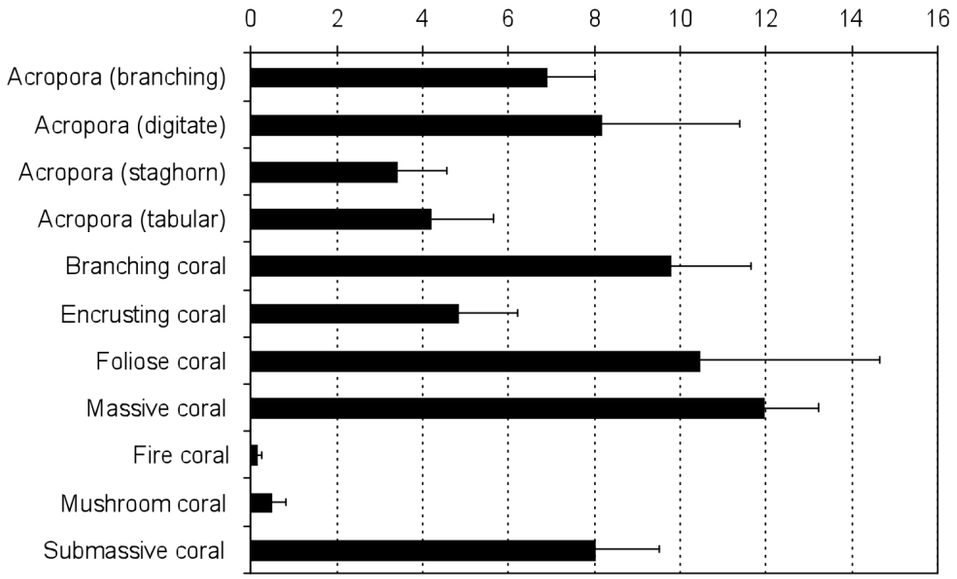


Figure 29: *Mean percent damage for the different coral growth forms (all size classes).*

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Table 14: *Pairwise comparison of the percent damage to coral growth forms (Kruskall-Wallis Non-parametric statistic and Dunn's Pairwise Comparisons) showing only the significant differences in percent damage for each coral growth form.*

Groups		Z-value vs. Critical value	P-value
Acropora (branching)	Massive coral	7.26842 >= 2.908	0.0000
Acropora (tabular)	Massive coral	5.56167 >= 2.908	0.0000
Encrusting coral	Massive coral	5.40713 >= 2.908	0.0000
Massive coral	Submassive coral	4.34777 >= 2.908	0.0000
Acropora (staghorn)	Massive coral	4.23544 >= 2.908	0.0000
Massive coral	Millepora	4.14852 >= 2.908	0.0000
Massive coral	Mushroom coral	3.88841 >= 2.908	0.0001
Acropora (digitate)	Massive coral	3.80336 >= 2.908	0.0001

3.3.1.8 IMPACTS TO CORALS

Observed impacts on the corals were recorded within 7 broad categories. The most common of these impacts was partial coral bleaching, followed by sediment damage, sponge infestations, coral diseases, Crown of Thorns starfish, and *Drupella*. The prevalence and severity of these impacts is described below.

Coral Bleaching

Low levels of coral bleaching were observed at 58% of the sites visited during the survey in 2007 (23 sites) which were widely distributed throughout the survey area. At the sites where bleaching was recorded only a few coral colonies were exhibiting 'partial bleaching', or 'paling', particularly on the upper surfaces of colonies. This may indicate that temperatures or light levels were seasonally high at these sites during the time leading up to the survey.

Partial bleaching was recorded most frequently on the branching corals, particularly branching, tabular and staghorn *Acropora* (Figure 30 a). Less than half of the sites where bleaching was observed (11 out of the 23 sites) had more than one colony that was bleached, and only one site had more than three colonies exhibiting bleaching (Site M04). While there was no apparent evidence to suggest that there had been a mass coral bleaching event within the past few months, there was evidence that some reefs had been impacted by a previous larger scale bleaching event.

Reefs that showed evidence of a previous large scale bleaching event (probably in 1998) were more apparent to the north of Port Sudan and inshore more than to the south and at offshore reefs. These impacted reefs often had either large patches of dead standing coral or patches of coral rubble composed of the remnants of branching corals (*Acropora*). At some sites, notably in sheltered locations, the areas of dead standing coral appeared almost fossilised as the structure of the branches and the corallites remained visible even though the skeleton had been overgrown by coralline algae.

At some of the sites where there was rubble it was still loose and there was little or no evidence of recolonisation, consolidation, or resettlement of new coral recruits. At other sites the rubble had been overgrown by coralline algae, which was binding the loose rubble pieces together and thereby forming a more stable substrate for other organisms to colonise. At these sites the consolidated rubble had often been colonized by soft corals, some smaller recruits of hard corals and the fire coral *Millepora*.

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Sediment Damage

Sediment was evident on coral colonies at 28% of sites surveyed in 2007. The site with the highest occurrence of sediment was behind the barrier reef at Shubuk (Site 28). Other sites with a moderately high proportion of sediment effected colonies included: Marsa Salak (Site 2), Sha'ab Anbar (Site 14), Talla Talla Segir (Site 26), Marsa Sheik Ibrahim (Site 30) and Qad Eitwid Cay (Site 32). Sites where there was only minor evidence of sediment effects included Ras Salak, Sha'ab Salak (Site 4 and Site 6), Seil Ada Kebir (Site 18), Dhanab Qirsch (Site 20) and Suakin South (Site 34). The sites where sedimented corals were recorded are all fringing reefs, either on the mainland or around islands, with the exception of Sha'ab Anbar and Dhanab Qirsch. The growth forms most commonly affected by sediments were sub-massive corals, foliose and encrusting corals, massive corals and tabular and branching Acropora (Figure 30 a).

Sponge Infestations

Sponge infestations were affecting coral colonies at 23% of the sites surveyed. These included a fine grey sponge (Plate 13 d) that covered large areas of the coral colony, and a bright reddish orange sponge (Plate 13 e). The site where most corals appeared to be affected by a sponge infestation was in Shubuk (Site 28), where 20% of the coral colonies were infested. Other sites where sponge infestations were recorded included Marsa Salak (Site 1), Sha'ab Anbar (Site 14 and Site 15), Sel Ada Kebir (Site 17), Talla Talla Kebir (Site 24), Talla Talla Segir (Site 26), (Site 32) and Towaritit (Site M04). Recent studies have indicated an increase in this threat, particularly within the Red Sea. The worst affected growth forms appeared to be sub-massive, massive, encrusting, branching and digitate *Acropora*.

Coral Diseases

Coral diseases were not common and were observed only at 7.5% of the sites surveyed (i.e. 3 sites). Coral diseases were recorded at Marsa Salak (Site 02), Sha'ab Salak (Site 06) and Sha'ab Anbar (Site 14), where there was only one recorded incident per site, affecting a massive coal, encrusting coral and branching *Acropora* (Figure 30 a).

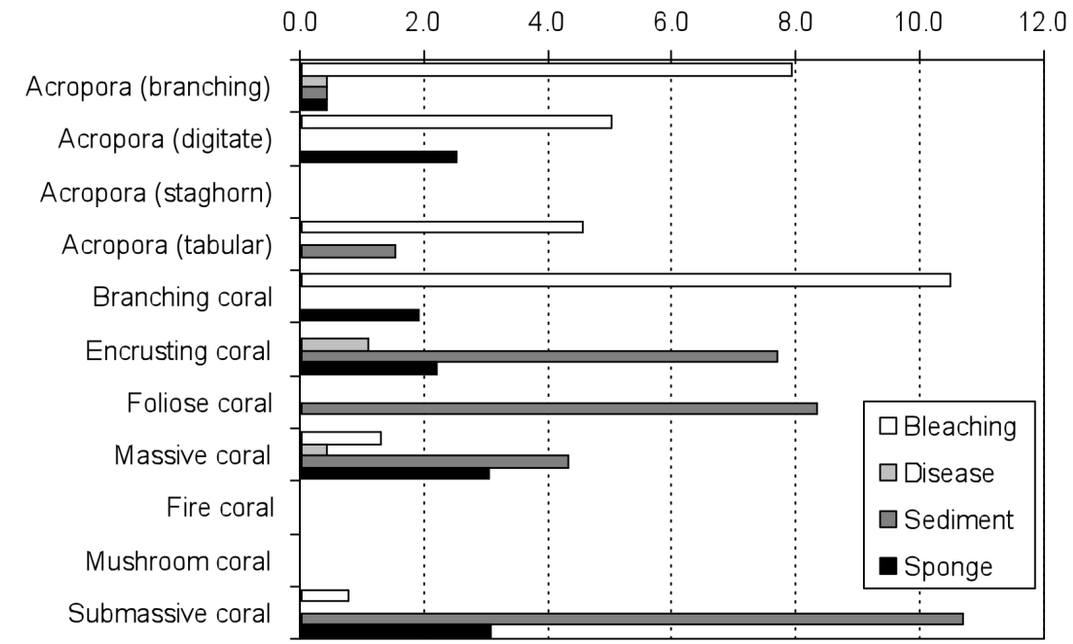
Crown-of-Thorns *(Acanthaster plancii)*

Evidence of COT impacts on the individual coral colonies sampled was recorded at 3 sites (Sites 23, 33, and 36). These figures are lower than the COT records from the belt transects, as would be expected due to sampling differences. The belt transects recorded evidence of COTs at 37.5% (15 sites). Both COTs and COT scars were observed at 5 sites (Sites 8, 10, 23, 32 and 33). COT animals were observed at 5 sites (Sites 11, 27, 31, 36 and M04) whereas COT scars alone were observed at 5 sites (Sites 14 22, 24, 26 and 34).

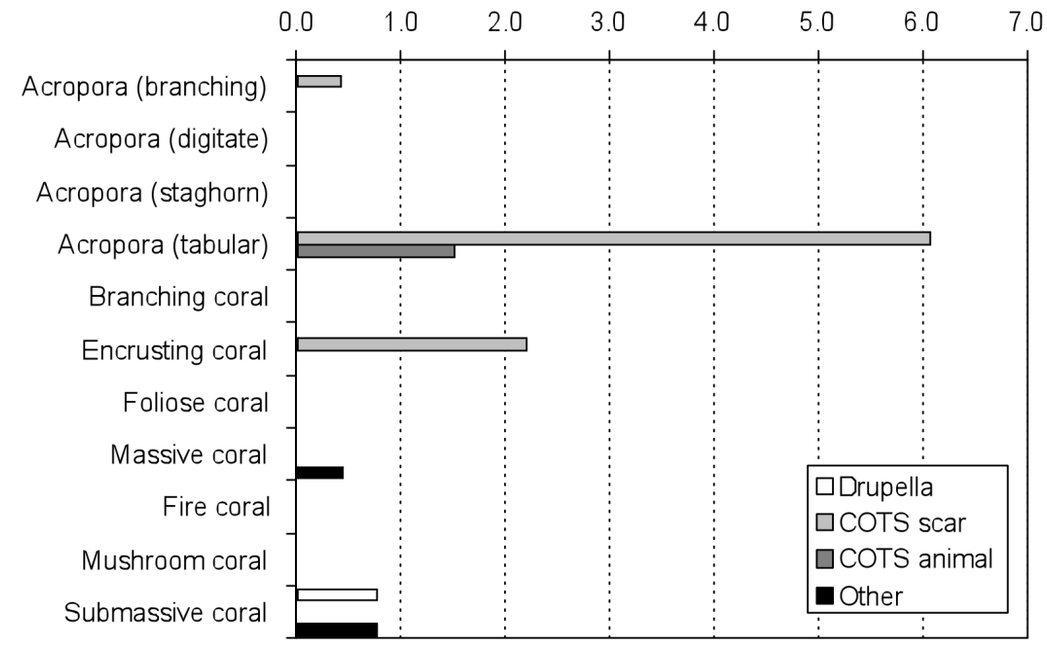
Corallivorous Gastropods

Four common corallivorous snails occur in the Red Sea: *Drupella cornus* (Roeding 1798), *Coralliophila costularis* (Lamarck 1816), *C. violacea* (Kiener 1836) and *Quoyula madreporarum* (Sowerby 1832). The most common of these is *Drupella*. During the 2007 surveys these gastropods were not found to be particularly common and they were only recorded to be impacting on corals within these surveys at one site and recorded within the belt transect at two sites (Site 20 and Site M03).

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(a)



(b)

Figure 30: *Percent occurrence of impacts on the different coral growth forms (all size classes) showing the occurrence of (a) coral bleaching, disease, sediment damage and sponge infestations and (b)* Drupella *damage, Crown of Thorns starfish feeding scars, and animals and other impacts.*

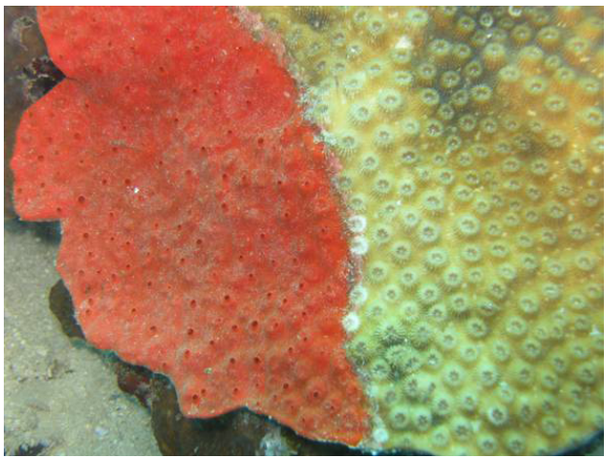
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(a)



(b)



(c)



(d)



(e)



(f)

Plate 14: *Photographs showing some of the impacts on/threats to corals observed on the reefs of Sudan:* **(a)** *'Partial' coral bleaching on the upper surface of a* Goniastrea *coral colony, which is paler than the sides of the colony;* **(b)** *Sediment collected at the centre of foliose coral colony (*Mycedium *sp.);* **(c)** *Red* Cliona *spp. sponge infestation;* **(d)***; Greyish green sponge infestation on a colony of* Pocillopora *sp;* **(e)** *Crown of thorns starfish (*Acanthaster plancii*) feeding amongst a bed of staghorn* Acropora, *the recent white feeding scars are clearly evident and* **(f)** *Coral colony damage caused by the corallivorous gastropod mollusc* Drupella *spp.*

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3.3.1.9 Discussion

While reefs elsewhere in the Red Sea have been researched intensively in the past, many of the reefs surveyed in Sudan during 2007 had never previously been studied. The results of this study therefore provide insights into the current status and composition of the reefs of Sudan, over a broader geographic area, and the opportunity to compare trends in the extent of reef development and coral community structure previously only observed on the reefs on the opposite eastern shore of the Red Sea (e.g. Ormond *et al.* 1984a, b, c; Sheppard & Sheppard 1991, DeVantier *et al.* 2000).

The Sudanese Red Sea supports extensive coral growth and hosts a broad diversity of both classical reef types and more unusual reef formations. Sudanese reefs include examples of classical fringing reef, for which the Red Sea is renowned, and nearshore and offshore barrier reef systems, as well as island fringing reefs and a variety of other reef formations within the Suakin Archipelago. The pattern of reef development appears broadly to mirror the pattern observed on the opposite Arabian shoreline as described by Sheppard & Sheppard (1991).

The mainland fringing reef extends along the coast of Sudan as far south as 19°N, where it is replaced by a nearshore barrier reef system at Shubuk. Southwards of Shubuk (not surveyed during this field phase due to security issues) the shoreline becomes increasingly sandy and there appears to be little or no reef development on the mainland shore as far south as 18°N, although there are submerged, offshore reef formations at this latitude. This follows the same pattern as is observed on the Arabian coast, where the classical fringing reefs only extend as far south as 18-20°N (Sheppard & Sheppard 1991) and where, southwards of 20°N, the mainland fringing reefs are reduced in size, the gradient of the sea floor lessens and the reef base meets soft substrates in increasingly shallow water.

The offshore barrier reef complex sits on top of a platform at the edge of the continental shelf and extends almost all the way along the coast of Sudan, as far south as Towaritit reef. Similar structures occur off the coast of Saudi Arabia and these were also initially considered as single independent reefs until bathymetric studies confirmed the linkages between them.

The barrier reef complex contains a type of reef that appears to be peculiar to the Red Sea and this increases their significance for conservation purposes at national, regional and international levels. Due to their uniqueness, Guilcher (1988) provided a new definition for the type of reef structure found off the coast of Port Sudan, which he called a "ridge reef"; he also identified it as occurring in Sinai, the Farasans and near Jeddah. He described ridge reefs as typically longitudinal ridges lying on the axis of the Red Sea, and probably resulting from a combination of normal faulting from the progressive opening of the Red Sea and upward movement of underlying salt domes (diapirs) along these faults[2].

The near-shore barrier reef structure at Shubuk is another of the more unusual reef features along this coast, composed of a series of platform reefs and a huge network of reticulated patch reefs in the northwest facing edge and patch reefs and fringing reefs within the area enclosed by these outer structures. The environment is shallow and silty; the waters are highly turbid, which creates a low light environment. The structure itself is perhaps most closely comparable with the Little Barrier Reef in Saudi Arabia. However, this area also has similarities with reefs in the more turbid conditions found in the southern Red Sea. On these reefs there is typically an increase in the occurrence of large brown algae (which occurs as far north as Yanbu on the Saudi Arabian coast) and lower coral diversity with higher cover (Sheppard & Sheppard 1991).

[2] There has also been further semantic debate regarding the use of the term "atoll" with reference to Sanganeb. The use of this term has remained somewhat controversial, as reef structures with a similar appearance are abundant along much of the Saudi Arabian Red Sea coast, though they are not usually referred to by this name.

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The Suakin Archipelago, situated in the southern waters of Sudan, has developed on the extension of the continental shelf. It is one of several important island groups within the Red Sea and, although it has received less attention than the other groups over the years, the archipelago is of marked importance both nationally and regionally. The reefs and islands within this archipelago substantially increase the area of reefal habitat available within the Sudanese coastal waters and within this part of the Red Sea, which is known to support particularly high diversity. The extension of these reefs offshore also greatly increases the biogeographical span and diversity of reef habitats. Furthermore, the inaccessibility of these reefs and islands enhances their significance, as they could provide areas away from direct human impacts on the mainland coast and refuges for some of the Red Sea's important bird and turtle nesting sites.

The surveys in 2007 found the reefs of Sudan to be in a moderate to good condition, with moderate to high living coral cover (average 35.7% for hard corals and fire corals) and with high coral species richness (291 scleractinian coral species and 3 species of the hydrozoan fire coral *Millepora*). The composition of the substratum on these reefs is typically dominated by scleractinian hard corals. However, cover can vary between 11% and 65% (average cover is 35.7%). Soft corals are also abundant and diverse, although cover is generally lower than hard corals at the depths surveyed (average cover is 7%), they may provide the dominant cover at some sites, particularly on deeper fore reefs as observed elsewhere in the Red Sea (Reigl *et al. 2003*). Similarly, the fire coral, *Millepora,* although common, was generally found in low abundances (average cover 1.3%) although it may cover >10% of the substratum at some shallow sites (maximum cover 12%), particularly on more exposed eastern reefs.

Comparison of the extent of total coral cover (hard and soft corals and *Millepora* average 44.3%) with results from studies elsewhere, reveals that cover is comparable with that found on Saudi Arabian reefs 10 years previously (in 1998-1999, where average total coral cover was also 44%) (DeVantier *et al.* 2000), suggesting that many of these reefs are in a good condition. There is, however, spatial variability. Hard coral cover was considerably higher on southern reefs than on northern reefs; conversely, the amount of dead coral, coral rubble and old eroded reef rock is higher, particularly in the north. While some of the differences in benthic composition observed in 2007 can be accounted for by the environmental trends in exposure and regional biogeographical trends north to south, others appear to be more indicative of variation in recent disturbance histories, in particular the severity of impact of recent mass coral bleaching events (see Box. 5 and Box. 6) and other impacts (e.g. *Acanthaster plancii* outbreaks).

Reefs to the north of Port Sudan had significantly lower coral cover (average 29.3%) than those to the south of Port Sudan (average 40%). The significant negative correlation of hard coral cover with latitude is accompanied by a positive correlation with longitude, as hard coral cover was higher on the offshore reefs and islands than was found on many of the mainland fringing reefs. There was also a significant negative relationship with water clarity, which was higher on the northern reefs at the time of the survey. The site with the highest hard coral cover was within the shallow turbid environment at Shubuk, while the only site in the north with above average hard coral cover was at Marsa Daror, another turbid site.

There are also geographical trends in amount of algal cover. Although macroalgae is generally not particularly common on these reefs, there is a significant increase in its abundance on southern reefs, which follows trends observed elsewhere in the Red Sea. Coralline algae and turf algal cover is more variable and abundant at some of the sites (average cover 13.3 % and 14 % respectively). These algae were often found growing over old eroded reef rock, dead standing coral skeletons, or overgrowing and consolidating areas of loose rubble, which is characteristic on reefs that have previously been subjected to a major disturbance event, such as bleaching.

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Typically, reefs that have been subject to mass coral bleaching are initially covered in dead coral skeletons. The skeletons remain in place for a short while after the event and undergo a taphonomic[3] sequence of breakdown, during which time they may be overgrown or colonised by other organisms, and eroded by organisms which graze or bore into the structure. The amount of coral rubble and exposed reef rock can increase substantially during this process. Ten years after a major disturbance event, although some dead coral skeletons may still be evident, many of the more friable structures will have broken down into rubble, or been so eroded that they become indistinguishable from the underlying reef rock. On the reefs of Sudan in 2007, the extent of dead standing coral, both with and without turf algae, was quite low and only marginally higher in the south than in the north, which suggests that the reefs have not been subject to a recent disturbance event. Conversely, however, the extent of coral reef rock, and reef rock with turf algal cover, was significantly higher (average 23.4%) in the north than in the south (8.5%) and it is these reefs that were probably subjected to a major disturbance event about 10 years ago.

Box 5: What is coral bleaching?

Corals are colonial filter feeding organisms. The majority of corals contain small symbiotic micro-algae (dinoflagellates), known as zooxanthellae, which live in the cells lining the gut and provide the coral's colour. This symbiosis benefits both the coral host and the micro-algal symbiont. The coral host provides nutrients (ammonia and phosphate) essential for the zooxanthellae to photosynthesise and, in return, the zooxanthellae may provide up to 95% of their host's energy requirement (amino-acids, sugars, complex carbohydrates and peptides). So, while a coral is capable of acquiring nutrients by filter feeding, the symbiosis is ultimately essential, not only to the survival of corals, but also to the reefs.

When a coral is stressed by changes in its environment it can exhibit a range of responses to cope with the stress, including a general stress response known as bleaching. Bleaching occurs when the coral expels the zooxanthellae (and/or their pigments) and the host tissue becomes transparent, revealing the white calcareous skeleton beneath. A number of different environmental stressors (salinity, light, shade, sedimentation, high or low water temperatures) may provoke the bleaching response in corals on a localised scale within the immediate vicinity of the source of the stress or over wide geographic areas.

Partial coral bleaching or paling occurs naturally during the summer months in response to seasonal variations in seawater temperatures and light levels, when these are close to their annual maxima. This is part of a natural seasonal cycle in the density of zooxanthellae, which are lowest during the summer months and highest during the winter months. Under normal conditions, the coral recovers as symbiont densities increase at the end of the summer months. More extreme changes in environmental conditions, such as sustained high sea temperatures or excessive light, can cause more dramatic bleaching responses over wider geographic areas from which corals may not recover. This is called mass coral bleaching.

The primary trigger for widespread or mass coral bleaching events is thought to be the combination of high sea water temperatures and light. This combination of factors increases the rates of biochemical reactions associated with the photosynthesis within the symbiotic microalgae that live within the coral host (zooxanthellae). These result in the production of toxic forms of oxygen that interfere with cellular processes and cause the corals to expel their zooxanthellae. The conditions that result in mass bleaching are typically associated with sustained high sea water temperatures and calm weather conditions. The latter contribute to the stress, as lower wind speed reduces the level of mixing in the water column and increases the levels of light penetrating through the water column.

[3] Taphonomy is the study of how organisms decay over time.

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Box 6: What is Reef Resilience?

A notable characteristic of mass coral bleaching events is the patchiness of the impact of these events, both in terms of the severity of visible bleaching and the extent of bleaching related mortality. Some reefs may avoid exposure to the environmental conditions that cause bleaching. On other reefs that are exposed to bleaching conditions, some corals (or a part of a coral colony) may bleach while others may not, and some may survive while others die. This variability can differ across a range of spatial scales within and between coral colonies, species, depths, reefs and regions (Brown & Suharsono 1990 ; Gleason, 1993; Marshall & Baird 2000). So some corals and/or reefs may be better equipped to withstand or recover from bleaching. Corals and reefs that evade exposure to the conditions that cause bleaching exhibit *avoidance;* those that do not bleach severely, despite exposure to bleaching conditions, exhibit bleaching *resistance;* and those that bleach when exposed to bleaching conditions but do not die exhibit bleaching *tolerance* (Salm *et al. 2001*).

Factors that have been shown to influence bleaching avoidance, resistance, tolerance and recovery fall into two categories: *extrinsic* environmental factors and *intrinsic* biological factors. The environmental factors that mitigate for the conditions that cause bleaching include: oceanographic or climatic influences that reduce seawater temperature (e.g. cold water upwelling; fast currents, mixing); enhanced water movement (e.g. topography, currents); and decreased light stress (e.g. cloud cover, shade, turbidity). The extent of the area of reef (i.e. ecoregion, reef, or different depths) that successfully avoids, resists or tolerates bleaching will be determined by the spatial extent of the environmental factor. The timing of when these influences occur with respect to the progression of the bleaching event (i.e. before, during or soon after the onset of bleaching) will determine whether they result in bleaching avoidance, resistance or tolerance.

Biological factors that can help the coral survive or withstand a bleaching event include a range of genetic, physiological and behavioural differences in either the coral host or the symbiont population (Knowlton *et al. 1992; Edmunds, 1994*) between or within species. Certain coral genera and growth forms are thought to be more susceptible to bleaching (e.g. *Acropora, Pocillopora, Seriatopora* and *Stylophora*), while others have been found to exhibit high levels of bleaching resistance and/or tolerance (e.g. *Porites*). Recent studies suggest that the condition of the coral prior to the onset of bleaching can influence whether they are able to resist or tolerate bleaching. Another biologically related bleaching resistance factor is the historical differences in the exposure of the site to thermal stress (e.g. acclimation or adaptation) (Glynn 1993, 2001).

The ecological (environmental and biological) factors that enable a coral to avoid, resist or tolerate bleaching are just part of a range of factors that may influence the ability of the wider system to withstand large-scale disturbance events in the long term (i.e. spatial resilience). Other factors that can influence the outcome of a bleaching event relate to the capacity of a reef to recover after such a disturbance. The factors that are thought to support recovery include: good water quality; healthy herbivore populations; good connectivity; high recruitment levels; and a low abundance of bioeroders, corallivores and disease (West & Salm 2003).

If there are factors that support the natural resilience of reefs, then these factors can be used alongside the existing methods (Salm 2000) to help guide managers in the selection, design, zoning and management of new MPAs and to modify the design of existing MPAs. These factors do, however, need to be tested to determine their reliability and whether they in fact consistently contribute significant, positive influences during coral bleaching events.

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Spatial variability in the impact of a previous bleaching event was apparent within reef systems inside and surrounding Dungonab Bay during the 2001 surveys (Kemp *et al. 2001*; PERSGA 2004a). The 2007 surveys have, however, revealed a wider pattern, showing that while some reefs in the north of Sudan were heavily impacted by bleaching, other reefs, particularly those in the southern and offshore, appear to have avoided the impact of this event. The geographical trends in live hard coral cover observed in 2007 matched those observed by the 2001 survey (PERSGA 2004a) and findings from studies on the northern Sudanese reefs in 2006 (APF 2006). The 2006 surveys found that hard coral cover was lower at Sanganeb Atoll MNP (average 29.6%) than at Dungonab Bay NP (average 32.4%) and that average cover (31.8%) was lower than that found on the southern reefs during 2007. The sites with the highest cover during the 2006 surveys were on the exposed outer reefs around Dungonab (Sha'ab Qumeira and Merlot) and the more turbid sites at the northern end of Dungonab Bay, at the entrance to the bay, around the islands within the bay and the mainland fringing to the south of Mohammed Qol. Similar trends were observed in 2001.

Environmental factors, which may have lessened the severity of damage from temperature related coral reef bleaching on the southern and offshore reefs of Sudan, require further investigation. Although it is likely that the observed lower damage is due to the interplay between factors that produced lower sea water temperatures (e.g. wind driven mixing in the southern Red Sea, faster water currents) or reduced light levels (e.g. turbidity, phytoplankton blooms) or to some combination of these factors (see Box. 6). The pattern of survival and mortality on Sudanese reefs certainly indicates that the worst affected areas were those subject to a combination of both elevated sea water temperatures and high light levels, the latter being inferred by the shading pattern on partially dead corals and the lower mortality on reefs with lower visibility.

There have been repeated mass bleaching events within the Red Sea and Gulf of Aden in the past decade (DeVantier *et al. 2000, 2004*; Turak *et al. 2007)*. Although the impact of these events has not been particularly well reported, the findings of this study do agree with observations made elsewhere. Reefs on the southern Red Sea coast of Yemen were impacted by mass bleaching in 1996 and again in 1997/1998, which resulted in extensive mortality (Turak *et al. 2007*). Bleaching was apparent on the northern and central reefs in Saudi Arabia in September-October 1998 and these reefs were patchily affected (DeVantier *et al. 2000, 2004*). Intense bleaching was apparent at Rabigh and Yanbu and variably distributed around Jeddah and northwards. The reefs around Ras Baridi, the Al-Wajh Bank and Gulf of Aqaba, which are influenced by cool water upwelling, showed little evidence of bleaching.

The differences in the meteorological conditions in the northern and southern Red Sea, and their influence on surface water movement patterns and mixing, may explain the higher levels of coral mortality in the northern Red Sea during the 1997/1998 bleaching event. The strong sea breezes, Haboob winds that drive higher wave energy conditions, particularly in the southern parts, and the onset of NE monsoon, which shifts the wind direction in the southern Red Sea, probably influenced the outcome of this event. Both these factors would increase mixing in the southern region, which may have reduced seawater temperatures and increased turbidity, thereby reducing the light levels.

The different wind patterns north and south also drive the shallow water circulation patterns in the Red Sea. During the summer months surface waters move southwards, down the Red Sea and out of the Bab el Mandab, bringing cooler northern Red Sea surface waters southwards. The situation is complicated, however, by the occurrence of a series of cyclonic and anti-cyclonic gyres. Off the coast of Sudan there is thought to be an anti-cyclonic gyre at 18-19°N, which moves the water in a clockwise direction, across the width of the Red Sea between Saudi Arabia and Sudan. The gyre may have brought cooler northern Red Sea waters down the Arabian coast and across to the southern Sudan. Further investigation of coastal water movement patterns off the coast of Sudan are needed to confirm this.

Despite the variability of the condition of the reefs surveyed, the species richness supported by these reefs is high. A total of 291 species of scleractinian hard corals were recorded from 59 genera, and 15 families and a further 30 taxa of other corals, including the hydrozoan fire corals, *Millepora* spp., soft corals and zoanthids, were also recorded. There are still some taxonomic uncertainties at the species level for some of the stony corals, particularly the soft corals, which were only recorded at genera level. The number of species found in Sudan compares favourably with the total of 340 species reported by Veron (2000) to occur within the whole Red Sea and with the combined total of 372 species from two recent studies that reported 260 species for the central and northern Red Sea coast of Saudi Arabia (DeVantier *et al.* 2000) and 219 species from the southern Red Sea coast of Yemen (Turak *et al. 2007)*. . The number of species is likely to be considerably

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higher once further studies, particularly on deeper parts of the reef tract and on other reefs in the Suakin Archipelago, are completed.

The coral species diversity recorded during this survey indicates that the reefs of Sudan host close to 80% of the species previously reported from the Red Sea. This fact alone underscores the urgent need for the protection of these reefs from other more manageable impacts. However, the findings also demonstrate that Sudan's reefs encompass a transitional zone for species that are more characteristic of both northern and southern Red Sea coral populations. The fact that Sudan's reefs provide a refugia for species from two biogeographical zones suggests that these reefs, and their associated communities, may act as source reefs, and could be very important in terms of maintaining the connectivity within the region. This emphasises the need to protect a greater proportion of the diversity of reefs found within Sudanese waters (see Section 3.5) and to protect representative areas across a wider geographic range than is currently gazetted within the existing MPAs (see Section 3.6).

3.3.2 Macro-invertebrates

Related to the IOC Handbook Ecological Indicators E1 & E3 (Table 1), and to the Socio Economic Indicator SE 5 (Table 3).

By Melita Samoilys

Two groups of mobile macro-invertebrates were surveyed: those that are exploited and those, such as sea urchins, which are not directly exploited, but which are indicators of other aspects of reef health.

3.3.2.1 NON-EXPLOITED INVERTEBRATES

Non-exploited groups of macroinvertebrates included sea urchins, the Crown-of-Thorns starfish (COTs) and *Drupella* (both predators of corals).

Sea urchins and starfish (echinoderms)

Species of sea urchins and starfish recorded during the surveys are listed in (Table 15). Starfish were rarely seen: only three species were recorded and, they were only recorded at eight out of the 40 sites, and had an overall density (species combined) across all sites of 0.1/100m^2.

Table 15: *Sea urchin and starfish species recorded during the survey.*

Sea urchins	Starfish
Diadema savigni	*Culcita sp.*
Diadema setosum	*Fromia ghardaqana* (endemic)
Echinometra mathaei	*Gomophia egyptiaca*

Diadema and *Echinometra* sea urchins are the two dominant genera on reefs and probably have the largest ecological impact in terms both of grazing of turf algae (*Diadema*) and of bio-erosion of reefs (*Echinometra*). Both sea urchin genera were conspicuously absent except at Sha'ab Shubuk and Qad Eitwid Cay in the south. The overall density along the coast of *Diadema* was 1.59/100m^2 and of *Echinometra* only 0.06/100m^2. The latter species was only observed at six sites out of the 40 surveyed.

An apparent N-S gradient, with greater sea urchin abundance in the south, was not statistically significant (Figure 31). The graph illustrates high variability in the abundance of sea urchins between sites and shows those sites where sea urchins are concentrated in the south, notably at Sha'ab Shubuk (Site 28) and Qad Eitwid Cay (Site 32) for *Diadema* spp.

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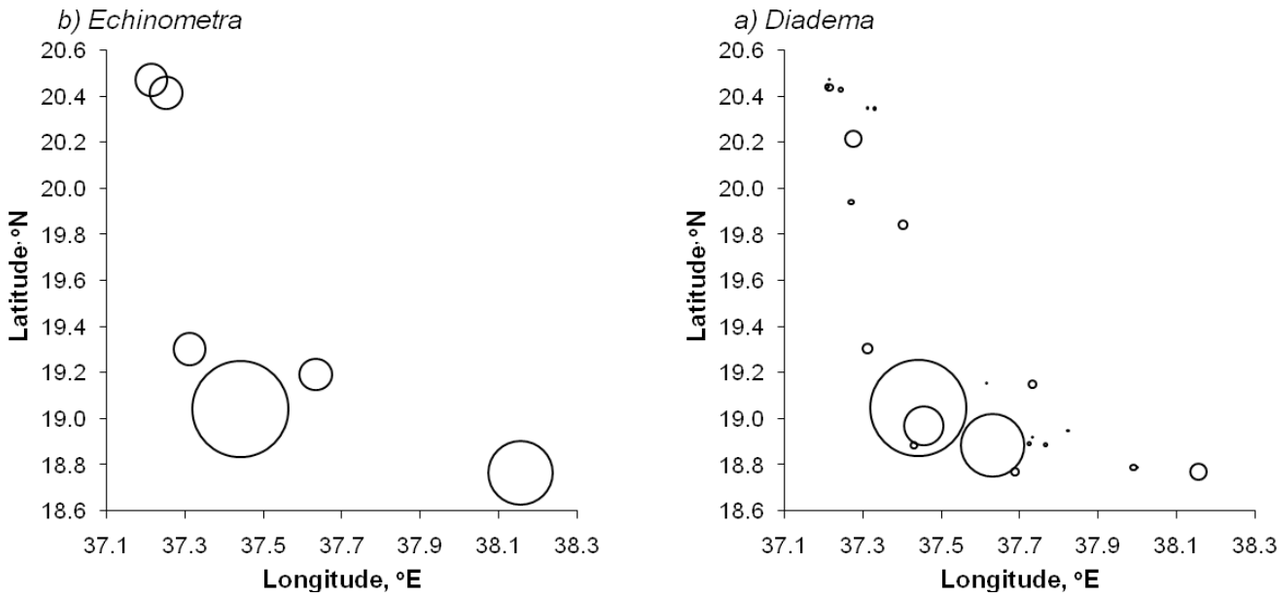


Figure 31 : *Bubble graphs illustrating the distribution of* Diadema *and* Echinometra *sea urchins along a latitude-longitude gradient. Bubble sizes correspond to the respective abundances.*

Correlations between sea urchin abundance and the substrate types revealed a weak but significant correlation between *Echinometra* and macro-algae (Pearson product-moment correlations, 0.4267 $p<0.01$). Sea urchins were not significantly correlated with other substrate types. Brown macro-algae are often a feature of degraded or damaged reefs (McCook 1999) as are *Echinometra,* and this might explain that correlation.

Since *Diadema* are grazers of turf algae it was expected that *Diadema* abundance might be negatively correlated with turf algae (McClanahan *et al. 1995*) but this relationship was not significant. This may be due to weak statistical power due to the almost complete absence of sea urchins at many sites. Very high turf algae cover was observed on the shallow dead coral at many of these sites.

Starfish and sea urchins share typical echinoderm life history strategies of being *r* strategists. Thus their populations tend to "boom and bust". Comparisons between the two taxa may therefore reveal anthropogenic impacts: the hypothesis is that starfish may reflect natural cycles in population abundance, whereas sea urchins may reflect fishing impacts (removal of predators: McClanahan *et al. 1995*). Starfish densities were lower than sea urchin densities. When plotted across the 40 sites, five sites show markedly higher abundances of sea urchins compared to starfish (Figure 32). These sites are labelled on the graph. According to this hypothesis, sites with high sea urchin densities may indicate overfishing or reef damage. Although higher densities were found at these five sites they did not represent outbreak densities. In addition, sea urchin densities were positively correlated with snappers and sweetlips, fish taxa that prey on sea urchins, and are taken in local line fisheries. We suggest the graph illustrates the remarkable paucity of these echinoderms on Sudan's coast.

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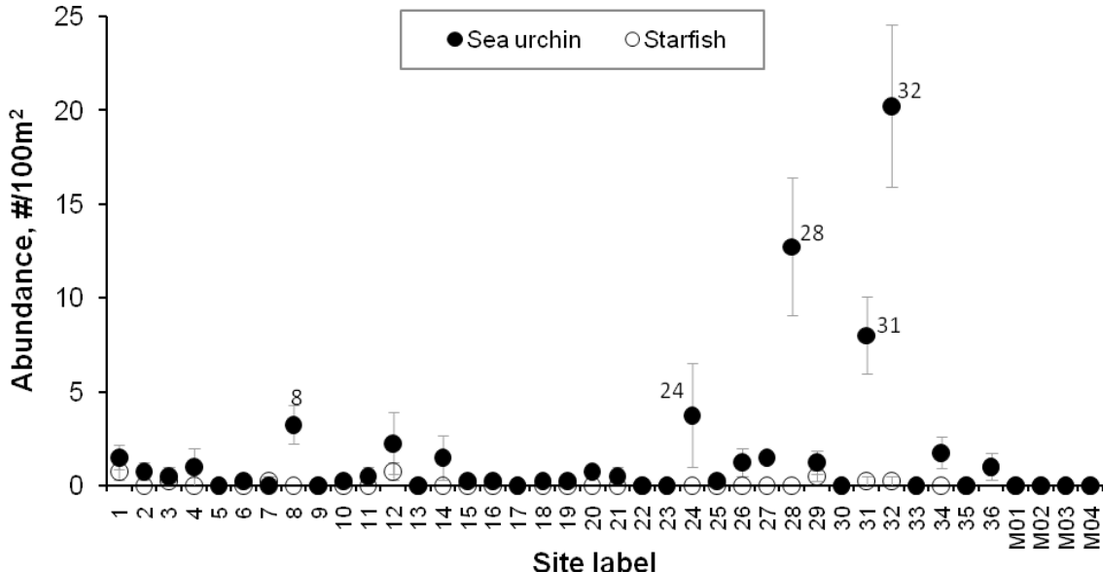


Figure 32: *Density plot of sea urchins (combined species) and starfish across sites.*

Acanthaster planci

Crown of thorn (COT) starfish (*Acanthaster planci*) were rarely seen, an average abundance of 0.12 adults/100m^2 was recorded across all sites (with one site, number 23, excluded: see below). This starfish feeds exclusively on coral, leaving a characteristic white scar on coral skeleton (IUCN 2004). Their densities are naturally low except when there is a population outbreak: this has been defined as an active outbreak at densities of over ~0.3 adults/100m^2; or an incipient outbreak of over ~0.3 adults and subadults/100m^2 (IUCN 2004). Only one site, Talla Talla Kebir (site 23) had a high density, of 11/100m^2, which is clearly an active outbreak. This site was excluded from the calculation of the average across all sites (0.12 adults/100m^2, above). The number of COT feeding scars at this site was also high (8 scars/100m^2). The second highest density was 2.5/100m^2 at Suakin South (Site 33) which is close to an incipient outbreak, again with an associated high level of feeding scars (11 scars/100m^2).

Drupella

Drupella cornus is a small gastropod corallivore that can cause extensive damage to coral reefs when it occurs in plague numbers, as seen in Western Australia (Ayling & Ayling 1987). The overall average density of *Drupella* recorded on the survey was 0.01 individuals/100m^2 which is very low, and they were only counted at two sites along the coast. This is no cause for concern.

3.3.2.2 EXPLOITED INVERTEBRATES

Exploited groups of macro-invertebrates included molluscs, such as *Trochus* and *Lambis,* lobster and sea cucumbers. These species are further discussed in the Rapid Fishery Survey (Section 3.4).

Molluscs (shells)

No *Trochus* were counted in any of the 40 sites. Only one *Trochus* gastropod was seen in the entire survey: on a quick site at Sha'ab Anbar. This may in part reflect the fact that the surveys targeted reef slope and not *Trochus* habitat, which is reef flat or reef crest. Nevertheless the lack of numbers is worrying and strongly suggests that this fishery is overexploited. Similarly, no *Murex* were found, and *Strombus* conch shells and *Lambis* spider shells were extremely rare (Table 16). The data were examined for depth correlations to see if they were more abundant in shallow sites. Kruskal-Wallis rank tests revealed no significant difference in abundance of these taxa between depth classes. Similarly Chi Square tests of association revealed no significant association of *Lambis* and clam densities with depth classes. However, density-depth class plots illustrate a slightly higher density of *Lambis* in the 8-10m depth class (Figure 33) which suggests that our

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surveys should capture these taxa. *Murex* spp., the rock shells, of which the large *Chicoreus ramosus* is the most conspicuous, were rarely seen in middens and were not counted once in the surveys (Table 16).

Table 16: *Average density of key mollusc species across the entire survey.*

Species	Average density (No./ 100m2)
Trochus	0.0
Lambis	0.1
Strombus	0.006
Murex/Chicoreus ramosus	0.0
Tridacna	2.36

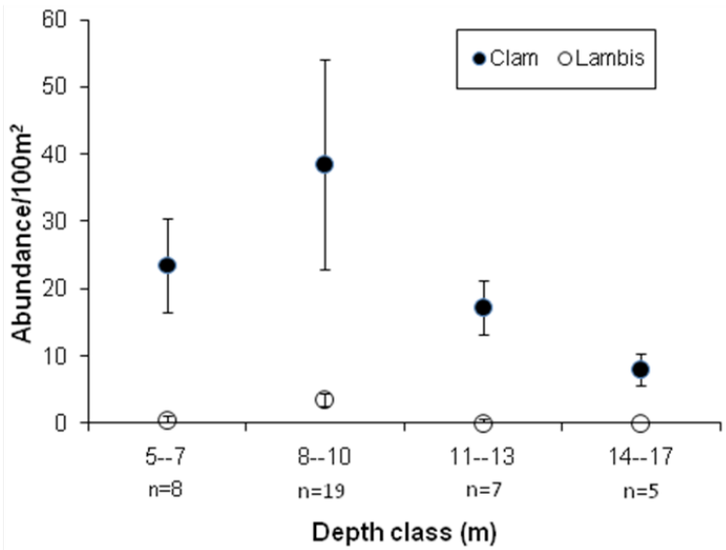


Figure 33: *Densities of* Lambis *and clams plotted against class depth. Error bars are the standard error of the means.*

The only molluscs seen in any numbers were the clams: *Tridacna* spp. at 2.36/100m^2. They also appeared to be more abundant at the 8-10m depth range (Figure 33) which corresponded with our survey sites. *Tridacna* were found in small numbers at middens on the islands, and at the mainland fishing camp at Marsa Salak. They are apparently considered to have medicinal properties and are harvested for this purpose and not as a general food item. They were not seen in the Port Sudan market.

In general all molluscs were rare and very few other species were counted in the surveys. Only two species were noted, both observed during quick sites at Marsa Sheik Ibrahim in the lagoon, not on a detailed survey site. Tiny gastropods, similar to *Nodolittorina natalensis* or *Clypeomorus* sp. (Richmond 1997), ~ 0.7cm in size, were seen piled up in large numbers in the clear water part of the lagoon near the reef edge on sand and also in seagrass. Many small *Strombus* sp., similar to *gibberulus* but more distinctly banded, 4cm in size, were also observed at Marsa Sheik Ibrahim.

Lobster

Lobsters (*Palinura* spp.) were not observed on any of the detailed sites or the quick sites. They are, however, nocturnal and therefore difficult to see during the day. They were observed in large numbers by the survey

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boat crew at Talla Talla Saqir on the reef flat at night. Apparently in Sudan there is a belief that if a fisherman goes hunting for lobster he will go mad, and they are therefore avoided. They were also not seen in the Port Sudan market.

Sea cucumbers

Very few sea cucumbers (holothurians) were seen throughout the survey. The species observed and the average density by value category of species are given in Table 17. A total of eight species were recorded; by comparison, a total of 22 species were recently recorded in Kenya (Muthiga and Ndirangu 2000). Although Red Sea diversity will be lower, 8 species in total is very low. These results suggest that some species have been fished out. If sea cucumber densities are combined an overall average of 0.05 individuals/100m^2 was recorded in Sudan.

Table 17: *Species list of sea cucumbers observed throughout the survey, and average density counted for each commercial fishery group during the detailed site surveys.*

Species observed / whole survey	Fishery value	Average density individuals / 100m2
Holothuria fuscogilva	High	0.025
Holothuria nobilis		
Holothuria atra	Low	0.019
Holothuria edulis		
Actinopyga mauritania		
Actinopyga miliaris		
Thelenota ananas		
Pearsonothuria graeffei	No commercial value	0.006

3.3.2.3 DISCUSSION OF MACRO-INVERTEBRATES

The abundance of key mobile macro-invertebrates, and particularly exploited species, throughout the surveyed areas was generally low. Even the sea urchins and starfish, usually common taxa on coral reefs, were found in very low numbers. Species richness was also low with few species observed.

This almost widespread disappearance of sea urchins was unexpected, puzzling and of concern. Sea urchins are important herbivores on reefs as they keep the levels of turf algae down. High turf algae can preclude the healthy settlement of coral larvae.

The densities of urchins found on the reefs surveyed in Sudan are very low compared with densities of between 8-25 urchins/100m^2 on healthy coral reefs in East Africa (Othina & Samoilys 2005). The causes and significance of the very low abundance of sea urchins throughout almost all of the survey area is unclear. Sea urchins are a key component of most coral reef ecosystems, being grazers that play an important role in controlling the growth of algae, thus maintaining a balance between algae and corals. The importance of these animals to coral reef ecosystems was illustrated in the Caribbean and tropical western Atlantic in the 1980s, when a pathogen killed up to 99% of *Diadema* in some areas. In places where overfishing had reduced the abundance of herbivorous fishes, the resulting overgrowth of large algae caused massive coral mortality, with little subsequent recovery and substantial consequent loss of biodiversity and reef structure (Hughes 1994; Lessios 1995).

Historical data on distribution and density of sea urchins in the Red Sea, especially of the important species *Diadema setosum*, is limited. Abundances may, however, be naturally low on some of the offshore

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deep water reefs, such as Sanganeb, as the absence of this species has been a repeatedly noted feature (Schuhmacher 1974, 1989; Kroll, in Schuhmacher *et al.* 1995). The same authors did, however, note that *Diadema* "is abundant in the northern Red Sea, where it plays a major role in controlling reef development".

The low numbers on the great majority of Red Sea reefs are confirmed by data collected by the Reef Check programme (Hodgson & Liebeler 2002) which recorded a significant fall in abundance of *Diadema* on coral reefs of the Indo-Pacific, including the Red Sea, between 1998 and 2001. The survey team involved in the 2007 survey included a number of scientists very experienced in survey work throughout the Red Sea region, as well as the wider Indo-Pacific and all these surveyors noted, even before data were analysed, that the abundance of *Diadema*, as well as other sea urchin taxa such as *Echinometra*, was exceptionally low.

Currently the causes and likely significance of the absence of *Diadema* from most of the reefs of Sudan remain unclear, but the situation is a cause for concern and needs to be monitored.

COT outbreaks can cause significant coral mortality, and were reported in the early 1990s in the Red Sea, from Egypt in Ras Mohammed Park and a massive outbreak off eastern Sinai (Zann in McClanahan 2000). The survey results from Sudan indicate that there is no need for concern at present since only two outbreaks were recorded and these were localised. However, the possibility of new outbreaks occurring means that COT surveys should be included in regular monitoring of Sudan's reefs, particularly in the Marine Parks, to keep a check on this potentially devastating corallivore.

For exploited groups of gastropod molluscs (*Lambis*, *Strombus* and *Trochus*) the results strongly suggest that exploitation levels are very high. By comparison, the combined density of these large molluscs on reefs protected from fishing in East Africa was 0.6 to 2.2/100m^2 (Othina & Samoilys 2005), which is almost 30 times higher than the combined density (0.05/100m^2) recorded in Sudan. The low densities in Sudan will in part reflect the habitat of the surveys: these molluscs tend to live on reef flats, in lagoons and in seagrass beds (Richmond 1997) which we did not survey quantitatively.

At every fisher camp observed on the mainland coast, large numbers of the shells of *Lambis* and *Strombus* were seen in the common and widespread middens, some of which were extremely large. Fishers harvest the operculum which is ground to make perfume, sold both locally and also exported; the meat is also eaten. The lack of *Trochus* numbers counted at survey sites is worrying, and strongly suggests this fishery is also heavily over-exploited. *Murex* spp., the rock shells, of which the large *Chicoreus ramosus* is the most conspicuous, were rarely seen in middens. However, they were also not counted once in the surveys, possibly because quantitative surveys of their usual reef-top and soft sediment habitats were not carried out.

Sea cucumber densities were more than an order of magnitude lower than those found on reefs in Tanzania, where densities range from 0.6 to 0.5 individuals/100m^2 on fished reefs and 1.6 to 2.6/100m^{2}on unfished reefs (Othina & Samoilys 2005) and between 0.35 and 7 individuals/100m^2 in Kenya (Muthiga & Ndirangu 2000). These comparisons strongly suggest severe overfishing of sea cucumbers in Sudan. Further results on the sea-cucumber fishery are presented in section 3.4 below.

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(a)



(b)



(c)



(d)



(e)



(f)

Plate 15: *Photographs showing 6 of the macro-invertebrates observed on the reefs of Sudan, including the sea urchins* **(a)** Diadema setosum *and* **(b)** Echinometra mathae, **(c)** *the cushion starfish* Asterodiscides *sp., and two starfish from the family* Ophidiasteridae: **(d)** Fromia *sp. and* **(e)** *the distinctive* Gomophia egyptiaca *and* **(f)** *a basket starfish.*

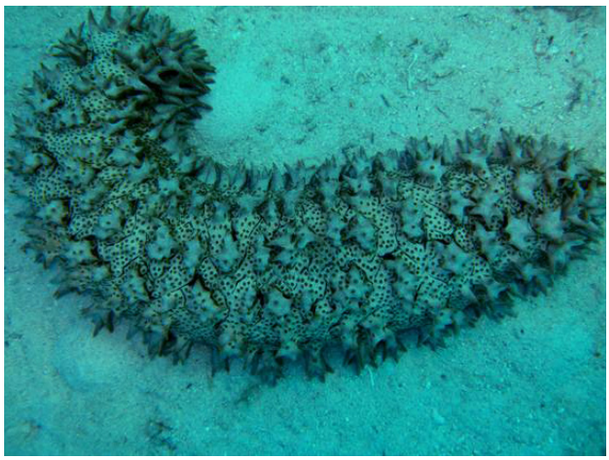
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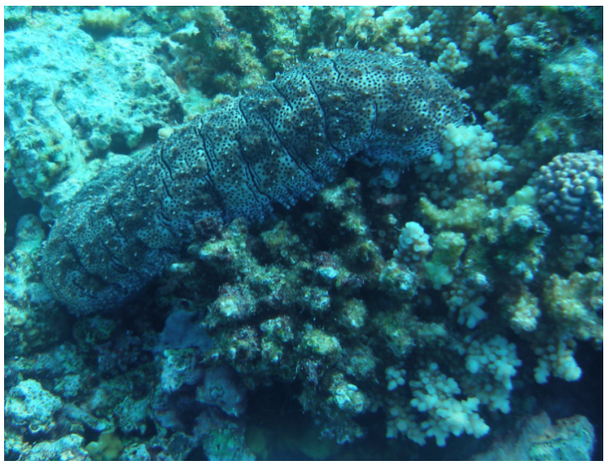
(a)



(b)



(c)



(d)

Plate 16: *Photographs showing 4 of the sea cucumbers observed on the reefs of Sudan including* **(a)** *the commercially highly valuable, and distinctive,* Holothuria nobilis, **(b)** *the moderately valuable* Holothuria atra, *showing its typical sand covered appearance,* **(c)** *the unusual* Thelenota ananas *and* **(d)** *the well camouflaged, typically reef dwelling,* Pearsonothuria graeffei.

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3.3.3 Reef Fish

Related to the IOC Handbook Ecological Indicators E1, E2 & E5 (Table 1)

By Jeremy Kemp

3.3.3.1 REEF FISH COMMUNITY STRUCTURE AND DIVERSITY

Fish communities characteristic of both the north-central Red Sea and the southern Red Sea occur in Sudan. The line dividing them lies to the south of Port Sudan, but is a gradual transition over a distance of several tens of kilometres, possibly 100km or more. All sites surveyed to the north of Port Sudan are home to fish communities characteristic of the central or northern Red Sea, while to the south of Port Sudan the picture is less clear. There is a tendency for inshore sites to be more closely related to southern Red Sea sites, but offshore sites, particularly at reefs between Port Sudan and Suakin, show a mixture of relationships, with some central and some southern Red Sea communities.

The fish community inside the extensive, shallow and turbid lagoon at Shubuk shows the strongest affinity with the fish communities of Eritrea and Yemen. This is probably a result of environmental conditions there being similar to those prevailing 100km and more to the south. This finding mirrors the findings of earlier surveys at Dungonab in the north (in 2001) which identified characteristically southern Red Sea fish communities in the shallow turbid waters of Dungonab Bay, and northern and central Red Sea communities outside the bay.

The overall species richness of the six non-fisheries indicator families shows no clear geographical pattern across the survey area, although there was some substitution of species with, for example, the typically southern Red Sea butterflyfish *Chaetodon larvatus* replacing the northern and central Red Sea species *C. austriacus* at many of the southern survey sites, particularly those closer inshore.

Species Richness

Figure 34 summarises the species richness of six families of coral reef fishes at all detailed survey sites. A total of 86 species were recorded in these families throughout the survey, and species richness per site varied from 24 to 48 (mean = 36.3). A cluster analysis of this presence-absence data (Figure 35) reveals a north–south divergence in species composition of fish communities, occuring at approximately the latitude of Port Sudan. This is also reflected in the community structure (including abundance counts) of butterflyfishes (Figure 36).

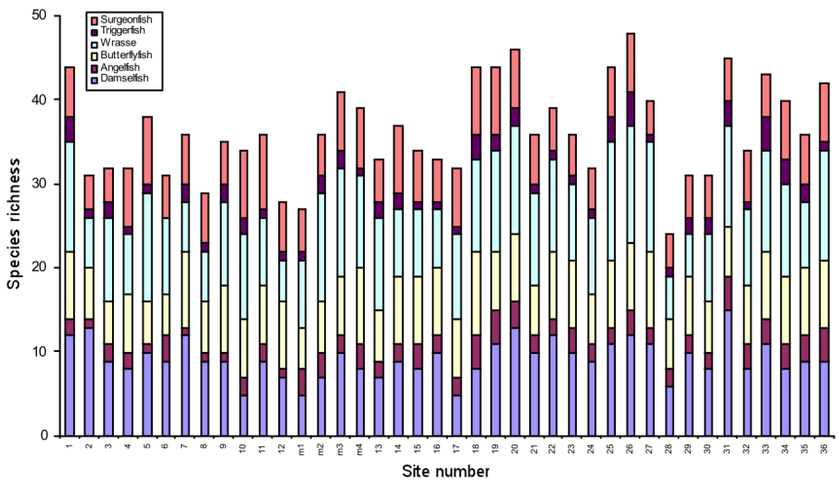


Figure 34: *Summary of species richness of six indicator families of reef fishes at all detailed survey sites. Species richness varies from 24 to 48 (mean 36.3 +/- 5.7) but there is no statistically significant trend in overall species richness between north (left side of the chart) and south (right hand side).*

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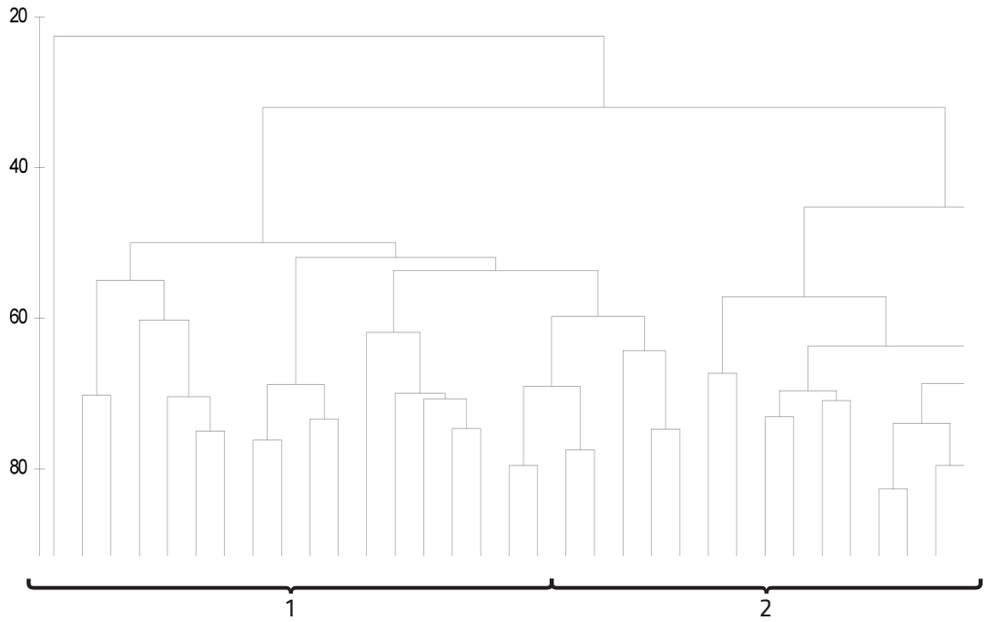


Figure 35: *Cluster analysis of presence–absence data of 86 species in six families (Bray-Curtis similarity, complete linkage). A division between the two main clusters (1 and 2) lies to the south of Port Sudan. Sites 14–18 (located at deep water offshore reefs to the ESE of Port Sudan) mostly fall into the northern group. The out-group in this analysis is Site 28, located in the semi-enclosed, shallow and turbid lagoon at Shubuk.*

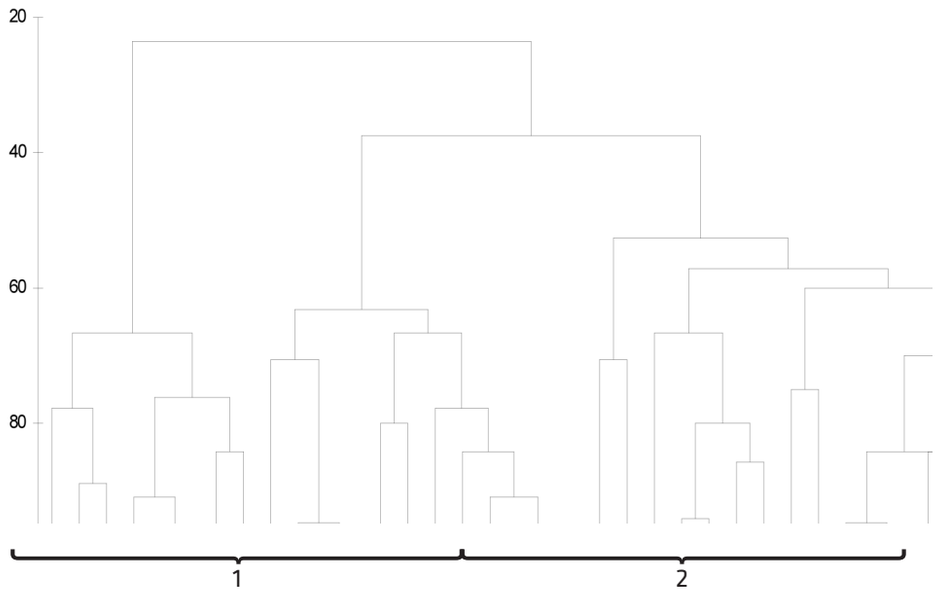


Figure 36: *Butterflyfishes and angelfishes: cluster analysis of abundance data (square root transformed, Bray Curtis similarity). Sites to the north of Port Sudan are largely confined to Cluster 2, and those to the south to Cluster 1. In this analysis Site 28 (the outgroup in the 6-family analysis) is subsumed within a sub-cluster consisting of inshore sites close to or south of Suakin.*

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Regional Context

A regional level analysis, including data from the entire Red Sea region[4], reveals that the north-south divergence within Sudan is consistent with larger scale patterns throughout the Red Sea (Figure 37). This analysis was carried out on species presence-absence data only, because of differences between data collection methods in different surveys. Sites in Sudan north of Port Sudan, and on deep water reefs in the vicinity of Port Sudan, tend to cluster with central and northern Red Sea communities in Saudi Arabia and Egypt. Sites close inshore in the area of Suakin and Shubuk cluster with southern Red Sea sites in Eritrea and Yemen.

Geographic patterns in fish species abundance are also apparent, for both biodiversity indicator groups and fisheries species.

Other Geographic Patterns

Patterns in the abundance of (non-fisheries) fish species distribution are also revealing. In particular, the abundance of obligate corallivores (fishes that are entirely dependent upon the presence of living hard corals for their food) shows a strongly negative and statistically highly significant correlation with latitude (i.e. their abundance is higher in the south and lower in the north). This matches the patterns of live coral cover noted during the survey. There is a similar relationship between trophic generalist butterflyfishes and latitude, although that relationship is not significant at the 5% level.

The apparent north-south trends in abundance of butterflyfishes (Figure 38 and Figure 39) giving a statistically significant negative relationship between abundance and latitude (r_s -0.5642, $p < 0.001$) among obligate coral feeders, was not matched among ecological generalists, nor by angelfishes. Nor are they matched by any trends in species richness of any of the other non-fisheries fish families surveyed (wrasse, damselfish, surgeonfish and triggerfish). This pattern is probably explained by the distribution of areas of high and low hard coral cover. Figure 40a illustrates the relationship between live hard coral cover and abundance of coral-dependent butterflyfishes (r_s=0.6734, $p<0.001$). The relationship between hard coral cover and trophic generalists is also positive, but non-significant (Figure 40b, r_s = 0.4414, p = 0.07).

3.3.3.2 DISCUSSION OF REEF FISHES

The patterns in reef fish distribution have implications for the design of national conservation and sustainable development strategies, particularly the development of a national network of Marine Parks and marine management areas. Currently, the two existing marine parks, at Dungonab and Sanganeb, are both in the biogeographically distinctive north-central Red Sea. There is no representation of the southern Red Sea biota, nor of the important ecotone, or transition zone, in any protected area or environmental management strategy.

[4] Unpublished data collected by J. Kemp, 1996–2005, in Yemen, Eritrea, Saudi Arabia and Egypt.

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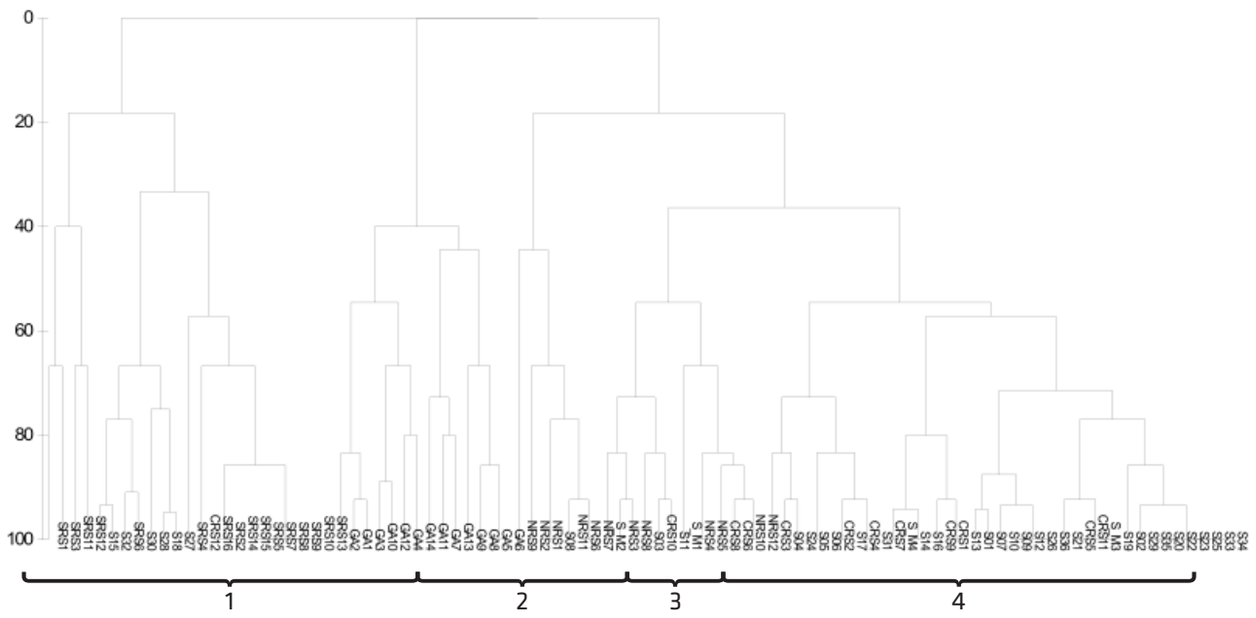


Figure 37: *Regional associations of butterflyfish communities at Sudan survey sites, as revealed by cluster analysis of butterflyfish assemblages from throughout the Red Sea and Gulf of Aden (presence-absence, Bray-Curtis similarity). GA = Gulf of Aden; SRS = Southern Red Sea (Massawa, Eritrea and Kamaran Islands, Yemen); CRS = Central Red Sea (Yanbu – Rabigh, Saudi Arabia); NRS = Northern Red Sea (Sinai, Egypt). All non-Sudan data collected by J. Kemp, 1996–2005. Cluster 1 is dominated by southern Red Sea sites, with six survey sites from the Suakin – Shubuk area of Sudan (15, 18, 27, 28, 30, 32).* **Cluster 2** *is entirely in the eastern Gulf of Aden sites, included as a geographical outgroup.* **Cluster 3** *consists of seven sites, six of which are from the northern Red Sea and one from Sudan (S8).* **Cluster 4** *consists of central Red Sea sites and several northern Red Sea sites, and includes sites from throughout the Sudan survey area, but excludes inshore sites south of Port Sudan.*

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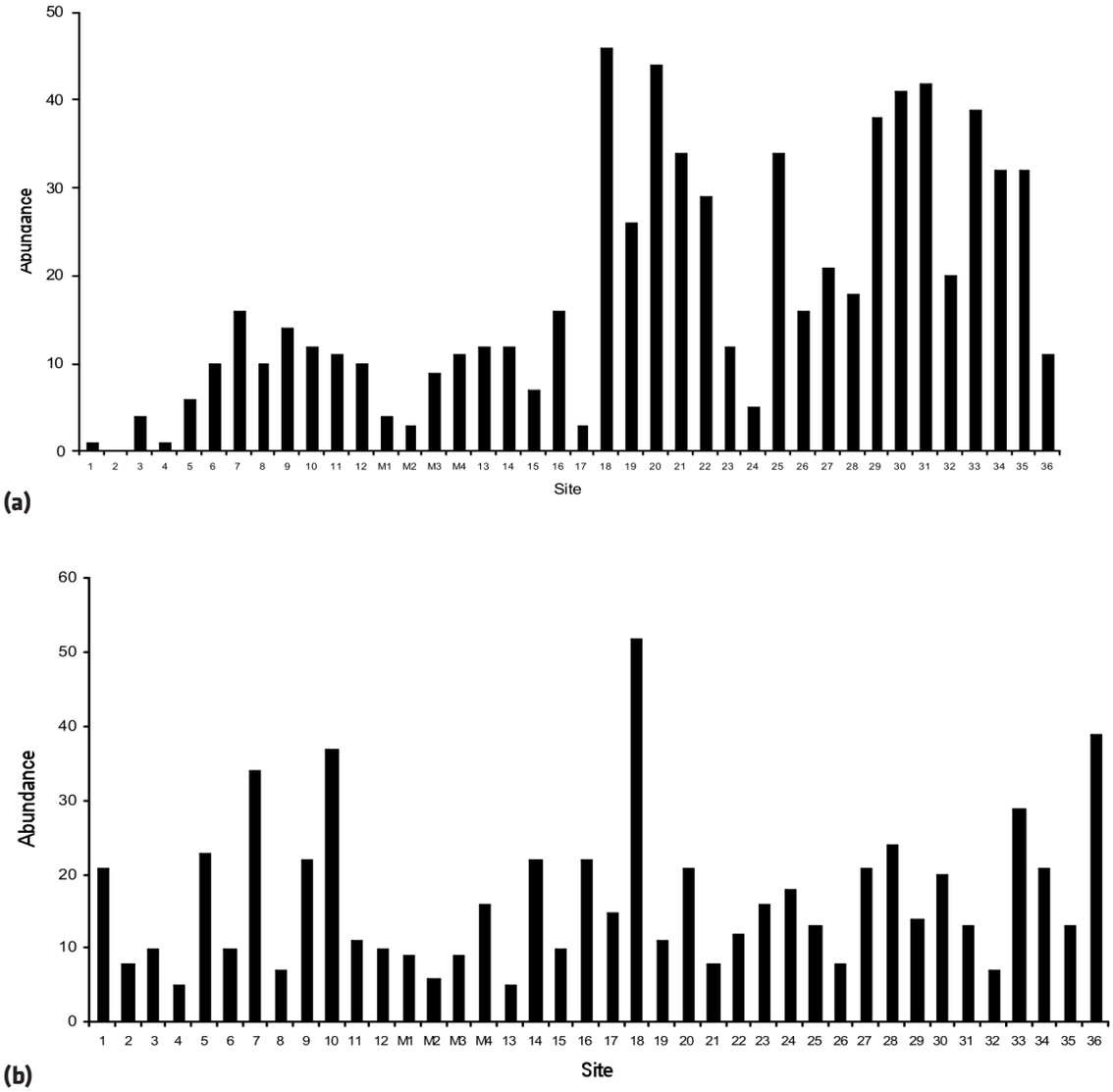
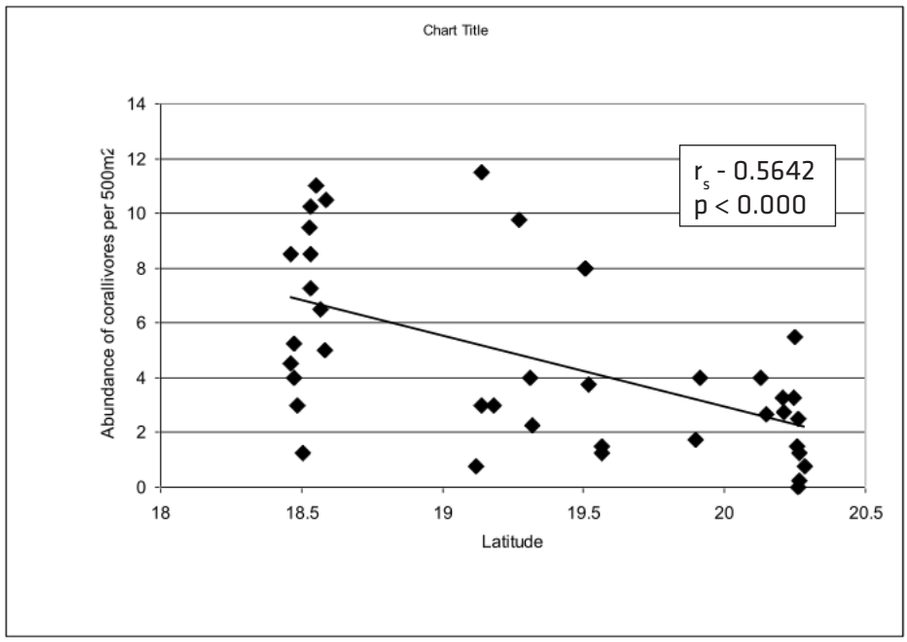
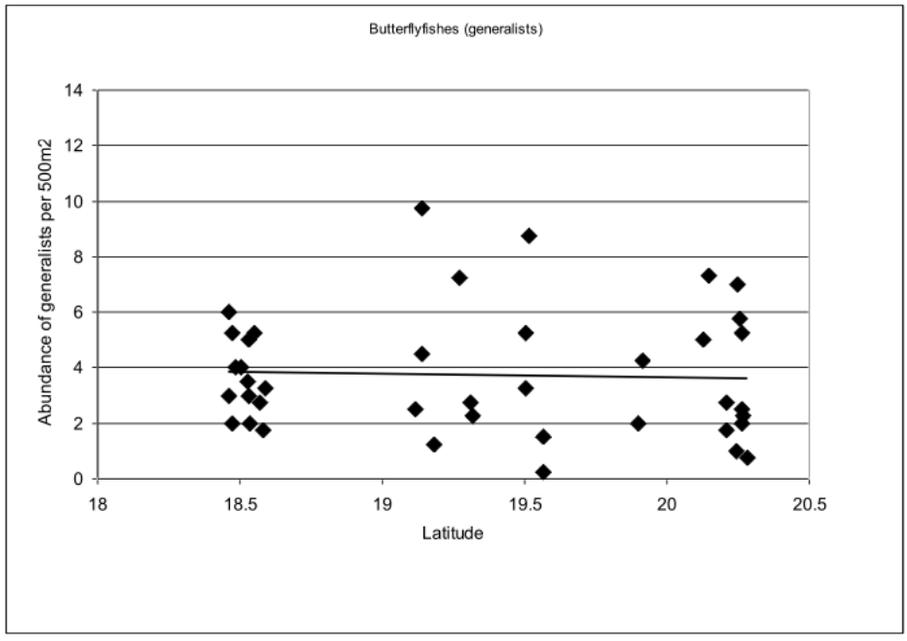


Figure 38: *Abundance per transect of* **(a)** *obligate corallivore butterflyfishes and* **(b)** *generalist butterflyfishes at detailed survey sites. In both charts north is on the left and south on the right hand side. The almost complete absence of corallivorous butterflyfishes at Sites 1 and 2 (heavily bleaching-impacted inshore sites at the northern edge of the survey area) is conspicuous, as is the relatively high abundance of corallivores at sites 19–36, to the south of Port Sudan.*

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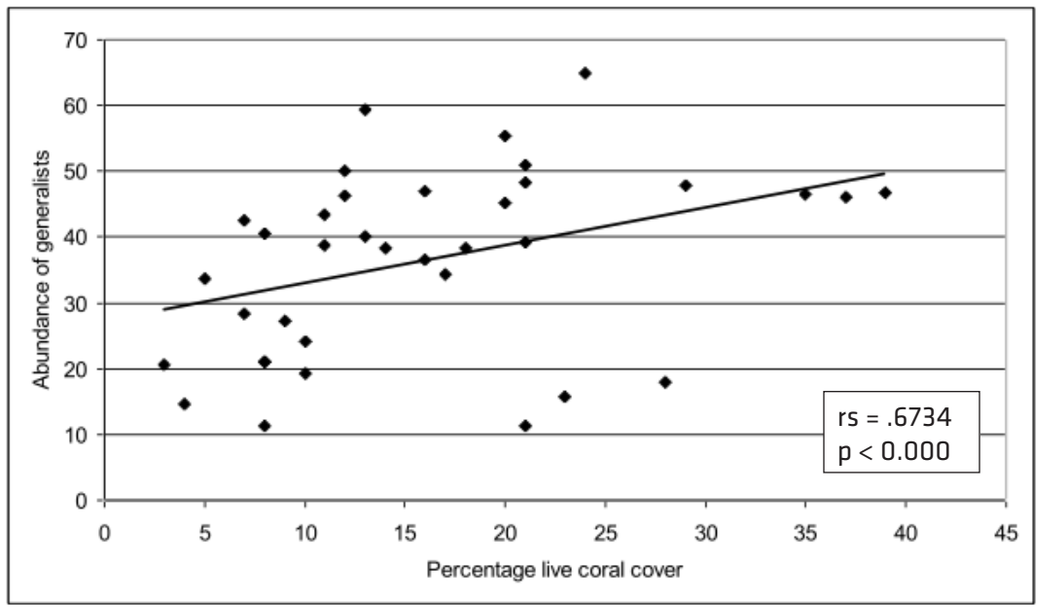
(a)



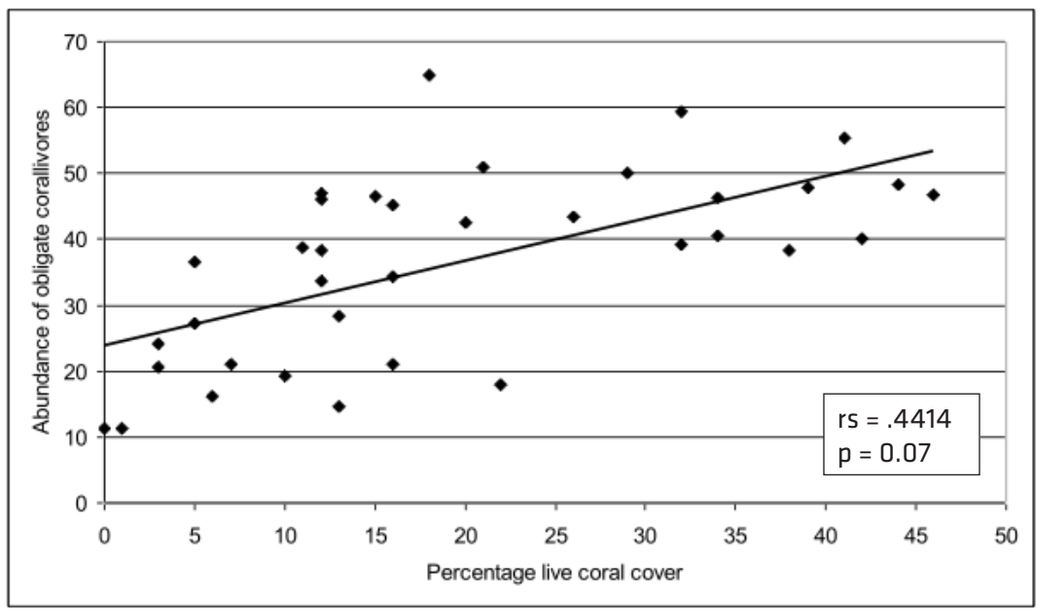
(b)

Figure 39: *Plot of abundances of butterflyfishes against latitude. (a) Plot of abundance of obligate corallivore butterflyfishes against latitude. The correlation between the two is strongly and significantly negative.* **(b)** *Abundance of generalist butterflyfishes against latitude, showing no statistically significant relationship.*

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(a)



(b)

Figure 40: *Shows (a) Abundance of obligate corallivore butterflyfishes plotted against hard coral cover, and (b) Abundance of generalist butterflyfishes against hard coral cover.*

3.3.4 Exploited Fin-Fish

Related to the IOC Handbook Socioeconomic Indicator SE 5 (Table 3)

By Melita Samoilys

The abundance of the five taxa (sweetlip, snapper, emperor, grouper, parrotfish) representing key fishery species was generally low throughout the 40 sites surveyed (see Annex 3) with an average total abundance for these taxa combined of 20 fish per 100m^2. Patterns in the distribution of these densities were analysed

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to try to understand (a) the reasons for the low densities of exploited species and (b) which areas are of most concern. Some of these species are further discussed in the Rapid Fishery Survey (Section 3.3.5).

Patterns in the distribution and abundance of these taxa were highly variable along the coast. Because the densities were so low and variable the statistical power to detect differences and thus to explain the patterns is low. Nevertheless, some patterns have emerged. Differences in density in relation to substrate type were found for parrot fishes (scarids), both the smaller species (less than 20cm TL) and the larger species (more than 20cm TL), snappers (lutjanids) and emperors (lethrinids) (Table 18). However, substrate did not explain a lot of the observed variation in fish abundance overall (R^2 values in all cases were below 50%, Table 18).



(a)



(b)



(c)



(d)

Plate 17: *Groupers* **(a)** Cephalopholis miniata *and* **(b)** *Najil* (Plectropomus pessuliferus); **(c)** *Emperor Angel fish* (Pomacanthus imperator) *and* **(d)** *Yellow Trevally* (Gnathodon speciosus).

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Table 18: *Stepwise multiple regression for fisheries taxa and benthic substrate showing direction of influence (t ratio) and significance levels (Prob) for whole model and for each variable. Only significant results (p<0.05) are shown, and those discussed are shown in bold type.*

Whole model								
Fish group	**Fish taxa**	**Model Variables**	**t Ratio**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**R Squared**
Snapper	**Small Snappers**	**small blocks**	**2.6**	**6.4**	**0.02**	**2.9**	**0.04**	**0.25**
		sponge	1.9	3.6	0.07			
		soft coral	-1.7	2.9	ns			
		dead coral	-1.3	1.8	ns			
	Large Snappers	small blocks	2.4	5.8	0.02	5.3	0.00	0.45
		calcareous algae	2.4	5.6	0.02			
		dead coral	2.0	4.0	0.05			
		sand	-1.3	1.8	ns			
		macro-algae	-1.4	2.0	ns			
Emperors	***Lethrinus***	**rubble**	**2.1**	**4.5**	**0.04**	**3.0**	**0.03**	**0.26**
		Large blocks	2.0	4.0	0.05			
		turf algae	1.4	2.0	ns			
		sponge	1.5	1.4	ns			
	Monotaxis	calcareous algae	3.3	10.5	0.003	5.8	0.01	0.24
		macro-algae	-1.4	2.0	ns			
Grouper	*Cephalopholis*	small blocks	2.6	6.7	0.014	3.4	0.04	0.16
		hard substrate(%)	1.4	2.0	ns			
	A. rogaa	macro-algae	2.3	5.2	0.028	3.6	0.04	0.17
		rubble	-1.6	2.6	ns			
	Epinephelus	bare surface	2.2	4.9	0.03	2.7	0.04	0.29
		hard substrate(%)	1.1	1.2	ns			
		sand	-1.4	2.0	ns			
		turf algae	-1.7	2.7	ns			
		macro-algae	-1.3	1.6	ns			
Parrotfish	**Parrotfish>20**	**rubble**	**1.9**	**3.4**	**0.07**	**3.4**	**0.01**	**0.24**
		soft coral	-2.6	6.9	0.01			
		calcareous algae	3.2	10.4	0.00			
		macro-algae	-1.8	3.4	0.08			
		sponge	-1.4	1.8	ns			
	Parrotfish<20	**dead coral**	**2.7**	**6.2**	**0.01**	**4.6**	**0.01**	**0.28**
		hard substrate(%)	-2.2	6.1	0.04			
		macro-algae	1.4	1.7	ns			
	All Parrotfish	**calcareous algae**	**6.5**	**2.5**	**0.02**	**3.1**	**0.02**	**0.37**
		dead coral	1.9	3.7	ns			
		sand	1.6	2.5	ns			
		soft coral	-1.7	2.6	ns			
		sponge	-1.8	3.2	ns			
		rubble	1.33	1.8	ns			
Wrasse	**Napol. Wrasse**	**calcareous algae**	**4.1**	**16.7**	**0.00**	**4.8**	**0.00**	**0.36**
		macro-algae	-1.5	2.2	ns			
		hard coral	1.2	1.3	ns			
		sand	-1.4	1.9	ns			
Total Fish		calcareous algae	2.5	6.4	0.02	6.4	0.00	0.35
		soft coral	-2.1	4.5	0.04			
		small blocks	2.0	4.1	0.05			

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3.3.4.1 PARROT FISHES

The abundance of parrot fishes was low, with an overall (small and large species combined) average abundance of only 4 fish/100m^2 and on some reefs parrot fishes were either absent or present only at 2 fishes/100m^2 (Figure 41).

The substrate variables that explained the variation in abundance of parrot fishes were dead coral and hard substrate, which contributed significantly to the distribution of small parrot fish species, while calcareous algae, rubble and soft coral were the significant contributors to the large species of parrot fishes (Table 18).

When all species of parrot fish were combined, the model explained 37% of the variation ($p<0.04$), with calcareous algae contributing significantly to the abundance pattern of these species (Table 18).

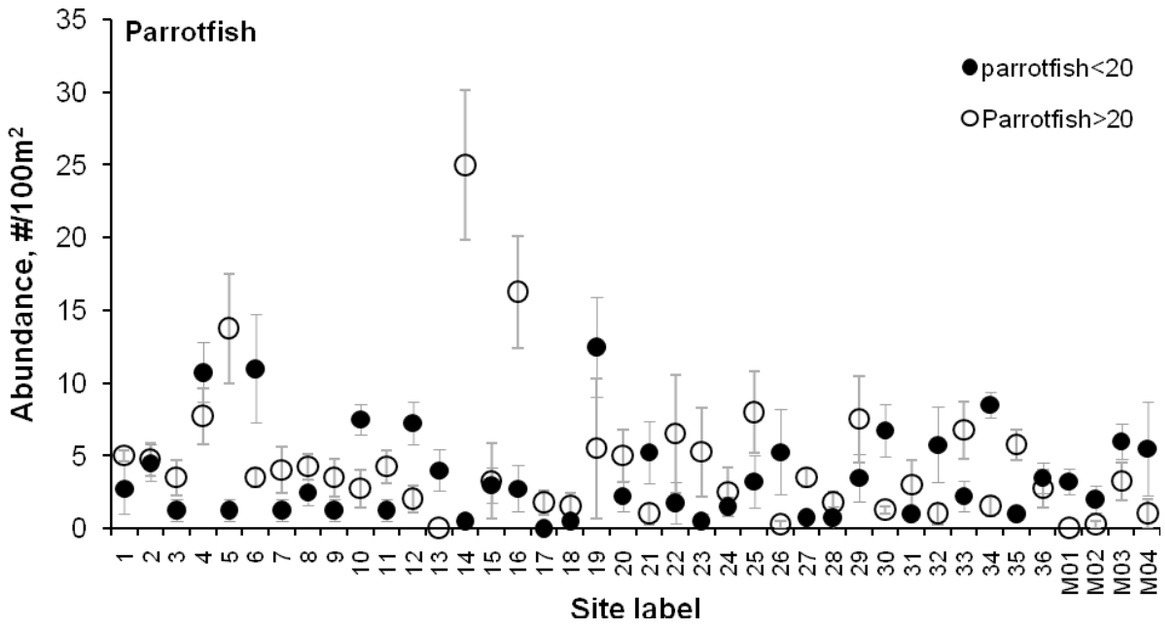


Figure 41: *Density plot of parrot fishes, both small species (<20cm TL) and large species (>20cm TL) for each site on the Sudanese coast.*

3.3.4.2 SNAPPERS

The overall abundance of snappers (Lutjanidae) was also noticeably low. This family comprise a range of species, and were counted in two groups:

- small colourful snappers that are common on coral reefs (e.g. *Lutjanus fulviflamma, L. kasmira, L. ehrenbergi*) and the black snapper (*Macolor niger*); these are generally not targeted in reef fisheries, particularly in handline fisheries. This appeared to be the case on Sudan's coral reefs, although *L. fulviflamma* and *L. kasmira* were observed in the Port Sudan market, and some netting was observed near shallow reefs which may capture these species;
- the larger species that are specifically targeted in the local fisheries (e.g. *L. bohar*).

If small species are not targeted in fisheries their population densities may be used as indicators of reef health and type, whereas the abundance patterns of the large species may reflect fishing pressure. In comparing the density patterns of the two groups across all sites no correlation was found between the densities of large snapper species and small snapper species (Figure 42).

In most sites, large snapper density was low, or even zero, compared to that of the small snappers. Under the fishing pressure hypothesis, sites where small species are abundant and large species are not may represent heavily fished sites. Large differences in small and large snapper densities were seen at Sites 16-18, 24 and 27-28 (Figure 42), suggesting these sites are over exploited.

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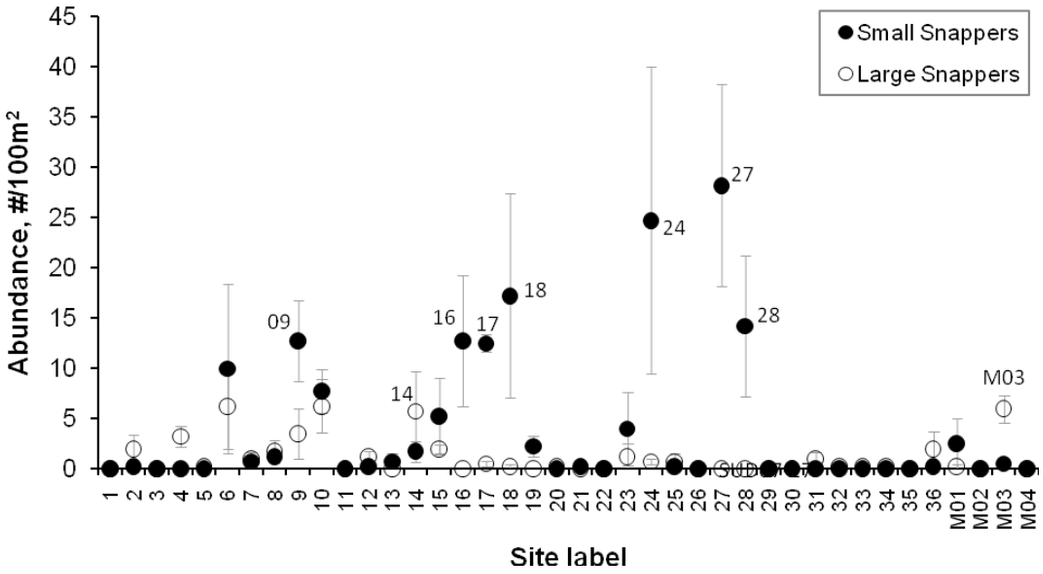


Figure 42: *Density per site for small and large species of snappers.*

Further analysis confirmed a significant difference in the densities of large snapper species and small snapper species (matched pair analysis: t= -2.5, p=0.009). Figure 43 illustrates the mean difference (and 95% confidence lines), and illustrates the sites where these significant differences lie. Sites that fall in the Small>Large region of the graph have significantly more small snapper species than large snapper species and vice versa.

Sites in the upper portion of the graph (Figure 43), MO3 (Towaritit near Port Sudan) and 14 (Sha'ab Anbar, Suakin archipelago) have significantly higher populations of large snappers, suggesting these sites are not fished or lightly fished. Certainly the abundance of the target species *L. bohar* was high at Towaritit, and apparently this reef is avoided by fishers because of security issues because it is near Port Sudan.

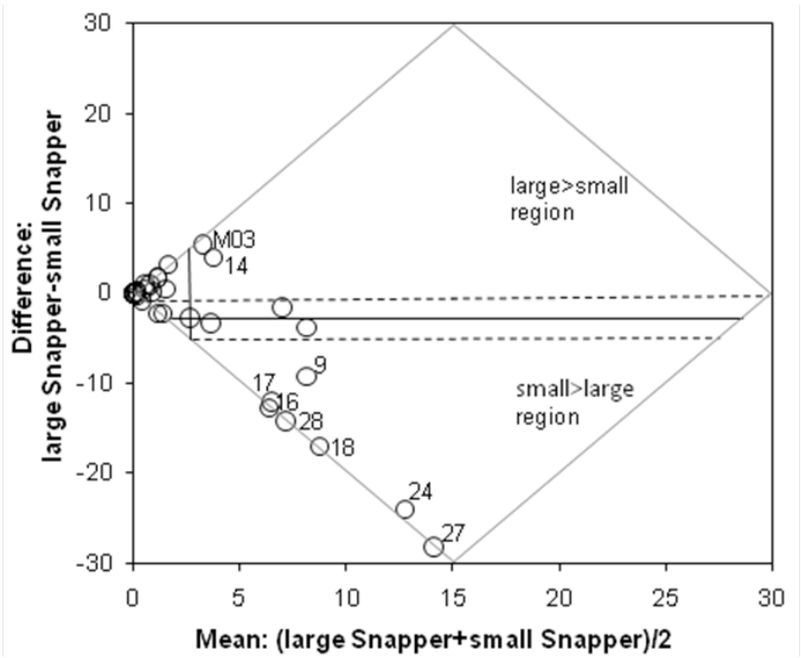


Figure 43: *A plot of the difference in density between large and small snappers on the y-axis, and the mean of the densities of large and small snappers on the x-axis. Mean line, and 95% confidence lines are shown. Sites where densities differ significantly are labelled.*

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3.3.4.3 EMPERORS

Four species of *Lethrinus* emperors are listed as targeted in Sudan's coastal handline fishery (Farah 1999) and this was confirmed in the fish market survey in Port Sudan (see Section 3.3.5 below). All were included in the surveys of this taxa group, and represent, along with large snappers and groupers, a high level trophic group of fishes, highly valued in reef fisheries. The other emperor surveyed was *Monotaxis grandoculis*, which is less targeted in the fishery, and if so only incidentally.

The abundance of lethrinid emperors was extremely low (Figure 44) with an average density of only 0.58 fishes/100m^2. At the majority of sites these emperors were absent all together (Figure 44). Rubble was the most significant substrate variable that affected lethrinid densities positively, explaining 26% of the variation in the density of lethrinids along the Sudanese coast (Table 18). It is hard to explain why lethrinid densities might be related to rubble. Since the relationship is not strong at 26%, it is not considered particularly useful in explaining the patterns.

At two sites in the Suakin archipelago lethrinid emperors were abundant: Sha'ab Shubuk (9.25 fishes/100m^2) and Talla Talla Segir (7.25 fishes/100m^2), and to a lesser extent at Marsa Salak in the north (2.75 fishes/100m^2). At Talla Talla Segir schools of *L. lentjan* were seen, and also *L. obsoletus, L. mahsena* and *L. atkinsoni*.

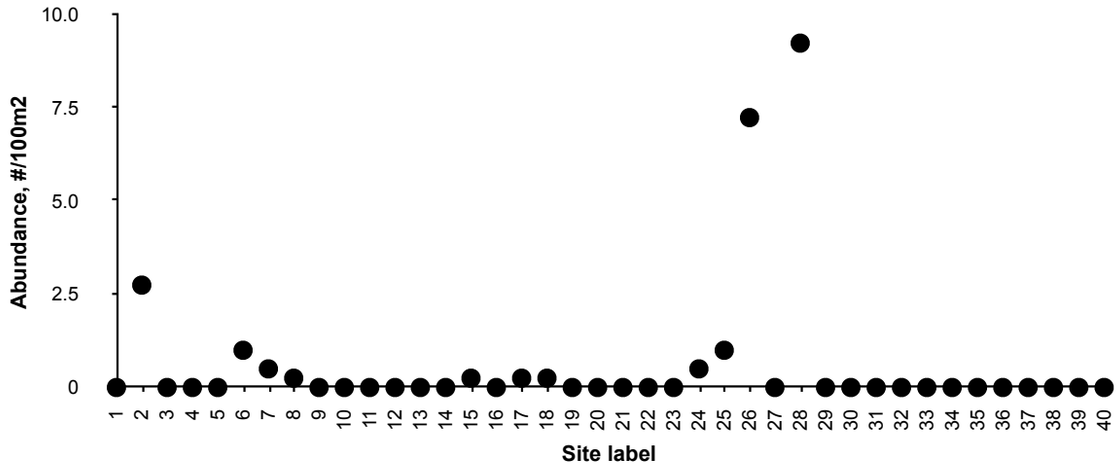


Figure 44: *Density per site for* Lethrinus *species of emperor.*

Lethrinids are known to prey on young sea urchins (IUCN 2004) and this abundance was correlated with *Diadema* sea urchin densities and with all sea urchin densities combined (Table 19, Figure 45). It is clear that the two sites near Suakin are driving this relationship, particularly Site 28 where high densities of sea urchins were recorded, though the relationship is weak, explaining only 11-12% of the variation (r^2 = 0.11/0.12).

High densities of sea urchin predators are considered to play an important role in maintaining low prey densities on reefs (McClanahan *et al. 1995*). The pattern seen in Sudan suggests a different dynamic: the high sea urchin densities were correlated with higher population densities of emperors, perhaps by providing an adequate food supply. However, this is not supported by Site 32, where the greatest densities of sea urchins were recorded but the density of lethrinids was zero. Fish abundance patterns are rarely explained by simple predator-prey relationships, but are invariably complex and multi-factorial. In addition, our analyses are weak because of the very low numbers recorded on this survey.

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Table 19: *Correlations between sea urchins and snappers, emperors and sweet lips, all of which eat juvenile sea urchins.*

Variable	by Variable	Correlation	Signif Prob
Diadema	*Lethrinus*	0.35	0.03
Sea urchin total	*Lethrinus*	0.34	0.03
Echinometra	Sweetlips	0.32	0.04
Echinometra	Small Snappers	0.21	Ns
Echinometra	Invertivore total	0.21	Ns
Diadema	*Monotaxis*	-0.16	Ns
Sea urchin total	*Monotaxis*	-0.16	Ns
Diadema	Large Snappers	-0.12	Ns
Sea urchin total	Large Snappers	-0.12	Ns
Sea urchin total	Sweetlips	0.08	Ns
Echinometra	*Lethrinus*	-0.07	Ns
Diadema	Sweetlips	0.07	Ns
Sea urchin total	Small Snappers	0.07	Ns
Sea urchin total	invertivore total	0.07	Ns
Diadema	Small Snappers	0.06	Ns
Diadema	invertivore total	0.06	Ns
Echinometra	*Monotaxis*	-0.05	Ns
Echinometra	Large Snappers	-0.02	Ns



Plate 18: *School of sweetlips* (Plectorhinchus gaterinus).

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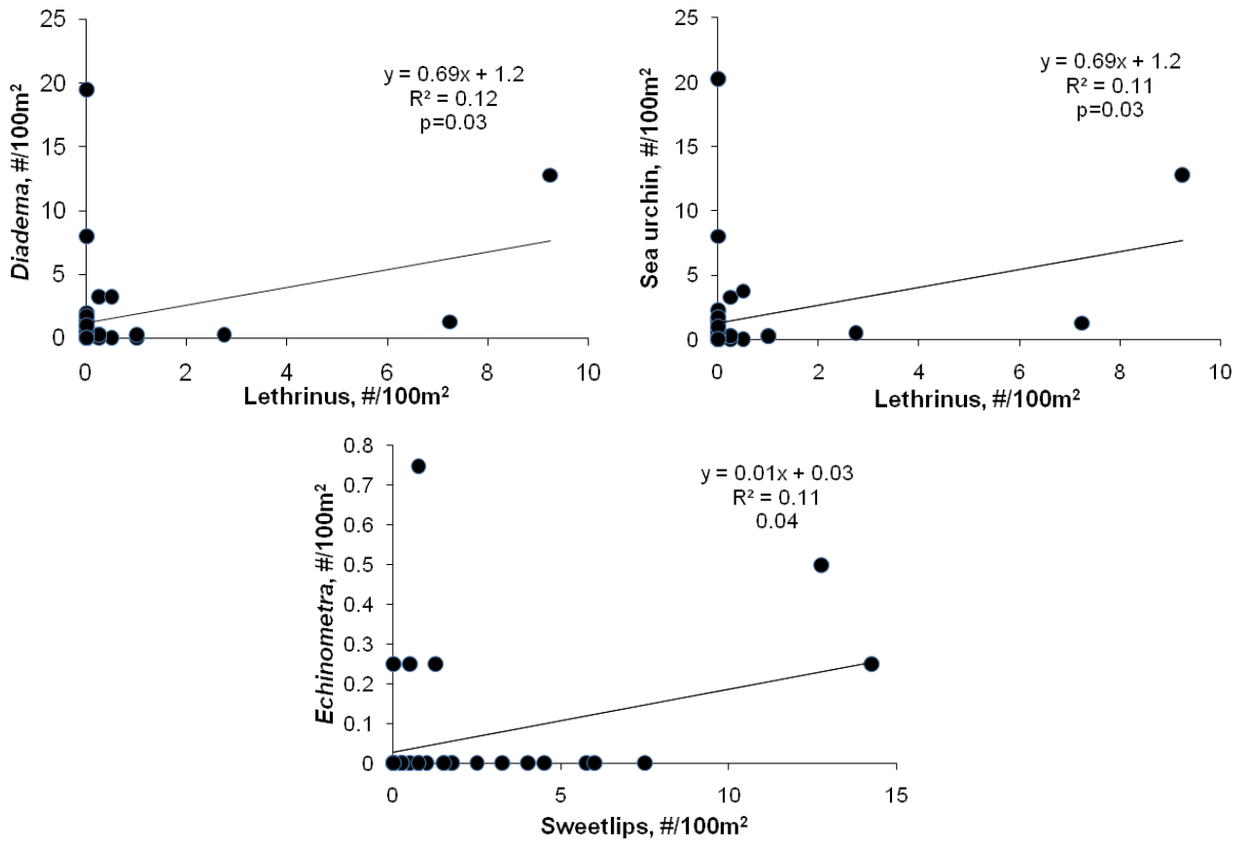


Figure 45: *Scatter plots of sea urchin density against density of lethrinid emperors and sweetlips, both predators of sea urchins.*

3.3.4.4 GROUPERS

The coral trout grouper (najil) was extremely rare, with an average density across all sites of 0.2 fishes/100m^2 (figure 46). This refers to two species, *Plectropomus pessuliferus* and *P. areolatus*. Of these, *P. pessuliferus* is usually common in the Red Sea and rare elsewhere, whereas *P. areolatus* is widespread, occuring throughout the Indo-Pacific (Heemstra & Randall 1993). The combined densities of these two species would suggest significant over-fishing.

There were some exceptions to this bleak picture, as higher densities were recorded at at Sha'ab Salak (Sites 3 and 6) in the north, and Sha'ab Tawil (Site 15) and Qad Eitwid cay (Site 32) in the Suakin archipelago, and Seil Adar Kebir (Site 18) far offshore from Suakin (figure 46).

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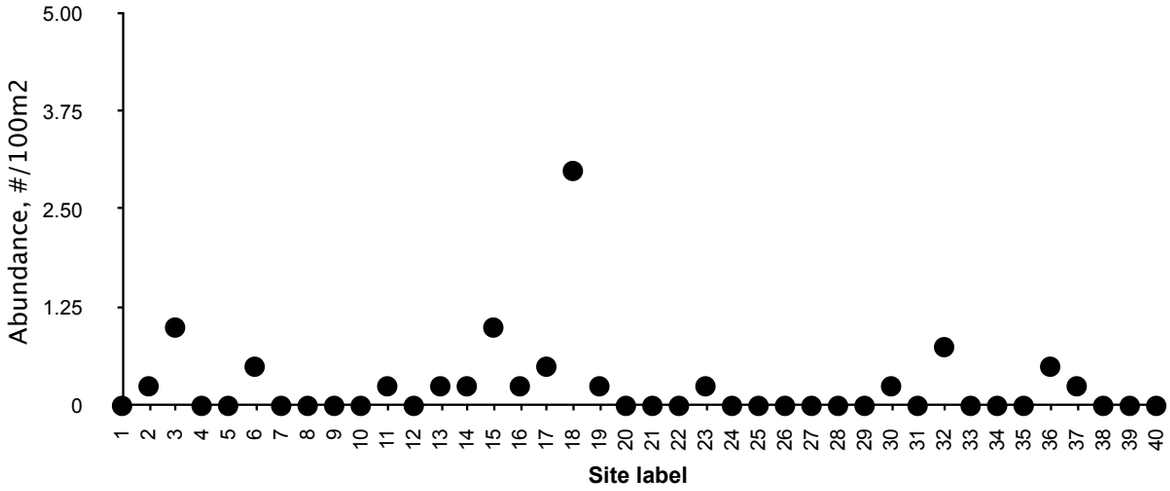


Figure 46: *Density per site for coral trout:* Plectropomus *spp. (najil).*

All other groupers excluding the coral trout (*Plectropomus* spp.) were generally uncommon, with the highest density recorded of 6.75 per 100m^2 (Figure 48). This includes all the small coral groupers such as the *Cephalopholis* species and *Aetheloperca rogaa*. If the commercially important *Epinephelus* species are examined alone, densities are extremely low (Figure 47) at an average density of 0.2 per 100m^2; these levels are below those required for sustainable levels for a viable fishery.

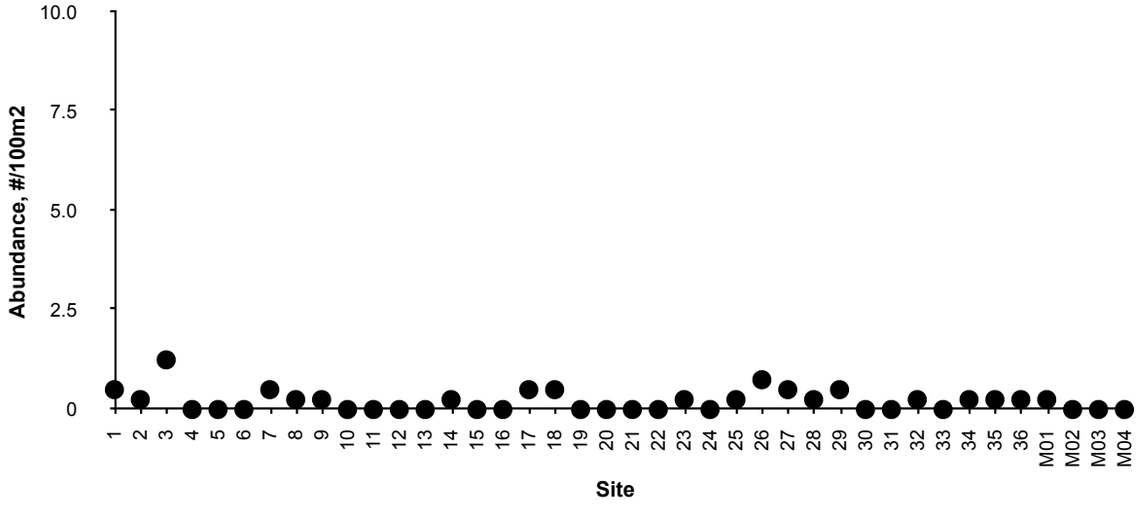


Figure 47: *Density per site for* Epinephelus *groupers.*

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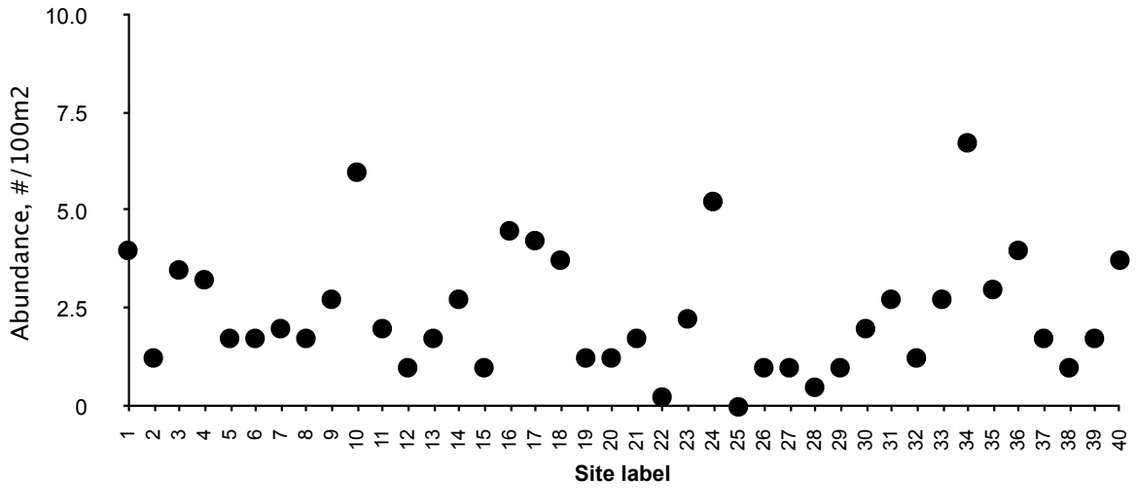


Figure 48: *Density per site for all other groupers (excluding coral trout).*

3.3.4.5 KEY SPECIES

Napoleon wrasse

Interestingly, calcareous algae were also the most significant substrate variable contributing positively to, and explaining 36% of, the abundance pattern of Napoleon wrasse (Table 18). This uncommon species is typically associated with high coral cover, with larger fishes found mainly on outer or deep reefs and steep slopes and passes (Sadovy *et al.* 2003). The overall average density of Napoleon wrasse in Sudan was 0.14 fishes/100m^2, close to the maximum densities reported for this species of 0.2/100m^2 (Sadovy *et al.* 2003) suggesting the populations in Sudan are healthy. Considering the survey sites were generally quite shallow (~ 10m depth) and not all on outer reef slopes, the true densities of Napoleon wrasse on Sudan's reefs are probably higher. They were not observed in the Port Sudan market (see Section 3.3.5) and we found no suggestion that they are fished in Sudan. Napoleon wrasse are heavily targeted for the live fish trade in SE Asia and, with their biology and naturally low densities, are considered highly vulnerable to extinction. The Sudanese populations are therefore significantly important globally, probably representing one of the few populations in good health that are probably not fished, or if so only incidentally.

Bump head parrot fish *(Bolbometapon)*

Not a single bump head parrot fish (*Bolbometapon muricatum*) was counted on the 40 survey sites (Annex 3), although they were seen occasionally during quick site visits and other dives. We suggest this is due to two factors: several of the sites were probably not ideal habitats for this species as they tend to favour deep outer reef slopes, and secondly they are targeted in Sudan's coastal fisheries, as evidenced by large numbers seen in Port Sudan's market (see Section 3.3.5).

3.3.4.6 DISCUSSION OF EXPLOITED FIN-FISH

These analyses show that factors other than substrate type are important for explaining the abundances of these key fisheries taxa. It is probable that fishing pressure and broad scale impacts on coral reef health such as coral bleaching are key factors driving the patterns of abundance. The results also illustrate that some reefs on the Sudanese Coast are healthier than others. Reasons for this may relate to natural levels of resilience and resistance to coral bleaching due to local conditions, such as cooling from local currents, shading and siltation (Grimsditch & Salm 2007).

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The numbers of parrot fishes are remarkably low for a family that is generally quite abundant on coral reefs, with expected densities of 8-20 fishes/100m^{2}on Indo-Pacific reefs (Samoilys & Carlos 2000; Samoilys *et al. 2007*). The relationship between substrate types is revealing in terms of coral reef recovery after bleaching. Parrot fishes are important herbivores which graze on algae, which in turn keeps hard substrate clean and suitable for coral recruits (young coral planula larvae) to settle and grow. Although parrot fishes may also graze the young coral recruits, they play an important role in maintaining substrate suitable for these recruits to settle on, and hence in reef recovery after coral damage. Calcareous algae are also important in maintaining hard substrate suitable for coral recruits to re-settle and grow, because they play an important role in cementing rubble, loose rubble being an unsuitable substrate for coral recruits. The results show that on those reefs where parrot fishes were more abundant calcareous algae were also more abundant. These are the reefs that are likely to recover better from or are more resilient to coral bleaching (IUCN 2008). Thus those reefs that have healthy reef fish communities - a higher abundance of parrot fishes, healthy benthic communities and a higher abundance of calcareous algae - are those reefs where recovery processes are functioning better.

The densities of other key fisheries groups, such as lethrinids, are also low. Densities for this group on Pacific reefs are three times those seen in Sudan, at around 1.5 fishes/100m^2 (Samoilys & Carlos 2000).

The low abundances of highly valuable coral trout grouper (najil) are a serious cause for concern. A con-specific (*P. leopardus*) possibly similar in behaviour and abundance to *P. pessuliferus*, occurs in the Indian Ocean at densities that range from 0.8 fishes/100m^2 in unprotected areas to 6 fishes/100m^2 in areas protected from fishing (Nardi *et al. 2004*). This represents between 4 and 30 times higher densities compared with the combined densities of two species recorded in Sudan. These low abundances are probably due to the valuable coral trout (najil) export fishery in Saudi Arabia (see Section 3.3.5 below).

3.3.5 Rapid Fisheries Survey

By Melita Samoilys

3.3.5.1 RESULTS

Six key fisheries were observed and described on Sudan's coast, as follows:

i. Handline/hook and line, for shallower reef fishes (groupers – gushar, najil) and deep water snapper;

ii. Gill net, bottom set for mullet, emperor, snapper, and surface set for pelagics, trevally, etc.;

iii. Collection of sea cucumber;

iv. Collection of *Trochus* ("kokkian");

v. Collection of molluscs (*Lambis* and *Strombus*) for perfume (dh'ufra) and meat; and

vi. Trawling for prawns and lizard fishes (*Saurida* spp. – "macaroni").

These six key fisheries are described below. There are also existing fisheries for sharks and a trade in aquarium or ornamental reef fishes, but these fisheries are not assessed here. The shark fishery is discussed in section 2.3.6 below.

A visit to the fish market in Port Sudan provided a preliminary indication of the types of coastal fisheries operating in Sudan that sell product locally. The species observed and their relative numbers are given in Table 20.

The species in the market indicate that the following kinds of fisheries by habitat and gear are occuring on Sudan's coast:

- Hook and line (handline) for coral reef fishes, various species;
- Netting near/on reefs for unicorn fishes (*Naso unicornis*) and spearfishing bump head parrot fishes (*Bolbometapon muricatum*);
- Hook and line fishing on the deeper continental shelf for deep water snapper (*Pristipomoides* spp); and
- Gill and/or seine netting in shallow sand, seagrass and mud areas for mullet, emperors, juvenile snappers and pomadasids.

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All of these fisheries were observed during the survey, and are described below. Other fisheries, primarily the mollusc (shells) and sea cucumber fisheries that were seen operating at sea but do not sell their product in Port Sudan, are also described. An exchange rate of around 1USD=2 SDP can be applied to the catch values provided.

Table 20: *Fish species seen in Port Sudan market, 4 November 2007, 9:00-10:00 am. Quantities are expressed as follows: Few = less than 5 fish; Several = > 5 < 20; Many = > 20. Note lack of pelagics (Spanish mackerel, tuna etc) – only trevally were seen.*

Groupers	Notes on quantity and fish sizes etc
P. pessuliferous	*Few. Juvenile seen, mainly adults*
P. areolatus	*One individual seen*
C. oligosticta	*One individual seen*
A. rogaa	*Several*
Variola louti	*Few. Juvenile seen, mainly adults*
Snappers	
L. fulviflamma	*Several*
L. kasmira	*Few*
L. bohar	*Juvenile seen, mainly adults*
L. argentimac	*One individual seen*
L. gibbus	*Few*
Pristipomoides sp.	*Many. Large sizes, juveniles not seen*
Emperors	
L. mahsena	*Several*
L. harak	*Many*
L. obsoletus	*Several*
L. olivaceus	*One large individual seen*
L. lentjan	*Many*
Parrot Fish	
Bolbometapon muricatum	*Several, headless*
Sweetlips	
Plectorynchus gibbosus	*Several*
P. albovittatus	*Several*
Trevally	
Carangoides sp	*Many*

Reef hook and line fishery

Hook and line fishing for reef fishes reputedly operated on a small scale artisanal level from largely non mechanised boats until the 1970s, when the MFA encouraged the development of this fishery (Farah 1999). With an injection of boats, outboard engines, trucks and ice factories, the fishery expanded and this activity increased when markets opened in Egypt and Saudi Arabia.

Hook and line fishers are local, although not necessarily Beja; many are from Port Sudan or Suakin. These fishers were the most difficult to interview because when encountered they were either travelling or fishing.

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Old fishing lines were found at Sha'ab Rumi, despite the high tourism level at this reef, suggesting that tourism does not deter fishermen. Tourist operators also fish this reef, some using spear guns despite the fact that this is prohibited.

Hook and line fishers use a variety of vessels (Table 21). They target: groupers (particularly najil), snappers (particularly *bohar*), deep water snappers (see below), trevally (*bayad*) and job fishes (*Aprion viriscens–farsi*). Buyers tend to travel by vehicle with ice boxes to buy from these fishers at known locations on the mainland, and take them back to Port Sudan's fish market.

Table 21: *Summary of information on the hook and line (handline) fishery obtained from interviews with fishers (in both coral reef and deep water).*

Snap shot of information from hook and line fishermen	
Fishermen's home port	**Port Sudan, Suakin; some in cooperatives, e.g. the Salabona Society**
Fishermen's age	**Variable - some young (20-30 yrs) some old (60-70 yrs)**
Number of fishers per vessel	**1-5**
Vessel and engine types	**4-6m wooden boats (houri) with diesel in-board or outboard engine (8-25hp); 4-7m fibreglass boat with 25-40 hp outboard; sailing outrigger canoe; dug out canoe**
Gear	**Hand lines with hooks, sardines bought for bait; ice boxes and ice**
Fishing trip – to fishing grounds	**N/A**
Fishing trip duration	**<15 days**
Fishing grounds	**North: Marsa Salak and Dungonab Bay; South: Suakin archipelago**
Catch per trip	**< 750 kg ("depends on God")**
Trend in catches	**Declining (fishers with >20 yrs experience)**
Value of catch	**Varies upwards and downwards**
Market chain	**Take catch to Port Sudan market; sell to buyers in trucks with ice boxes in Suakin and Marsa Salak**

Hook and line fishing for deep water snappers

Fishers seen fishing for deep water snappers (*Pristipomoides* spp. ["*kooreb*"] and *Etelis* spp. ["*hamur*"]) were from Port Sudan and had travelled north to Marsa Salak to fish (Table 21), just south of Dungonab Bay and Mukkawar Island National Park. These fishers were sold bait by local fishermen who catch sardines in the lagoons using cast nets from small paddle canoes (*remas*).

Gill netting

Little information was obtained on this gear. Fishers tend to use this gear in conjunction with handlining to target different species at different locations, state of tide or time of day. For example, shallow bottom set gill nets are used along the shore line or on the reef flats to capture mullet ("*arabi*"), emperor, sweetlip and snapper as the tide goes out. Typical shore line catches are 5kg per net per set. Surface set gill nets in deeper water are used to catch pelagics such as Spanish mackerel and trevally. Bottom set gill nets in deeper water (~30m) are set at night. Some of these fishers target sharks (see Section 3.3.6). The Port Sudan market survey suggests that nets of some sort must be used to catch the bump headed parrot fishes, *Bolbometapon muricatum* ("*hamar el bahr*") and unicorn fishes (*Naso unicornis*).

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Trochus – mother of pearl – export fishery

The trochus fishery is said to have operated since the 1920s, providing mother-of-pearl for the European button market (Farah 1999). This export fishery developed on a commercial scale in Sudan in the 1960s, and then declined dramatically in the 1980s and 1990s, reputedly due to overfishing (Farah 1999).

The fishers we interviewed were from Suakin and had travelled for at least 4 hours to reach the reefs (Table 22) around Sha'ab Anbar, where they collect the shells. They live on board their wooden *houri* boat and do not fish for other species.

Table 22: *Summary of information on the trochus fishery obtained from interviews with fishers.*

Snap shot of information from trochus fishermen	
Fishers' home port	Suakin
Fishers' age	mainly < 30yrs, one ~70 yrs
Number of fishers per vessel	6
Vessel and engine	Wooden 8m clinker built "houri", diesel inboard, 2 tender boats – "rema"
Gear	Hand collection; plastic drums to store shells
Fishing trip – to fishing grounds	4 hrs
Fishing trip duration	2-3 weeks
Fishing grounds	Sha'ab Anbar, Suakin archipelago
Catch per trip	N/A
Trend in catches	Declining
Value of catch	1,350 SDP per 1 tonne
Market chain	Basha factory in Port Sudan, which processes them and then exports them to Europe

Only one *Trochus* gastropod was seen in the entire survey, on a quick site survey at Sha'ab Anbar. None were counted in the biodiversity surveys (see above). This strongly suggests this fishery is overexploited or may have collapsed, though the fishermen did not mention it was no longer viable economically.

Sea cucumber export fishery

Sea cucumbers have been fished in Sudan for export to Singapore and Hong Kong since around the early 1980s (Farah 1999). This is a valuable global industry, and with the current rate of growth in the Chinese economy the demand for sea cucumbers will continue to rise. There is therefore potential for a valuable export fishery, and also for the collapse of such a fishery if it is not regulated and managed properly.

Sea cucumbers are collected from shallow reefs areas to depths of 60m. They are cleaned to remove the intestines and then placed in a barrel of salt. Then they are boiled for an hour, and then sun dried.

The following companies in Port Sudan were named: Aaid Company, El Ahmour, Al Batan and Al Gelad from Khartoum which has a branch in Port Sudan. They provide all the gear (Table 23) and export the dried sea cucumbers to Asia.

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Table 23: *Summary of information on the sea cucumber fishery obtained from interviews with fishers.*

Snap shot of information from sea cucumber fishermen	
Fishers' home port	Port Sudan and Suakin; also divers from Tanzania and Egypt
Fishers' age	Divers are <40 yrs; >50 yr olds maintain camp, dry cucumbers, usually in charge.
Number of fishers per operation	15-30; 4-6 divers per fibreglass boat
Vessel and engine per operation	2-4 fibreglass 7m boats with 25-30 hp outboard engines for diving; 1 houri with tender vessels for transporting dried product to Suakin/ Port Sudan.
Gear per operation	SCUBA gear: 40-100 tanks, 1-2 compressors; hand collection with net; boiling drums; mats for sun drying; sacks for transporting dried sea cucumbers
Fishing trip – distance travelled	N/A
Fishing trip duration	1 month. ~8 months per year (due to weather)
Fishing grounds	Fish all reefs from Port Sudan to Suakin archipelago except Towaritit and Bashair oil terminal where fishing is prohibited. In Suakin archipelago they fish from camps on islands: Salada Kebir, Talla Talla Kebir, Talla Talla Segir, Harorayeat
Catch per trip (1 month)	1993: 26,000 individuals on snorkel 2007: 6-7,000 individuals on SCUBA
Trend in catches	Severe decline: hard to find and most fishers are diving to >40m to find them
Value of catch	4-7 SDP per individual
Market chain	Buyers/companies in Suakin, Port Sudan, Khartoum and Egypt; exported to Asia. 1 buyer exports 2-3000 t/month to Hong Kong

Table 24: *Species list of sea cucumbers observed at fishing camps; average density counted for each commercial fishery group during the biodiversity survey; fishery value categories assigned during biodiversity survey and interviews, and prices. Densities from biodiversity survey (medium and low value species were combined) provided here for comparison. 1 SDP = ~ 0.5USD.*

Species observed at fishing camps	Arabic	Price per individual	Fishery value	Average density individuals/100m2
Holothuria fuscogilva	*abushutur*	7 SDP	High	0.025
H. nobilis	*abushutur*			
Actinopyga mauritania	*abushereira*	4 SDP	Medium	0.019
Thelenota ananas	*abushok*		Medium	
Holothuria atra	*abusonoun*	N/A	Low	
H. edulis	*abudam*		Low	
A. miliaris	*abukaboub*		Low	
H. parva	*abukaboub*		Low	

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The biodiversity survey found populations of sea cucumbers to be severely depleted. Densities were 10 times lower in Sudan than those on fished reefs and around 100 times lower than those on unfished reefs in East Africa (Muthiga & Ndirangu 2000; Othina & Samoilys 2005). One old fishermen who has fished sea cucumbers since the 1970s said he had seen a large drop in catch rate, saying that catches are around 25% of what they were in the early 1990s, and that in the 1990s sea cucumbers were collected by fishers using snorkels (Table 24). These figures suggest severe overfishing. In addition, species diversity was very low, at 8 species in total, suggesting that some species may have been fished out.

Trawling for prawns and lizard fishes

At the time of the survey two large (~20-30m) bottom trawlers from Egypt were licensed to fish in the Suakin archipelago area, with a permit for 20 days only from MFA. The fishers on board also hire fibreglass boats with outboard engines from MFA. With these they fish around the reefs and islands by hand line and gill net. One such Egyptian was interviewed (Table 25).

Table 25: *Species taken by Egyptian trawlers. Non trawl gear represents catches from fibreglass boats. Information from Egyptian fisherman.*

Arabic	English	Fishing gear
Macarona Gamberi Barbuni ? ? ? Cabouria Bayad abiyat	Lizard fishes Prawns Goat fishes Slipper lobsters Squid Cuttlefish Crabs White trevally	Trawl
Mugil or arabi Gusher Najil Agam Bayad ?	Mullet Groupers Coral trout Small barracuda Trevally Mixed pelagics – tuna, Spanish mackerel, barracuda	Set shoreline gillnet Handline Long line with single hooks “ “ Trolling

The mullet are highly sought after by the Egyptians. They are salted in large blue containers and taken back to Egypt. The final product is called *farsirh*.

Apparently the trawl fishery is set to expand, with 20 new licences to be issued to Egyptian owners. There appeared to be no regulation of the fishery, for example there are no closed seasons or areas, and it was not clear that any stock assessment had been done on the two target species: lizard fishes (*Saurida* spp.) and prawns.

Mollusc fisheries

Lambis and *Strombus* gastropods are exploited for their opercula (*dh'ufra*) which are used to make perfume (*khumbra*). The meat is also eaten after boiling. No mollusc fishers were found during the survey so the information on this fishery is based on observations of discarded shells, informal discussions with the crew and Sudanese colleagues, and from the village interviews conducted by Harrison in Dungonab and Mohammed Qol in Dungonab Bay and Mukkawar island National Park (Harrison 2007).

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Both men and women collect the shells, and it is the women who make the perfume, some of which they keep for use by themselves and their husbands, the rest they sell (Harrison 2007). Some is exported to Yemen and Somalia. Two types of perfume are made, one for men and one for women. Around 2000 shells are needed to make 0.5kg of perfume, which is very expensive and this has increased the fishing pressure on these animals (Farah 1999). The fishery is said to have operated for centuries. However, fishing and the exploitation of marine life are not part of the ancient cultural activity of the Beja coastal people, who only started such activity around the 1940s (Pantuliano 2002). Therefore the exact origin of this fishery, and who practices it, are not precisely known.

Large middens were seen in several places on the mainland (e.g. Marsa Salak) and on the islands in the Suakin archipelago. For example, there were several middens on the small peninsula at Marsa Salak which is a well used fisher camp with good road access. Shells in the middens are predominantly (80%) *Lambis* and *Strombus* with some *Murex* gastropod shells, turtle bones and *Tridacna* clams among them. The fish buyers, who drive up from Port Sudan to buy fish from hook and line fishers operating in the area, may also buy the mollusc opercula for the perfume industry. Middens were also seen throughout Dungonab Bay and Mukkawar Island National Park in 2001 (Kemp et al., 2002) and 2006 (pers. obs.) An enormous midden of *Lambis* and *Strombus* shells was discovered at Marsa Suakin South on the reef flat, which from a distance looked like an island. Presumably it represented a favoured site for cleaning the molluscs to extract the meat and opercula, used over decades of fishing for these molluscs in the area.

The very low densities of *Lambis* and *Strombus* in the biodiversity survey (see Section 3.3.2) suggest that this traditional fishery has seriously over exploited these species.

3.3.5.2 DISCUSSION

Most of Sudan's coastal fisheries appear to be semi-commercial or artisanal, with some industrial fishing (trawling). This contrasts with many coral reef regions of the Indo-Pacific where there is still much small–scale subsistence fishing (Wells *et al.* 2007). For this reason fewer species tend to be taken, because high value species are targeted, such as groupers and sea cucumbers. There is great potential for thriving and lucrative marine fisheries in Sudan, due to its diverse and productive marine habitats. However, there appears currently to be little management and serious levels of over exploitation. Recommendations for each of the fisheries referred to above are set out below.

3.3.5.3 REEF HOOK AND LINE FISHERY

It is recommended that closed zones are established as a matter of urgency to help restore the populations of commercially important reef fishes, such as the groupers and snappers. The Dungonab Bay and Mukkawar Island National Park provides an ideal management framework, and legislation should be enacted for these to become closed zones on Sudan's northern coastline (Samoilys 2008). Closed zones within this large Park (~3000k km^2) may suffice to provide adequate management protection for reef stocks on the northern coast. This would serve to seed the Marsa Salak area where fishing pressure appeared to be high, and thus hopefully help stocks recover in that area. Similar areas need to be considered in the Suakin archipelago, although enforcement will be very difficult.

The globally renowned SCUBA diving site of Sha'ab Rumi should be a closed zone since the fishing is depleting the fish that tourists wish to see. The two activities are not compatible and there are many other reefs that can remain open to fishermen. In addition, the tourist operators should be advised to set an example and not fish their dive sites. In particular, spearfishing should be prohibited immediately as it conveys the wrong message to the Sudanese crew, visitors and tourists.

Closed zones should also be situated so that they protect the spawning aggregation sites of groupers and snappers. Both taxa are known to form large aggregations to spawn, which are highly predictable in space and time.

There are two species of coral trout or najil (*Plectropomus*) in Sudan's waters. The abundance of both was so low (see Section 3.3.4 above) that it is hard to imagine how they could sustain a proper fishery. The potential for a productive fishery on coral trout is probably high, given what we know about the biology of coral trout and the operation of such a fishery on Australia's Great Barrier Reef. If properly managed this would be an important and valuable fishery for Sudan. The preferred management of coral trout requires: areas that are

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permanently closed to fishing; protection of spawning aggregations; and size limits. The first two criteria are certainly feasible in Sudan, and should be supported by the tourism industry. Size limits could be enforced without great difficulty at the export stage when product is inspected.

Controlling the export of product is also highly recommended as a way of limiting effort in this fishery, and this would not require extensive enforcement. The export of coral trout to Saudi Arabia is currently closed by Saudi Arabia. This closure should be not only maintained by the Sudanese authorities but also extended to all exports until stocks recover. The impacts of the closure should be monitored by underwater visual census (UVC) surveys (as was done in the biodiversity survey) of these species as they are highly amenable to this method (Samoilys and Carlos 2000). It is strongly recommended that the MFA work closely with the fishers in the closures and the monitoring.

3.3.5.4 SEA CUCUMBERS

The biodiversity survey, and the catch per unit of effort figures obtained, indicate that Sudan's sea cucumber population densities are at critically low levels. Sea cucumbers are a valuable resource and if Sudan is to retain its sea cucumber populations for future generations and as a valuable export fishery it is strongly recommended that a moratorium be placed on this fishery. It should be closed until stocks recover. In the meantime Sudan could explore mariculture of the high value *Holothuria scabra* sea cucumber which is now increasingly well understood and feasible (Conand and Muthiga 2007). There are several management groups and networks for sea cucumbers (Conand and Muthiga 2007) and it is recommended that the RSS's Marine Fisheries Administration and the ICZM Office join these groups to contribute to the growing regional expertise in the management of these valuable fisheries.

Serious health hazards within this fishery in Sudan are also posed by SCUBA diving. Fishers receive no training and no dive computers or dive tables are used. Fishers are regularly diving to depths of 40m and more, and deaths have been reported. An immediate measure would be to prohibit collection on SCUBA, a measure that has been introduced in other countries (e.g. Kenya) to prevent overfishing as it protects the deeper populations which then re-seed the shallow areas. The inaccessible deep areas function as closed zones where breeding stocks are protected. If the fishery is opened up later and SCUBA is allowed it is essential that it be regulated for health and safety, and that investors/companies be required to provide SCUBA training to their divers.

3.3.5.5 LOBSTER

The highly valuable tropical lobsters are probably unexploited in Sudan as there is no tradition of eating these animals and no export fishery. This is therefore a potential fishery for development. Care must be taken to establish input and output controls so that the fishery is developed and managed sustainably. There are plenty of examples to learn from, both in the region (in Kenya where the fishery is being assessed for Marine Stewardship Council (MSC) certification) and in Western Australia where the fishery is tightly controlled and has been awarded MSC certification.

3.3.5.6 MOLLUSCS

Population levels of *Lambis* and *Strombus* gastropods, as measured on the biodiversity survey, suggest that these species are heavily overexploited for the perfume industry. We recommend that areas be closed to shell collecting, in cooperation with local fishers, to help populations recover. Dungonab Bay and Mukkawar Island and the villages Mohammed Qol and Dungonab would be ideal places to trial this management approach (see Harrison and Samoilys 2007). The impacts of the closures should be monitored to assess population recovery by conducting abundance surveys of the molluscs. This monitoring should be done with local fishers to engage them in the management of the fishery. However, alternatives will need to be offered to local men and women who collect these shells as this may be their only source of income.

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3.3.5.7 TRAWLING FOR PRAWNS AND LIZARD FISH

It is recommended that Regulations, including a closed season and closed zones, are introduced for the trawl fishery, and that stock assessment research is conducted on both the target species, prawns and lizard fish. The fishery also needs to be carefully controlled so that it does not conflict with other users, such as local fishers and the marine parks. The MFA should consider not hiring fibreglass boats for reef fishing to these trawl vessels since this is in direct competition with Sudanese fishers, and several of the species taken in the handline reef fisheries are already overexploited, in particular the najil grouper.

3.3.6 Sharks and Rays

Related to the IOC Handbook Ecological Indicators E1, E2, E3 and E5 (Table 1), and to the Socio Economic Indicator SE 5 (Table 3).

By Nigel Hussey and Steve Kessel

3.3.6.1 INTRODUCTION

Sharks and rays are long-lived animals that mature late and, generally, have low fecundity (Holden 1974; Camhi *et al.1998*). This life history strategy, coupled with high mobility, makes many sharks and rays extremely vulnerable to over-exploitation (Musick, 1999; Steven *et al. 2000*). Moreover stocks of animals, including many shark species, which commonly migrate across international boundaries, are extremely complex to manage. Population decline and depletion can occur rapidly and recovery requires substantial, long-term management efforts (Steven *et al. 2000*).

In many regions of the world there is a lack of baseline information on abundance and movements of shark and ray species (IUCN, 2005). Such data are a fundamental requirement for determining the most appropriate management strategies for sites/regions or particular species (FAO 2005). The life history of many shark species means that the type of data required for effective elasmobranch management can only be collected through long-term research (FAO, 2005). Consequently, the purpose of this preliminary field survey was to test the practicalities of initiating such a long-term research programme within the Sudan region of the Red Sea.

This preliminary field survey focused on three specific objectives:

- To identify the main shark and ray species present at survey sites and to gather coarse information on abundance, size and sex.
- To initiate a placard tagging programme and "in-water" reporting scheme, to be continued throughout the Audit Survey period and beyond.
- To compile video/photographic material.

The specific objectives achieved were as follows.

1. Established contact with diving operators in the region to identify species present at sites and record seasonal abundance;
2. Enlisted the dive operators to be involved in the "Diver network reporting programme" for abundance, species/size/sex composition and in-water tag reporting;
3. Appointed local dive operator programme co-ordinator;
4. Identified all observed shark and ray species at each survey site;
5. Visually estimated abundance of shark and ray species present at each site;
6. Identified size classes and sex of sharks and rays present;
7. Collated photographic/video data on shark/rays sighted at each location;
8. Undertook gillnetting at possible nursery sites and recorded accurate length/sex measurements and took fin clips for Red Sea genetic bank;

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9. Initiated a NUMBER placard shark and ray tagging programme;
10. Initiated a NAME placard tagging programme on the Manta ray aggregations of Dungonab Bay Marine National Park;
11. Identified core sites suitable for the positioning of bottom monitors, through personal observations and correspondence with the dive operators.

3.3.6.2 RESULTS

The Diver Reporting Network Programme:

Data on shark and ray observations were recorded and logged from December 2007 onward, by five of the dive boats involved in Sudan. Data collated thus far encompasses the period December 2007 to April 2008.

Data recorded are from a total of 267 dives at 13 diving sites (Chab Rumi, Sanganeb, Angarosh, Sha'ab Suedi, Quita El Banna, Merlo Reef, Jumna, The Pinnacle, Sha'ab Ambar, Seil'Ada, Sha'ab Quseir, Abington and Umbria).

Sightings were recorded of 6 species of shark: Grey reef (*Carcharhinus amblyrhynchos*), Scalloped hammerhead (*Sphyrna lewini*), Whitetip reef shark (*Triaenodon obesus*), Silvertip (*Carcharhinus albimarginatus*), Silky (*Carcharhinus falciformis*) and Nurse (*Nebrius ferrugineus*). Also recorded were sightings of 4 species of ray: Manta (*Manta birostris*), Blue spotted (*Taeniuralymma*), Stingray (*Dasyatidae* sp.) and Eagle ray (*Aetobatus narinari)*.

However, sightings of rays were very rare. Ray species were sighted in only 17 of 267 dives. Moreover, three shark species (Grey reef, Scalloped hammerhead and Whitetip sharks) were observed more frequently than the other shark species (Figure 49).

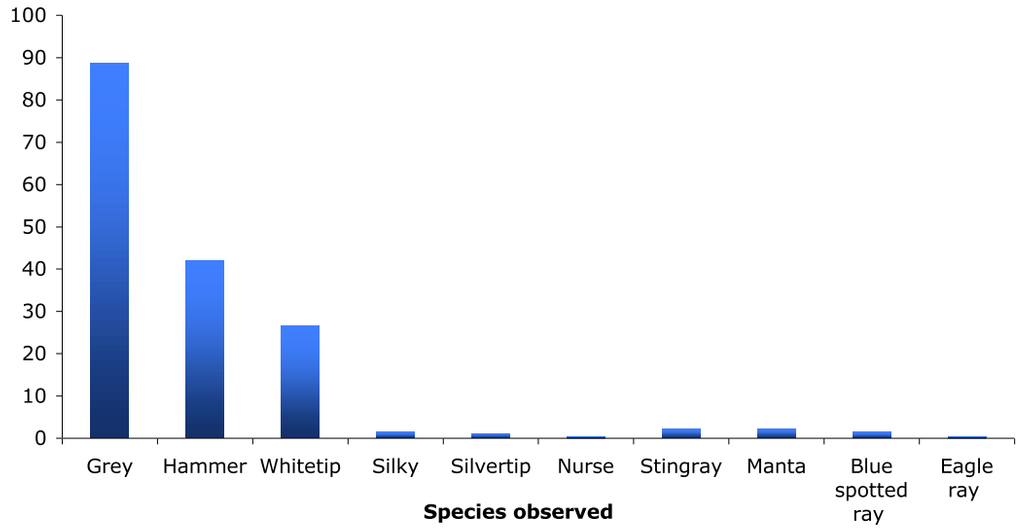


Figure 49: *Proportion (%) of each shark and ray species observed during 267 dives between December 2007 and April 2008.*

In addition, comprehensive data were collated for two sites which are regularly visited by divers: Chab Rumi and Sanganeb. Preliminary analysis of the data and results are presented below. Analysis focused on two of the main species observed: the Scalloped hammerhead (*S. lewini*) and the Grey reef shark (*C.amblyrhynchos*) and on the most visited site, Chab Rumi.

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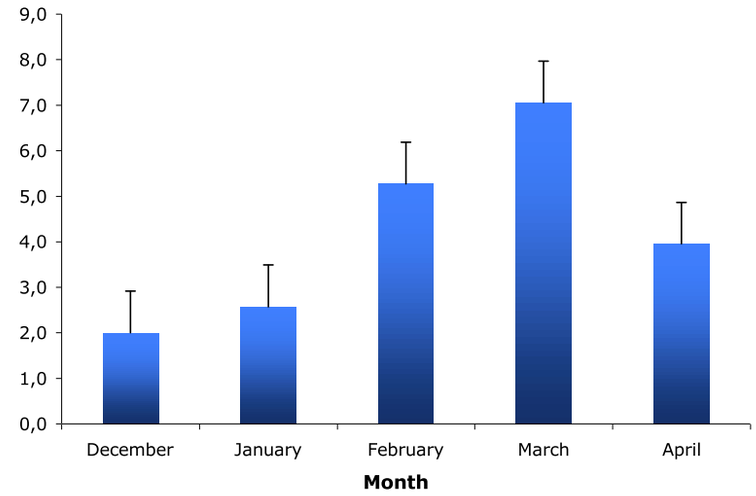


Figure 50: *Mean number (+SE) of Scalloped hammerhead sharks* (S. lewini) *sighted during dives at Chab Rumi per month.*

The presence of *S. lewini* (Figure 50) at depths observable by recreational divers is believed to be seasonal and principally driven by water temperature profiles. From this preliminary analysis it appears that *S. lewini* are most abundant during the month of March, which coincides with water temperature of around 24-25°C, suggesting that these animals display a preference for this temperature range.

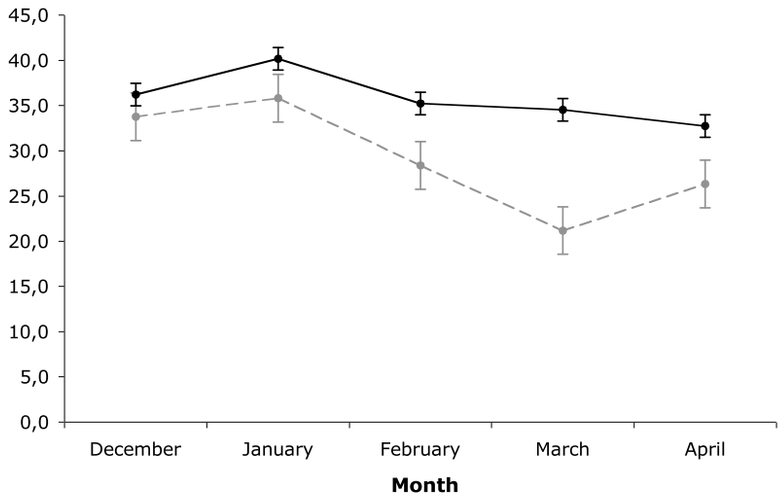


Figure 51: *Mean monthly depth (+/- SE) of observed Scalloped hammerhead sharks (S. lewini) at Chab Rumi between December 2007 and April 2008. Solid black line: mean monthly maximum depth; broken line: mean monthly minimum depth.*

Mean minimum depth (Figure 51) is lowest for *S. lewini* during the month of March, suggesting an appropriate temperature profile. This would be 24-25°C at a depth of ~17m. This coincides with the month when most sightings were made by divers, although this may be partly because it is easier for divers to encounter these sharks when they are at shallower depths.

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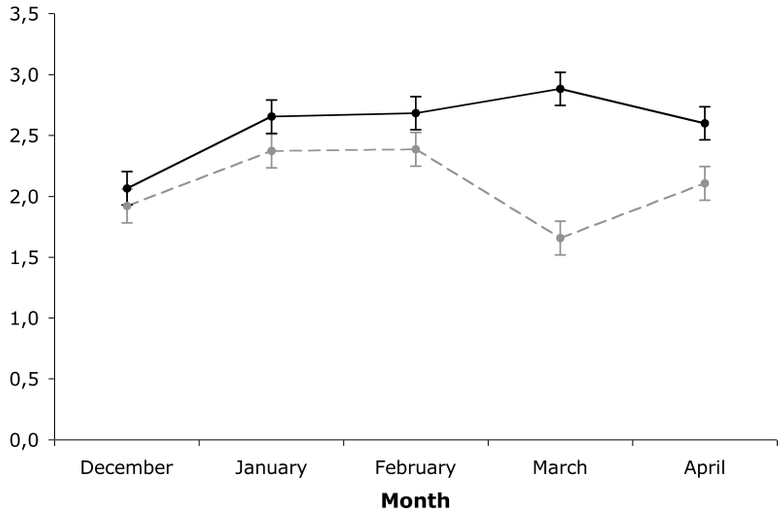


Figure 52: *Mean monthly estimated size (+/- SE) of Scalloped hammerhead sharks* (S. lewini) *sighted at Chab Rumi between December 2007 and April 2008. Solid black line: mean monthly maximum size; broken line: mean monthly minimum size.*

In March a particularly large range of sizes of *S. lewini* are observed at the site. This suggests that residency at a given site might be dependent on maturity; i.e. immature individuals may remain on the site (demonstrate site fidelity), only increasing their home ranges when they become mature. The application of long-term acoustic tags and the positioning of monitoring stations will answer this question in the future of this study. The preliminary data also suggest that the resident animals are mostly female and that male animals are only present during the month of March, indicating that these sites may be used for mating. This also suggests that resident and nomadic individuals may be defined by sex.

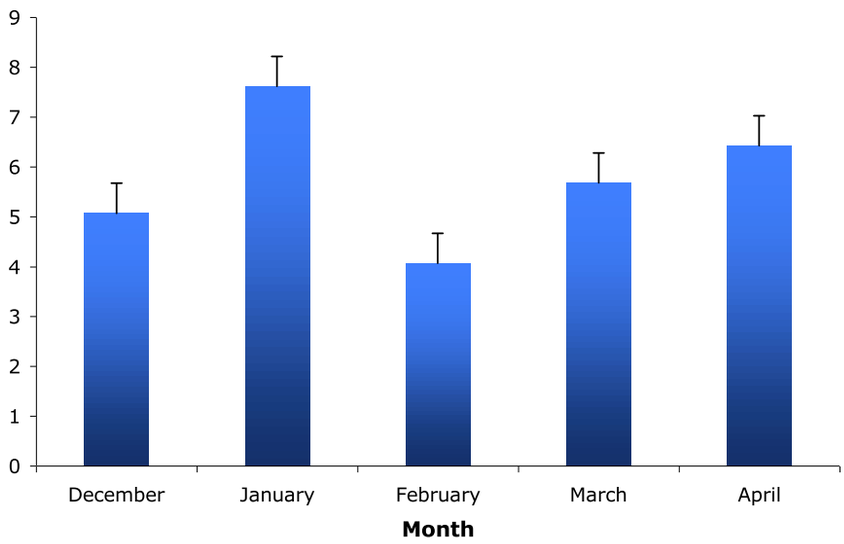


Figure 53: *Mean (+SE) number of Grey reef sharks (C. amblyrhynchos) sighted during a dive at Chab Rumi per month.*

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No obvious seasonal trends in the occurrence of Grey reef sharks at Chab Rumi were observed (Figure 53). In conjunction with the placard tag results, this suggests that the animals are resident on these sites throughout the year.

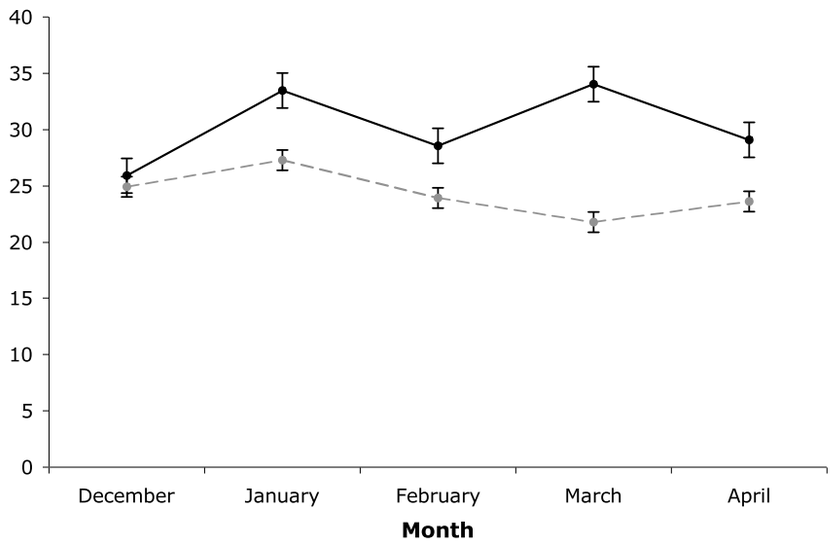


Figure 54: *Mean monthly depth (+/- SE) of observed Grey reef sharks (C. amblyrhynchos) at Chab Rumi between December 2007 and April 2008. Solid black line: mean monthly maximum depth; broken line: mean monthly minimum depth.*

The depth range preference of the Grey reef sharks did not alter on a seasonal basis and was within the range of 25-35m (Figure 54). Most Grey reef sharks were sighted either on plateau ledges or patrolling along the edge of a plateau.

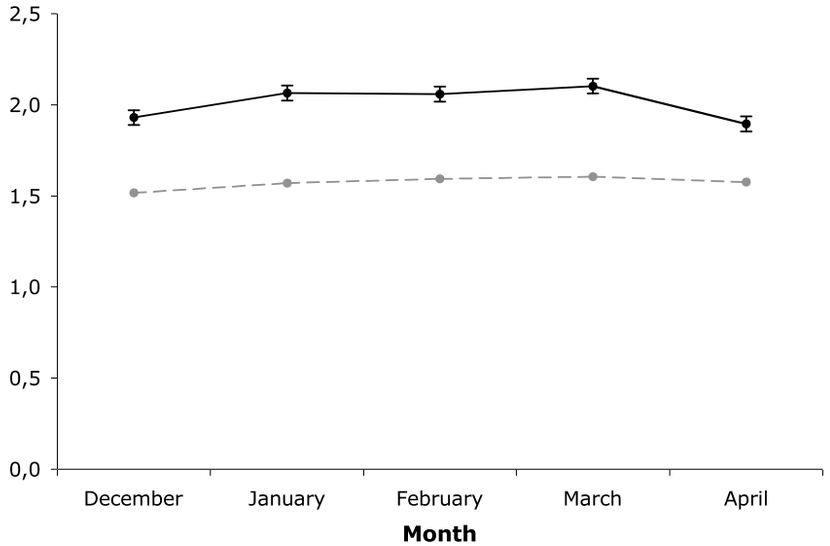


Figure 55: *Mean monthly estimated size (+/- SE) of Grey reef sharks (C. amblyrhynchos) observed by divers. Solid black line: mean monthly maximum size; broken line: mean monthly minimum size.*

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The size range of Grey reef sharks observed included both sub-adult and adult animals (Figure 55). The smaller individuals were probably immature; however, no obvious juvenile animals, i.e. newborns, were sighted. Discussions with dive operators revealed that small Grey reef sharks (<1m) have been observed within the offshore reef lagoons, suggesting this habitat may perform a critical nursery role for this species. Most Grey reef sharks observed were females, although males were sighted throughout the season. This suggests that the males are more nomadic and that females exhibit a preference for specific sites. The preliminary data collected to date is proving invaluable in developing hypotheses and for developing experimental design for a larger scale monitoring project.

Bait drum surveys

Bait drum surveys were not particularly successful, for two reasons. Firstly, the survey locations (determined by the overall biodiversity programme) were not always appropriate for shark and ray species, from the point of view of habitat type/depth etc. Secondly, the survey was conducted at the end of the summer period when the water temperature remained high (29-31°C). It is known that sharks either inhabit much deeper water at this time of year or move to different locations (along unknown migration routes). More success was achieved in incidental sightings during fish scraping dives and at known shark aggregation sites, for example Chab Rumi. Given the behaviour observed, it is likely that these shark sightings were incidental sightings, rather than being caused by attraction to the bait. Information on size classes and sex was obtained. Underwater video/photographic material was recorded at sites where sharks/rays were present, and this material was subsequently archived.

Species observed "in water" throughout fieldwork phase were:

1. Grey reef shark (*Carcharhinus amblyrhynchos*)
2. Scalloped hammerhead shark (*Sphyrna lewini*)
3. Blacktip reef shark (*Carcharhinus melanopterus*)
4. Whitetip reef shark (*Triaenodon obesus*)
5. Tawny nurse shark (*Nebrius ferrugineus*)
6. Manta ray (*Manta birostris*)
7. Eagle ray (*Aetobatus narinari*)
8. Blotched fantail ray (*Taeniura meyeni*)
9. Pink whipray (*Himanturafai*)
10. Blue Spotted ribbontail ray (*Taeniura lymma*)
11. Marbled electric ray (*Torpedo sinuspersici*)

Species observed "dead" at fish market or on beaches:

1. Zebra shark (*Stegostoma fasciatum*)
2. Arabian smooth-hound (*Mustelus mosis*)
3. Bigeye thresher (*Alopias superciliosus*)
4. Bowmouth guitarfish (*Rhina ancylostoma*)

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Plate 19: *The shark team explored a fish market to identify caught shark and ray species.*

Nursery Ground Surveys

The results of gillnetting are presented in Table 26. From several conversations with fishers at survey sites, the suspected locations of Scalloped hammerhead (S. lewini) nursery grounds were identified. The locations were:

- Coastal region North of Port Sudan;
- Coastal region of Shubuk East and
- Ras Aziz.



Plate 20: *A juvenile Blacktip reef shark* (C. melanopterus) *caught at night by gillnetting.*

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Table 26: *Information on gillnet sets undertaken during the biodiversity survey period. (PCL = Precaudal Length, FL = Fork Length, TL = Total Length).*

Date	Location	Time	Species	PCL (mm)	FL (mm)	TL (mm)	Sex	Notes
02/11/07	Harorayeet	afternoon						Juvenile blacktip reef (*C. melanopterus*) observed in water. No animals caught
06/11/07	Talla Talla Kabir	night	Blacktip reef (*C.melanopterus*)	39.0	42.0	52.1	M	
	"	"	"	41.0	45.1	54.0	F	
	"	"	"	39.1	43.9	53.1	F	
	"	"	"	38.0	43.0	50.0	M	
07/11/07	Talla Talla Saghir	night						No animals observed or caught
08/11/07	"	morning	Blacktip reef (*C.melanopterus*)	40.1	45.2	55.0	M	Caught by local fishermen early morning
11/11/07	Marsa esh Sheikh Ibrahim	morning						No animals observed or caught
11/11/07	Marsa esh Sheikh Ibrahim	night						No animals observed or caught

Placard Tags

NUMBER placard tags were applied 'in water' to 6 individual sharks and 'NUMBER' and 'NAME' placard tags applied to 42 rays. Within the Dungonab Marine Park, in the area of Mohammed Qol/Mesharifa, 'NAME' placard tags were applied to 34 manta rays which commonly form a large aggregation in the region. Further South (Dhanab al Qirsh), a new manta aggregation site was identified and number tags were applied to 4 animals. Information detailing the sharks and rays tagged as part of this survey are presented in (Table 27)

Table 27: *Specific details of the elasmobranches tagged as part of the Biodiversity Survey.*

Date	Location	Species	Number tagged	Tag Number / Name	Sex	Size (m)	Depth (m)	Temp (oC)
26/10/07	Sha'ab Rumi	Grey reef (*C. amblyrhynchos*)	1	1	F	1.8	22	29
01/11/07	Dhanab al Qirsh	Manta ray (*M. birostris*)	1	3	?	3	6	29
02/11/07	Dhanab al Qirsh	Manta ray (*M. birostris*)	1	4	?	3.5	6	29
"	"	Manta ray (*M. birostris*)	1	2	?	2.5	6	29
"	"	Manta ray (*M. birostris*)	1	5	F	2.5	6	29
"	"	Manta ray (*M. birostris*)	1	7	?	3	6	29
06/11/07	Talla Talla Kabir	Eagle ray (*A. narinari*)	1	8	?	1.2	15	29
07/11/07	Talla Talla Kabir	Blotched fantail ray (*T. meyeni*)	1	6	F	1.3	5	29
07/11/07	Talla Talla Saquir	Pink whipray (*H. fai*)	1	10	M	1.3	3	29
09/11/07	Shubuk East	Tawny nurse (*N. ferrugineus*)	1	9	M	2.3	6	29
15/11/07	Sha'ab Rumi	Grey reef (*C. amblyrhynchos*)	1	11	F	1.8	22	28
16/11/07	"	Grey reef (*C. amblyrhynchos*)	1	12	F	1.8	22	28
"	"	Grey reef (*C. amblyrhynchos*)	1	13	F	1.3	22	28
"	"	Grey reef (*C. amblyrhynchos*)	1	14	F	1.4	22	28
19/11/07	Mohammed Qol	Manta ray (*M. birostris*)	34	'NAME' placard tags.	M & F	Size range: 1.4 – 3.5m	1	28

With the exception of the Manta rays in Dungonab Marine Park, the location of tagging on the body of the animal was recorded for all shark and ray species. In the case of the Manta rays at Dungonab, the actual tagging location was recorded using GPS at the surface. All tags were positioned well and re-sightings have already been recorded for four of the Grey reef sharks at Chab Rumi (Figure 56) and Manta rays at Dungonab, by recreational divers and park warden staff/fishers, respectively

An internet website is currently in development for entry of re-sightings of both sharks and rays by the recreational dive industry/park warden staff. Survey protocols (for Manta rays) are being put into place with Park staff at Dungonab.

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Of the five tagged Grey reef sharks, four have been re-sighted to date under the Diver network reporting program. Figure 56 shows the number of times each of these individuals has been re-sighted over the five-month data period. All re-sighting occurred at the site where sharks were tagged (Chab Rumi), suggesting the sedentary character of the marked sharks, at least during part of the year.

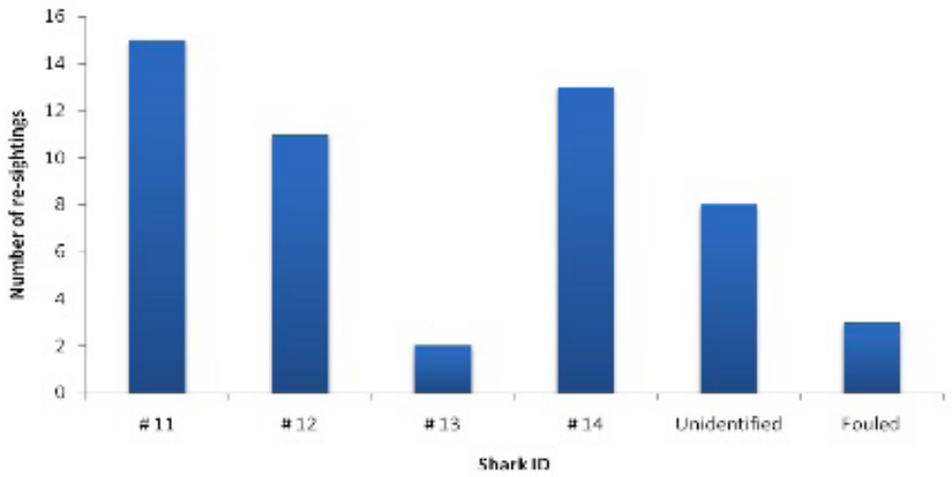


Figure 56: *Number of placard tagged Grey reef shark re-sighting from December 2007 to April 2008.*

The tags were applied in early November 2007 and no tags became so fouled that the shark could not be identified until 25 March 2008. Therefore, the lifespan of the unique ID tags in the field was around four months. NB: action has already been taken to further develop anti-fouling placard tags to increase their field life for the long-term shark and ray monitoring programme. The monofilament wire of each tag is also individually coded and labelled with a return address, so the tag itself, even though fouled, will remain effective should the animal be captured. Early feed-backs suggest that this tagging programme is very popular among the recreational divers visiting the region.

Site selection for future research

Sites of particular interest were documented for future research possibilities. The intention was to find sites where fixed bottom monitor receivers could be positioned, in order to record and archive temporal and spatial movements of Scalloped hammerhead sharks (*S. lewini*), Grey reef sharks (*C. amblyrhnchos*) and Manta rays (*M. birostris*). This was achieved by personal observations and through extensive discussions with dive operators. Two cleaning stations for Grey reef sharks, located on Chab Rumi South plateau and Sanganeb North plateau, were also documented. These highlight the importance of these sites in the ecological life cycle of those species. Dive operators have also reported the presence of Pelagic thresher sharks (*Alopias pelagicus*) on Sanganeb North plateau, suggesting that these cleaning stations are utilised by multiple species.

3.3.6.3 DISCUSSION

The timing of the biodiversity survey was such that it was only possible to provide a very partial assessment of the abundance and distribution of sharks and rays in the surveyed areas of Sudan. However, communication with dive operators reveals that the adult shark populations (principally sub-adult and adult animals) in Sudan are relatively healthy, at a number of known, regularly dived sites.

Through the development of the "Dive Operator Shark Recording Programme", a long term data set will be generated that will provide baseline data on sharks and rays present throughout the diving season at key monitoring sites. It is important to note that it would not be possible to generate the level of data that this programme is expected to achieve through "normal" fieldwork. The participation of the dive industry in this part of the project is critical and extremely valuable.

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Application of placard tags in the field was successful and all animals returned to normal behaviour shortly after the tag was applied. The re-sighting of several animals demonstrates the application of this approach for coarse level monitoring of the residence and movement of sharks and rays.

Extensive data has been collected by the recreational dive operators involved and by their dive clients through the Diver reporting network. This preliminary phase show that collaboration with the recreational dive industry for applied research and management purposes is possible. Furthermore, specific ecological trends of the species observed from the preliminary data analysis are consistent with existing literature and also provide new insights into the behaviour of these species. Thus, "in situ" monitoring by divers can be used as an accurate tool to monitor shark and ray populations in the Red Sea.

However, to ensure the continued collection of data, it is imperative that direct contact is maintained with the dive operators involved. This enables data feedback to the operators, to explain why the collection of data is important and how it can be applied. The Diver reporting network is currently being advanced through discussions with regional operators.

It is important to highlight, however, that Dive Operators have raised concerns about the presence of foreign fishers specifically targeting sharks.

Through both "in water" surveys and extensive discussions with dive operators, sites have been selected for the future positioning of acoustic bottom monitors. It is essential that this type of monitoring programme be put in place to determine large-scale temporal/spatial movement patterns and residency times of key species. A combination of the above methodological approaches will then ensure the development of appropriate management plans for elasmobranches in the region.

Preliminary observations from gillnetting in nursery areas present worrying results. For the sampling effort undertaken, it would have been expected that more juvenile animals would have been caught in the nets. At Talla Talla Saqhir no animals were caught in a set gillnet, and one local fisher caught only one animal in a net set throughout the night at the same location. A nursery area is a location where multiple animals should be present (Feldheim & Edrén 2002; Feldheim *et al.* 2002). These results suggest that the gillnetting undertaken by fishers on offshore reefs, one of their principal fishing methods, may be heavily impacting on juvenile shark populations. Discussions with fishers revealed that their catches consist primarily of small to medium sized sharks, reflecting the location of their fishing effort in nursery areas. Although many fishermen were not directly targeting sharks and rays, they are caught as by-catch and their fins removed. It would appear that, although it is illegal, shark fins are still being exported from Sudan and there is a possibility that this demand may increase; fishers may then deliberately target these animals. There was also some evidence that the flesh of "juvenile" animals is more highly prized than that of mature animals. This size-class of animal was not exploited as a fishery until relatively recently, but the fishing effort is now intensifying. More extensive, nursery area, work is required in the future to identify sites and determine the impact of fishing pressure (Heupel & Simpfendorfer 2005). Baseline data on shark fisheries in the region (all size classes) is currently lacking, and is necessary for good management.

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Plate 21: *Shark finning and gillnets are the main dangers for sharks in Sudan.*

3.3.7 Quick Site Surveys

Of the 753 sites completed during this survey there were 568 quick sites, 152 depth records, 22 georeference points and 12 records which were disregarded. Of the 568 quick sites, 87 sites were on entirely bare substrate on, either sand, silt, rubble or a combination. These sites were included in the initial cluster analysis and then excluded from subsequent analyses. A total of 14 habitat types were identified from this process and these were used to assist in classifying the marine part of the satellite image (see Section 3.4).

3.3.8 Rapid Ecological Assessment (REA) Surveys

By Rebecca Klaus

The Rapid Ecological Assessment was carried out in two phases (Table 28). The first phase was carried out during October and November 2007 by the international survey team, as one part of the boat-based survey. The boat-based survey REA sites are all located in the southern part of the survey area, primarily in the islands to the east and south of Suakin (see Figure 57, below).

The second phase, the Land Based Survey (LBS) was carried out during August 2008 by a team from Red Sea University. The land-based REA survey was carried out from the southern boundary of the Dungonab Bay and Mukawwar Island Marine National Park southwards to the town of Suakin, along the mainland coast only.

Table 28: *Summary of REA survey dates and site numbers.*

	Dates	Site numbers	Number of sites
Boat-based survey (BBS)	October – November 2007	R01 – R11	11
Land-based Survey (LBS)	August 2008	01 – 37	37
			48

The LBS August 2008 data were not compatible with the data from BBS, and so only the results of the BBS are presented Figure 58, Figure 59 and Figure 60 below.

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3.3.8.1 BOAT BASED REA SURVEY

Table 29 and Table 30 summarise the semi-quantitative findings of the boat based REA survey.

The overall survey design was heavily compromised by problems with the land-based REA survey results, including consequent very small sample size. This means that effective statistical analyses of these data are not possible. However, the data do provide some qualitative insights into the situation prevailing in the area of the reefs and islands to the south and east of Suakin at the time of the survey.

Seagrasses and marine algae are widespread, and were recorded at 45% and 86% of sites respectively. This accords with the widespread occurrence of both groups elsewhere, particularly as recorded during surveys of the Dungonab Bay and Mukawwar Island Marine National Park carried out in 2002 and 2006 (Kemp *et al.* *2002; PERSGA 2004; African Parks Foundation 2006*).

Typically of the northern and central Red Sea, well developed coral reefs were a dominant subtidal feature of the majority of sites. Reefs were only absent from three sites (26% of the total) all of which were in the area of Shubuk lagoon where, although well developed, important and very unusual coral reef communities do occur, soft sediments can be dominant over large areas.

Impacts directly observed subtidally were limited to Crown-of-Thorns (*Acanthaster plancii*) feeding scars and coral bleaching at one REA site (Site 11) and algal overgrowth of recently dead corals at five sites (45%). At only one of those sites (Site 4) was the overgrowth more extensive than would be expected to occur naturally. At that location it possibly indicated eutrophication of a section of reef adjacent to a sea cucumber fishers' camp, where sewage, food waste and waste from sea cucumber processing were accumulating in a shallow inshore area with limited water exchange.

A widespread subtidal impact that was indirectly observed was fishing, both in the form of fishing boats active at the time of the survey, and in the form of discarded waste products such as mollusc shells, which were extremely widespread and indicate that there is almost nowhere in the Sudanese Red Sea that provides a refuge from extractive uses for these groups.

Site 4, the location of a sea cucumber fishery camp mentioned above, was perhaps the most heavily impacted site subtidally, with scores of zero for all subtidal fauna and flora apart from reefs (a measure that includes dead and overgrown corals) and algae. This was probably due to the localised eutrophication previously mentioned.

Above the high tide line birds and halophytic terrestrial plants were present at 100% of sites surveyed, with birds being particularly abundant (scoring 3, 4 or 5 on the semi-quantitative scale) at five sites, or 45% of the total.

Islands tend to be favoured by nesting turtles because of safety from predation, and turtle nesting pits were recorded at four sites, or 36% of the total. Turtle nesting activity was particularly abundant at two sites (Sites 1 and 2) both located on the same relatively small island.

Mangroves were recorded only at the single mainland site included in the boat-based REA survey, and those mangroves were very heavily impacted by a combination of browsing by livestock and felling of whole trees, leaving only a narrow band of trees, all apparently in poor health, along the seaward edge of the stand.

Impacts above the high tide line were primarily litter, driftwood and other rubbish, which were recorded at 91% and 86% of all sites, respectively, and construction, recorded at 28% of sites. Construction was at low levels wherever it was recorded during the boat-based REA, consisting almost entirely of the small temporary shelters used for fishing camps. The only exception was Site 10, where more substantial construction was apparent along the line of the newly paved coast road south of Suakin, although that construction was almost entirely outside the REA survey quadrat.

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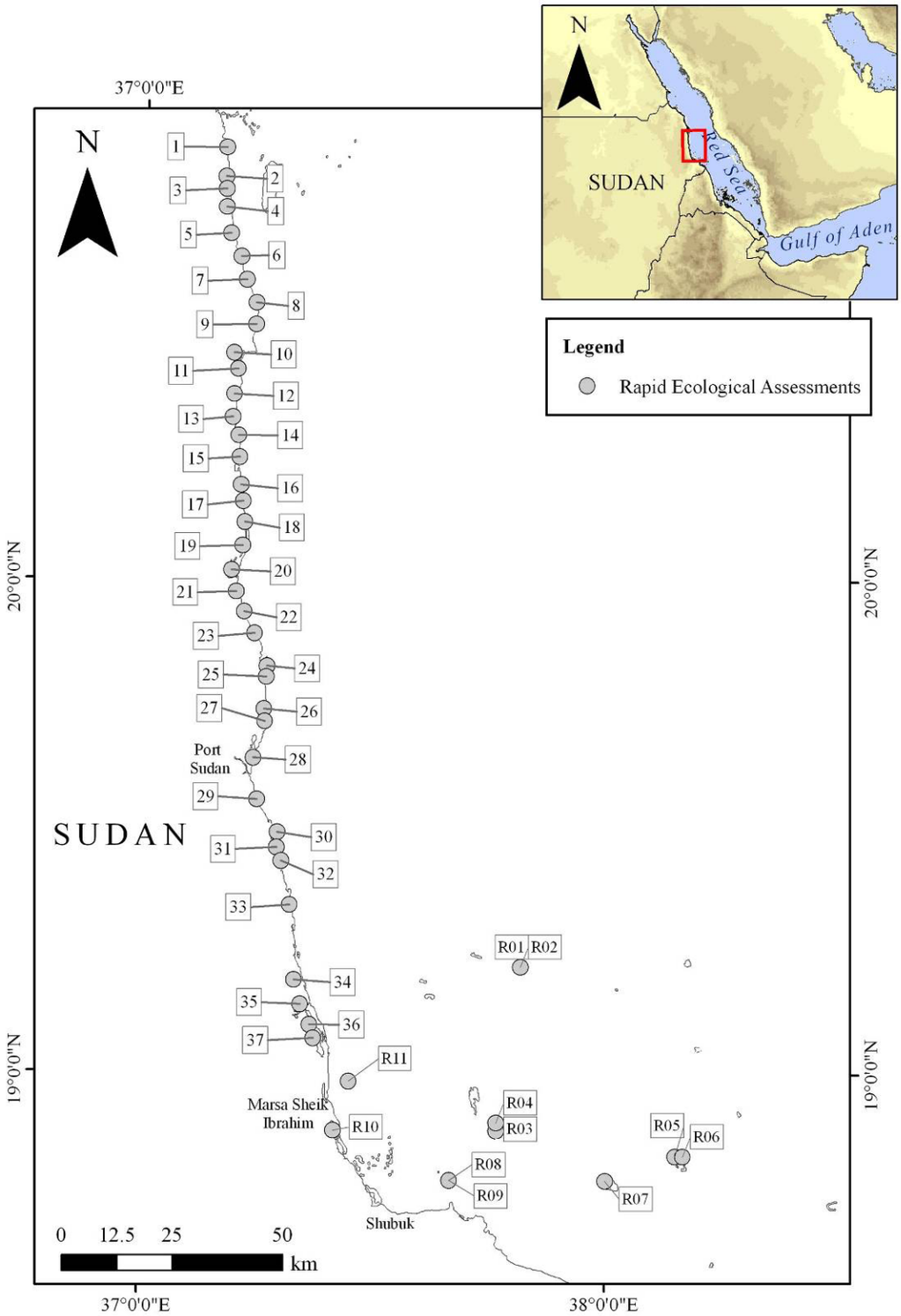


Figure 57: *Location and numbering of Rapid Ecological Assessment survey sites. Sites R01 – R11 were surveyed during the boat-based survey of 2007. Mainland coastal sites numbered 1 to 37 were surveyed over a 4-day period in August 2008.*

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Table 29: *Summary of semi-quantitative survey results for flora and fauna, at REA sites surveyed during the boat-based survey. Birds and halophytes were ubiquitous, being present at all sites surveyed. Only nesting turtles and terrestrial mammals were completely absent, neither of which is surprising given that the surveys were carried out during the daytime (turtles nest primarily at night) and that all except one of the sites were on relatively small isolated islands, where native mammals are unlikely to occur, except for small creatures such as rodents, which are largely nocturnal.*

	Site											
FAUNA and FLORA	R01	R02	R03	R04	R05	R06	R07	R08	R09	R10	R11	Occurrence
Mangroves	0	0	0	0	0	0	0	0	0	2	0	9%
Seagrasses	0	0	3	0	3	2	3	0	2	0	0	45%
Halophytes	3	2	3	3	3	3	3	4	4	1	3	100%
Algae	2	1	2	3	3	2	3	0	0	1	2	82%
Reefs	5	2	4	3	2	1	2	0	0	0	4	76%
Birds	5	2	3	2	2	5	2	4	2	2	3	100%
Nesting Turtles	0	0	0	0	0	0	0	0	0	0	0	0%
Turtle nest pits	4	4	0	0	2	0	0	0	0	0	1	28%
Swimming Turtles	0	0	1	0	2	0	0	0	0	0	0	18%
Terrestrial Mammals	0	0	0	0	0	0	0	0	0	0	0	0%
Marine Mammals	0	3	0	0	0	0	0	0	0	0	0	9%
Fish	4	5	4	0	4	4	2	1	0	0	4	76%
Macro Inverts	2	3	2	0	5	5	3	0	4	0	3	76%

Table 30: *Summary of semi-quantitative survey results for Human and Natural Impacts, at REA sites completed during the boat-based survey. The only impacts that were not observed were the presence of 'pots' (large fish traps), absent throughout the survey area, and of Crown-of-Thorns starfish (CoTs), which were observed at detailed survey sites but not at any REA sites.*

	Site											
IMPACT	R01	R02	R03	R04	R05	R06	R07	R08	R09	R10	R11	Occurrence
Construction		0	0	2	0	0	1	0	0	2	0	28%
Fish Direct		2	2	2	0	0	1	0	1	1	0	56%
Nets		0	0	0	2	0	0	0	0	1	0	18%
Pots		0	0	0	0	0	0	0	0	0	0	0%
Oil		1	0	0	0	0	0	0	0	0	0	9%
Litter		3	4	4	5	3	3	0	2	5	4	91%
Driftwood		3	2	0	2	2	1	0	1	0	0	56%
COTS (animal)		0	0	0	0	0	0	0	0	0	0	0%
COTS (scar)		0	0	0	0	0	0	0	0	0	2	9%
Bleaching		0	0	0	0	0	0	0	0	0	2	9%
Algae on coral		1	1	3	1	0	1	0	0	0	0	45%

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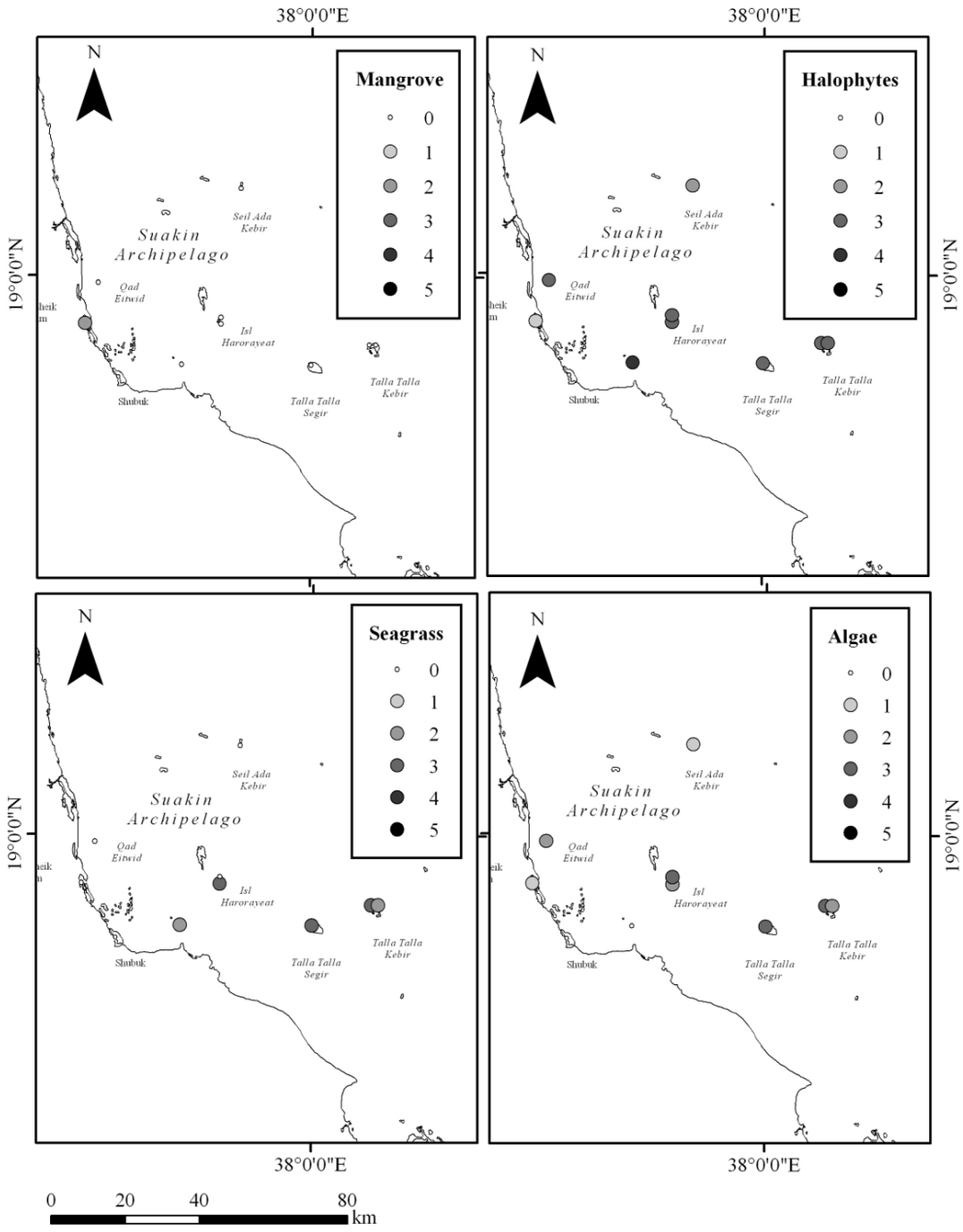


Figure 58: *Abundance and distribution of key groups of coastal and subtidal plants recorded during the boat-based REA surveys.*

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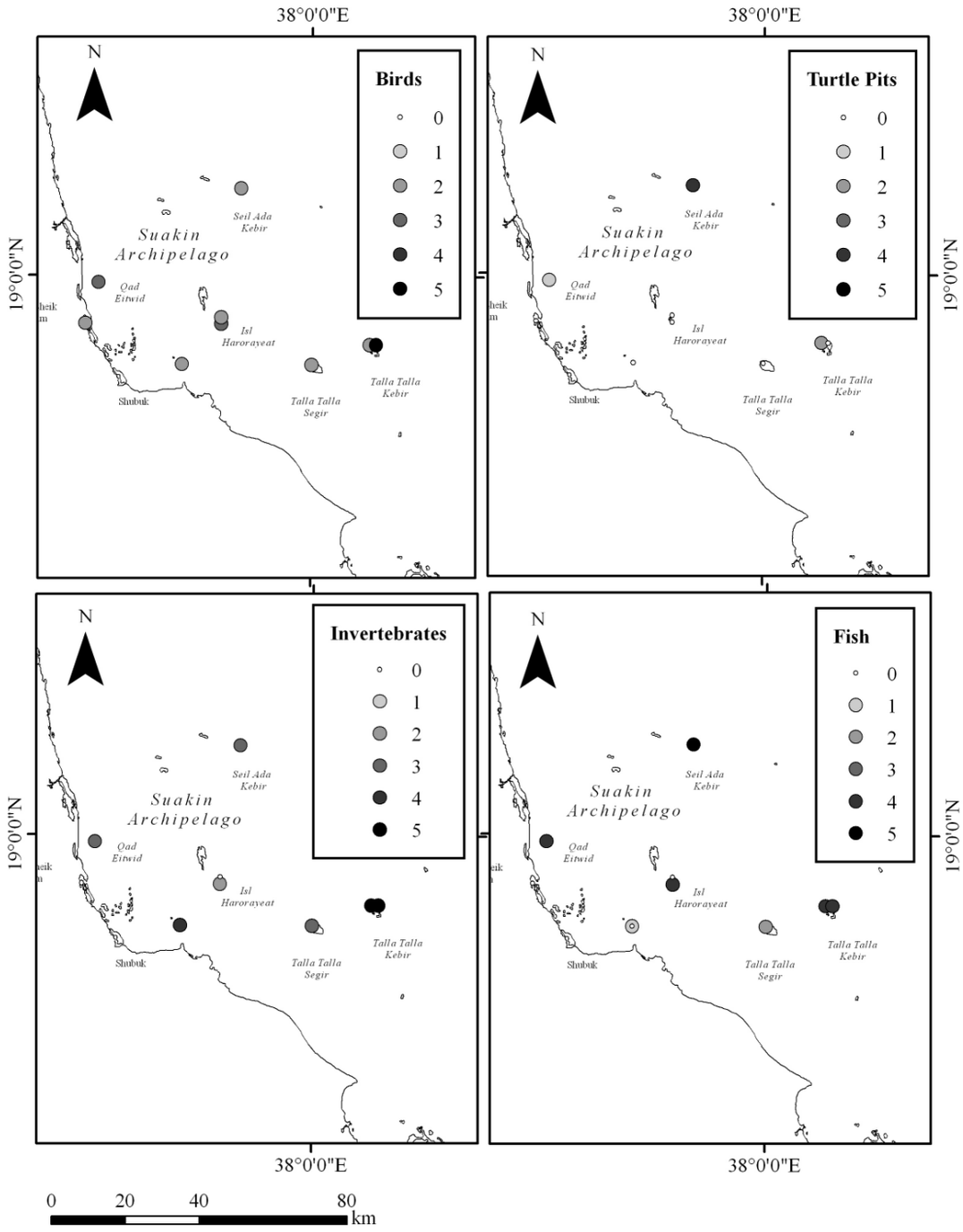


Figure 59: *Abundance and distribution of birds, turtle nests, invertebrates and fish in the boat-based REA surveys. Higher abundances of both birds and turtles at island sites is to be expected: these groups tend to be found in higher numbers here because of the relative absence of terrestrial predators.*

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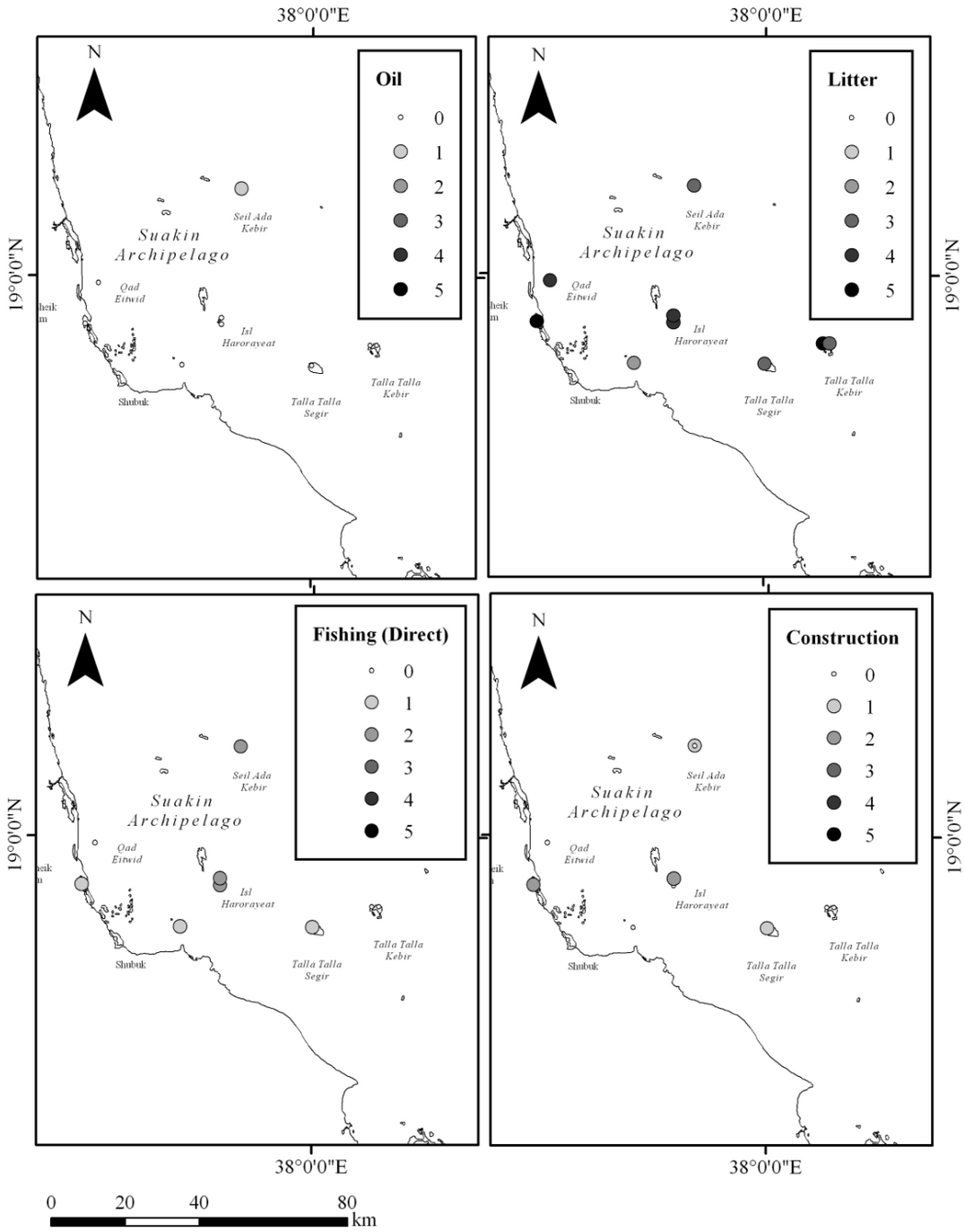


Figure 60: *Distribution of some key impacts as recorded by the boat-based REA surveys, showing that litter and fishing are the most prevalent impacts on these islands.*

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3.3.9 Coastal Habitats and Vegetation Surveys

A total of 80 land-based vegetation site surveys and 148 quick site surveys were completed within the 4-day survey by the team from the Red Sea University. These surveys spanned a 200km stretch of coast from Dungonab Bay to south of Suakin. The sites were generally located within the land-based REA sites, and were clustered together in groups of 4 in close proximity. Only the results of the coastal vegetation sites are considered here[5].

3.3.9.1 COASTAL VEGETATION

The coastal vegetation recorded during these surveys (as listed in Table 31) includes 6 types of halophytes, most of which are characteristic of salt marsh communities, the dominant species of mangrove tree known to occur in the region (*Avicennia marina*) and the invasive shrub *Prosopis* sp. At 14 of the 80 sites (17.5% of sites) no species were recorded. The majority of these were sites where there was 100% bare substrate (13.5% of sites) and the remainder were sites where there was between 75% and 98% bare substrate but no species named. These sites are excluded from the subsequent analysis.

Table 31: *The vegetation types recorded and the number of sites and percentage occurrence of each.*

Species	Number of Sites	% Occurence
Atriplex sp.	23	34.8
Aeluropus sp.	9	13.6
Arthrocnemum sp.	20	30.3
Calotropis procera	1	1.52
Saueda sp.	9	13.6
Zygophyllum spp.	23	34.8
Prosopis sp.	7	10.6
Avicennia marina	6	9.09

Mangroves

- ***Avicennia marina*** fringes the shoreline in many areas, typically growing in pure stands. At sites where mangrove was recorded the canopy height was generally no more than 2m and the trees generally provided less than 50% cover. *Avicennia marina* was found to co-exist with *Zygophyllum* sp. This species of mangal tree is common throughout the region and found to grow in sheltered areas: lagoons and embayments. The tree is often found on the terrestrial side of the shoreline, often behind sand bars and sometimes associated with freshwater springs. The tidal mud associated with the mangrove vegetation of the Red Sea coast is usually grey or black and often foul smelling (anoxic).

Salt marsh

- ***Atriplex* sp.** (Family Chenopodiaceae) is the most common species found at the sites surveyed (35% of sites). Chenopods such as *Atriplex* are salt tolerant, xenomorphic (plant characteristics determined by ability to resist drought) shrubs and sub-shrubs. Although it is not known which species of *Atriplex* is found along the coast of Sudan, the most common species in the coastal environment of Egypt is *Atriplex farinosa*. Many species are valued as livestock forage when fodder availability is low, especially in arid and salt-affected areas.
- ***Arthrocnemum* sp.** (Family Chenopodiaceae) was found at 30% of sites. An *Arthrocnemum glaucum* community is known to occur along the Sudanese and the southern Egytian coast. The community type is

[5] Both these survey methods were meant to concentrate on coastal habitats; however, a large number of the quick site surveys recorded the presence of marine grasses and algae as the dominant cover under the category "grasses".

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typically composed of a single layer of *Arthrocnemum*, often between 30 and 50cm high, but it is also often associated with *Atriplex farinose* in the shoreline area.

- ***Aeluropus spp.*** (Family Poaceae) were found at 13.6% of sites. Two morphologically and ecologically similar species of this creeping grass are known to occur along the Red Sea coast of Sudan and Egypt (*A. brevifolius* and *A lagopoides*). These species usually form the grassland community occupying the fifth zone of the salt marsh. The grass may form patches or mats of dense growth. The soil of the *Aeluropus* community is frequently cemented by a surface accumulation of salts. Further inland, the *Aeluropus* zone may be mixed amongst islands of *Sporobolusspicatus* grassland where sand deposits and the water table are deeper.
- ***Zygophyllum* sp.** (Family Zygophyllaceae) was the other most common genus found during these surveys and was present at over a third of sites (33.5% of sites). *Zygophyllum* spp. is associated with salt marsh communities and is known to be ubiquitous along the Red Sea coast of Sudan (Kassas 1957) and southwards to the Sudan-Eritrean border, where is can cover extensive areas. This succulent halophyte tolerates a wide range of conditions, and individual plants may provide sparse cover in an area of dried salt marsh, or it may form mounds or continuous layers covered in sand. The wide range of ecological conditions tolerated by the *Z. album* community type is also reflected in the number of common associates with differing ecological requirements. Common associates include the halophytes *Aeluropus, Atriplex Arthrocnemum* and others, and xerophytes such as *Calotropis procera* as found in this survey.
- ***Suaeda* spp.** (Family Chenopodiaceae) was found at 13.5% of sites. This is another succulent halophyte. The ecological range of this genus and its most common species, *S. monica*, extend beyond the limits of the salt marsh to the fringes of the coastal and desert plain. The species may be found with a wide range of associate species. It may form mounds or hillocks on sand, and is known to cover large stretches of the Sudanese coast (Kassas 1957).

The following community types are known to be common in the salt marshes along the coast of Sudan (Kassas 1957), but were not reported in this survey.

- *Halopeplis perfoliata* is typical of salt marsh vegetation, where it occupies the third zone in from the shoreline, which is usually lower in level than the second, where waves and detritus may form an elevated sand bar.
- *Limonium axillare* is a non-succulent excretive semi-shrub halophyte which is common in the salt marshes and nearshore coastal environment of Sudan (Kassas 1957).
- *Sporobolus spicatus* is a halophytic grass which can provide cover of 20-60% and may be found in association with *Aeluropous*.
- *Tamarix nilotica* is one of the most common excretive halophytic bushes on the whole Red Sea coast. It is found in various habitats and has various growth forms. It may form thickets in the salt marsh. As a woody plant, *T. nilotica* is often used for fuel and hold purposes, and its sparseness may be due to overexploitation rather than to ecological factors.

Invasive and Pest species

Prosopis (mesquite) is an evergreen leguminous shrub/tree. This non-native species has now become an invasive pest species in Sudan and during this survey it was recorded at 10% of the sites visited.

The most common species of mesquite found in Sudan is thought to be *Prosopis juliflora*: this was the species originally introduced in 1917 from southern Africa and Egypt. The original introduction of mesquite was intended to be beneficial. The high tolerance of the plant to a range of environmental conditions, including drought meant it could be used to stabilise soils and as wind protection, as well as for fuel, timber, fodder and edible pods. However, its foliage is unpalatable to most ungulates (goats, sheep and camels) although the seeds pods are consumed and this is how the plant spreads.

Between 1978 and 1981 the tree was planted as shelterbelts around Port Sudan and Tokar. The rate of spread in eastern Sudan, as revealed by aerial photographs, successively taken in 1962, 1978 and 1992, and a survey undertaken in 1996, was initially low. However, the rate increased substantially to 3.71km^2 per annum between 1978 and 1992. Between 1992 and 1996 the average rate of spread increased to 4.6km^2 per

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annum (Elsidig *et al. 1998*). In 2004 the infested area was estimated to be between 880 and 1,000km^2 in the Tokar area (El Bashir 2004). In most of the infested sites mesquite forms impenetrable thickets that smothered and excluded native vegetation and substantially changed community structure. Indigenous tree species were replaced by mesquite (Elsidig *et al.1998*).

Other invasive species may pose a threat to Sudan's coastal flora in future, as has occurred in Egypt. The Egyptian coast has been under development for more than 20 years. The establishment of coastal villages, resorts and hotels and the creation of gardens demanded the import of more fertile, less saline soils from inland areas. The soils were collected from the Nile Region, and with them the seeds of the weeds and other plants found along the banks of the Nile Valley and Nile Delta. The seeds have spread and so far a total of 51 invasive species from 42 genera and 18 families have been recorded.

3.4 HABITAT AND BIOTOPE MAPPING

Linked to the IOC handbook Ecological Indicator E9 (Table 1)

By Rebecca Klaus

3.4.1 Introduction

Understanding the extent and spatial distribution of different coastal and marine habitats is a fundamental requirement for the conservation and management of coastal ecosystems. Information on habitat distribution is not only important as a baseline for planning and zoning purposes, but it is also now widely accepted that the protection of individually threatened species and overall biodiversity can be achieved through the conservation of the heterogeneity of the habitats that allowed the diversity to emerge. A cost-effective, efficient and well established technique to map and quantify marine habitats is to use remote sensing data and geographical information systems (GIS).

The remotely sensed data selected for use in mapping the marine and coastal biotopes of Sudan is from the Landsat 7 satellite, which carries onboard the Enhanced Thematic Mapper (ETM+) sensor. The Landsat series of satellites has been operating since 1972 and the data they acquire are amongst the most widely used type of remote sensing data for mapping both terrestrial and marine environments. While the data these satellites acquire is only of a medium resolution (30m by 30m pixels) they are suitable for use in mapping large areas such as are required for Sudan. These data are both more affordable than higher resolution datasets and more easily manageable.

Landsat 7 was launched in April 1999, and the ETM+ sensor continues the database of imagery that begun in 1982 by the Landsat 4 Thematic Mapper, by providing the same spectral wave bands. This allows for change detection studies. The wavebands recorded by this sensor include a blue band, which makes the data particularly suitable for use in the marine environment. Furthermore, the ETM+ sensor also includes a higher resolution panchromatic band (15m by 15m pixels).

3.4.2 Methods

3.4.2.1 STAGE I IMAGE PROCESSING (PRE-FIELD SURVEY)

Six contiguous Landsat 7ETM+ satellite images were acquired from the Global Land Cover Facility[6] (GLCF) (Table 32). Preliminary processing of four of Landsat 7ETM+ data was completed prior to the field phase by CEDARE (Centre for Environment and Development for the Arab Region and Europe) in Cairo, Egypt. They used these four images to prepare some true colour composite maps for selected areas along the coast, at a scale of 1:100,000 and 1:50,000, using the bands ETM1, ETM2 and ETM3. Additional maps were prepared using the higher resolution Quickbird data that is available from GoogleEarth. Both these sets of maps were then printed on A3 paper and laminated for use during the field surveys.

[6] Source for this data was the Global Land Cover Facility, www.landcover.org.

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Table 32: *The Landsat 7ETM+ satellite data obtained for the coastal region of Sudan from the Global Land Cover Facility.*

Path / Row	Acquisition Date	Sensor	Producer	Attributes	Format
3 37/45	12 October 1999	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF
3 4/5	4 June 2001	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF
3 33/46	4 June 2001	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF
3 30/47	1 June 2000	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF
3 29/47	25 March 2001	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF
3 13/24	14 October 1999	ETM+	EarthSat	Ortho, GeoCover	GeoTIFF

3.4.2.2 STAGE II IMAGE PROCESSING (POST-FIELD SURVEY)

The techniques that have been employed to create the habitat maps for Sudan are the same as have been used previously, both in Sudan and throughout the wider Arabian region (Klaus 1999; Klaus & Turner 2000; Klaus & Turner 2004; PERSGA 2004) and Indian Ocean (Turner & Klaus 2006). The methods used to collect ground-truthing data are described in Section 2.1, and the following describes the image processing techniques used to correct the images for atmospheric and geometrical aberrations and to create the habitat maps.

Atmospheric Correction and Georeferencing

The Landsat 7ETM+ satellite data were georeferenced using the ground control points (GCPs) collected during the field surveys (Latitude Longitude WGS84), those collected during the PERSGA surveys and a digital coastal atlas known as the World Vector Shoreline (1:250,000). The georeferenced images were then radiometrically corrected and atmospherically corrected using the standard 6S code method (Green *et al.* 2000).

Image masking

The corrected Landsat 7ETM+ images were then subdivided to create separate "coastal" and "marine" images. These images were created by reassembling the most appropriate wave band combinations for use in mapping coastal land (ETM bands 3, 4 and 5) and marine areas (ETM bands 1, 2 and 3). A band ratio technique (ETM4/ETM1) was used to create a mask image that distinguishes areas of land as distinct from areas of sea. The resulting mask image was used to exclude areas of sea in the "coastal" image and areas of coastal land from the "marine" image. This masking process effectively sets the pixel values in the excluded area to zero, in order to reduce the spectral variability in the images and enhance the accuracy of the supervised classification process. Areas identified as "deep water" in the "marine" image (ETM1-3) were also masked (pixel values set to zero) to further minimise the spectral variability in that scene.

Coastal Biotope Mapping

Coastal biotopes (habitats and vegetation cover types) were identified from the REA surveys, vegetation transects and ground-truthing surveys completed by the Red Sea University, and from other general observations recorded during the field phase and the coastal geographical mapping efforts. These data were used to identify and map the coastal habitats and vegetation types using a partially supervised classification of the prepared coastal land (Landsat 7ETM+ satellite image (ETM3, 4 and 5). Areas of coastal vegetation were identified using Normalised Differential Vegetation Index (ETM 4-ETM3/ETM4+ETM3). This NDVI image was combined with the partially supervised classification to create the final set of coastal biotope maps.

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Marine Biotope Mapping

Marine biotopes identified from the cluster and SIMPER analyses of the detailed transect surveys and ground-truth data collected during the field surveys were used to develop the primary set of spectral signatures for the supervised classification of the prepared "marine" image. Not all of the biotopes identified during the field surveys were spectrally separable in the image, due mainly to the spatial variability in water clarity, water depth and sediment types. Where the biotopes that had been identified from the ground-truth data were not spectrally separable in the image, they were either combined or further refined using these additional datasets. The final signature set was then used to perform the supervised classification of the Landsat 7ETM+ satellite data.

3.4.3 Results and Discussion

The results of the coastal and marine habitat mapping are shown in and described further below.

3.4.3.1 COASTAL HABITAT MAPS

The Red Sea coast of Sudan is bordered by a narrow lowland coastal plain ranging between 2 and 10km wide, backed by an area of coastal desert, and then by the Red Sea Hills (see Figure 61). These main geomorphic units are described in more detail below.

Red Sea Hills

The Red Sea Hills form a prominent escarpment about 200km wide by about 700km long, N-S along the coast of Sudan. The hills are part of the Nubian Shield that is covered by basement rocks of Upper Proterozoic. The rocks are by and large exposed and vegetation is negligible in most parts, and these are simply classified as "rock" in the habitat map. The geology of small parts of the Red Sea Hills has been mapped previously using Landsat Thematic Mapper (TM) data (e.g. Keane 1997) using different image processing techniques to distinguish geological features and identify mineral resources, although these techniques have not be used in this study.

The basement complex of the Red Sea Hills is known to consist of granite intrusive into meta-sedimentary and metavolcanic sequences. Sediments (Upper Mesozoic to Quaternary) often overlie the rocks of the igneous suite. Granitics are found and these are related to the Nubian Sandstone and are widespread in northern Sudan (Whiteman 1971). Another feature of geological interest which is evident in Figure 61, is the ring complexes, formed from petrographic rock types. These near circular depressions are of volcanic origin and are found scattered both within the hills and on the coast.

Coastal Desert

The coastal desert extends between the coastal range of hills and mountains on the inland side and the salt marsh belt within the coastal plain. The dominant habitats found in the coastal desert are rocky pediments (desert pavements) at the foothills of the escarpments (occasionally reach the shoreline), and alluvial fans (with low to medium salinity), composed of mainly of gravel and other finer sediments.

Vegetation cover within the coastal desert is typically low. While there are patterns of vegetation zonation, changes in topography, surface deposits and the relationship with the mountains result in microclimatic changes: this complicates the pattern of zonation. Vegetation is usually constrained to the water courses and drainage systems, some of which are only seasonal. The soil within these drainage basins is typically less saline than closer to the shore, but it is often formed of gravel. The downstream area may form deltaic basins, with aeolian deposits which may forms sheets, mounds or hills.

The zonation pattern described above is evident in the Tokar Delta region, in the south of Sudan, (see Figure 62). Around Tokar Delta moderate to dense vegetation follows the path of this water course widening towards the coastal plain. Although much of the vegetation is likely to be agricultural, as well as naturally vegetated habitats, a substantial proportion is also likely to be *Proposis,* but further fieldwork would be needed to determine the extent of each type of vegetation.

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There are areas of moderately dense vegetation to the north of Port Sudan, and inland of Suakin. Both these areas are known to be colonised by dense *Proposis,* and these were clearly apparent on the satellite images (Figure 63). The total area of *Proposis* mapped is 46.8km^2, but this is likely to be an underestimate, both because of the lack of ground-truth data inland, and because the satellite images are now 10 years old, and it is likely that this species with have spread.

Coastal Plain

The main habitats found in the REA surveys can be summarised as follows:

- Exposed rocky shelves (with low to medium salinity);
- Raised fossil reef beaches (1-3m above sea level);
- Sand sheets (composed of quartz);
- Sand beaches and sand dunes, occasionally connected to a lagoonal mangrove;
- Sabkhas (often with a crystallised salt crust on the surface and barren of vegetation) and
- Mangroves and salt marshes.

The shore is usually composed of a depositional sedimentary surface covering coralline rocks (fossil reef rock). Sandy and muddy coastal plains are scattered between carbonaceous rocks, beach terraces and wadi sediments, and this is evident in Figure 61, although some of the rocky habitats appear as sand on the classified image where the rock is covered by sediments.

The coastal plain immediately behind the shore is formed from a band of alluvial gravel and sand and muds, as illustrated in Figure 61. The hydrology is characterised by permanent water deficit. Although there are numermous wadis, which cross the coastal plains, they are dry most of the year, apart from during the rainy season.

The coastal plains support mainly halophytic vegetation, and two main types are found: mangroves composed mainly of *Avicennia marina*, and salt marsh communities, which include a more diverse range of species (see Section above).

There is 23.3km^2 of mangrove along the Sudanese coast. There are few large expansive mangrove forests, most of the mangroves occuring in smaller patches, unevenly distributed along the coast (Figure 62).

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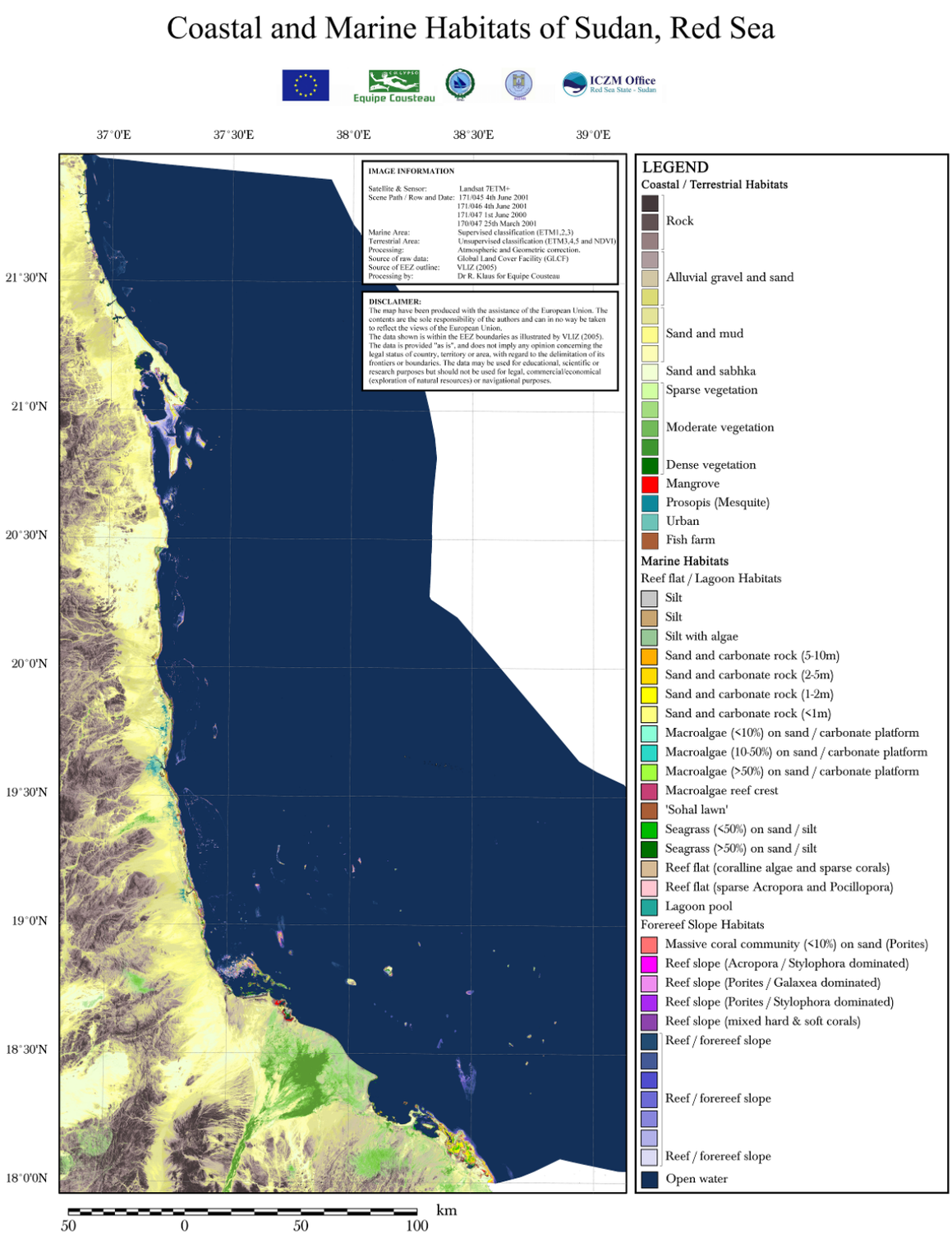
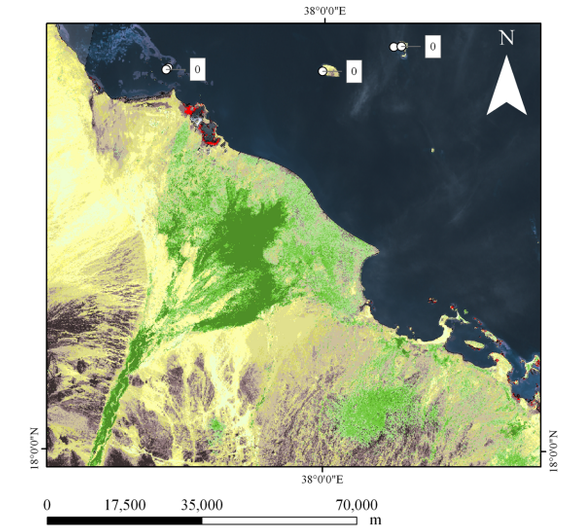
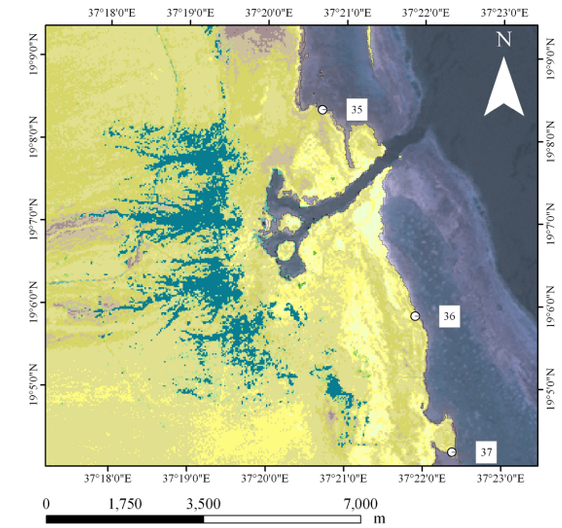


Figure 61: *Marine and terrestrial habitats of Sudan.The maps are derived from Landsat 7ETM+ satellite images. The marine and terrestrial areas show the classified habitats.*

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(a)



(b)

Figure 62 : *Maps illustrating the terrestrial habitats along the mainland coast of Sudan, showing:* **(a)** *the densely vegetated Tokar Delta, and* **(b)** *the area of Prosopis (shown in blue) inland from Suakin along the coastal road. Also shown are the location of REA sites surveyed in 2007 (circular marker). The maps are derived from Landsat 7ETM+ satellite images. The marine area is shown as a natural colour composite. The terrestrial areas show the classified habitats. The key is given in Figure 61.*

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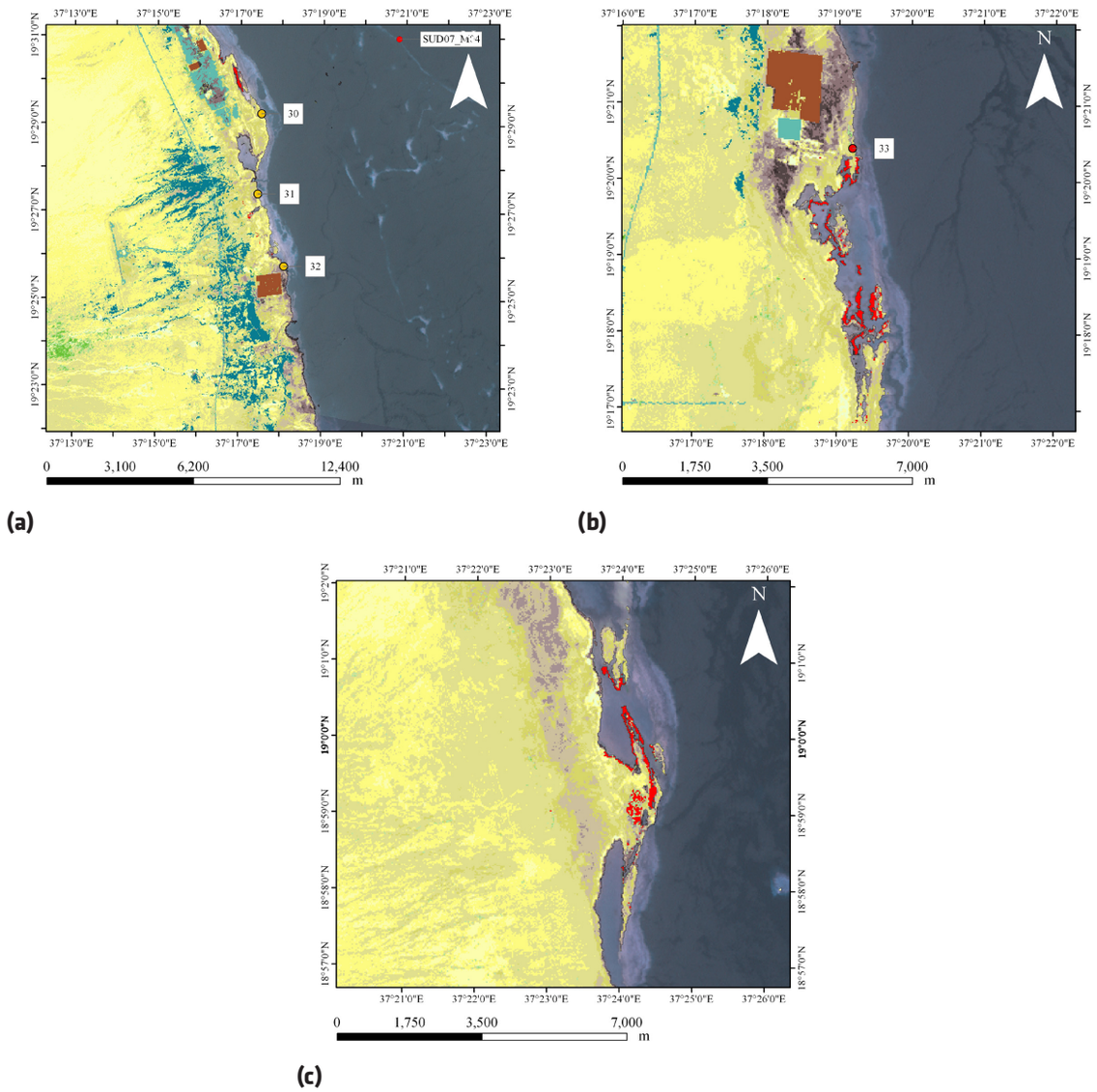


Figure 63: *Mangrove habitats (shown in red) along the mainland coast of Sudan, and the location of REA sites surveyed in 2007 (circular marker). The maps are derived from Landsat 7ETM+ satellite images. The marine area is shown as a natural colour composite. The terrestrial areas show the classified habitats. The key is given in Figure 61.*

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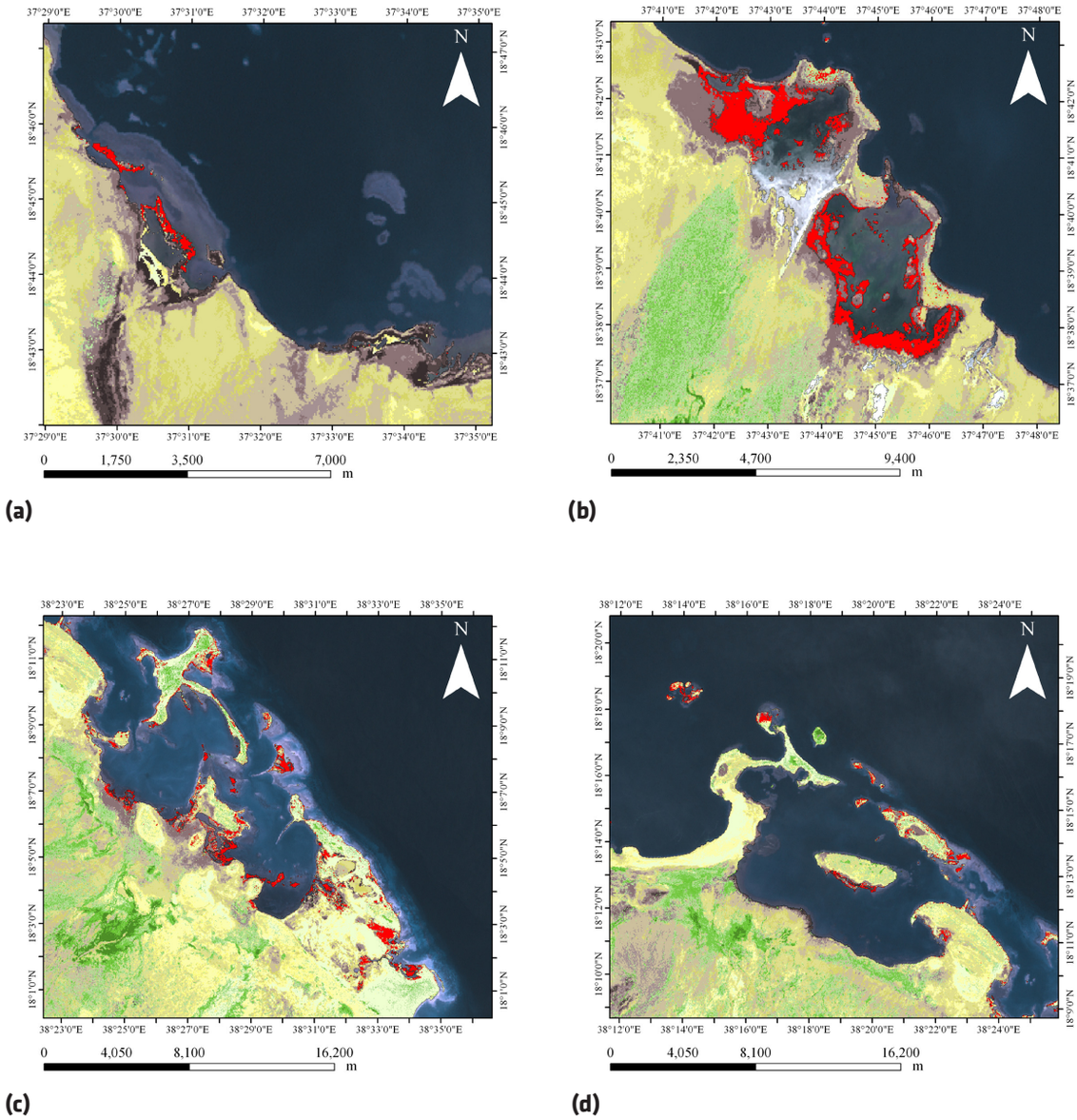


Figure 64: *Mangrove habitats (shown in red) along the mainland coast of Sudan, and the location of REA sites surveyed in 2007 (circular marker). All the sites shown are south of Suakin towards to the southern border. The maps are derived from Landsat 7ETM+ satellite images. The marine area is shown as a natural colour composite. The terrestrial areas show the classified habitats. The key is given in Figure 61.*

3.4.3.2 MARINE HABITAT MAPS

The marine habitats mapped are illustrated in Figure 61 and the extent of these habitats is shown in Table 33. The marine area mapped within the EEZ boundaries covered a total area of 66,604.4km^2. The majority of the EEZ of Sudan consists of deep open water, at depths beyond the limits that can be mapped using Landsat 7ETM+ (>20m). Shallow water habitats cover a total area of 1734km^2, which includes 1373km^2 of reef and lagoon habitats. The reef and lagoon habitats mapped are composed of fore reef slopes (58%), sand and carbonate platform (14.5%), seagrass on sand and silt (7.8%), macro-algae on the reef crest (5.9%), silt

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(5.3%), macro-algae on sand and carbonate platform (3.5%) and reef flat (3.2%). The habitats where hard and soft corals are typically dominant (fore reef slope and reef flat) cover a total of 843.9km^2 (61.5%). The marine habitats mapped within the areas surveyed in 2007 are illustrated in Figure 65, Figure 66, Figure 67, Figure 68, Figure 70 and Figure 71.

Table 33: *Area of marine habitats derived from the classified Landsat 7ETM+ satellite images.*

Marine Habitats	Area (km2)	%
Deep open water (>20m)	64870.4	97.40
Shallow coastal water	360.6	0.54
Reef and lagoon habitats	1373.3	2.06
Total Area (within EEZ)	66604.36	
Reef and Lagoon Habitats	**Area (km2)**	**%**
Silt	73.3	5.3
Sand / carbonate platform	199.2	14.5
"Sohal lawn"	12.0	0.9
Macro-algae (reef crest)	80.4	5.9
Macro-algae on sand / carbonate platform	48.7	3.5
Seagrass on sand / silt	107.1	7.8
Lagoonal pool	8.7	0.6
Reef flat	44.3	3.2
Fore reef slope	799.6	58.2
Total Area of reef and lagoon habitats	**1373.3**	

Table 34: *Sudan's coastal length (derived from the Landsat 7ETM+ satellite images)*

Coastal length (including Hala'ib Triangle)	Length (km)
Mainland coast	2044.73
Islands	882.02
Total	2926.75
Coastal length (excluding Hala'ib Triangle)	**Length (km)**
Mainland coast (without Halib Triangle)	1600.58
Islands	661.08
Total	**2261.66**

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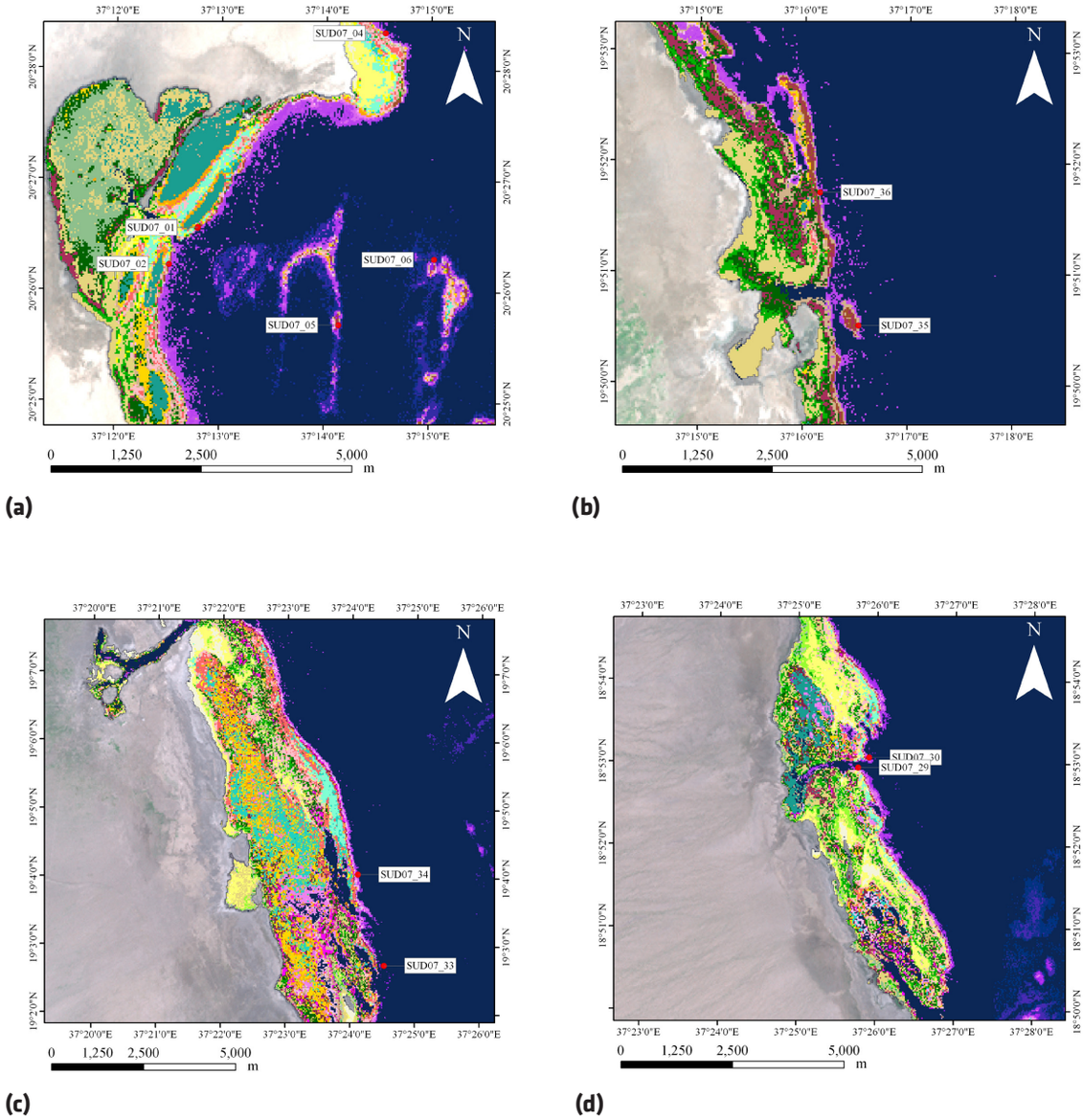


Figure 65: *Habitat maps illustrating the composition of the fringing reef habitats along the mainland coast of Sudan, and the location of sites surveyed on these reefs in October 2007 (red circular marker).* **(a)** *Marsa Salak, and the narrow fringing reef around the headland at Ras Salak;* **(b)** *The fringing reef in front of Marsa Daror;* **(c)** *The broad fringing reef and lagoon south of Suakin (in the north-west corner of the map) and* **(d)** *The dissected fringing reef at Marsa Sheik Ibrahim. The maps are derived from Landsat 7ETM+ satellite images. The terrestrial areas are shown as a false natural colour composite. The marine areas show the classified marine habitats. The key is given in Figure 61.*

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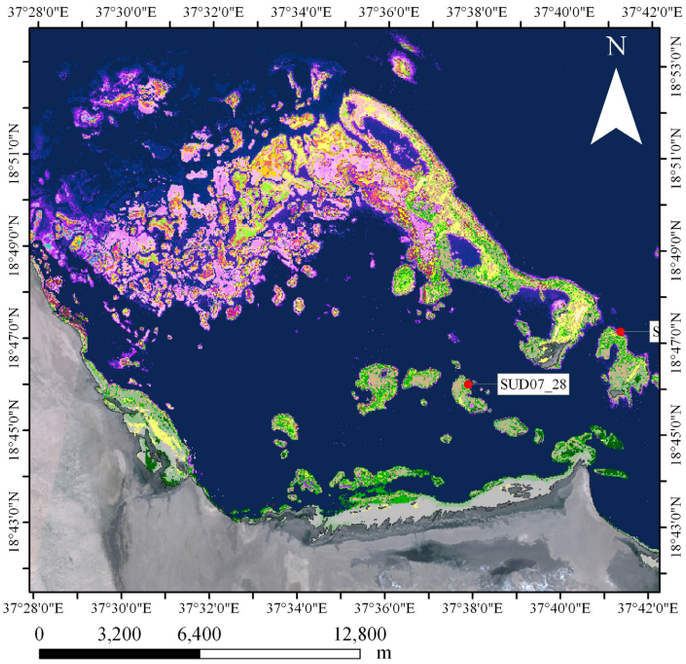


Figure 66: *Habitat maps illustrating the composition of the barrier reef complex at Shubuk. The map is derived from Landsat 7ETM+ satellite images. The terrestrial area is shown as a false natural colour composite. The marine areas show the classified marine habitats, the key for which is given in Figure 61.*

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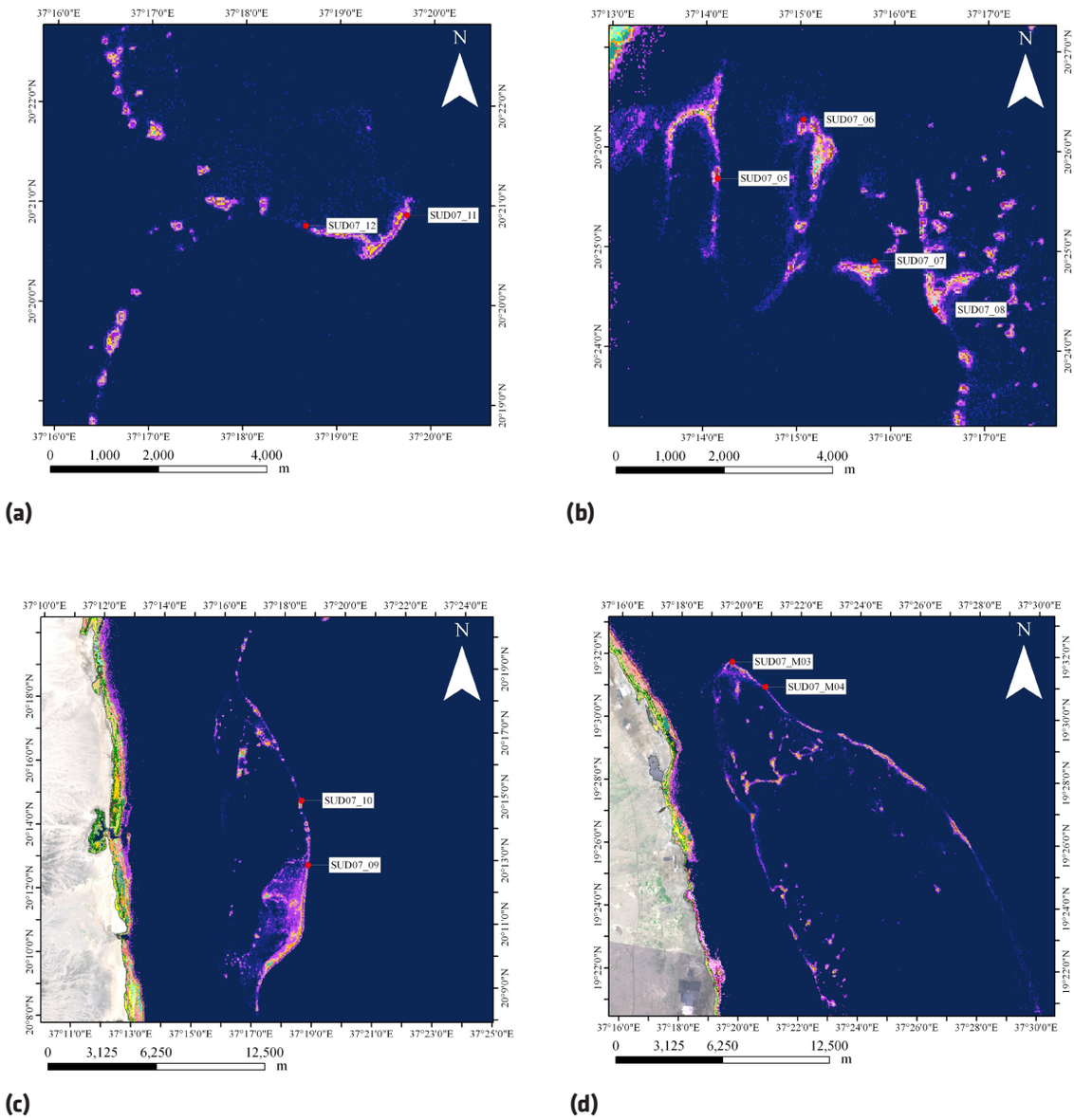
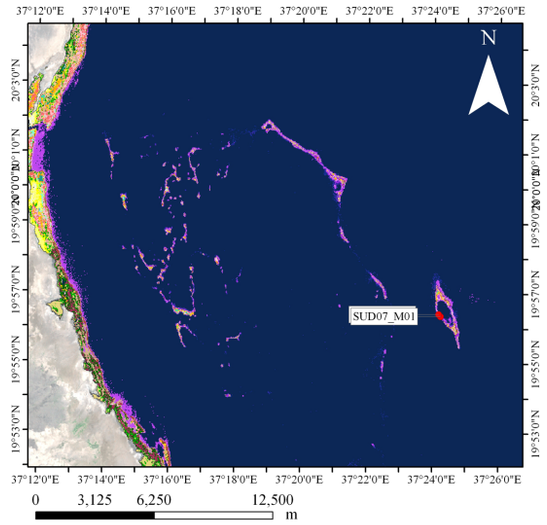
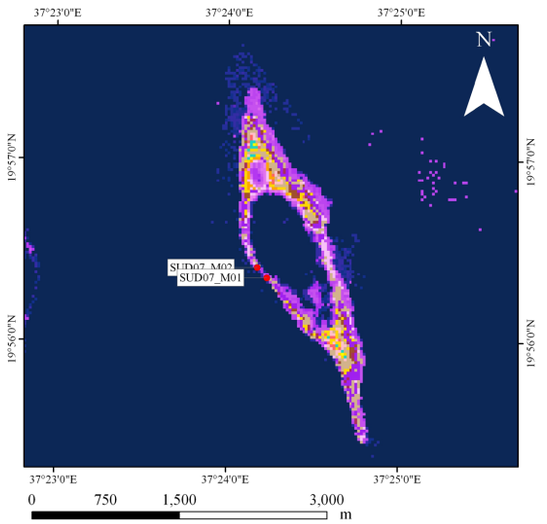


Figure 67: *Habitat maps illustrating the composition of the reef types found within the barrier reef complex off the coast of Sudan, at:* **(a)** *Sha'ab Salak,* **(b)** *Gorna,* **(c)** *Sudi and* **(d)** *the northern end of Towaritit, and the location of sites surveyed on these reefs in 2007 (red circular marker). The maps are derived from Landsat 7ETM+ satellite images. The terrestrial areas are shown as a false natural colour composite. The marine areas show the classified marine habitats, the key for which is given in Figure 61.*

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(a)



(b)

Figure 68: *Habitat maps illustrating the composition of the reef types found within: (a) the barrier reef complex off the coast of Sudan, and (b) the appearance of Chab Rumi, and the location of sites surveyed on these reefs in 2007 (red circular marker).The maps are derived from Landsat 7ETM+ satellite images. The terrestrial areas are shown as a false natural colour composite. The marine areas show the classified marine habitats, the key for which is given in Figure 61.*

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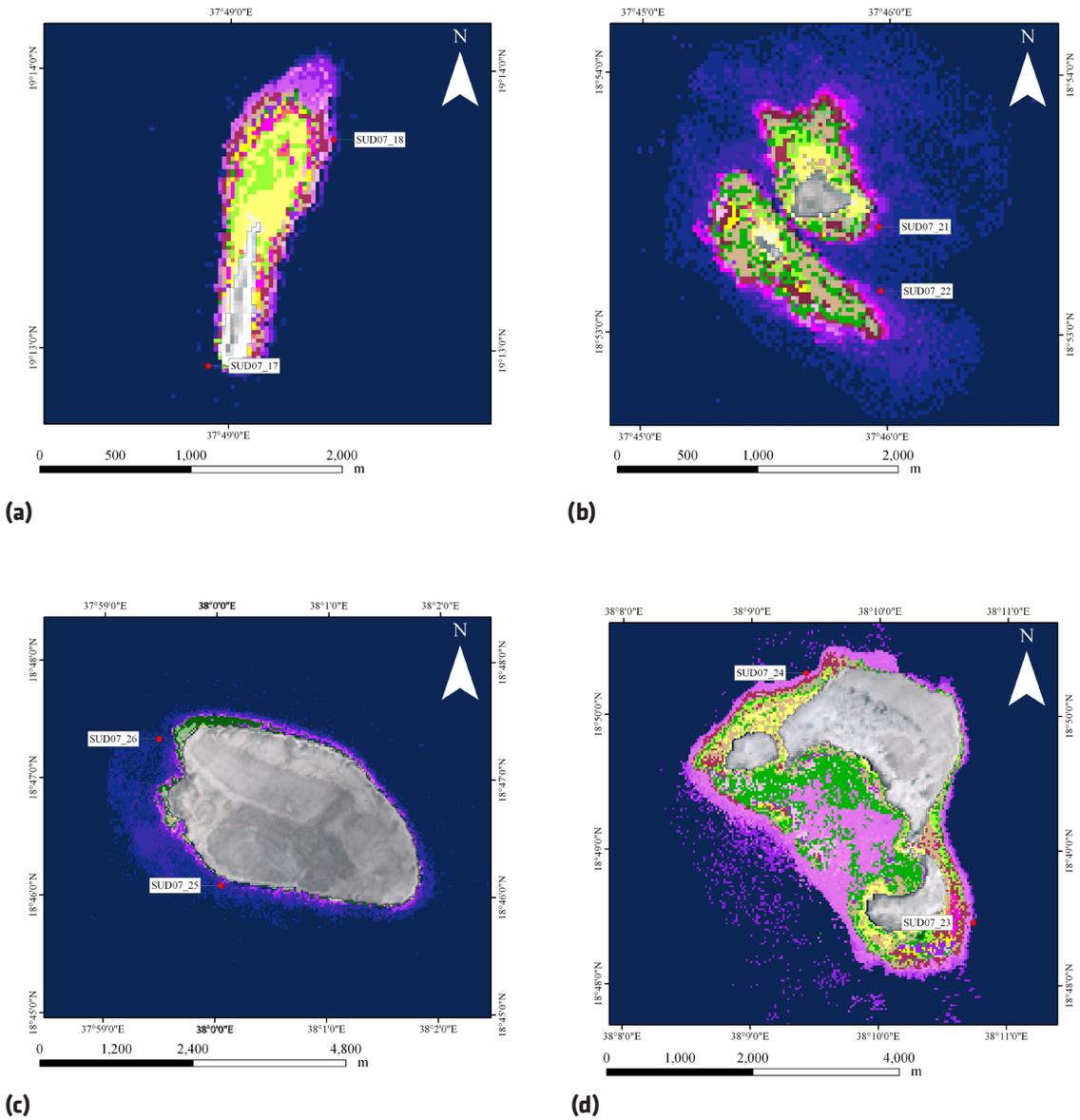


Figure 70: *Habitat maps illustrating the composition of island fringing reefs within the Suakin Archipelago.* **(a)** *Seil Ada Kebir, with extensive reef development to the north of the island;* **(b)** *Isle Harorayeat, comprised of two islands both with fringing reefs, separated by a reef lined channel;* **(c)** *Talla Talla Segir, a flat island with a narrow fringing reef and* **(d)** *Talla Talla Kebir, the most westerly island surveyed, is actually three islands separated by narrow channels, encompassed by a fringing reef, with a narrow reef around the northern coast and a broad bay to the south. The maps are derived from Landsat 7ETM+ satellite images. The terrestrial areas are shown as a false natural colour composite. The marine areas show the classified marine habitats, the key for which is given in Figure 61.*

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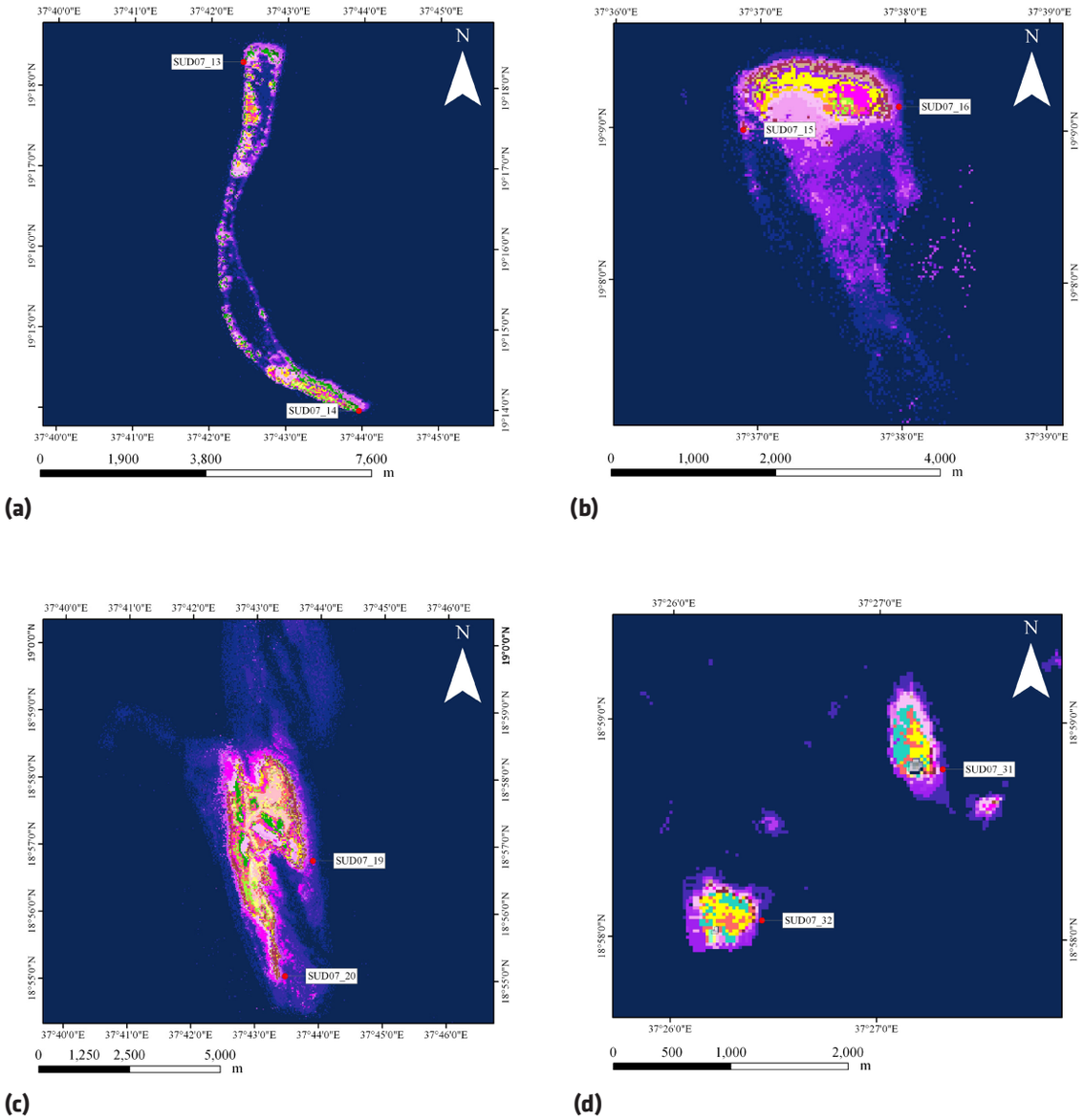


Figure 71: *Habitat maps illustrating the composition of other reef formations from the Suakin Archipelago, including:* **(a)** *Sha'ab Anbar;* **(b)** *Sha'ab Tawil;* **(b)** *Dhanab Qirsh and* **(d)** *Qad Eitwid and Qad Eitwid Cay, and the location of sites surveyed on these reefs in 2007 (red circular marker). The maps are derived from Landsat 7ETM+ satellite images. The terrestrial areas are shown as a false natural colour composite. The marine areas show the classified marine habitats, the key for which is given in Figure 61.*

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3.5 GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Activity linked to IOC Handbook Governance indicators (Table 2):

- ✓ **G13: Use of technology to enable and support ICZM**
- ✓ **G8: Sustained availability and allocation of human, technical and financial resources for ICZM, including the leverage of additional resources.**

3.5.3.1 WHAT IS A GIS AND WHAT IS ITS RELEVANCE FOR ICZM?

A GIS is a computer system capable of assembling, storing, manipulating and displaying numerous different types of geographical information. It includes the operating personnel and the data that go into the system (Figure 72).

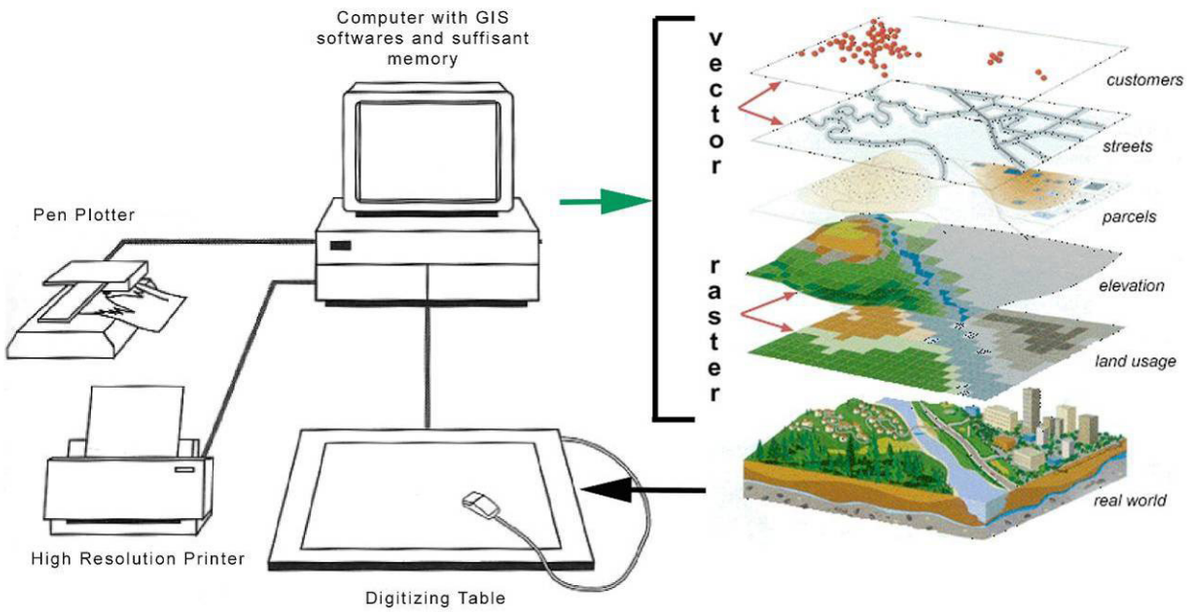


Figure 72: *Key hardware and processes of a functional GIS.*

Coastal zones are complex and dynamic places, subject to multiple resource demands and possible conflicts. The coasts of Sudan face particular challenges related to the management of all resources associated to the coastal zone, the economic development and the risks associated with this development.

The complexity of a coastal zone hosting important but fragile ecosystems, such as corals and mangroves, makes them inherently difficult to manage. Good quality and timely information that is easily understandable is key: it can assist coastal managers and decision makers to make the best choices.

A Geographic Information System (GIS) is one of the best decision-support systems which can be used in the management of spatial resources. GISs reflect many of the underlying principles of ICZM: interdisciplinarity, holistic aspect and integration of data. GISs are thus increasingly seen as a key tool in the preparation, delivery and monitoring of ICZM programmes (Figure 73).

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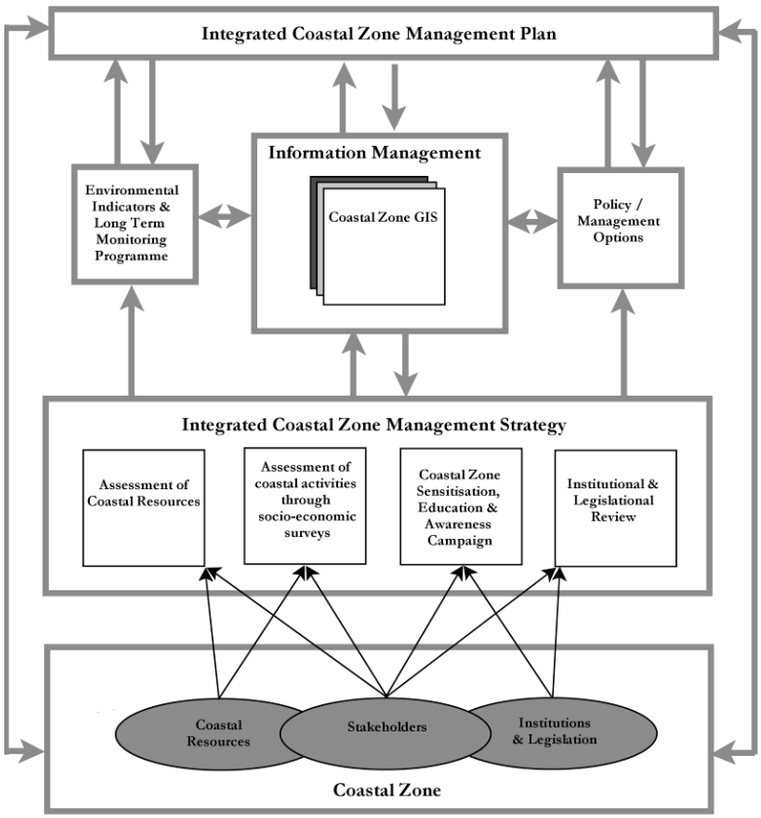


Figure 73: *GIS in an ICZM framework.*

Specific uses for GIS in ICZM programmes in Sudan might include:

- Assessment of Coastal Resources;
- Assessment of costal activities and conflict mapping;
- Development planning;
- Hazard management;
- Environmental Impact Assessment and
- Awareness raising, outreach and public participation.

3.5.3.2 IMPLEMENTING GIS IN RSS

The implementation of a GIS is a complex task that could be highly political and sensitive in a country like Sudan. Some data are considered to be strategic, and the partners selected to develop a Governmental GIS must be approved by the Red Sea State. The process itself requires that the relevant organisations are able to work together and can agree on access and data sharing. As a result, discussions surrounding the needs associated with the GIS often raise complex inter-institutional issues of relevance to the governance structure. This is inevitable, and the need to resolve these issues is part of this process. The original intention was to develop a GIS for the Red Sea State in partnership with Computer Man College in Khartoum. An initial assessment of this institution and their staff was undertaken in April 2007. While the staff did not have the skills necessary for processing satellite images of the marine environment they did have a very good understanding of remote sensing and, with a little training, would have been able to process the images and prepare the baseline maps necessary for the survey work, while developing their capacity at the same time. This process was initiated, the satellite images were given to the staff and they were ready to start work on the images. This collaboration did not, however, progress as anticipated due to issues at an institutional level (RSS and CMC) which the project was unfortunately unable to resolve. As a result, it became necessary to identify an alternative partner, agreed by the new governor of the Red Sea State, for the preparation of the

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baseline maps and the development of the first phase of a GIS for the State. Following this, our consultant visited Port Sudan in July 2007 to assess the existing GIS capacity and resources, and to identify the training and equipment needs for the establishment of a GIS within the RSS. A report was prepared that outlined local existing capacity and recommended various actions and alternatives. A summary of the key findings are given below.

3.5.3.3 THE CURRENT SITUATION IN THE RSS

The Red Sea State had limited capacity for information management and for GIS mapping. This situation was a state-wide issue that affected many of its Ministries and needed to be addressed urgently at State level. Some Ministries and their departments had people who had been provided with training in data collection, data handling and GIS technologies, and had a general understanding of the principles and possible application of these technologies. However, there were very few actual facilities within the Ministries where the necessary software and hardware was available, or where they were using the technology routinely in day to day work. It was therefore highly likely that even those people who had already been provided with training would require further GIS training: as with any skill, ability declines without practice, and the software evolves over time.

The Ministry that appears to have the largest number of staff who have been trained in these technologies was The Ministry of Physical Planning and Urban Utilities. This Ministry had some staff members within various Departments who had received some training in GIS over the past 2-4 years.

3.5.3.4 SUMMARY OF GIS CAPACITY IN THE RSS

Ministry of Physical Planning and Urban Utilities:
Survey Department

- *GIS Technicians*: 2 people trained in 2004 in GIS and ICZM, and 3 trained in South Africa.
- *GIS Facilities*: One or two computers available within Ministry. No GIS software, although crack copies of the software were in use. Employees were using personal laptops.
- *GIS Data*: Various hard copy datasets, mainly accessible through the Khartoum Office; limited access to satellite images and GIS data.

Planning Department

- *GIS Technicians*: 2 people trained in 2004 (one has since died, and the other is now employed as Mayor).
- *GIS Facilities*: None, one computer within offices, no software.
- *GIS Data*: None

Consultancy Group

- *GIS Technicians*: 2 people trained in 2004, one training in Malaysia, the other reportedly has limited GIS ability.
- *GIS Facilities*: One or two computers, and no software, although crack copies of the software are in use. Employees use personal laptops.
- *GIS Data*: A GIS technician had GIS data on his laptop.

Sea Ports Authority

- *GIS Technicians*: 3 people trained in South Africa.
- *GIS Facilities*: unknown.
- *GIS Data*: unknown.

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The Ministry of Environment and Natural Resources:

Information Centre

- *GIS Technicians:* None (two computer technicians).
- *GIS Facilities*: One or two computers and printer. No GIS.
- *GIS Data*: Various hard copy datasets, no access to GIS data.

FAO Office (in the process of establishment)

- *GIS Technicians*: None.
- *GIS Facilities*: None. Two computers, photocopier. No GIS.
- *GIS Data*: None available in Port Sudan yet, although FAO office in Khartoum has GIS Officer.

Given the limited local capacity identified within the RSS, it was necessary to identify alternative means to proceed with the development of the GIS unit Phase I without CMC.

3.5.3.5 CENTRE FOR ENVIRONMENT AND DEVELOPMENT FOR THE ARAB REGION

The regional Centre for Environment and Development for the Arab Region and Europe (CEDARE, see section on Consortium of partners) has been identified and selected as a suitable partner for future GIS work in the RSS. A work-plan for preparing the GIS data and establishing GIS Units within the ICZM Office has been agreed and the following activities performed.

Hardware & Software selection

All hardware for the three units were purchased and installed in Port Sudan. CEDARE developed the hardware specifications, which were sent to the ICZM office in Port Sudan and to vendors. A selection committee was formed in CEDARE and the decision taken to select Delta Services Enterprises, as suggested by the ICZM office in Port Sudan and as its offer met the specifications required for this project. It was also recommended because it is based in Port Sudan and it will be able to provide a local, technical backstop to the Unit, as well as provide and support the warranty for the hardware.

All software was requested through ESRI NEA, as Sudan is in their sales territory. ESRI NEA offered to give CEDARE a 40% discount. The resulting budget saving was re-allocated to the training budget, as explained in the training section. The requested software includes four ArcGIS 9.2, ArcView, one ArcGIS Spatial Analyst Extension and one AcrGIS Image Analysis Extension. In addition, licences for Anti Virus and Microsoft Office were ordered to be installed in the computers in Port Sudan.

A mission from CEDARE:

1. Made sure that all the purchased hardware and software were in place and functioned well and met the agreed specifications;
2. Installed all software on the machines and ensured that there were no technical difficulties or conflict between the hardware and software;
3. Conducted training in Advanced GIS and Remote Sensing, and on-the-job training in solving hardware/software conflicts and
4. Installed remote sensing data (LandSat images 1990-2000) on the machines, as well as other GIS data donated by CEDARE.

Training courses

A training course was conducted in the CEDARE premises on the use of GIS and remote sensing for coastal management. It focused on the introduction of GIS; more specifically, on the use of ArcGIS. Seven participants from Red Sea State participated in the course.

The course stressed hands-on training in using the ArcGIS software. In particular: an introduction to ArcGIS 9.x; exploring GIS concepts and displaying data; querying the database; working with layers; and map symbology.

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Working with “layout” and “editing data” were also introduced. The training covered the “spatial analysis functions and geoprocessing”. It also included several presentations from national and regional experts on the use of GIS applications in integrated coastal zone m anagement.

A site visit to a functional GIS unit inside the Egyptian Environment Affairs Agency was conducted to show the participants how their unit should operate and the type of application it could usefully produce for the decision makers.



Plate 22: *Training of ICZM Staff in GIS by CEDARE.*

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4 The Marine Protected Areas of Sudan

Linked to following IOC Socioeconomic indicator (Table 3):

- ✓ **SE 13 : Protection of coastal heritage resources**

4.1 SUDAN'S MARINE PROTECTED AREAS

The Government of Sudan (GoS), in recognition of its unique natural marine heritage, has established two nationally and internationally important flagship national parks to help protect and sustainably manage Sudan's marine resources. The parks, Sanganeb Atoll Marine National Park (SMNP) and Dungonab Bay-Mukkawar Island National Park (DMNP), were gazetted by official decree in 1990 and 2004 respectively.

The gazetting of DMNP followed the PERSGA[1] Strategic Action Programme for the Red Sea and Gulf of Aden (SAP 1), an initiative funded by the Global Environment Facility (GEF). The PERSGA MPA-SAP supported the baseline surveys inside DBNP in 2002 and the development of *Site-Specific Master Plan with Management Guidelines* for both SMNP and DMNP (Kemp et al., 2002).

Sudan's marine parks encompass a very diverse range of habitats, support high levels of biological diversity, provide representative examples of Sudan's marine environment and, by extension, the RSGA region more generally. Together, these parks provide a major *national, regional and global* contribution to marine and coastal conservation efforts.

As national parks, both SMNP and DMNP fall under the overriding jurisdiction of the Federal Government. However, the Federal Government designates and defines the involvement of the different State-level Ministries through the *Interim National Constitution (2005)*, Part 13, Chapter II: *"rights in land owned by the government of Sudan shall be exercised through the appropriate or designated level of government"*. The Red Sea State therefore has authority over some decision making regarding the parks, especially in terms of basic management issues, enforcement, development and land-use, and day-to-day issues[2]. Where decisions or activities falling under concurrent competence (joint power) may conflict with national interests, the State Government must coordinate with the Federal Government.

The African Parks Foundation (APF)[3] was invited by the GoS to take primary management responsibility for the parks and to work with the Sudanese Wildlife Conservation General Administration (WCGA) accordingly. APF signed a partnership agreement with the WCGA for the management and rehabilitation of DMNP

[1] PERSGA is an intergovernmental body dedicated to the conservation of the coastal and marine environments found in the Red Sea, Gulf of Aqaba, Gulf of Suez, Suez Canal, and Gulf of Aden surrounding the Socotra Archipelago and nearby waters. PERSGA's member states include: Djibouti, Egypt, Jordan, the Kingdom of Saudi Arabia, Somalia, Sudan and Yemen. PERSGA's legal basis stems from Article XVI of the Regional Convention for the Conservation of the Red Sea and Gulf of Aden, (The Jeddah Convention) signed in 1982. (www.persga.org).

[2] The Interim Constitution grants individual States authority to manage their natural resources. Because the marine/coastal environment is complex in nature, however, and many issues (such as fisheries, ports, oil extraction, as well as the national parks and associated tourism) have broader and national implications, the division of powers and extent of authority for the various government levels and institutions should be more clearly defined.

[3] The African Parks Foundation is the first private sector park management institution in Africa. It manages parks in public-private partnerships with governments on a long-term basis by combining world class conservation practice with business expertise. To achieve its integrative conservation goals, African Parks partners with a variety of entities including bilateral and multilateral donors, conservation NGOs, the private sector, foundations and individuals. Since its inception in 2000, African Parks has accepted responsibility for managing seven national parks in five different countries. Sudan's Marine Parks are the only marine areas managed by African Parks (www.african-parks.org).

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and SMNP in 2005, and subsequently assumed full management responsibility over the parks in July of that year. APF began negotiations regarding the terms of a new 20-year Agreement[4]; when these failed APF left Sudan.The parks are currently not being managed.

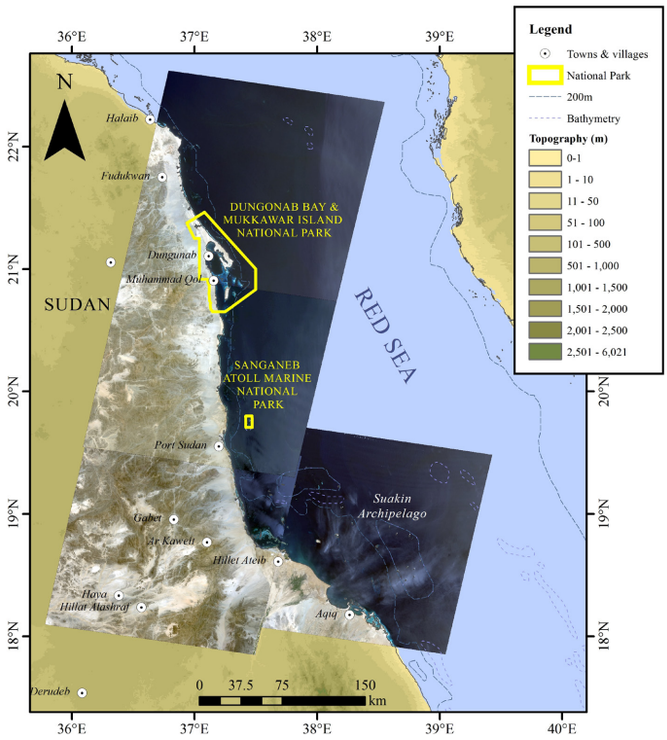


Figure 74: *Map showing the location of Sudan's existing Marine Protected Areas: Sanganeb Atoll Marine National Park (SMNP) and Dungonab Bay-Mukkawar Island Marine National Park (DMNP).*

4.1.1 Sanganeb Atoll Marine National Park (SMNP)

Sanganeb Atoll Marine National Park (SMNP) was the first marine protected area (MPA) to be declared by Sudan. As the only genuine atoll in the Red Sea, it is a regionally unique geological structure. The Atoll is entirely submerged, with the Sanganeb lighthouse (Figure 74) and its few surrounding buildings being the only part of SMNP to occur above the sea's surface.

SMNP is located in the central Red Sea, away from significant human impacts, approximately 30km north-east of Port Sudan at 19º 42'N, 37º 26'E. The existing boundaries of SMNP enclose an area of about 22km^2 (a rectangular block of 7.3km by 3.2 km around Sanganeb Atoll) and approximately 1km from the reef edge. The area of reef flat and shallow fore reef is approximately 2km^2, and the area of enclosed lagoon is approximately 4.6km^2. Around this core zone, a buffer zone is proposed that will extend the protection accorded to the park to a minimum distance of 6,000m from the reef edge, which will increase the area of the park to 270km^2. The buffer zone was designed to control potential impacts from sources such as shipping, fishing, mineral exploration and exploitative activities.

SMNP is a unique example (perhaps the best in the entire region) of the deep-water offshore reefs of the central Red Sea. It is considered to be within the Red Sea's centre of biodiversity. It has been regarded as an important area by marine biologists since at least the 1970s and was first identified as a viable UNESCO World Heritage Site as early as the 1980s. During the UNESCO World Heritage Marine Biodiversity Work-

[4] Following the withdrawal of African Parks in August 2008, as explained in section 1.1.4 above, if no effective management system is put into place to replace APF's presence, the proposed World Heritage status for the areas will be almost impossible to achieve, given that evidence of strong and long-term management is a prerequisite for inscription.

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shop, held in Vietnam in 2002, the MPA was identified by the attending international experts as an area displaying "significant components of Outstanding Universal Value" (Hillary, Kokkonen and Max, Proceedings of the World Heritage Marine Biodiversity Workshop: Hanoi, Vietnam, 25 February to 1 March 2002, World Heritage Paper No. 4). Furthermore, the Atoll lies within one of two proposed Ramsar sites identified along the Sudanese coast (UNEP, Post-Conflict Environmental Assessment, 2007).

SMNP supports a wealth of marine life and breathtaking underwater vistas, with reef slopes rising 800 metres from the seafloor. SMNP's diverse coral reefs and habitats support at least 361 fish species, as well as resident populations of dolphins, sharks, and marine turtles, which also use SMNP as a resting, breeding and feeding area. SMNP also hosts nurseries and spawning areas for key fishery species, which help support biological processes further afield throughout the Red Sea. Hydrographical, oceanographic and ecological conditions also make SMNP an optimal coral reef growth area, and recovery from the 1998 coral bleaching impacts is evident.

The combination of the above-mentioned features has long granted Sanganeb Atoll the reputation of being amongst the best dive sites in the world, and makes the Park an excellent candidate for World Heritage status.

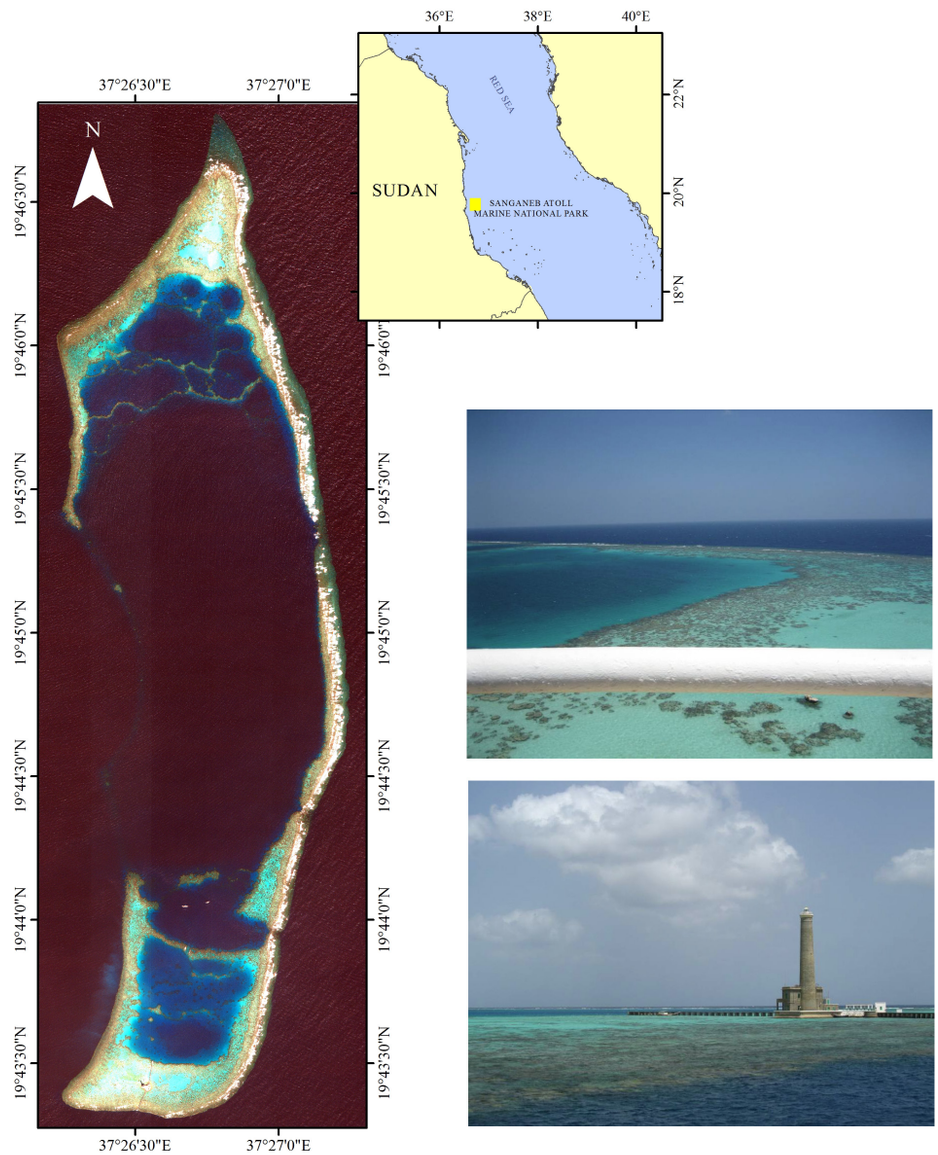


Figure 75: *Sanganeb Marine National Park, habitat map and photographs showing the view from the lighthouse.*

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4.1.2 Dungonab Bay-Mukkawar Island Marine National Park (DMNP)

The Dungonab Bay-Mukkawar Island National Park MPA (DMNP) was declared a National Park following biological and ecological surveys carried out in 2002 (Kemp et al., 2002). The surveys were carried out as part of the GEF funded PERSGA Strategic Action Programme for the MPAs in the Red Sea and Gulf of Aden (SAP 1). The PERSGA SAP 1 also supported the development of a *Site-Specific Master Plan with Management Guidelines* for both SMNP and DMNP. Following APF's involvement they began the development of a new Management Plan for DMNP (Samoilys 2008) which also included village level planning (Harrison and Samoilys 2007). APF also conducted a socio-economic assessment to establish sustainable livelihood options for people living within the DBMNP area (Harrison 2007).

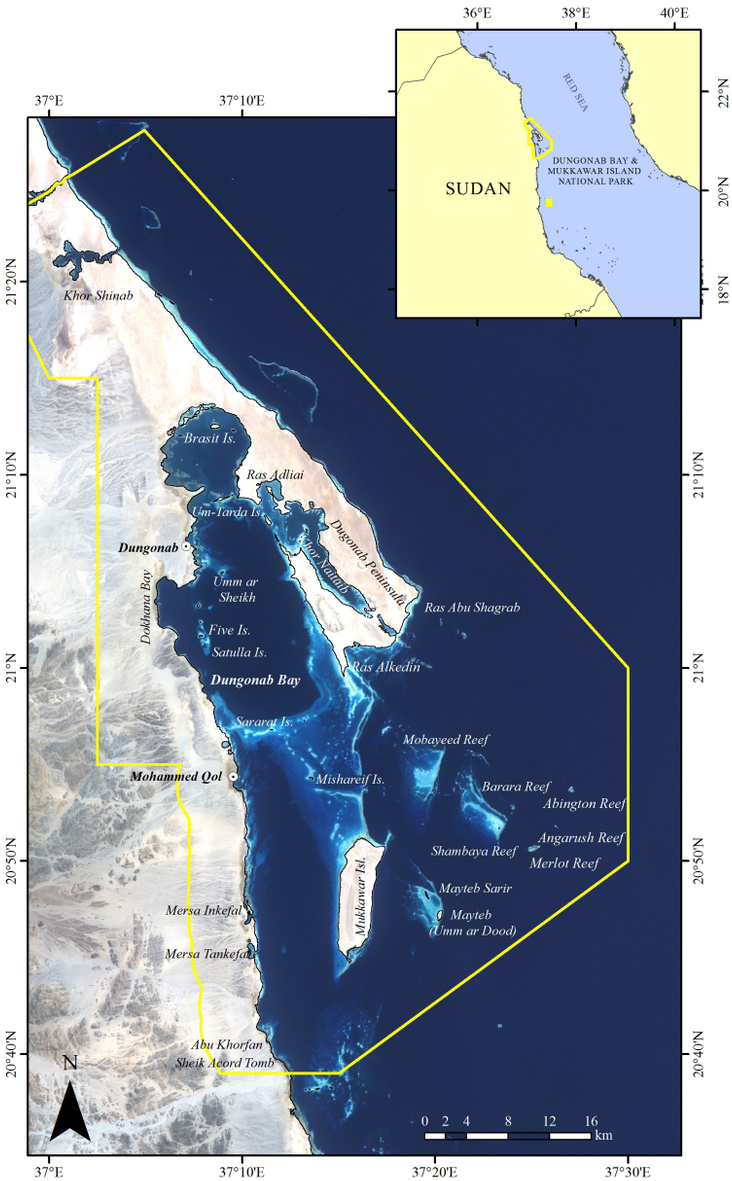
DMNP lies on the central Sudanese Red Sea coast, with its southern boundary approximately 125km north of Port Sudan. DMNP's total area equates to 2,800km^2 (of which 800 km^2 is land and 2000km^2 is marine). On its western (landward) side DMNP includes a substantial "buffer zone" of coastal land between 5km and 10km wide. This buffer zone includes the two principal villages of the area, Mohammed Qol and Dungonab.

On its eastern (seaward) side the MPA extends between 6km offshore at its northern end, and 30km offshore in the area of Mukawwar Island and the large complex of reefs to the south of the Dungonab Peninsula. The MPA extends a straight-line distance of approximately 70km north-south, and slightly over 40km east-west at its widest point. The total length of coastline in DMNP, including Dungonab Bay and Peninsula and the major islands, is over 200km.

The importance of DMNP cannot be overemphasised. The Park is not only aesthetically spectacular, with its unspoilt coastal landscapes and diverse seascapes (Figure 76), but it also supports high levels of biodiversity, including many endemic and endangered species. DMNP contains an array of habitat types, including extensive coral reef complexes, mangroves, seagrasses and intertidal and mudflat areas, which all enable the survival (breeding, feeding and resting) of significant populations of endangered dugong, sharks, Manta rays and dolphins, not to mention numerous other fish and invertebrate species. DMNP's extensive beaches, islands and coastal plains support large populations of seabirds, which have granted the entire area the international recognition as an "Important Bird Area" (IBA) by BirdLife International. These beaches also serve as important nesting areas for at least three species of marine turtle. The area was first recommended as a potential biosphere reserve in 1980.

Furthermore, DMNP holds much promise from a scientific perspective, as areas within the Park (namely Dungonab Bay) showed remarkable resilience in the face of the 1998 global coral bleaching event. The area could therefore provide valuable insights into optimal conditions that may resist climate-change-induced bleaching impacts (Klaus & Kemp, in prep.)

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Boundary Marker points:		
Marker number	Latitude	Longitude
1	21°25.506′N	37°01.13′E
2	21°22.53′N	36°56.32′E
3	21°15.00′N	37°0.00′E
4	21°15.00′N	37°02.50′E
5	20°55.00′N	37°02.50′E
6	20°55.00′N	37°06.80′E
7	20°39.00′N	37°08.85′E
8	20°39.00′N	37°12.05′E
9	20°39.00′N	37°15.00′E
10	20°50.00′N	37°30.00′E
11	21°0.00′N	37°30.00′E
12	21°27.84′N	37°04.926′E

Figure 76: *Dungonab Bay & Mukkawar Island National Park.*

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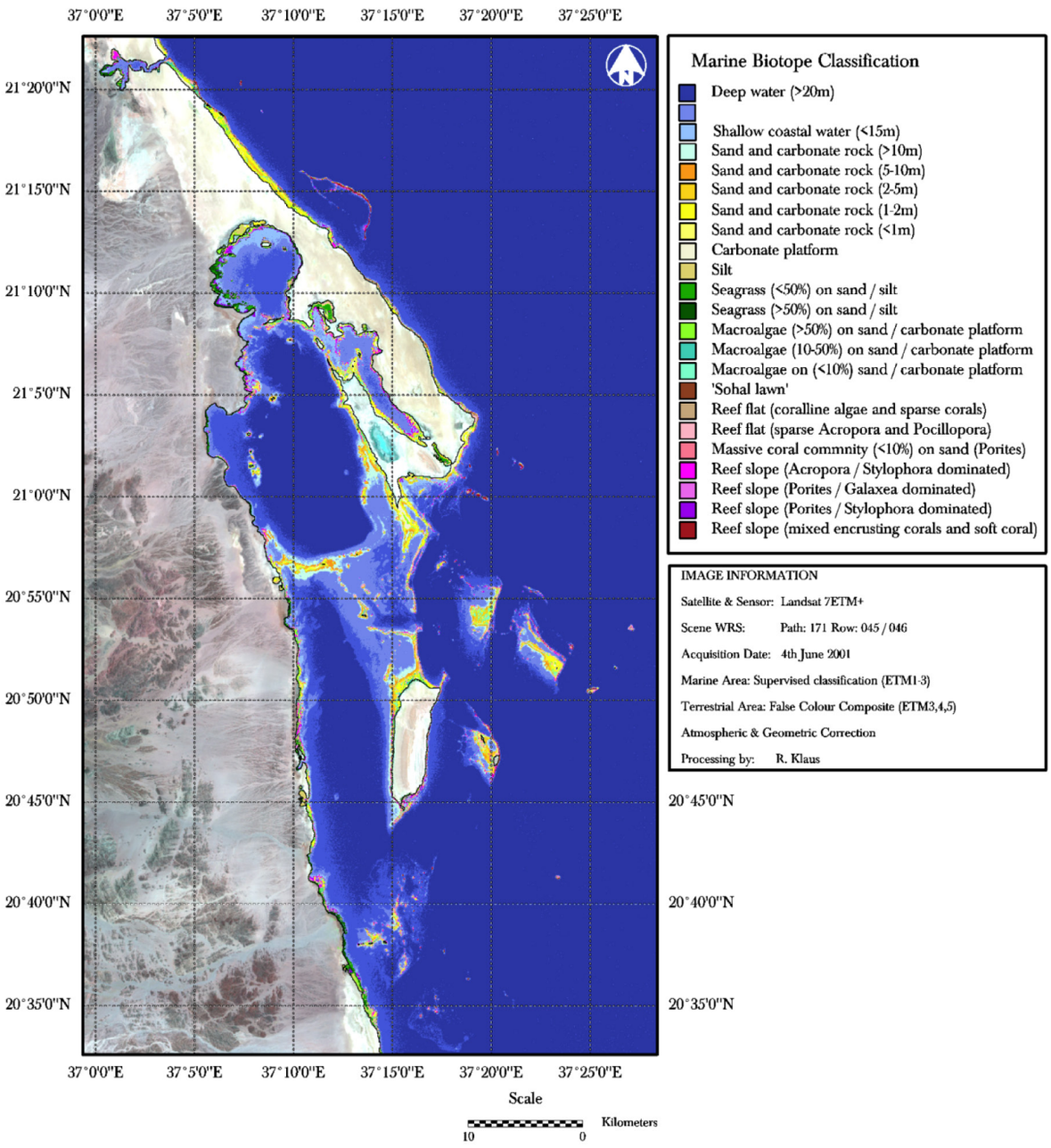


Figure 77: *Habitat diversity of the Dungonab Bay & Mukkawar Island National Park (Kemp et al., 2002).*

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Figure 78: *Examples of some of the bird species known to occur within Dungonab Bay-Mukkawar Island Marine National Park (DMNP).*

4.2 WORLD HERITAGE NOMINATION: PROCESS AND POSSIBILITIES

The serious pursuit of World Heritage (WH) status for Sudan's two MPAs commenced in 2006 alongside the ICZM activities in RSS. Accordingly, the development of a WH nomination for a serial site between DMNP and SMNP was included in the ICZM Survey Project Document:

The first step in the process towards WH nomination is the inclusion of proposed site(s) on Sudan's Tentative List[5]. Sudan first placed Sanganeb Atoll on its Tentative List (TL) in 1994 and updated this listing in 2004. In 2007 the ICZM Survey drafted a new TL for a serial site, entitled the Sudanese Red Sea MPA Network, that links together SMNP and DMNP. The new TL has been submitted to the HCENR in Khartoum and is awaiting approval and submission to the UNESCO World Heritage Centre Headquarters in Paris. The Survey has also drafted a complete WH nomination file for the proposed serial site. However, the nomination cannot go forward until after the new Tentative List has been approved.

As stated in the draft WH nomination document, the proposed Sudanese Red Sea MPA Network conforms with all four WH criteria used by the WH Committee to evaluate the potential of proposed natural sites for WH inscription:

[5] The WH nomination can be summarised as follows: (1) creation and submission of a Tentative List for potential sites; (2) preparation of a nomination file for a select site on the TL and submission to the WH Committee by the stated deadline; (3) if the Committee deems the nomination complete, it will transfer the file to an advisory body (in the case of proposed natural sites the advisory body is IUCN) which will then independently evaluate the WH potential of the site and communicate this (along with recommendations) to the WH Committee; (4) the WH makes the final decision as to whether or not a proposed site merits inscription on the WH List and can approve, defer or reject a nomination proposal. Sites must be considered of 'Outstanding Universal Value' and fulfil at least one of the evaluation criteria identified by the WH Committee (in the case for natural sites, four criteria are used). (http://whc.unesco.org/eng/nominationprocess/).

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Criterion vii: Contain Superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance:

The intrinsic aesthetic quality of the terrestrial and underwater features found in the Sudanese Marine Parks cannot be overemphasised. DMNP comprises a highly diverse complex of pristine habitats, including coral reefs, overlying fossil reefs (sometimes up to 15m high), mangroves, seagrass beds, extensive unspoilt beaches, bays and lagoons. The Red Sea Hills, rising to over 1500m, create a stunning backdrop to the area's gently sloping coastal plain. Beneath the surface, thriving coral reef kingdoms team with life and boast a myriad of colourful marine species, some completely unique to Sudan's marine ecosystem.

The unique topography of Sanganeb Atoll encloses a large central lagoon and is marked by a dramatic 800m rise from its base on the continental shelf. The drop-offs from the reef flat to the reef slope create vertical cliffs that host a spectacular diversity of fish and coral species. The combination of impressive geological structures and rich marine life, coupled by the superb water visibility reaching depths of up to 70m, has awarded Sanganeb the long reputation of being amongst the best dive-sites worldwide.

Criterion viii: Be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features:

The Red Sea forms part of an extended rift valley caused by the faulting and movement of the Arabian and African continental blocks. As a result, the Sudanese Parks encompass a broad range of structurally diverse and complex corals reefs that are representative of the reef types found off the coast of Sudan, and whose geological character was formed by this continental dislocation. The combination of well developed biogenic fringing coral reefs and offshore reef complexes has granted Sudan the distinction of being referred to as 'the central Red Sea barrier reef'.

These Parks also contain examples of unique or more unusual reef types, such as the deep Sanganeb Atoll, and the narrow coral reefs and shallow communities found within DMNP. Rising 800m from the Red Sea continental shelf, Sanganeb Atoll is the only geological structure of its type in the Red Sea, which raises interesting questions about the formation of atolls in general, and about the formation of Sanganeb Atoll in particular. Furthermore, SMNP exhibits perhaps the best example in the entire region of the deep-water offshore reefs of the central Red Sea.

Criterion ix: Be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals:

The combination of optimal temperature, visibility and salinity conditions creates an environment of exceptional regional and global coral growth and reef development within the Sudanese Parks. Due to these conditions, the number of coral species observed in the Sudanese Red Sea is greater than in either the northern or the southern Red Sea. Furthermore, SMNP serves as an important larvae export area, acting as a source of recruits for all species of plants and animals present in and around the reef, including invertebrates and fish species. SMNP also hosts important spawning sites for key fishery species.

The highly unusual salinity and temperature ranges found within Dungonab Bay have given rise to nature and ecology unique to the Red Sea Region and perhaps the entire world. These unusual conditions further help the Bay act as an important refuge for coral communities against the impacts of climate-change induced coral bleaching. DMNP's unique 'biogeographically displaced' species (representative of both northern and southern Red Sea species groups) encompass a variety of fish and coral communities more usually separated by several hundred kilometres.

Criterion x: Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation:

Sudan lies at the centre of biodiversity in the Red Sea and boasts high levels of endemism in fish and invertebrate species. The wide range of habitats present in both Parks will help ensure long-term protection of viable populations of important plant and animal species essential to the sustained health of biodiversity, making these Parks critical areas from both the global conservation and the scientific research standpoints.

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DMNP's key role for biodiversity conservation rests mainly with: (a) the varied and diverse fish and invertebrate communities it contains; (b) the optimal conditions of Dungonab Bay for coral reef resilience in the face of climate change; (c) the dependence of threatened/endangered flagship species (including a globally significant dugong population, at least three species of marine turtle and an abundance of key predators such as sharks) on the Park's ecosystem services and habitats (including some of the most expansive Regional seagrass beds representing at least 9 of the 10 Regional species, and extensive beaches allowing large-scale turtle nesting); (d) the seasonal aggregations of Whale sharks and Manta rays to DMNP are unique to the entire Western Indian Ocean region; (e) the entire Park area has been internationally recognised as an Important Bird Area (IBA) for both resident and migratory birds.

Sanganeb Atoll also serves as a biodiversity 'hotspot', lying at or close to the centre of marine biodiversity in the Red Sea and boasting hard and soft coral fauna that is amongst the richest in the region. Thriving on this rich reef ecosystem, over 300 fish species (including pelagics) inhabit SMNP. SMNP also hosts significant populations of globally important and endangered species, including: sharks, cetaceans, Napoleon wrasse (a vulnerable species according to the 1996 IUCN Red List species), grouper and marine turtles. SMNP also acts as an important spawning ground for key fishery species as well as a larvae export area.

4.2.1 Benefits and Implications of World Heritage Inscription

If properly utilised and harnessed by State parties[6] WH status can result in several benefits and implications for protected areas. Perhaps most importantly, WH listing provides an additional international layer of protection for conservation areas that can help buffer against unwanted development or deleterious resource use.

By signing the WH Convention, Governments commit to conserve the values for which sites have been inscribed, meaning all activities that take place within or near WH sites must not jeopardise their 'outstanding universal value'. WH status can therefore provide an impetus for authorities and stakeholders to: develop effective, long-term conservation management plans; strengthen legal mechanisms for protected areas; ensure sustainable use; encourage multi-sector participation in planning, management and site functioning; undertake monitoring, reporting and research activities; solicit collaboration in addressing site needs; and promote public awareness on the importance of protecting the natural environment and the inscribed site(s).

Furthermore, because of the potential for elevated visibility and international recognition following WH designation, inscribed properties can more easily benefit from enhanced opportunities (but without guarantees) for external financing, access to international expertise and sustainable tourism opportunities (and associated financial returns) over the long-term.

4.2.2 Next Steps for World Heritage Status of DMNP and SMNP:

The critical steps to be achieved before the Sudanese MPA Network can be nominated include:

- Approval of the Tentative List and submission to UNESCO WH Centre in Paris;
- Review, updating, finalisation and approval (by both State and Federal Governments) of the draft WH nomination prepared during the ICZM Survey;
- A clearly defined, effective and long-term management system for the Parks;
- A clearly defined delineation of responsibilities between State and Federal levels, and among the various implicated Ministries at both levels;
- Renewed communication and collaboration with WH experts for further progress in the WH nomination process.

[6] In order for the benefits of WH designation to be fully realised, States, organisations and local stakeholders must fulfil their responsibilities to maintain site integrity and maximise site potential

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4.3 RECOMMENDATIONS

The Sudanese Red Sea has to some extent escaped the widespread degradation that is evident on many other large areas of reef, both within the Red Sea and globally. However, this situation is changing rapidly. There are a number of serious and rapidly growing threats, including:

- Rapid and substantial coastal population growth;
- Rapid urban expansion, made environmentally unsustainable by urban planning and provision of public services and infrastructure which are insufficient to respond to growing populations and weak governance;
- Off-shore oil and gas exploration and oil extraction; increased ship traffic and associated risks, such as navigational hazards and oil spills;
- Unsustainable additional construction activities (such as dredging in the case of port development);
- Unsustainable fisheries, both for fin fish and invertebrates, with little active management. This is already evident at a national scale and includes both artisanal reef fisheries and the growing industrial-scale fisheries; and
- Increasing spread of tourism southwards from Egypt to central and southern parts of the Red Sea.

The combination of increasing human impacts with the anticipated increases in the frequency and intensity of global scale disturbances (increasing sea temperatures, sea level rise and associated threats from ocean acidification) pose a serious threat to the ecological integrity of these reefs and their associated biological communities. There is an urgent need for Sudan to adopt an integrated ecosystem-based approach to the management of the marine environment, including both cross-sectoral integration of planning for sustainability and the creation of a wider network of multiple-use and other marine protected areas.

In order to help achieve this, several specific recommendations arise from the marine and coastal habitats and biodiversity survey, which are described in more detailed below.

Hab HABITAT AND BIODIVERSITY

R-Hab-1 Complete geographically comprehensive baseline habitat and biodiversity studies in the following areas: While the 2007 surveys aimed to fill the gaps in understanding of the distribution and diversity of marine communities outside of the marine parks, it was not possible to access all of the areas due to logistical issues, including limited time, security and safety. Geographical gaps therefore remain, and further baseline surveys are required in the following areas:

- From Dungonab Bay (at approximately 21°15'N), northwards to the Egyptian border;
- From Shubuk (19°N), southwards, as far as possible, in the direction of the Eritrean border;
- Remote outer reefs, in the Suakin Archipelago, particularly those within the eastern and southern parts (also see recommendation R- HAB-4).

R-Hab-2 Develop and implement a National Strategy for the Management of Marine and Coastal Flagship Species: Sudan is host to important populations of a number of internationally significant flagship species, but there is only limited knowledge about the current health, status and distribution of these populations. This component should include:

- National scale surveys of flagship and threatened species and species groups (turtles, dugong and birds). These surveys need to consider seasonal patterns in migration and nesting.
- Continuation and extension of the shark and ray research programme.
- All such programmes should include design and implementation of national monitoring and management programmes *including long-term institutional capacity building strategies, without which sustainability of monitoring and management programmes will not be achievable.*

R-Hab-3 Establish a baseline water quality monitoring programme with sampling stations situated along the coast: At present, while there is some understanding of the broad environmental conditions within the Red Sea, there is relatively little specific information available about the water quality and hydrographic conditions within Sudanese waters. A baseline water quality monitoring programme with sampling

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stations situated along the coast will provide a better spatial understanding, increase understanding about distribution patterns of certain species and enable the early identification of pollution issues and other anthropogenic impacts. This programme should include:

- A basic water quality monitoring programme (salinity, sea water temperature, dissolved oxygen, nutrients including phosphates, nitrates, silicates etc);
- Productivity studies, including the use of satellite based remote sensing data (e.g. SeaWIFs) and zooplankton and phytoplankton studies; and
- Specific oceanographic studies (currents etc.) to increase understanding of the coastal processes and relative connectivity between areas along the coast, to help in planning for management.

R-Hab-4 Implement a detailed, specifically management-oriented, survey programme of the Suakin area and Shubuk: The results of the current surveys have highlighted the national importance of the Suakin Archipelago and adjacent mainland coastal reefs and lagoons, particularly in terms of the richness and diversity of marine communities that these islands and reefs support. It is therefore recommended that particular consideration be given to developing management strategies to protect the offshore islands and reefs, the mainland shore/fringing reefs in the Suakin Archipelago and the Shubuk reefs, islands, lagoon and shore. Both biological and socio-economic surveys will be needed in order to prepare detailed and specific management recommendations that will lead directly into the participatory development of a zoning plan and management for the entire area, including the mainland coast.

R-Hab-5 Implement fisheries management for sustainability: This currently appears to be largely lacking, and unsustainable fishing practices are having widespread and obvious effects on the majority of reefs throughout the survey area. Specifically:

- Establish closed zones (no-take zones) within existing Marine Parks as a matter of urgency, to maintain spawning and nursery grounds for exploited reef fishes. Ensure these closures are incorporated in a wider network of MPAs along the entire coast. Closed zones should also be situated so that they protect the spawning aggregation sites of groupers and snappers. Both taxa are known to form large aggregations to spawn which are highly predictable in space and time. The globally renowned SCUBA diving site of Sha'ab Rumi should be a closed zone where spearfishing should be prohibited.
- It is recommended that Sudan keep the "nagil" grouper fishery closed, irrespective of the export market, and that the "nagil" populations are monitored (by underwater visual census surveys) to measure recovery. The export fishery should not be re-opened until healthy population densities are restored.
- The sea cucumber fishery should be closed immediately and specific studies undertaken to determine the viability of establishing alternatives, such as aquaculture. If populations recover and the fishery is re-opened then a quota system should be introduced and no-take zones or closures enforced. Since SCUBA is used in this fishery it is essential that it be regulated for health and safety, and that investors/companies be required to provide SCUBA training to their divers.
- It is recommended that areas be closed to collecting of *Lambis* and *Strombus* gastropods for their opercula for the perfume industry, in cooperation with local fishers, to help populations recover. Dungonab Bay and Mukkawar Island and the two villages Mohammed Qol and Dungonab would be ideal places to trial this management approach, and the impacts of the closures should be monitored to assess population recovery by conducting abundance surveys of the molluscs with local fishers to engage them in the management of the fishery.
- It is recommended that Regulations, including a closed season and closed zones, are introduced for the trawl fishery, and that stock assessment research is conducted on both target species (prawns and lizard fish).

R-Hab-6 Urgently incorporate basic considerations of sustainable development into coastal development and infrastructure projects and initiatives at both the national and State levels: To include, for example, policy decisions on minimum distance of development (including roads) from the shore. Failure to do this at an early stage will incur incremental costs associated with environmental degradation and increased difficulty of management in the future. For example, the survey report and site specific management plan for the Dungonab Bay and Mukawwar National Park (PERSGA 2002, 2003) specifically included recommendations for a coastal set-back for the new road throughout the park. Those recommen-

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dations were not acted upon; possibly, they never even reached the responsible agencies for discussion. As a result, the management of that Park will, *in perpetuity*, be more challenging because road was routed so close to the shore.

R-Hab-7 Support the development of local collaborative management schemes for traditional fisheries, fully involving resource users in decision making, as well as monitoring and surveillance tasks. Community-based approaches to the monitoring, control and surveillance of coastal marine fisheries and protected areas are being adopted in many regions around the world. There are numerous advantages to supporting participatory approaches to the management of resources and opportunities exist in Sudan where this type of management could be demonstrated.

R-Hab-8 Adequately fund the marine Fisheries inspection and data collection services operating out of the Red Sea ports to enable monitoring of catches and offshore fisheries, including foreign vessels. Monitoring of catches by foreign vessels in Sudanese waters is currently lacking and further support and investment is urgently needed to implement inspection and data collection services.

R-Hab-9 Implement urgent management measure for the sea cucumber fishery: This fishery presents a serious hazard to human health, due to the practice of collecting product by SCUBA diving, an immediate measure would be to prohibit this practice in order to protect the deeper populations that then re-seed the shallow areas. If the fishery is opened up to collection by SCUBA again in the future, then it would be essential that it be regulated for health and safety, and that investors/companies be required to provide SCUBA training to their divers.

GIS GEOGRAPHICAL INFORMATION SYSTEM (GIS): A TOOL FOR ICZM DECISION MAKING

R-GIS-1 Continue to support the development of GIS to provide the basis for Marine Spatial Planning for the Red Sea State. All of the geospatial data collected during the ICZM Project has been integrated into a Geographical Information System (GIS), which can be improved and enriched with new datasets as these become available. With further development, the GIS would provide the basis for Marine Spatial Planning, to facilitate the sustainable use and conservation of the Red Sea State coastal and marine resources.

R-GIS-2 Establish and train a regional team of GIS specialists: There is a need to train a team of GIS specialists to increase capacity for data collection, data handling and geospatial data management and to establish an institutional home for the GIS.

R-GIS-3 Conduct an assessment of GIS capacity needs and identify appropriate institutional arrangements: The ICZM Project was able to assist the Red Sea State in the short term, by providing some GIS training and equipment. But capacity constraints are widespread in the RSS and these are not restricted to GIS and data management issues. A capacity needs assessment would help pinpoint current training and equipment requirements and help to identify possible institutional arrangements / options to ensure that a coastal and marine GIS unit could be sustained and managed into the future.

R-GIS-4 Develop a GIS Website and use it for awareness raising: The development of a website to showcase the marine and coastal geospatial data collected to date would help to raise awareness of the rich biodiversity and natural resources hosted within the Sudanese Red Sea among the general public and key stakeholders in Sudan and internationally.

R-GIS-5 Expand the applied use of remote sensing and GIS to improve decision making in RSS: The ICZM Survey resulted in the preparation of a basic GIS database for the RSS, which integrated the data gathered during this survey. Further work is now needed to increase the applied use of GIS and moreover to integrate the use of operational remote sensing data products for monitoring and assessing coastal and marine resources and oceanographic processes (e.g. sea surface temperature), to improve hazard management, oil spill planning and Environmental and Social Impact Assessment amongst others.

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MPA INTERNATIONAL SIGNIFICANCE OF SUDAN'S MARINE PROTECTED AREAS

R-MPA-1 Implement effective management of the two existing globally and nationally important MPAs at Sanganeb and Dungonab: Sudan's two national parks capture a significant proportion of the marine biological diversity of the northern part of the Sudanese coast. These MPAs could provide the foundation for the maintenance of ecosystem functions (connectivity, resilience, persistence) in Sudan and act as the nucleus for the establishment of a national MPA network. Further broad based support is now urgently needed to realise the effective management of these existing MPAs. The support would need to include institutional capacity building, monitoring, control and surveillance, amongst other aspects.

R-MPA-2 Expand the existing MPA network to meet the recommended 10% protection of all coastal and marine habitats by 2020. If Sudan is to meet its obligation to the CBD and the new Aichi target then it should be aiming to protect 10% of all marine and coastal habitats and 17% of all terrestrial habitats by 2020. Priority areas for the expansion of the MPA network could be identified using a Systematic Conservation Planning (SCP) approach and spatial decision support tools such as MARXAN. SCP is a method for identifying geographic areas of biodiversity importance to help decision-makers identify where to allocate limited biodiversity conservation resources to minimize the loss of biodiversity, ecosystem services and other valuable aspects of the environment. SCP is a robust evidence-based, conservation planning approach, the benefits of which have been demonstrated in both marine and terrestrial environments and across different scales (local, national, regional to global). SCP is an iterative process that requires the involvement of a broad range of government and other stakeholders and it is currently best practice in this field.

R-MPA-3 Implement Next Steps and Way-Forward for World Heritage Status of DMNP and SMNP: The critical steps to be achieved before the Sudanese MPA Network can be nominated include:

- Approval of the Tentative List and submission to UNESCO WH Centre in Paris;
- Review, updating, finalisation and approval (by both State and Federal Governments) of the draft WH nomination prepared during the ICZM Survey;
- A clearly defined, effective and long-term management system for the Parks;
- A clearly defined delineation of responsibilities between State and Federal levels, and among the various implicated Ministries at both levels;
- Renewed communication and collaboration with WH experts for further progress in the WH nomination process.

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