Ecology and Environment of
Boubyan Island in Kuwait

Isolated in the northwestern corner of the Arabian Peninsula, Boubyan Island remains intact with natural resources enriched by the fresh water from the Euphrates and Tigris rivers.

This book represents the most comprehensive database on the Island provided by the Kuwait Institute for Scientific Research (KISR) based on field studies from 2004 to 2006. It includes hundreds of images and illustrations with scientific information related to: habitats, geomorphology, air quality, soil and topography, wildlife and vegetation, weather and marine life, environmental impact assessment and sustainable master planning for future development. Incorporating a diverse range of scientific and ecological planning expertise, this work provides a foundation and background for an integrated, environmentally driven development approach to sustain the island's natural systems and processes.

"This scientific analysis conducted on Boubyan and Warbah Islands provides strong justification for decision makers to conserve the habitats and biodiversity of these islands. This has resulted in the establishment of the Mubarak Al Kabeer Marine Reserve in the north of Boubyan Island, covering about 60% of its total area."

Piet Wit, Chair, Commission on Ecosystem Management (CEM)
International Union for Conservation of Nature (IUCN)

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ISBN: 978-99966-37-08-7
90000
9 789996 637087

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Ecology and Environment of Boubyan Island in Kuwait

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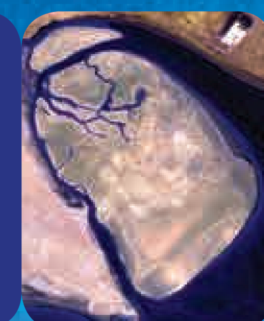
Ecology and Environment of
Boubyan Island in Kuwait



KISR Kuwait Institute for Scientific Research

Samira Ahmad Sayed Omar and Waleed Y. Roy
Kuwait Institute for Scientific Research

His Highness Sheikh Sabah Al-Ahmad Al-Sabah, Amir of the State of Kuwait

His Highness Nawaf Al-Ahmad Al-Jaber Al-Sabah, Crown Prince

Ecology and Environment of Boubyan Island in Kuwait

Samira Ahmad Sayed Omar and Waleed Y. Roy

Published by the Environment and
Life Science Research Center
Kuwait Institute for Scientific Research
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Published by KISR in collaboration with J. Ross Publishing, USA. Printed in 2014.

Omar, Samira A.
Ecology and environment of Boubyan Island/Samira A. Omar and Waleed Y. Roy
Kuwait: Kuwait Institute for Scientific Research, 2013.
ISBN: 978-99966-37-08-7
Depository No. 692/2013
1 – Environment-Kuwait
2 – Nature-Effect of human beings on.
3 – Human ecology-Kuwait
4 – Boubyan Island-Kuwait
i. Roy, Waleed Y.
KW-KcNLK GE320. K8 304.2

Foreword

Boubyan Island was, until recently, virtually unknown, tucked away close to the shore between Kuwait and Iraq, separated from the mainland by the Gulf of Subbiyah and not visited by anyone except the occasional scientist or passing fishing boat. From the mainland it appeared little more than a low mudflat. The 863 km^2 island was also off-limits for many years, due to its close proximity to Iraq. Much of the surface is virtually impassable in any case, covered with soft mud, blisteringly hot in the summer, apparently desolate and with no opportunities for agriculture. It seemed like that rare anomaly—an untouched land in the 21st century. Yet the unpromising appearance concealed rare biological riches, including vast flocks of seabirds and waders that pass through on migration and breed on the shallow mudflats.

The isolation changed abruptly when the Government of Kuwait made the decision to open a multi-billion-dollar port facility on the eastern coastline of the island, serviced by a brand new road bridge from the mainland, and combining a thriving business and living community. The port will serve as the main gateway to Kuwait, Iraq and the surrounding area and thousands of people will soon be living on the island.

At the same time the Government was quick to recognize the important wildlife values of Boubyan, and the decision was made to set aside the majority of the island as a strict nature reserve. Conserving the unique ecology and biodiversity now poses major challenges to the new port authorities and to the Government of Kuwait, which will have to contend with the influx of many people, risks of invasion by problem animals such as cats and rats, and potential pollution to the inland waterways. To understand what will be required to manage the protected areas to the high standards expected, and to build up a baseline of information about the status of the island, the Kuwait Institute for Scientific Research (KISR) worked with a range of partners to carry out the most detailed survey ever of the biological and cultural values of Boubyan and nearby Warbah Islands.

The results are reported in the following book: a distillation of research by many of KISR's scientific staff over a number of years. They have built up a distinctive snapshot of the plants and animals living on the island and in the surrounding waters, the weather patterns, chemical conditions, soil structure, geomorphology and surrounding tidal flows. This is not a simplified account, but a detailed exposition and record for scientists.

The authors also provide a clear conservation target for the island's developers to build a port and city without displacing the distinct ecological assemblages and important species that already live there. The data collected will form the basis of monitoring systems and provide the information needed to develop a detailed protected area management plan.

I commend this authoritative book as a valuable addition to our understanding of the natural sciences in Kuwait, and more broadly as a contribution to knowledge of the Arabian Peninsula.

Dr. Naji Al Mutairi
Director General
Kuwait Institute for Scientific Research

Acknowledgments

The editors would like to acknowledge the upper management of Kuwait Institute for Scientific Research (KISR) for their support and encouragement. Thanks are also due to the administration units at KISR for their technical assistance.

The editors would like to thank Nigel Dudley and Sue Stolton from Equilibrium Research, U.K. and Helen Miller and Jonathan Gledson of Miller Design, U.K. for making it possible to produce the document in its current presentation.

Thanks are also due to Mega Projects Agency/Ministry of Public Works, HOK (Hellmuth, Obata & Kassabaum Planning Group, Canada) and GC (Gulf Consult, Kuwait) for their support to KISR and for funding the survey projects conducted on the island.

Preface

The inflow of nutrient-rich fresh water from the Euphrates and Tigris Rivers, depositing its silt load in the extensive mudflats and salt marshes at the head of the Gulf, gave birth to Boubyan Island and enriched the main ecosystems found there.

Although the island has rich natural resources, it was not developed by the State of Kuwait due to its location and some physical characteristics that hindered its development. The topography of the island is low, the soil is saline and silty, and most of the surface area is bisected by deep intertidal channels and characterized by swamps. Much of the perimeter is comprised of sabkha, a hard crystalline saline surface, and the island lacks freshwater resources, which are essential for agricultural development.

Many preliminary studies were conducted on Boubyan Island, including the Soil Survey of the State of Kuwait project carried out in 1999 by the Kuwait Institute for Scientific Research (KISR) in collaboration with the Public Authority for Agriculture and Fish Resources (PAAFR). Part of the soil survey was conducted on the island and gave a general description of its soils.

In 2004, the Government of Kuwait decided to develop the island for multiple functions and uses. The Mega Projects Agency/Ministry of Public Works established a contractual agreement with HOK Canada, an international consultant planning group, and Gulf Consult (GC), a local Kuwait architectural and engineering office, to provide all necessary services needed for the *Environmental Assessment and Preparation of a Master Plan for Boubyan Island*. The Kuwait Institute for Scientific Research was subcontracted by HOK/GC as a consultant to conduct specific technical services relating to the project activities.

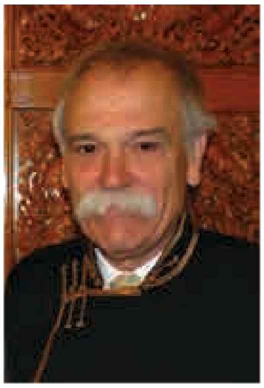
The overall objective of the project was to inventory, assess, and evaluate the existing environmental and ecological status of Boubyan Island, neighboring Warbah Island, and the surrounding marine areas. In addition, the project wanted to provide alternative land use studies based on field survey findings, culminating in a sustainable master plan.

KISR carried out a wide range of field studies, including topography, remote sensing, data management, meteorology, environmental impact assessments, and site planning inventories for fisheries, soils, flora, and fauna.

This book represents the outcome of the field studies carried out by KISR staff members, conducted over 25 months from 2004-2006. The book is organized into four sections: 1. The Physical Environment, 2. Environmental Monitoring and Environmental Impact Assessment, 3. Terrestrial and Marine Environments, and 4. Planning for Sustainable Development. The purpose of publishing this book is to provide a comprehensive, scientific compilation of available information, accessible to both scientists and planners, to be used as a reference to guide further development of the island.

The Editors
Dr. Samira Ahmad Sayed Omar
Eng. Waleed Y. Roy

Preamble



The Commission on Ecosystem Management (CEM) is one of the International Union for Conservation of Nature's (IUCN) six scientific commissions. CEM is a worldwide network of 1,000 volunteer experts working on ecosystem management related issues such as ecosystem based adaptation to climate change, disaster risk reduction, the Red List of Ecosystems, fisheries, and ecosystem restoration and services. One objective of CEM is to provide information on ecosystems and conservation of biodiversity. CEM works closely with other commissions, regional offices, and global thematic programs of IUCN. CEM pays specific attention to the input into its work of traditional and cultural knowledge and skills present in local and indigenous communities.

There are about 100,000 islands in the world that support 20% of our global biodiversity. CEM has several thematic groups that cover global themes and work in line with the overall mission of the Union. Among these thematic groups are networks of experts on island ecosystems and wetland ecosystems. Both ecosystems have culturally and economically unique characteristics; however they are under pressure from overexploitation of natural resources, climate change, and unsustainable development. These have caused and still cause major losses of biodiversity in island and marine ecosystems.

In the West Asia Region, which includes the Arabian Gulf Region, many islands host unique wildlife species and provide economically important marine resources that have been under pressure from overfishing, oil pollution, expansion in coastal developments, and climate change. The inflow of sediment- and nutrient-rich fresh water from the Euphrates and Tigris Rivers gave birth to the Boubyan and Warbah Islands of Kuwait and enriched the main ecosystems of these islands. The northern part of Boubyan Island has important features such as lagoons that provide a haven for the reproduction of shrimp and larvae of economically important fish resources.

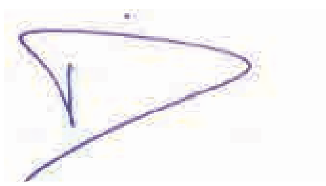
Limited efforts have been made to date to evaluate the natural habitats and wildlife resources on these islands and the need for their conservation. This book provides comprehensive information on the ecology and environment of Boubyan Island, prepared by scientists from the Kuwait Institute for Scientific Research (KISR). The readers of this book will find useful baseline information with images, illustrations, and data related to:

- Habitats and ecosystems of Boubyan Island
- Soil and topography
- Wildlife and vegetation
- Marine life
- Biodiversity
- Sustainable master planning and development

The book is organized into four sections: 1) Physical Environment, 2) Environmental Monitoring and Environmental Impact Assessment, 3) Terrestrial and Marine Environments, and 4) Planning for Sustainable Development. It provides a science-based document to be accessed by both scientists and planners, as well as to be used as a reference for future projects on Boubyan and Warbah Islands.

This scientific analysis conducted on Boubyan and Warbah Islands provides strong justification for decision makers to conserve the habitats and biodiversity of these islands. This has resulted in the establishment of the Mubarak Al Kabeer Marine Reserve in the north of Boubyan Island, covering about 60% of its total area.

CEM is committed to protect, manage, and sustainably use the natural resources of the world's islands. This book about Boubyan and Warbah Islands of Kuwait will undoubtedly contribute substantially to that goal. I therefore would like to express our compliments and gratitude to all the collaborators to this important publication.



Piet Wit, Chair, CEM

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Introduction

Kuwait occupies approximately 18,000 km^2 in the northeastern part of the Arabian Peninsula. The total area of the country includes nine islands. These nine islands together comprise about 1000 km^2. There are three large islands (Boubyan, Failaka and Warbah) and six small islands (Miskan, Awhah, Kubbar, Qaruh, Umm Al-Maradim and Umm an-Namil).

Boubyan Island is the largest island of Kuwait, located in the northeast of the country. Its large area (863 km^2) and unique strategic location make it of vital importance to the State of Kuwait in all aspects. It is located in the northwestern corner of the Arabian Gulf, in close proximity to the borders of Iraq, and is the second largest Island in the Gulf. Boubyan and Warbah islands are natural sanctuaries for wildlife, and due to the military conflicts that have occurred within the region over the last few decades, and the fact that the area has been heavily secured since the early 1990s, the islands have been little disturbed by human development. Boubyan and Warbah Islands are now Kuwait's last true wilderness areas.

Since 1970, minor studies were carried out on Boubyan Island. These were included in a detailed report in 1983 by the Ministry of Planning, to evaluate physical parameters associated with chemical, geochemical and the geographical features. Potential uses of the island were proposed, including a wildlife park and aquaculture projects. However, most of the studies focused on the soil type, general marine environment and water quality.

Limited efforts have been made to date to evaluate the natural habitats and wildlife resources on the island. The main reason for the lack of adequate information on wildlife could be attributed to the fact that most of the island's surface consist of sabkha in the south and salt marshes in the north that are difficult to access and survey. Another reason for an absence of data has been the restricted nature of the area, prohibiting free access to the island. In addition, many species utilizing the island are migratory birds, and these are on the island for only limited periods of time throughout the year.

The shift of Boubyan Island towards saline lands through seawater intrusion and subsequent evaporation has affected the environment and substantially altered its natural resources. It is a significant island formation, affected by a high concentration of water-soluble salts, creating an unusual and important ecosystem. Along the coastline of Kuwait in general, and in Boubyan Island in particular, salt accumulation has been accentuated and the area involved is becoming larger. Thus, Boubyan Island is greatly affected by both salinity and a high water table, which have together changed the soil's physical and chemical properties, as well as the type and distribution of the vegetation.

The Government of Kuwait, represented by the Mega Projects Agency/Ministry of Public Works, provided funds for the project *Boubyan Island: Environmental Assessment and Preparation of a Master Plan*. The international and local consultant team (HOK Planning Group, Canada and Gulf Consult [GC]) requested the Kuwait Institute for Scientific Research (KISR) to conduct environmental baseline studies and fieldwork survey investigations for the sustainable development of both Boubyan and Warbah Islands. The main objective of this book is to provide baseline information on the physical, biological, and atmospheric characteristics of Boubyan Island and to consider this information in the implementation of the master plan for the sustainable development of the island.

Note on place and feature names

Different translations from the Arabic script to Latin script of places names in Kuwait means that some graphics in this volume contain different spellings of Boubyan (e.g., Bubiyan) and surrounding areas.

Other important Arabic terms used in this document are:

- khors - tidal creeks or inlets
- nabkha or nebkha - sand drifts building in the lee of shrubs
- sabkha - salt flats

Section 1

The Physical Environment

1

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Section 1

Chapter 1: Remote Sensing Studies

Abstract

Various satellite data, such as Landsat, Radarsat, IRS, MODIS and OuickSCAT, were used to help undertake an environmental assessment of Boubyan Island to assist in preparation of a Master Plan. Dedicated Internet-user support from the National Oceanographic and Atmospheric Administration (NOAA), USA and the Jet Propulsion Laboratory, Physical Oceanography, Pasadena, CA, USA has been extremely useful in extracting sea surface temperature and ocean wind vector. The raw data from Landsat, Radarsat and IRS were processed with the remote sensing software PCI Geomatica.

Remote sensing has been useful for fieldwork and GIS applications. Several images were generated for Boubyan and Warbah Islands such as: enhanced Landsat 7 image (March 6, 2001 and April 29, 2003); GPS location for ground truthing and representing field visits; a satellite image of northeast Kuwait; Landsat 7 ETM+ image showing road access; Radarsat image; infrequency image showing a wide spectrum of terrestrial features; unsupervised classified images for fieldwork and site selection for field studies; vegetation images; pseudo-shaded relief images; enhanced IRS images (May 23, 2003); MODIS sea surface temperature images; ocean wind vector images and a color image generated from Landsat TM data, recorded on April 29, 2003.

Visual and computer-aided interpretation of remote sensing of processed output has led to successful extraction of geomorphological and physiographic information, limited by sensor capability and time availability.

Introduction

Boubyan Island is one of nine islands of Kuwait in the northeasterly coastal shoreline with Warbah adjoining it at the northwest. Located in the northwest of the Arabian Gulf, it is the largest island in area, situated between latitudes 29° 58' and 29° 35' northerly and longitudes 48° 23' and 48° 02' easterly (**Fig. 1**). The maximum altitude of Boubyan Island is approximately 5 m. Boubyan is a barren uninhabited island with both terrestrial and marine habitats. The climate is more or less the same as that of the rest of Kuwait.

Boubyan Island and Warbah Island together comprise about 6% of Kuwait's total land area, covering 863 and 37 km^2 respectively. Boubyan and Warbah are of strategic importance to Kuwait, since they represent Kuwait-Iraq-Iran triangular borders. A road bridge, built from 1981 to1983 with total length of 2380 m, joins Boubyan Island to mainland Kuwait.

Boubyan Island is about 45 km x 27 km, and its orientation is approximately northwest and southeast. The longest distance east-west is about 32 km and north-south is about 45 km. The total coastline of Boubyan Island is about 142 km. The island lies at the estuary of the tidal estuary of Shatt Al-Basrah, which is about 30 km from the eastern part of the island.

The width of Shatt Al-Boubyan near Subbiyah power plant is about 2.5 km. The coastal water is muddy with high concentrations of suspended clay and silt. Based on visual observation, the water current is apparently very high (of the order of more than 1 m/sec). The intake and discharge

Fig. 1. Location image of Boubyan Island (Landsat 7, recorded on March 6, 2001)

Fig. 2. Reconnaissance soil map of Kuwait (KISR, 1999a)

of water for the power plant, along with the tide-induced currents and some local waves generated by the winds, make the current pattern highly complicated.

An initial literature survey indicated that little research has been carried out on Boubyan Island; in particular there have been few studies using remote sensing techniques. Although remote sensing studies have taken place over the whole of Kuwait they are insufficient for the current project to prepare a sustainable management master plan for Boubyan.

A reconnaissance soil map of Kuwait and a land use map (**Figs. 2 and 3** respectively), prepared by the Kuwait Institute for Scientific Research (KISR, 1999a) and the Public Authority for Agriculture and Fish Resources (PAAFR), are useful in the supervised and unsupervised classification of the island using image processing and analyzing software.

Reconnaissance Field Surveys

Field trips were conducted in September 2003, and Global Positioning System (GPS) locations of interest were noted for ground truthing. The locations were plotted on the image generated from a 2001 Landsat image (**Fig. 4**), and descriptions of identified features from the field visit are given in **Table 1**. Trips to the southern part of the island were covered by jeep, while the northern part was explored by boat through channels to get an overall view of the topography, oceanography, general physiography and other features.

Remote Sensing Technical Approach

Interpretation was needed to extract meaningful information from the remotely sensed images of Boubyan Island. Data may be used to detect, identify, measure and evaluate the significance of environmental and cultural objects and spatial relationships. Data also can be used to create maps, or to collect statistics for various features related to occurrence, frequency, and patterns, and may be used to detect historical changes in Boubyan Island.

Image Processing

The satellite data, such as Radarsat, Landsat and Indian Remote Sensing (IRS) data, were processed using PCI's Geomatica software. Image processing software is the latest version of PCI's software. The image processing unit is built around a networked Sun server and two Sun Sparcstations.

All the satellite data were geometrically corrected and radiometrically normalized before further processing for image analysis. Images were co-registered with the base image, which was already co-registered with a base map. Normalizing the images radiometrically means to normalize the dependence of haze caused by scattering at different times, which is important for seeing the changes that occur in different years. The images were co-registered using Universal Transverse Mercator (UTM) coordinates. For each image, 25 ground control points (GCPs) were selected, and resampling was done for two images at a time with second order polynomial and the nearest-neighbor method. Generally, the accuracy varied from 0.25-0.35 pixels, but attempts were made to keep the co-registration accuracy of two images under 0.35 pixels both in the x and y directions.

Various outputs were generated supporting field investigation, information interpretation and extraction. The output images were produced in scales of 1:150,000, 1:130,000 and 1:75,000 depending upon the spatial resolution of satellite data under study.

Remote Sensing Imaging Output Generated

Landsat 7 Image of Boubyan Island

A Landsat 7 Enhanced Thematic Mapper Plus (ETM+) bands 2, 4 and 7 color composite image (Fig. 1) of Boubyan Island was generated from the image recorded on March 6, 2001, projecting through blue, green and red filters. These bands represent the three spectral groupings of the TM band, namely the visible (band 2), near-infrared (band 4) and mid-infrared (band 7), with their functions as follows:

- Band 2: Measurement of visible green reflectance peaks of vegetation for vigor assessment.
- Band 4: Determining biomass content and delineating water bodies.
- Band 7: Study of geology, soil and hydrothermally altered zones.

Fig. 3. Land use map of Boubyan Island and the surrounding area (KISR, 1999a)

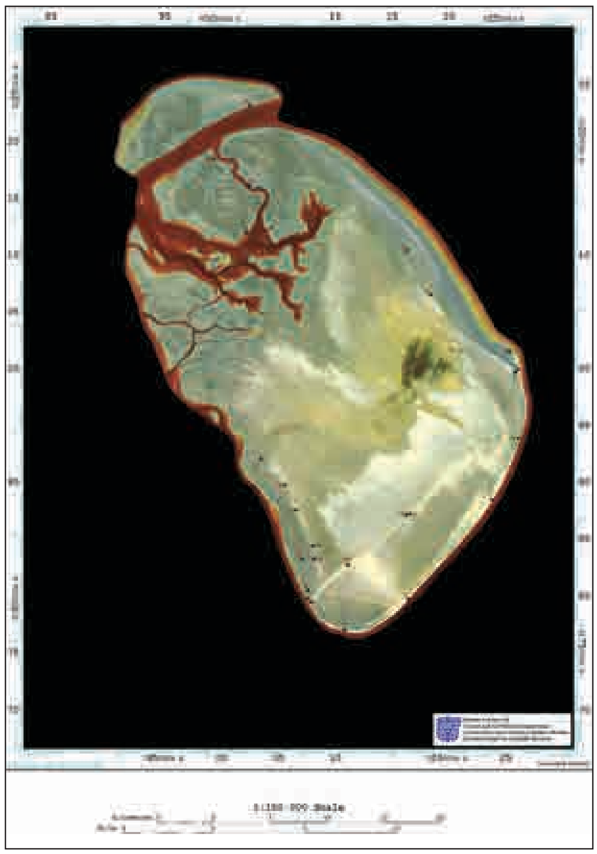

Fig. 4. GPS location plotted for ground truthing on Landsat image recorded on March 6, 2001

1

Table 1. GPS Location of Study Sites at Boubyan Island in September 2003

S. No.	GPS Reading		Geographical Position		Description/Comments
1	29d 36'.669"	N	29d 36'37.5"	N	Check post
	48d 10'.691"	E	48d 10'30.9"	E	
2	29d 36'.423"	N	29d 36'25.38"	N	Iraqi vehicle debris
	48d 10'.653"	E	48d 10'39.18"	E	
3	29d 35'.065"	N	29d 35'3.90"	N	Tidal inlet
	48d 12'.508"	E	48d 12'30.48"	E	
4	29d 36'.456"	N	29d 36'27.36"	N	Military fortification
	48d 16'.039"	E	48d 16'2.78"	E	
5	29d 41'.066"	N	29d 41'3.96"	N	Military fortification
	48d 20'.732"	E	48d 20'43.92"	E	
6	29d 43'.919"	N	29d 43'55.14"	N	Salt crust
	48d 22'.281"	E	48d 22'16.86"	E	
7	29d 47'.213"	N	29d 47'12.78"	N	Sandy beach
	48d 22'.347"	E	48d 22'20.82"	E	
8	29d 47'.100"	N	29d 47'6.00"	N	Salt crust
	48d 22'.217"	E	48d 22'13.02"	E	
9	29d 48'.106"	N	29d 48'6.36"	N	Muddy beach
	48d 21'.954"	E	48d 21'57.24"	E	
10	29d 50'.898"	N	29d 50'53.88"	N	Dead palm trunks
	48d 17'.700"	E	48d 17'42.00"	E	
11	29d 53'.036"	N	29d 53'2.16"	N	Oil well
	48d 16'.431"	E	48d 16'25.86"	E	
12	29d 36'.972"	N	29d 36'58.32"	N	Vegetation
	48d 10'.649"	E	48d 10'38.94"	E	
13	29d 38'.165"	N	29d 38'9.90"	N	Three water tanks
	48d 12'.828"	E	48d 12'49.68"	E	
14	29d 40'.412"	N	29d 40'24.72"	N	Intersection of roads
	48d 16'.033"	E	48d 16'1.98"	E	
15	29d 40'.497"	N	29d 40'29.82"	N	Abandoned military camp
	48d 16'.189"	E	48d 16'11.34"	E	
16	29d 38'.496"	N	29d 38'29.76"	N	Oil pollution
	48d 10'.989"	E	48d 10'59.34"	E	
17	29d 38'.493"	N	29d 38'29.58"	N	Oil pollution
	48d 10'.285"	E	48d 10'17.10"	E	
18	29d 39'.099"	N	29d 39'5.94"	N	Man-made pits
	48d 10'.919"	E	48d 10'55.14"	E	
19	29d 40'.810"	N	29d 40'48.60"	N	Exposed groundwater
	48d 10'.047"	E	48d 10'2.82"	E	
20	29d 42'.030"	N	29d 42'1.80"	N	Military debris
	48d 09'.528"	E	48d 09'31.68"	E	
21	29d 43'.289"	N	29d 43'17.34"	N	Vegetation, mudflats
	48d 08'.239"	E	48d 08'14.34"	E	
22	29d 53'.984"	N	29d 53'59.04"	N	Muddy shore with coast berm
	48d 07'.838"	E	48d 07'50.28"	E	
23	29d 56'.358"	N	29d 56'21.48"	N	Main channel Khor Milah
	48d 07'.888"	E	48d 07'53.28"	E	
24	29d 57'.660"	N	29d 57'39.60"	N	Entrance Khor Milah
	48d 06'.109"	E	48d 06'6.54"	E	
25	30d 00'.015"	N	30d 00'0.90"	N	Warbah Coastal Guard Center
	48d 08'.254"	E	48d 08'15.24"	E	

Satellite Image of Northeast Kuwait

A Landsat 7 ETM+ color composite image was generated showing the accessibility to Boubyan Island from Kuwait City (**Fig. 5**). The multispectral image was digitally processed using bands 7, 4 and 2 projecting through red, green and blue filters. The image was enhanced with a root-enhanced algorithm and by modifying the lookup table for better visual interpretation of various features.

Different shades and textures represent the various geo-terrestrial features based on the different magnitudes of reflectance for a specific range of spectrum recorded on March 6, 2003, by sensors onboard the Landsat 7 satellite.

Landsat 7 ETM+ Image Showing Road Access

An image (**Fig. 6**) was generated considering fieldwork in the southern part of Boubyan showing road access during different seasons. Five traveling routes were identified. The roads were categorized into three safety levels, as follows:

- Safe for all seasons;
- Safe during summer; and
- Unsafe at all times.

Unclassified Image for Boubyan and Warbah Islands

A modified infrequency image (**Fig. 7**) was generated from fused Landsat 7 imagery (recorded on March 6, 2001). The modified infrequency function produces an output image where infrequently occurring gray levels are assigned high gray levels in the output and vice versa from synergistically combined multispectral bands 2, 3 and 4 with higher resolution panchromatic band 8 of ETM+. Hence, the output unclassified image has spectral details of the multispectral bands with spatial details of the panchromatic band, which supplies information for research into a range of different related disciplines. The pseudo-color image represents different shades and brightness depending upon the magnitude of reflectance collected by sensors based on topography, roughness, soil moisture, salinity, physical and chemical properties of soil, water turbidity and depth, vegetation distribution and density, etc.

The subset of the area of interest (AOI) covering Boubyan and Warbah Islands was selected with outer boundaries extending to the marine area with a buffer zone to avoid the confusion of uncertain shoreline or land-sea boundary. The subset gives the advantage of enhancing the satellite data in a more specific manner.

Fig. 5. Satellite image of northeast Kuwait (Landsat 7, March 6, 2001)

Fig. 6. Landsat 7 (March 6, 2003) image showing road access

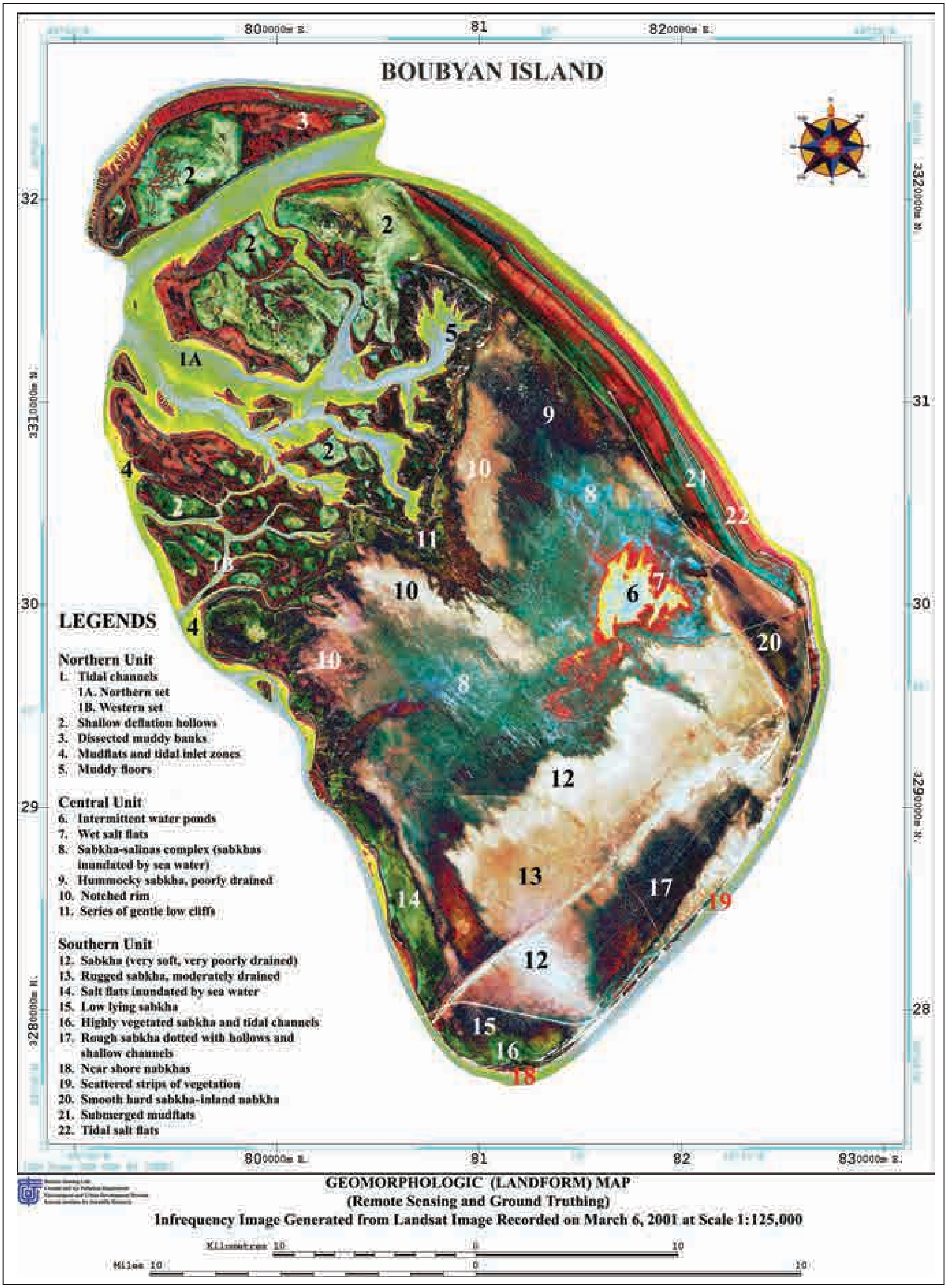

Fig. 7. Infrequency image generated for Boubyan and Warbah Islands (Landsat image recorded on March 6, 2001)

Radar Image

The radar image (**Fig. 8**) was difficult to interpret due to complicated causes of reflectance. Surface "smoothness" or "roughness" with respect to radar depends on wavelength and incident angle. The radar image was influenced by the fact that:

- A smooth surface reflects in one direction (specular);
- A rough surface scatters radiation in all directions (Lambertian or diffuse); and
- Rough surfaces tend to depolarize radiation.

The radar images used were from Radarsat Synthetic Aperture Radar C-band standard beam mode (north to south) from October to November 1996. The bright tones represented relatively high backscatter areas, which included vegetation and sabkhas.

Radar provides its own source of illumination and, unlike optical remote sensing, such as Landsat TM and IRS, is not constrained by poor weather conditions. Radar backscatter is a complex interplay between the system and target parameters, such as wavelength, resolution, polarization, look angle and look direction. In the flat aeolian desert environments of Boubyan Island, the principal parameters modulating radar backscatter are surface roughness (e.g., vegetation density and distribution), sand dunes, soil moisture (e.g., sabkhas), and man-made structures.

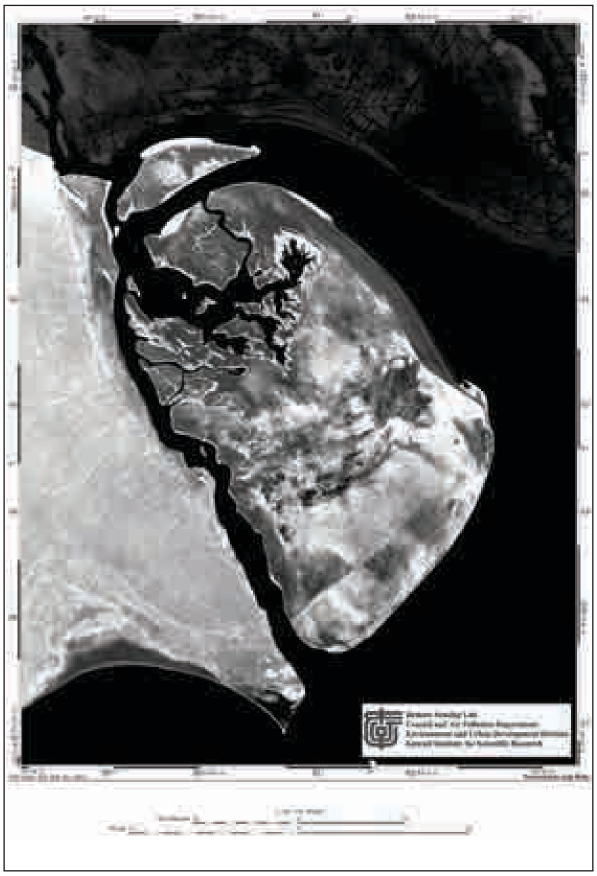

Fig. 8. Radar image of Boubyan and Warbah Islands of Kuwait (1996)

Pseudo-shaded Relief Image

The pseudo-shaded relief image (**Fig. 9**) was regenerated from modification of the existing pseudo-relief image of Kuwait, which was produced using topographic data. A computer-generated artificial light source illuminates the elevation data to produce a pattern of light and shadows. Slopes facing the light appear bright, while those facing away were shaded. On flatter surfaces, the pattern of light and shadows can reveal subtle features in the terrain. Shaded relief maps are commonly used in applications such as geologic mapping and land use planning. The pseudo three-dimensional perspective view was generated using topographic data overlaid on Landsat. It can also be generated using images from SPOT, IKONOS, or other false color images. Producing such images with finer contours at a level of 25 cm for flat topography of Boubyan Island would in the future provide more detailed information.

Processed IRS Image

The Indian Remote Sensing (IRS) 5 m color image obtained from fusion of appropriate bands from a multispectral Landsat 5 TM (bands 1, 2, 3) image with an IRS 5 m B/W image obtained from the IRS satellite was subjected to post-processing to generate an image (**Fig. 10**) showing the surface features. The IRS image was recorded over Boubyan on May 23, 2003.

Unsupervised Classified Product

The objective of unsupervised classification (**Fig. 11**) was to classify Boubyan Island into 10 different arbitrary/uncertain classes to guide field investigators in a full ground truthing exercise, thereafter leading to proper supervised classification in the future. Automated unsupervised classification was applied to examine a large number of unknown pixels and divide them into 10 classes based on natural groupings present in the Landsat image values of bands 1, 2, 3, 4, 5 and 7 (grouping into three channels), which were collected on March 6, 2001.

The classes that resulted from unsupervised classification were spectral classes based on natural groupings of the image values and the identity of spectral classes would not be initially known. They can be utilized and verified with site visits to determine the identity and informational values of the spectral classes, and would be useful for supervised classification and making thematic maps.

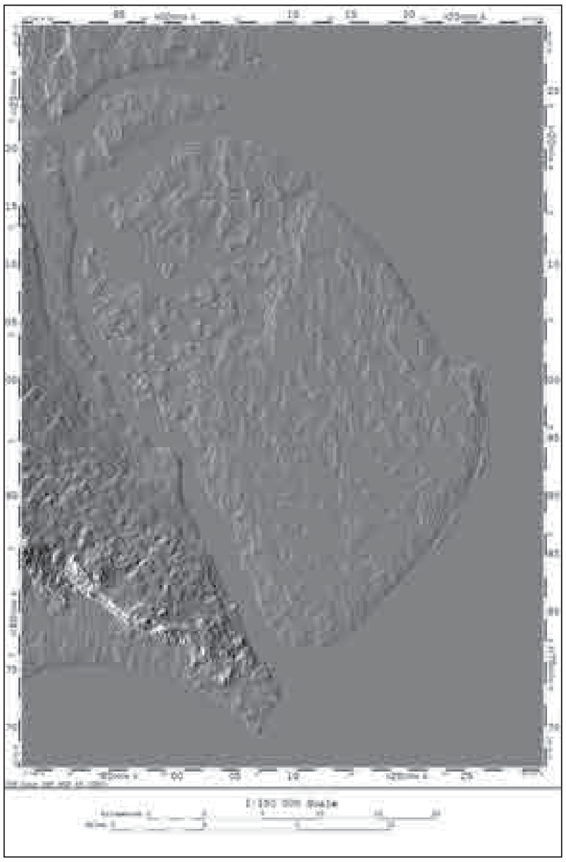

Fig. 9. Pseudo-shaded relief image of Boubyan and Warbah Islands of Kuwait (1996)

Fig. 10. Enhanced IRS image recorded on May 23, 2003 of Boubyan and Warbah Islands of Kuwait

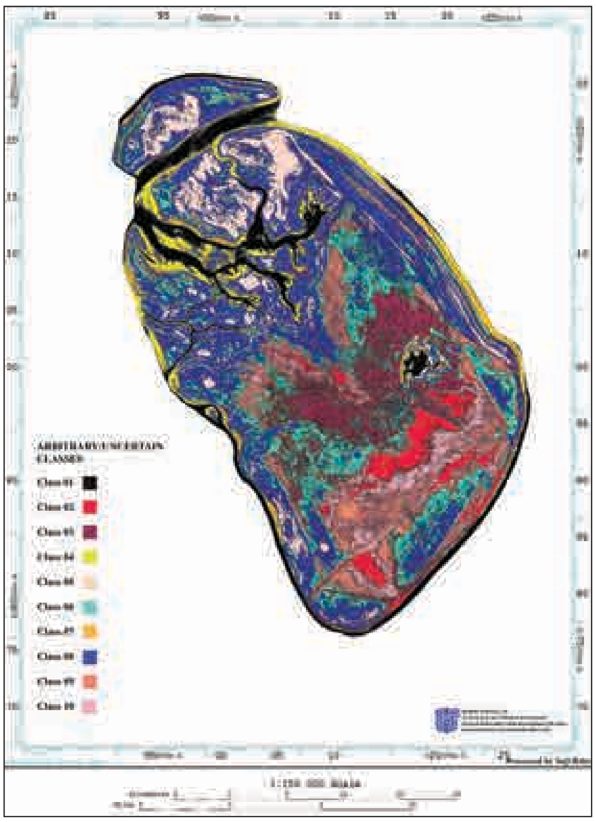

Fig. 11. Unsupervised classified image from Landsat image of March 16, 2001 of Boubyan and Warbah Islands of Kuwait

Fig. 12. Vectorized map from interpreted 2001 Landsat image of Boubyan and Warbah Islands of Kuwait

Vectorized Map Generated from Landsat Image of 2001

A Landsat image of 2001 was vectorized using Geomatica software to produce a map (**Fig. 12**) showing the topographic features and geographical demarcations (e.g., coastline, borderline, wadis/drainage, main road, vegetation scattered).

Normal Differential Vegetation Index

Figure 13 is a normal differential vegetation index (NDVI) image (not scaled and not colored), which was developed for Boubyan Island using bands 3 and 4 of the Landsat image of April 29, 2003. A pseudo-color image will be produced later, and scaling will be done with ground verification carried out at different seasons, and correlated with the interpretation carried out previously. This image is therefore preliminary and will be developed into a final scaled pseudo-color NDVI image. Hence, the scaling converts a value between -1.0 and 1.0 into a pixel value that is appropriate on a gray tone (Fig. 13).

Factors which influence the identification of vegetation on Boubyan Island are as follows:

- Background reflectance from soil, because vegetation is distributed discretely and is not continuous, as found during the field visit;
- Difference in greenness of vegetation due to a masking effect from the dust/sand deposit on vegetation caused by the desert environment of Boubyan; and
- Coarse spatial resolution of satellite data, which supports vegetation identification or calculation of a vegetation index, as compared to the magnitude of density and coverage of vegetation.

A vegetative index value is calculated from remotely sensed data to quantify the vegetative cover. NDVI is a type of product known as a transformation, which is created by transforming raw image data into an entirely new image using mathematical formulae to calculate the color value of pixels or, in other words, an index that provides a standardized method of comparing vegetation greenness between satellite images. NDVI images were generated by the general formula NDVI = (near IR band – red band)/(near IR band + red band).

The NDVI equation above produces values ranging from -1.0 to 1.0. Generally, values greater than zero are considered as vegetated areas (but vegetation value typically ranges from 0.05 and 0.55). Higher index values are related to higher levels of healthy vegetation cover. Values less than zero are considered as non-vegetated areas, such as barren land, water, buildings, roads, clouds, etc. But Boubyan Island does not satisfy the conditions necessary for calculating NDVI based purely on the algorithm and considerable field checking is required.

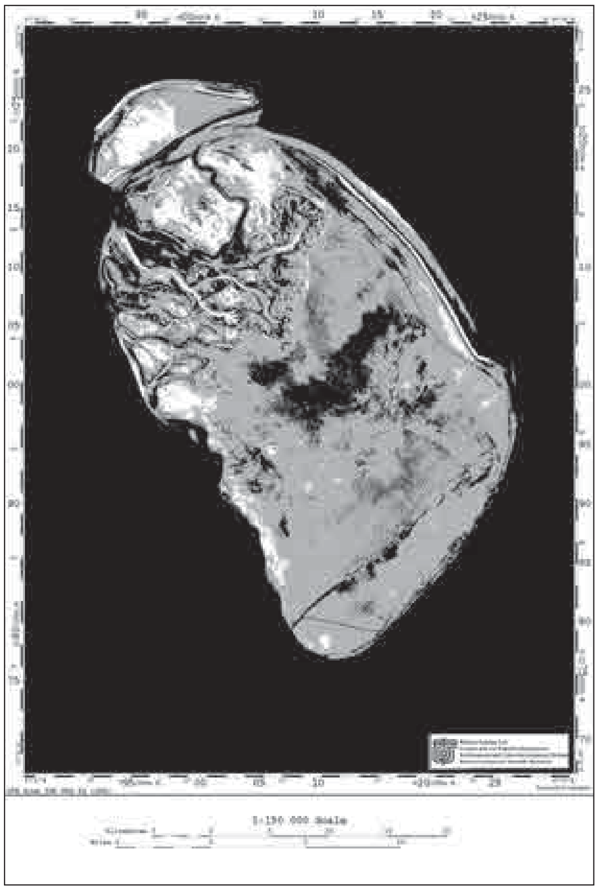

Fig. 13. NDVI image with gray tone of Boubyan Island

Ocean Parameters

Ocean parameters, such as sea surface temperature and wind over sea, play a significant role in determining the periodic physical, chemical and biological changes occurring in marine areas. The marine area of Kuwait stretches from 24.0° N to 30.0° N and 46.0° E to 60.0° E, to the Arabian Sea. The sea surface temperature and ocean wind vector map for the Arabian Gulf were prepared with support from the User Services Office, Jet Propulsion Laboratory, and Physical Oceanography Distributed Active Archive Centers, Pasadena, CA. The PO.DAAC Ocean ESIP Tool (POET) enables sub setting, plotting, and viewing of PO.DAAC's data products, such as sea surface temperature and ocean wind vector. This interface was developed by Ocean, a member of the Earth Science Information Partners (ESIP) Federation, under contract from the National Aeronautics and Space Administration. Ocean ESIP provides improved satellite data products and simulation model output in support of global change studies of oceans.

The sea surface temperature (SST) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard the NASA Terra satellite represents high sensitivity thermal infrared remote sensing. Monitoring pockets of cold and warm water in the ocean can help determine overall ocean movement at any moment in time. SST is therefore an important parameter for biophysical studies of marine environment.

1

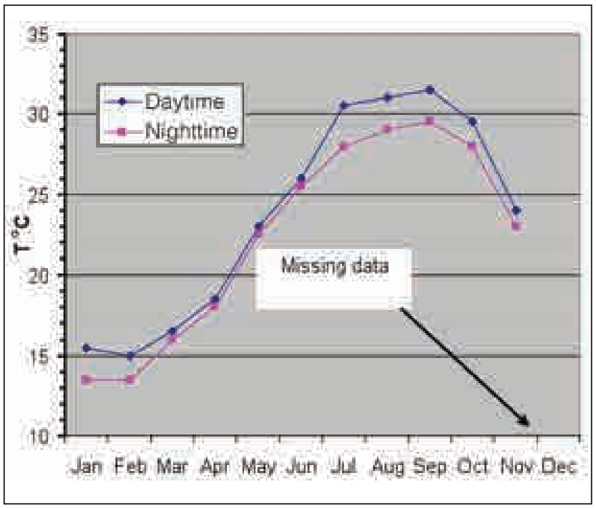

Fig. 14. Graph showing day and night sea surface temperature (SST) by month for 2003

Table 2. Sea Surface Temperature

Month (during 2003)	Daytime sea surface temperature in °C	Nighttime sea surface temperature in °C
January	14 to 17	13 to 14
February	14 to 16	13 to 14
March	15 to 18	15 to 17
April	17 to 20	17 to 19
May	22 to 24	22 to 23
June	25 to 27	25 to 26
July	29 to 32	27 to 29
August	30 to 32	28 to 30
September	31 to 32	29 to 30
October	29 to 30	27 to 29
November	23 to 25	22 to 24
December	Not available	Not available

Satellite data from MODIS were used to derive SST. Polar orbiting satellites that orbit the earth at an altitude of about 500 miles are designed to see the earth's surface temperature, taking pictures that represent these temperatures as colors. The images taken of the ocean are sent back down to earth as SST maps.

The dynamic nature of the marine environment presents many challenges to officials in charge of managing sustainable fisheries (Edward, 2000). Various studies related to remotely sensed SST, salinity, partial pressure of CO_2, primary productivity, etc. can be seen in the literature. Much research has been undertaken to parameterize the partial pressure of CO_2 in ocean water (pCO_2) with SST or salinity (Boutin et al., 1999; Loukos et al., 2000). The general consensus is that the relationships between SST and pCO_2 are not globally applicable and that they change in space and time (Lee et al., 1998). Seasonal SSTs thus help track gulf streams.

Sea Surface Temperature around Boubyan Island

Table 2 shows the day and night SST around the vicinity of Boubyan Island for each month during 2003, from which the following information can be summarized:

- The range of daytime SST for the year 2003 was from 14-32°C and the range of nighttime SST was from 13-30°C.
- The maximum daytime SST occurred during July to September, and reached a maximum value of 32°C, while the minimum daytime SST was about 14°C, which occurred during January.
- The maximum nighttime SST occurred from July to September and reached a maximum value of 30°C, and the minimum nighttime SST was about 13°C, which occurred during January.
- The difference between the daytime and nighttime SST during any month was from 1-3°C only.

A graph (**Fig. 14**) was plotted for daytime and nighttime temperature from January 2003 to November 2003. The graph shows inversion of temperature during the months of January, February, August, September and October.

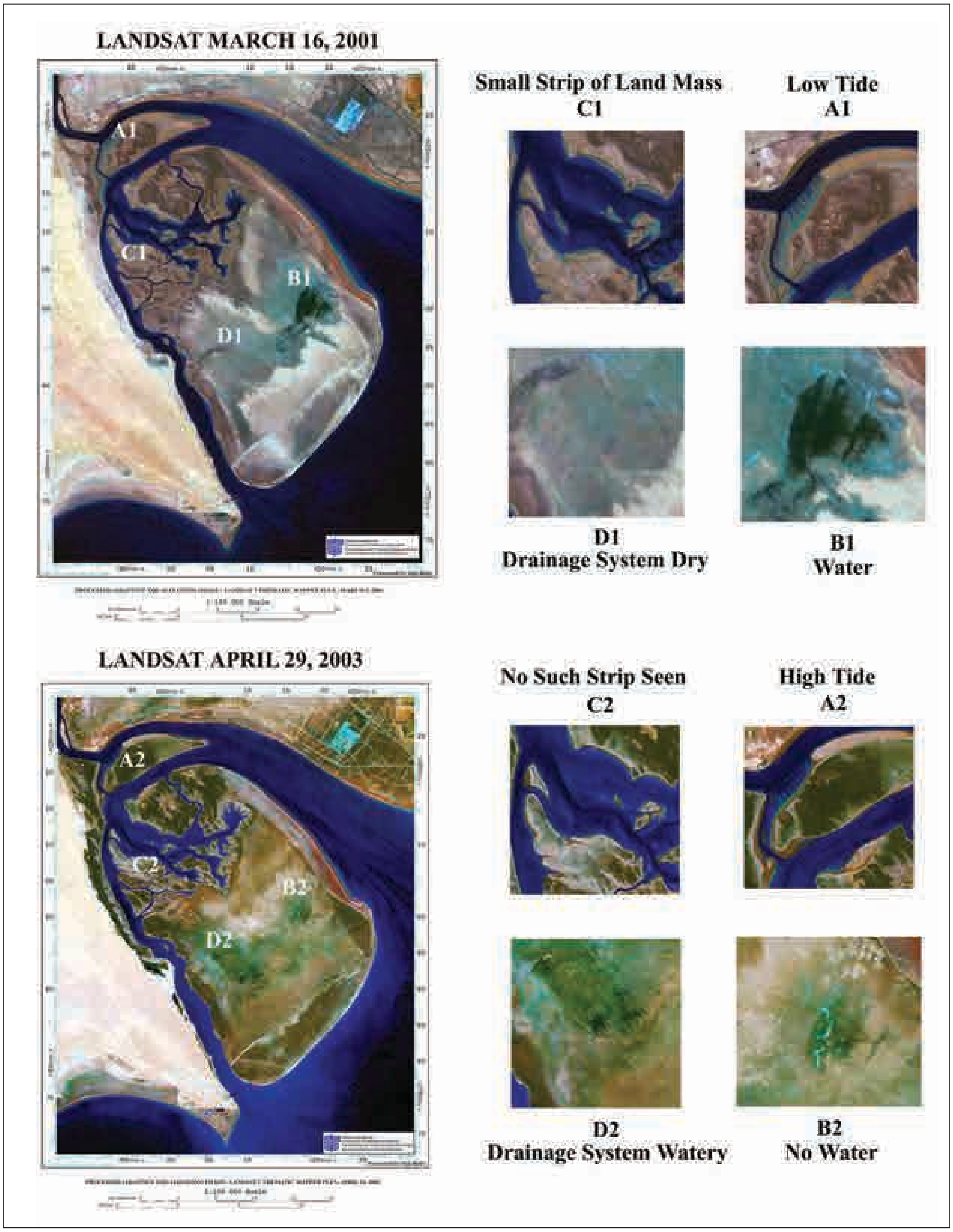

Fig. 15. Landsat images of 2001 and 2003 showing comparative study of Boubyan Island in Kuwait

Natural Color Composite Image (April 29, 2003)

A natural color composite image (**Fig. 15**) was generated using bands 1, 2 and 3 of Landsat 7 enhanced data obtained on April 29, 2003. The multispectral image was digitally processed using bands 1, 2 and 3 projecting through red, green and blue filters. The image was enhanced with an adaptive enhancement algorithm and by modifying for better visual interpretation of various features.

Geomorphology and Physiography

Boubyan Island is almost flat, with very little undulation. The soil is a mixture of clay-silt-sand. The tidal variation of 3-4 m during spring causes significant horizontal movement of water on the island, and hence a significant part of the island is under the influence of tidal flat. This is one of the main reasons why during low tide and with significant evaporation of the seawater, most of the surfaces are covered with a thin salty film. In a few places, oil tar deposits can be seen on the surface of the soil.

The seabed of the intertidal zone is muddy, with a slippery top surface and a very poor bearing capacity, especially under wet conditions. Any scientific fieldwork in the tidal flat needs to be approached carefully; otherwise people may sink into the mudflat.

Visual inspection of the south and southeast part of the island showed that the difference in elevation between the highest and lowest point may be no more than 1.0 m. Hence, a contour plot of the ground of the island was not required, and it can be considered as flat for most purposes. Since there are no obstructions by plants or trees or buildings, the airflow is free and chilly during winter. Concrete defense bunkers can be seen every few kilometers from southwest to southeast.

There are only a few desert plants around these areas. Ammunition and cartridge shells used by the American and British forces during the Gulf War are still lying in a few places. Some damaged vehicles, barbed wire, etc. also remain. The tidal flat of the southeastern part is full of wooden trunks, plastic material and gunny bags filled with dates.

Apparently, sediments brought by Shatt Al-Basrah and Shatt Al-Arab and deposited around the island have significantly changed the coastal morphology. Boubyan will be an interesting and challenging area for coastal engineering studies into evolution of coastal morphology, physical oceanography measurements (current, tides), collection and analysis of the sediments, biological activities in the intertidal mudflats, etc. The island has a sedimentary

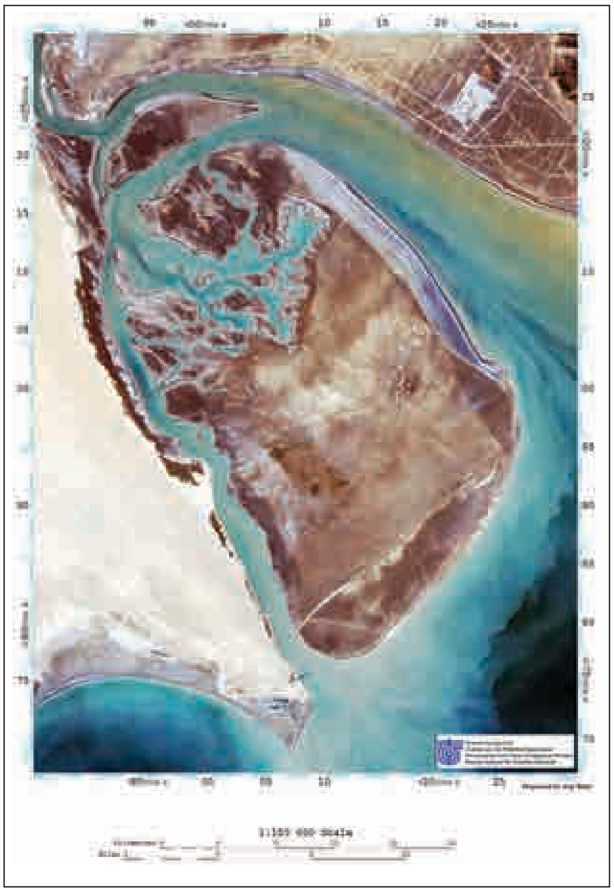

Fig. 16. Natural color composite image of Boubyan Landsat image (April 29, 2003)

formation and low salinity of surrounding waters. The satellite images show the features that dominate the two islands: a low flat surface split into channels and filled with water by the ebb and flow of the tide.

The image in Fig. 7 clearly shows some parallel nonlinear features of topographic importance indicating the prevailing northwest winds. The northern part of the island shows well demarcated tidal zones. The white shades or different magnitude of bright areas represent high reflectance due to the smooth surface, saline dry soil, salt crust, fresh aeolian sands, etc. The dark areas of various shades define the low reflectance and greater absorbance of radiation due to moisture content, chlorophyll, roughness, soil and water properties or other terrestrial features.

Comparative studies of Landsat images (**Fig. 16**) of the Boubyan terrestrial zone, obtained during low and high tide on March 6, 2001 and April 29, 2003, represent tidal extent. The satellite images show both inland and tidal channels. Boubyan Island is very dynamic and experiences continuous changes over time due to environmental influences, which can be studied from multitemporal images of the area.

Table 3. Ocean Wind Vector

Month (2003)	Daytime wind		Nighttime wind	
	Wind speed (m/sec)	Direction	Wind speed (m/sec)	Direction
Jan	8 to 9	S	6 to 8	SE
Feb	6 to 8	SSE	2 to 4	E
Mar	9 to 12	SSE	9 to 10	SE
Apr	2 to 4	WSW	3 to 5	E
May	9 to 11	SE	3 to 5	ESE
Jun	2 to 4	WSW	1 to 3	
Jul	Not available	Not available	2 to 4	
Aug	Not available	Not available	4 to 6	
Sep	Not available	Not available	4 to 5	
Oct	1 to 3	NE	Not available	Not available
Nov	11 to 13	SE	Not available	Not available
Dec	7 to 8	S	10 to 11	ESE

Vegetation Distribution

Vegetation distribution is discrete with the exception of a few areas of greenery around the coastal margin. The vegetation carpet can be interpreted visually from a number of processed satellite data from Landsat and IRS (Fig. 10). The location of a few dense areas of vegetation is shown in the vectorized map (Fig. 12) generated by interpreting enhanced Landsat images and ratio images from 2001.

Ocean Parameters

The SST and ocean wind speed are required for environmental studies for the Master Plan of Boubyan Island.

Ocean Wind Vector around Boubyan Island

Table 3 and **Fig. 17** give the day and night wind vector details around the vicinity of Boubyan Island for each month during 2003. They show:

- The range of daytime wind speed for 2003 was from 1-13 m/sec, and the range of nighttime wind speed was from 1-11 m/sec.
- The maximum daytime wind speed occurred during November and reached 13 m/sec while the minimum daytime wind speed was about 1-3 m/sec, which occurred during October.
- The maximum nighttime wind speed occurred during December and reached 11 m/sec, while the minimum nighttime wind speed was about 1-3 m/sec and occurred during June.

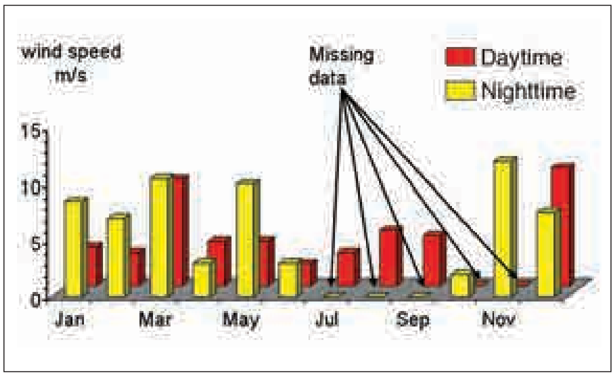

Fig. 17. Graph showing AM and PM ocean wind by month (2003)

Water Color Image

The marine environment is vital for petroleum, navigation, shipping, fisheries, etc. A water color image (**Fig. 18**) was developed from bands 1, 2 and 3 from a Landsat image recorded on April 29, 2003. The spectrum of water color in Fig. 18 gives important information about the distribution of various properties of the water surrounding Boubyan Island. The image was correlated with information collected from the marine environment during preliminary field investigations. The color composite image of TM bands 1, 2, and 3 was developed by projecting through blue, green, and red filters. The lookup table of each band was modified to enhance the stratification of spectral color of water.

The visible range of the electromagnetic spectrum from 0.4-0.7 μm helps in the study of water quality. The penetration of radiation is strongly governed by the turbidity, bio-organisms and chemistry of water. Color images from the Sea-Viewing Wide-Field-of-View Sensor (SeaWiFS) have contributed greatly to understanding global primary productivity. Among the active satellites, Landsat TM is the most suitable for qualitative determination of chlorophyll and suspended sediment concentration (Kwarteng and Al-Ajmi, 1997).

In Fig. 18, the land areas are masked to white to expose the marine area for presentation of maximum information about the bands' ability to penetrate water influenced by turbidity and depth. The colored area shows shallow water and suspended matter, while the darker black area represents deeper water. The previous literature study from Kwarteng and Al-Ajmi (1997) stated that the areas around the mouth of Shatt Al-Arab indicate an abundance of free flowing phytoplankton, confirming that Shatt Al-Arab is an important source of nutrients for the northern Arabian Gulf. Beds of sargassum, a variety of brown algae, are commonly observed in shallow water (Bishop et al., 1995; Kwarteng and Bishop, 1994), but it is thought that none of the reflection in Fig. 18 is due to sargassum.

According to field observations, the light sky blue shades along the southern coastline of Boubyan Island in Fig. 18 show suspended sediments. The brown color may represent green algae and other phytoplankton but this needs to be confirmed. Marine conditions such as tide, current and other ocean dynamic activities can sometimes be an influence, emphasizing the need for ground truthing.

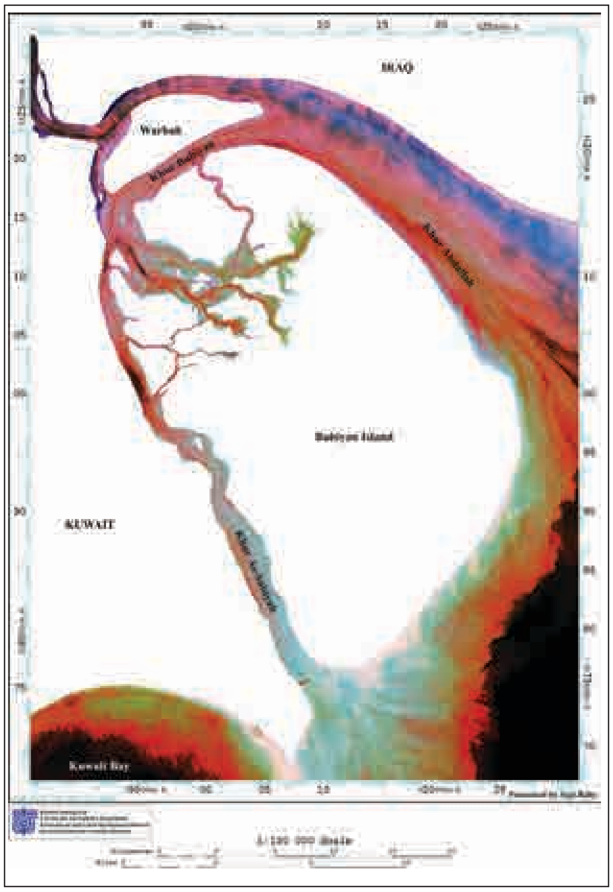

Fig. 18. Water-color Landsat image for Boubyan Island in April 2003

Climatic Conditions

The climatic conditions in the State of Kuwait are hot and arid, with scant rainfall. Hot and dry summer winds are usually experienced for the greater part of the year. The prevailing wind direction is northwestern, representing 60% of total wind throughout the year (**Fig. 19**). Northwestern winds are hot and dry during the summer due to the long distance they travel over the deserts of Saudi Arabia, Syria, Jordan and Iraq. They have an average speed of 4.78 m/s. For studies of sand transport, this average far exceeds the threshold shear velocity (~0.6 m/s) required to transport a particle of average size (0.4-2 mm diameter). During the spring, the contribution of southeastern wind increases to match that of the northwestern wind. This change is accompanied by an increase in the high wind velocities. Maximum wind speed can reach 29.5 m/s while maximum reported gust speed is 37.6 m/s. Strong southeastern winds can cause severe dust storms, which can reduce visibility to a few meters. April is well known for its sudden dust storms, which are accompanied by thunderstorms. During the winter, the wind is mainly northwestern, although southeastern winds occur for periods of a few days due to the effect of Mediterranean depressions.

Hot and dry strong northwestern winds are common in June and July, whereas humid light southeastern winds prevail in August and September. Scorching heat, cloudless skies and long days are the features of the summer season. As the northwestern winds descend from the Zagros Mountains they collect sand from the dry desert, causing dust storms. The frequency of dust storms depends on the amount of rainfall in the previous winter season. The prevailing wind direction is northwestern in October and southeastern/eastern in November. The average number of dust storms drops to one in October and November combined.

The mean total rainfall is about 110 mm a year, with no specific trend, averaging eight rainy days a year. However, rainy days might exceed 40 days in some years and in this case mean total rainfall rate can reach 336 mm. Rain affects patches of Kuwait rather than the whole country. Rain can start in November and continue very intermittently until April, with January being the rainiest month, and sometimes, there is also occasional rain in October and May.

The average annual temperature is 26°C. In July, the average temperature is 37.4°C and maximum can reach 45°C. The diurnal range (difference between the day and night temperatures) in the summer is about 17°C, leaving the nights unpleasantly hot. The maximum recorded temperature was 50.8°C in June 1954. The weather is warm to hot in October and mild to cold with occasional thunderstorms in November. The weather is coldest in January, with the temperature reaching about 12°C. Minimum recorded temperature is -4°C measured in 1964. During the spring season, the temperature varies substantially even during a single day.

Boubyan Island Data

Wind Data

The location of Boubyan Island is unusual due to it being an island close to land on the western side. The sea and land breezes affect wind data. For August, the main wind direction is northern as seen in **Fig. 20**, with an average recorded wind speed of 6.92 m/s during the recording period, with wind speeds in the range 5.7-8.8 m/s representing 36.7% of the wind data and wind speeds in the range 3.6-5.7 m/s representing 35.3% of the wind data. A field survey, covering terrestrial areas of both Boubyan and Warbah Islands and some tidal channels dissecting both islands, selected appropriate sites for monitoring dust, sand, groundwater level, air pollutants and overall weather conditions. The dust deposition rates measured in Boubyan and Warbah Islands from November 2003 to January 2005 reflect dust from three sources: long distance dust deposition mainly less than 5 μm in diameter; dust deposition from regional sources, mainly from the Mesopotamian Floodplain, in 20-40 μm size fractions; and local dust deposition of relatively coarse material in 50-70 μm grain size fractions. This conclusion was supported by the Brunauer, Emmet and Teller (BET) surface area, which illustrates the variation of the surface area over time in both Boubyan and Warbah Islands. The interrelationship of the variations in dust fallout, groundwater level and trapped sand over time clearly shows a close relationship between the dust fallout with the drop in groundwater level, while there is no relation with the amount of trapped sand.

Mobile sand movements and air pollutants are the lowest in Kuwait. Also the weather data from Ras Al-Sabiya shows close similarity to the Boubyan meteorological station.

To collect information on wind direction, 547 velocity vectors were collected over the month of August, 194 of which were for vectors with angles between 326-333° (mostly northern). The frequency distribution is shown in **Fig. 21**. For September, the main wind direction remains northern, as in August (Fig. 21); however the average wind speed drops to 4.93 m/s with 0.15% flow vectors falling in the calm wind criterion; 40.7% of the wind vectors were for wind speeds between 3.6-5.7 m/s as seen in **Figs. 22** and **23**. There is a more even distribution of the wind angle for this month compared to August, with 119 vectors out of 653 with angles between 326-333° in the above-mentioned wind speed range. For October, the wind direction is less clearly defined. The southeastern wind direction is clear and this agrees with information found in the literature and listed above. The average wind speed is 4.58 m/s with 0.30% measured vectors falling in the calm wind criterion. The wind class frequency distribution (**Fig. 24**) shows that 44.8% of the wind vectors have a magnitude of 3.6-5.7 m/s. The frequency distribution (**Fig. 25**) confirms the above conclusion and 128 vectors out of 670 fall in the above-mentioned wind speed range and have angles between 79-169°. For the month of November (**Fig. 26**), two main wind directions occur: northwestern, which is the prevailing wind direction over the year, and southeastern due to Mediterranean depressions. The average wind speed is 5.02 m/s with 40.3% of the wind vectors having a magnitude between 3.6-5.7 m/s (**see Fig. 27**); 105 vectors out of 672 fall within the above-mentioned speed range with angles between 79-169° (southeastern), while 125 vectors have an angle between 259-349° (northwestern).

The prevailing wind direction for the period from August-November 2004 is northern with an average wind speed of 5.29 m/s (**Fig. 28**). Here, 416 vectors out of 2542 have angles between 326-333° (northern direction; see **Fig. 29**).

Atmospheric Temperature

The monthly average atmospheric temperature is in good agreement with the monthly average given by the Civil Aviation Authority for 1957-2002 as can be seen in **Fig. 30**. However, the monthly maximum and minimum values seem to differ slightly when compared with the Civil Aviation Authority data as seen in **Figs. 31** and **32**.

Relative Humidity

The monthly average relative humidity for August was about 20% and increased to 60% in November (**Fig. 33**).

Ras Al-Subbiyah Data

The data for Ras Al-Subbiyah in comparison to Boubyan Island meteorological station data appear to be similar in mean temperature, wind speed, relative humidity and other parameters. Temperature, relative humidity and rainfall are shown in **Table 4**.

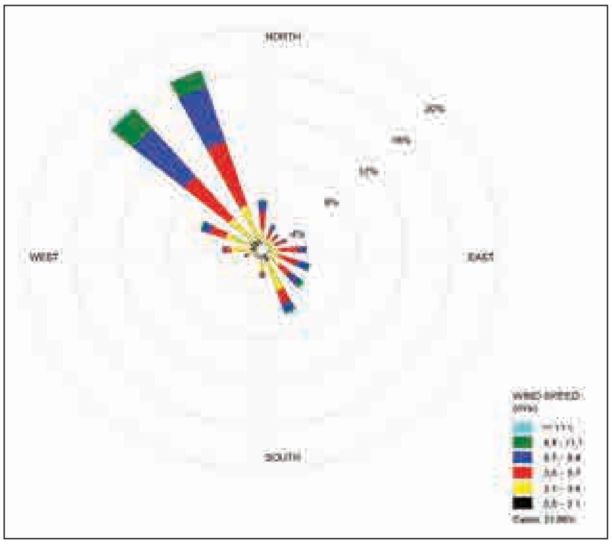

Fig. 19. Average wind speed data for Kuwait 1999-2000

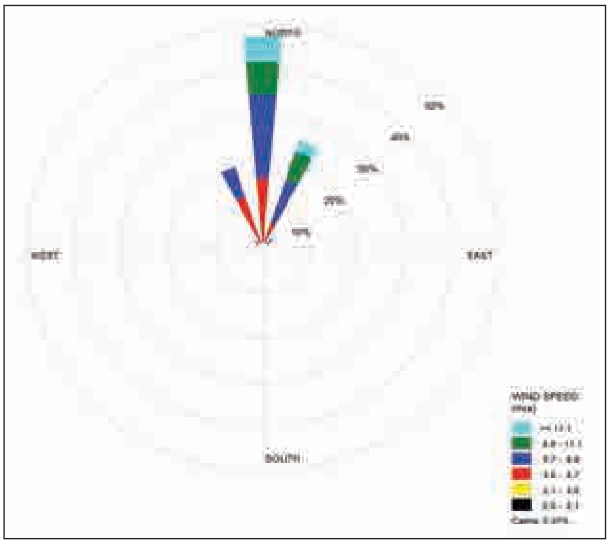

Fig. 20. Wind rose plot for August 2004, Boubyan Island Weather Station

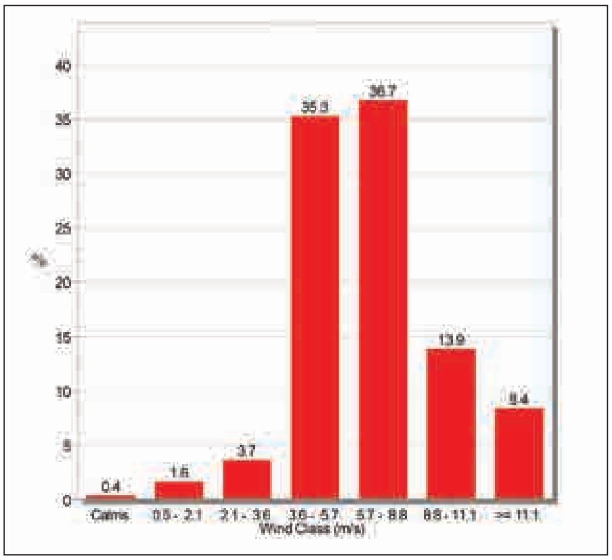

Fig. 21. Wind class frequency distribution for Boubyan wind data August 2004

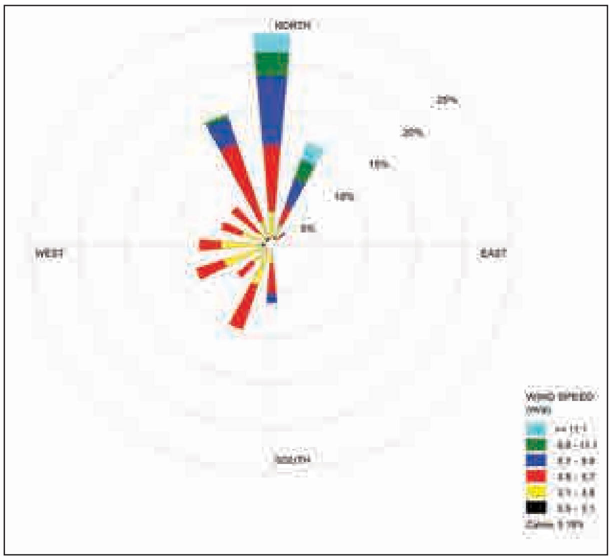

Fig. 22. Wind rose plot for September 2004, Boubyan Island Weather Station

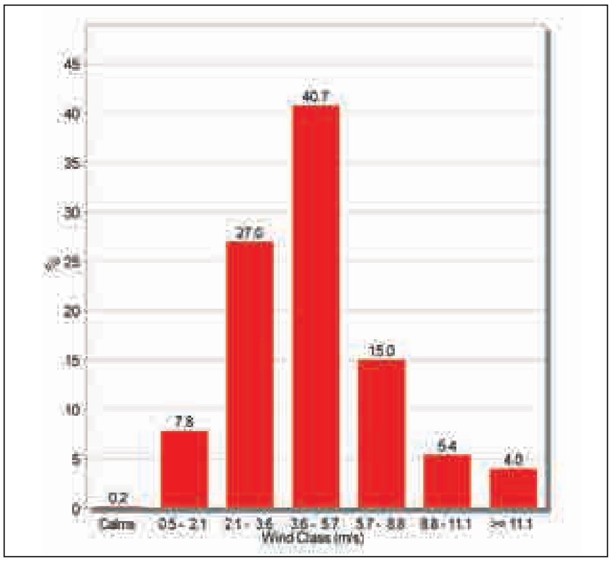

Fig. 23. Wind class frequency distribution for Boubyan wind data September 2004

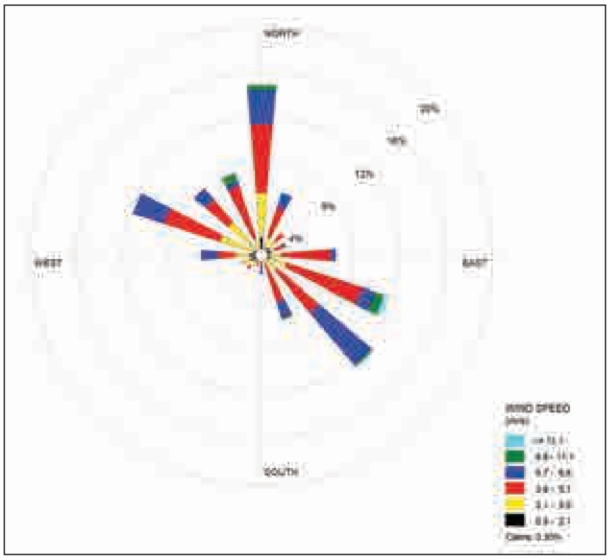

Fig. 24. Wind rose plot for October 2004, Boubyan Island Weather Station

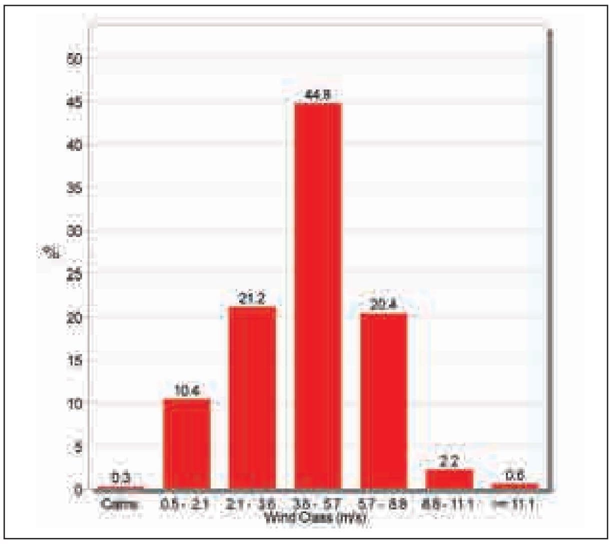

Fig. 25. Wind class frequency distribution for Boubyan wind data October 2004

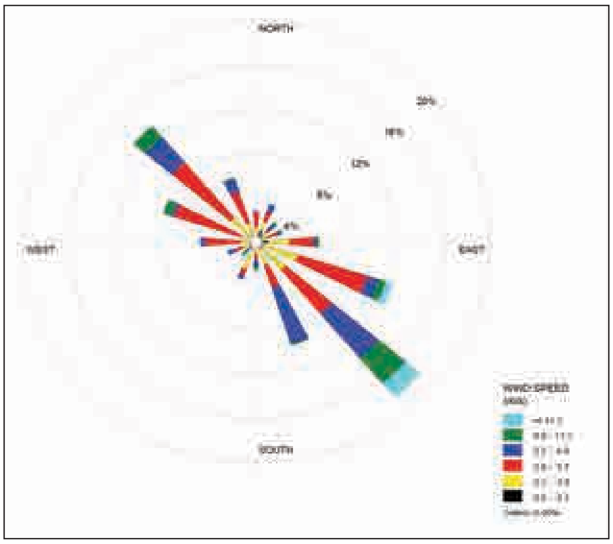

Fig. 26. Wind rose plot for November 2004, Boubyan Island Weather Station

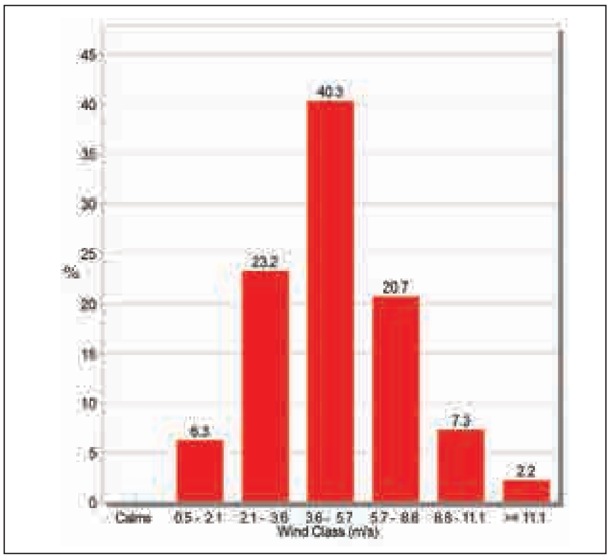

Fig. 27. Wind class frequency distribution for Boubyan wind data November 2004

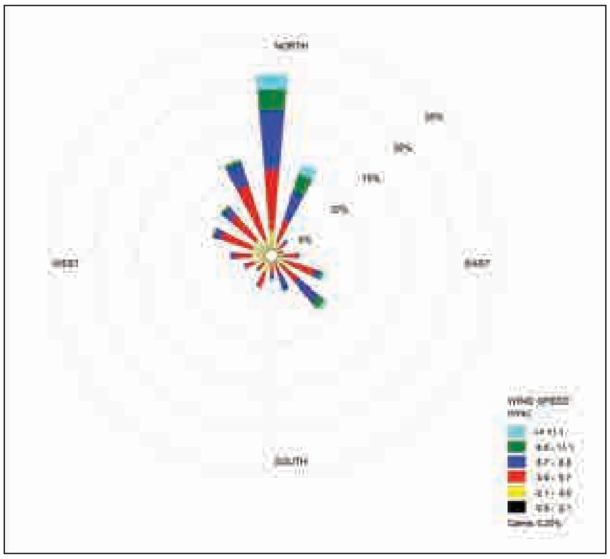

Fig. 28. Wind rose plot for August-November 2004, Boubyan Island Weather Station

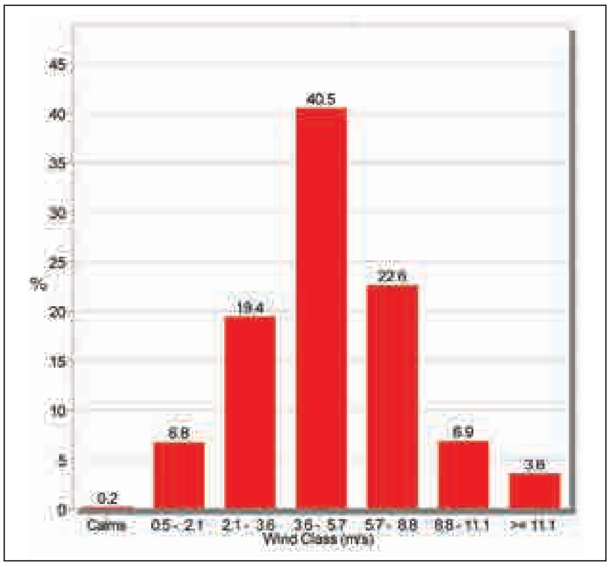

Fig. 29. Wind class frequency distribution for Boubyan wind data August-November 2004

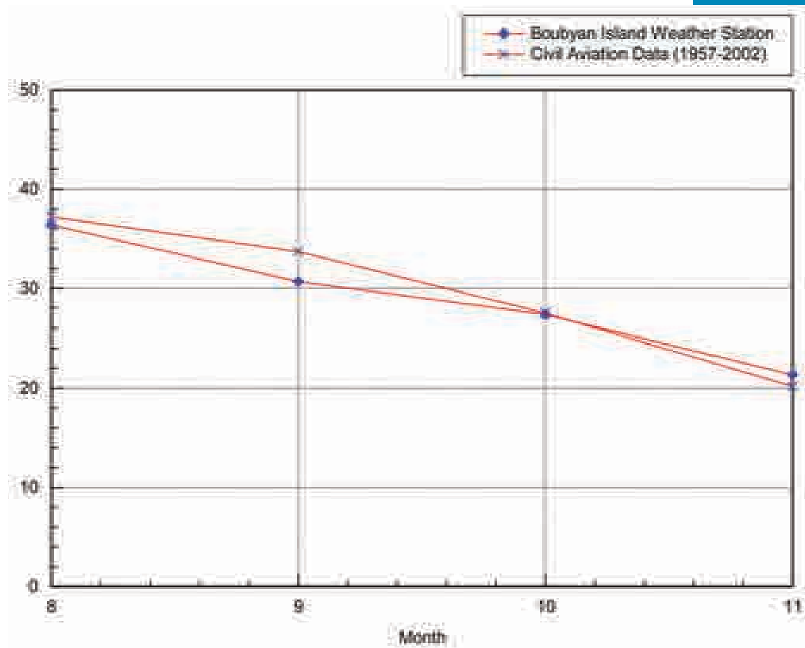

Fig. 30. The monthly average atmospheric temperature (°C) at Boubyan Island

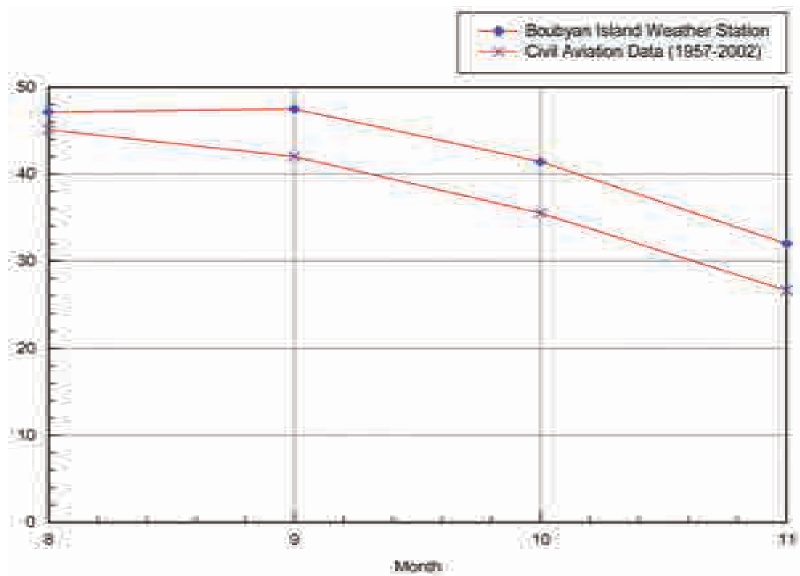

Fig. 31. The monthly maximum atmospheric temperature (°C) at Boubyan Island

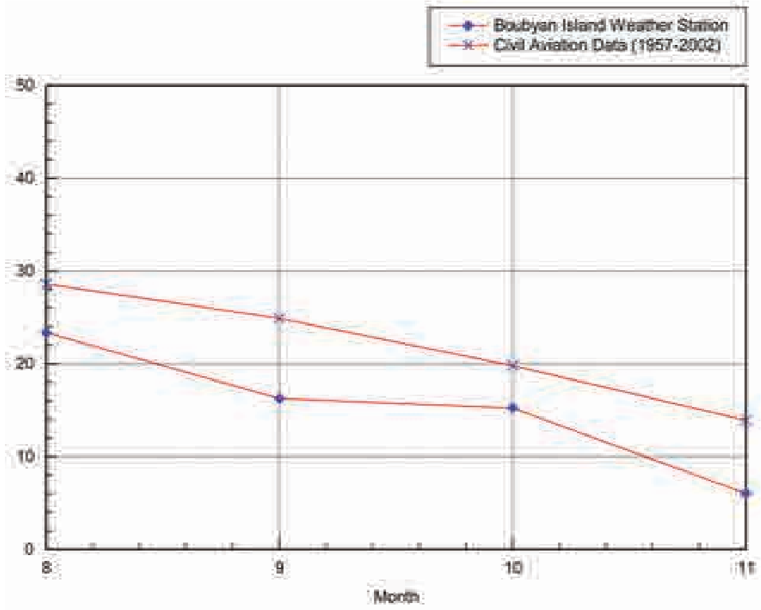

Fig. 32. The minimum atmospheric temperature (°C) at Boubyan Island

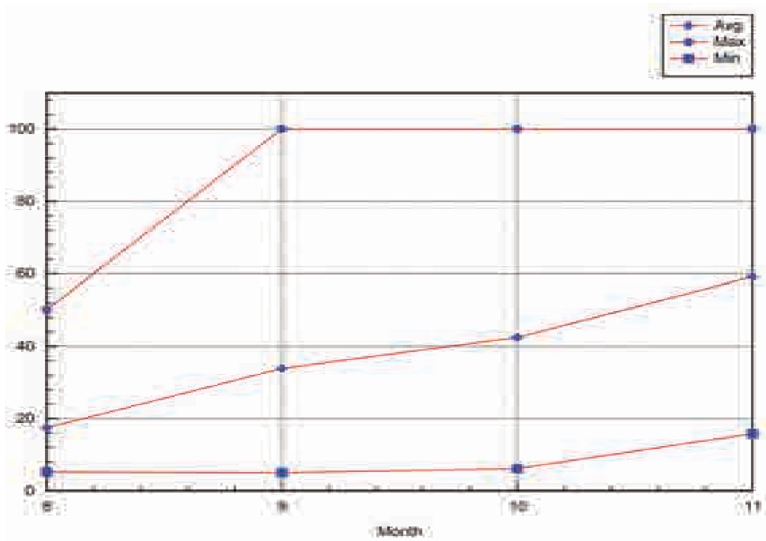

Fig. 33. The monthly average relative humidity at Boubyan Island

Table 4. Meteorological Data for Ras Al-Subbiyah 2003-2004

	Temperature			Relative Humidity			Rainfall		
Month	Degrees C			%			mm		
	Max	Mean	Min	Max	Mean	Min	Total	Mean	Max
October	32.18	29.11	20.36	76.63	49.18	21.0	5.0	0.007	0.2
November	25.85	20.31	15.42	84.93	53.42	29.5	0.5	0.001	0.5
December	19.42	14.56	10.19	95.23	75.79	52.3	33.0	0.044	6.0
January	17.91	14.94	11.99	97.19	81.35	65.3	79.5	0.107	7.5
February	28.20	15.63	6.60	99.50	59.82	17.2	3.0	0.004	3.0
March	27.48	22.01	16.63	66.27	40.24	22.8	0.0	0.000	0.0
April	30.68	24.04	18.98	79.02	46.01	19.7	8.5	0.012	2.5
May	35.53	31.80	27.57	53.03	29.46	10.3	0.0	0.000	0.0
June	40.52	37.19	33.13	42.53	16.27	7.8	0.0	0.000	0.0
July	40.93	38.10	34.58	66.71	25.98	6.5	3.5	0.005	3.0
August	40.90	38.24	35.45	36.51	18.14	9.4	0.0	0.000	0.0
September	38.05	33.30	29.84	77.56	34.78	11.1	0.0	0.000	0.0
October	34.39	29.47	22.40	94.32	45.48	13.1	0.0	0.000	0.0
November	26.80	21.09	10.90	88.24	65.90	42.6	5.5	0.008	3.5

Conclusions and General Observations

Short-term remote sensing studies coupled with reconnaissance field surveys have led to the following conclusions:

- The island is very dynamic and is considerably impacted by local climatic conditions. There is a major marine influence on Boubyan Island.
- The island is a flat plain, low area with little undulation. The northern parts have rich sedimentary deposits brought from Shatt Al-Basrah and Shatt Al-Arab. The soil shows a wide spectrum of water or moisture content. Some places are regularly submerged due to the influence of rainfall, tide and flowing water from Shatt Al-Basrah and Shatt Al-Arab.
- Boubyan Island is ecologically functional, but at the same time very vulnerable to human interference. In-depth analysis to obtain more environmental information could be aided by further remote sensing research.
- Visual inspection of the south, southeast and northern part of Boubyan Island and parts of Warbah Island shows that the difference in elevation between the highest and lowest point may not be very significant.
- Interpretations of satellite images show that the southeast of Boubyan Island and northwest of Warbah Island have thick tidal zones and very disturbed coastal areas. Tremendous inundation by coastal waters can be seen.
- A few patches or carpets of vegetation are confined to coastal areas, which get submerged by tidal activities. Inland vegetation is at low density or made up of isolated individual plants.
- The ocean color image is affected by periodic marine changes related to tide, current and other ocean dynamic activities, meaning that ground truthing plays a particularly important role in interpreting the color image.

2

Chapter 2: Topography

Abstract

A topographic survey of Boubyan Island was conducted using a precise differential GPS survey technique and a final contour map was produced. In addition to field survey measurements, several information sources were employed in preparation of the contour map, including a geomorphological map, air photo and Ministry of Defense (MOD) map. The contour map was prepared using Surfer and Autocad programs allowing a contour interval of 0.25 m and is the first detailed contour map showing the topographic features of Boubyan Island.

Introduction

Boubyan Island consists of layers of deposited silt accumulated from Shatt Al-Arab. The island is level, with an elevation varying from 0.0 to 6.0 m. Evaporation of groundwater and surface water has created a hard surface crust of sabkha at the south perimeters of the island. The semi-dry area in the middle is of elevated clay deposited during ancient flood events. The northern part is muddy terrain dissected by two systems of tidal channels. The island contains swamps, sabkha and elevated clays with shallow coastal water, creating problems for onshore and offshore transportation. Mobilization requires special equipment and supporting cranes for such difficult environments.

The main objective of research was to perform a detailed topographic and utility survey of Boubyan Island for the preparation of the island's development Master Plan. Topographic studies were required for the following purposes:

- To capture the necessary ground level information, boundaries and surface details;
- To identify terrain levels; and
- To provide an appropriate mapping base for the preparation of plans.

These requirements were satisfied by a combination of existing data and new site surveys. Existing data included all available maps, topographic plans, bathymetric plans and Kuwait Municipality Utility Data Management System (KUDAMS). New site surveys included the recovery of established benchmarks and a new topographic survey.

Literature Review of Geotechnical Investigations of Boubyan Island

An extensive review has been conducted of existing information on geotechnical investigations and soil properties of Boubyan Island, to compile any existing geotechnical data.

Internet Search: Although a systematic and guided search on the Internet was conducted, no geotechnical data were found. However, several sites were found containing satellite and shuttle imagery of the island or historic data.

National Science and Technology Information Center (NSTIC) Search: The catalogue of KISR reports was searched for any relevant studies. Only one Ph.D. proposal on Boubyan Island was found but this contained no information relating to the topography of the island.

Existing Soil Reports: Leading geotechnical investigation companies, such as SEMATCO, Gulf Inspection, INCO Lab and Middle East Survey, were contacted to find any available soil reports. Only two soil reports, or rather soil logs, of depth up to 30 m were found. These two reports contain different classifications of the soil as detailed below.

In reference to the first borehole log (INCO Lab), the subsurface formations at the site can be summarized as follows:

- Layer A: Loose to very loose, light brown to black, calcareous sand with silt and traces of shell fragments.

This layer is encountered at the ground surface and extends down to a depth of 3.0 m.
- Layer B: Very soft to very stiff gray, calcareous sandy clay/silt. This layer is encountered below layer A and extends down to the end of boring (at a depth of 30.0 m from the existing ground surface at the time of investigation).

Groundwater is encountered in the borehole at a depth of 1.5 m below the ground surface at the time of investigation (February 2003).

As for the second borehole log (SEMATCO), the subsurface formations at the site can be summarized as follows:

- Brown to gray fine grained, weakly to strongly cemented, calcareous, very silty sand. This layer contains percentages of clay varying from slightly clayey to clayey. It is encountered at the ground surface and extends down to the end of boring (at a depth of 15.0 m from the existing ground surface at the time of investigation).
- Groundwater is encountered in the borehole at a depth of 3.30 m below the ground surface at the time of investigation (July 8, 2003).

It can be seen from the above subsurface formations that the formation is contradictory. While soil is mainly classified as sandy clay/silt in the first report, the soil formation according to SEMATCO is mainly very silty sand. It is also noted that the available boreholes lack some physical tests to correctly classify the soil, such as sieve analysis and/or liquid and plastic limit tests.

Another soil log was extracted from a Dames and Moore report. The logs were drilled to a depth of about 165 feet (50 m) at the location of the LPG loading platform about 7 miles to the east of Boubyan Island in the Arabian Gulf. The subsurface formations at the site can be summarized as follows:

- Layer A: High plasticity clay intercalated by thin layers of peat. This layer is encountered at the mud line (beginning of boreholes) and extends to a depth varying from 50 to 60 feet.
- Layer B: Poorly graded sand. This layer is interbedded by layers of clay and silty sand. It is encountered below layer A and extends to a depth ranging from 120 to 130 feet.
- Layer C: Low plasticity clay. This layer is intercalated by thin layers of gypsum. It is encountered below layer B and extends to a depth varying from 150 to 155 feet.
- Layer D: Low compressibility silt. This layer is encountered below layer C and extends to the end of borings (at about 165 feet from the mud line).

Exploratory Tests

Four test pits were drilled to a depth of 1.0 m on October 15, 2003. Disturbed samples from the test pits were collected, soil samples examined and the depth of each sample recorded. Samples were then tested at the KISR material laboratory, including sieve analysis, liquid limit and plastic limit tests. The soil mainly consists of:

- Light brown, calcareous, sandy silt for the first 0.1 m.
- Followed by a layer of light brown, calcareous, sandy clay and silt to a depth of 0.5 m.
- Underlain by a layer of light brown, calcareous clay and silt to the end of exploration (at a depth varying from 0.7 to 1.0 m from the natural ground surface at the time of exploration).
- Groundwater is encountered in the test pit (1) at a depth of 0.7 m below the ground surface at the time of investigation (October 15, 2003).

In conclusion, it can be said that there is very little or no geotechnical data related to Boubyan Island and a dedicated geotechnical investigation is required.

Topographic Survey

A detailed topographic survey of Boubyan Island was carried out to prepare a digital contour map that will serve as a base map in the integrated GIS system containing all data and thematic layers of the project.

Conducting a topographic survey of Boubyan Island poses unusual and serious challenges on several accounts. First, accessibility is a major problem which requires not only careful planning but also trial and error and takes far more time and effort than needed in other open terrain. There are only two paved raised roads running east-west, near the southern border of the island. Safe and trouble-free mobility along these roads, even when using reliable four-wheel-drive jeeps, can only take place under very restricted good weather conditions. Light or moderate rainfall makes driving a painful experience which risks not only the vehicles but also the safety of personnel. Driving during or after heavy rainfall is impossible. Getting off-road to conduct survey works poses additional problems since driving over the vast areas of very soft sabkha requires light and non-conventional means of transportation. Second, Boubyan Island is a restricted area which requires special security permits and it is not uncommon for working team members to be prevented from entering the island due to slight typing errors in their permits or sudden change of rules at the gate depending on the commanding officer. These factors and others have resulted in exceptionally high downtimes during which work cannot proceed either due to weather conditions or security measures.

Plate 1. Base GPS unit positioned at a benchmark point

Plate 2. Rover unit

Fig. 34. Locations of benchmarks

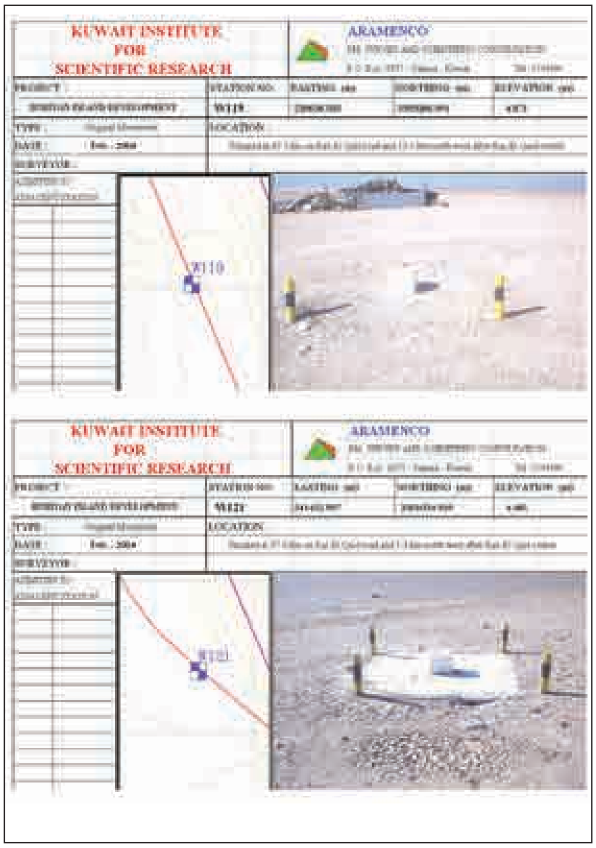

Fig. 35. Example of MOD benchmarks

A detailed survey of Boubyan Island has been conducted using a kinematic GPS survey method of the stop-and-go approach using the Stratus system. Stratus is a product of the Sokkia Company and is a complete single-frequency GPS receiver system for precise surveying, offering high accuracy in the x, y and z measurements (2 mm in the horizontal, 4 mm in the vertical direction). The Stratus system components include the Stratus integrated receiver and data post-processing software. The heart of the Stratus system is the GPS receiver, which incorporates a survey-grade GPS receiver, antenna and batteries; it collects and records signals broadcast from GPS satellites and stores this information in its internal memory.

The kinematic GPS survey setup consists of a base or stationary GPS unit and a rover or moving GPS unit. The base unit is positioned at a control point whose coordinates are known (**Plate 1**) and the rover unit moves around it (**Plate 2**) sending survey measurements to the base unit, which stores data to be processed at the office.

To establish border contour lines along the perimeter of the island, a bathymetric survey was performed using two GPS navigators and two echosounders for double measurement sources. Data were compiled by date and time and then corrected according to the high/low tide tables, equations and measurements.

Table 5. GPS Coordinates for Control Points

Point No.	UTM-WGS 84		Lat/Lon.		Elevation
	E	N	Lat.	Lon.	
K1	227282.622	3279193.55	N29 36 46.0	E48 11 01.8	5.218
K5	230992.619	3278625.865	N29 36 60.5	E48 13 20.1	4.033
K10	235482.349	3278876.135	N29 36 42.1	E48 16 06.6	3.727
K15	239006.866	3282364.475	N29 38 38.0	E48 18 14.5	3.592
K20	242280.678	3285987.665	N29 40 38.1	E48 20 13.1	3.182
K25	244829.385	3286783.491	N29 41 05.8	E48 21 47.1	4.209
K30	245914.106	3295106.68	N29 45 36.7	E48 22 20.4	3.847
W191	235332.207	3286783.491	N29 40 58.6	E48 15 54.1	4.3
W195	229849.911	3278926.196	N29 36 39.4	E4812 37.4	4.345
W119	238638.303	335086.991	N29 50 55.1	E48 17 41.0	4.871
W121	241432.597	3301024.505	N29 48 45.4	E48 19 28.6	4.481
W196	231370.000	3299561.000	N29 47 50.2	E48 13 15.4	3.8
W136	219545.000	3292265.000	N29 43 44.0	E48 06 02.3	8.3

Benchmarks

For the purpose of conducting the GPS survey, several benchmarks were employed as shown in **Fig. 34**. The main benchmarks are the permanent benchmarks that were established by the Ministry of Defense (MOD) in Boubyan Island and its vicinity, which are identified by labels starting with the letter W followed by a number, e.g., W196. An example of the information from MOD benchmarks and other permanent benchmarks used during the survey is shown in **Fig. 35**. Temporary benchmarks were specifically established mainly along road 1/S and are identified by labels starting with the letter K followed by a number, e.g., K10. Coordinates of the benchmarks are given in **Table 5**.

Air Photo of Boubyan Island

The topographic survey team also compiled an air photo of Boubyan and Warbah Islands to provide a definite source of information on topographic features to complement field survey data. This provides an efficient and accurate means to understand the island's features. The high-resolution air photo of Boubyan and Warbah Islands was prepared by compiling high-resolution air photo tiles at a scale of 1:29,000 produced by an air survey conducted in 1992. Air photo tiles are arranged and indexed in rows as shown in **Fig. 36**. Overlapping and matching individual tiles were compiled first for each row and then completed rows were compiled. The completed air photo is shown in **Fig. 37**.

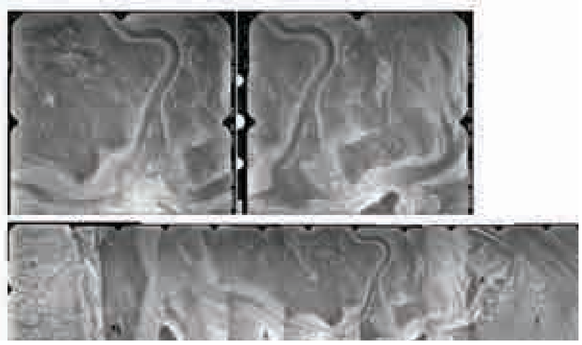

Fig. 36. Compiling one row from individual tiles

Fig. 37. Completed air photo

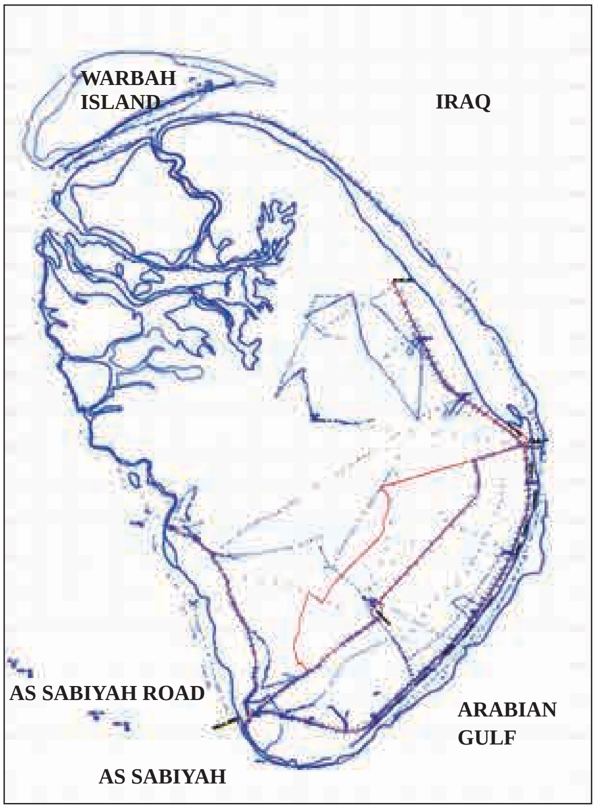

Fig. 38. Field survey raw data coverage

Fig. 39. Ministry of Defense map

A team of four specialists carried out the job as follows:

- Scanning around 200 air photo sheets covering the required area.
- Compiling, overlapping and matching scanned tiles using Photoshop software, row-wise and then column-wise.
- Checking and revising the compiled map.

The air photo was examined to identify significant topographic features in terms of high and low level areas. One of the main criteria is the change in color tone on a gray scale. Generally, dark tones indicate low level terrains and bright areas indicate terrain of higher level. Verification and ground truthing using targeted field GPS surveys were conducted to confirm the topographic feature.

Contour Map

An improved contour map (version 5) was prepared incorporating all topographical features of Boubyan Island. Several sources of information were employed:

1. Field survey. Extensive coverage using GPS survey, which produced better representation of the topographic features. Raw data coverage is shown in **Fig. 38**.
2. Air photo (Fig. 37).
3. Geomorphologic map (Fig. 7).
4. Ministry of Defense map (**Fig. 39**).

The composite nature of the different sources of information used to obtain a reliable contour map is shown schematically in **Fig. 40**. The contour map version 5 is shown in **Fig. 41**.

Datum

Elevations measured either offshore or onshore refer to the largest scale British Admiralty Chart No. 1214. This is the Lowest Astronomical Tide (LAT). The same level is used by MOD in establishing benchmarks.

Tidal Effects and Water Levels

During the bathymetric survey and offshore island survey, the effect of tides on water levels was measured by echosounders. A tidal gauge was established at the coast guard station at Subbiyah by placing a measuring tape on the end vertical pile of the coast guard station pier and this was used to take local tide measurements. Tidal effects are also available at neighboring Shuwaikh and Shuaiba ports in the form of tide tables provided by Kuwait Ports Authority (KPA); these contain full year measurements for the last 20 years or more. These data were compared with measurements collected at the coast guard station at Subbiyah during an offshore survey to convert echosounder readings to the LAT data.

Definition of Island Borders

Two definitions were established for the island border:

1. Highest water level of +4 is considered as the border of the island, which is not covered by water all the time.
2. Lowest water level of +0.00 is considered as the border of the intertidal zone, which is partially covered with water or dry depending on water level.

These two definitions were identified and confirmed using three approaches correlated to KTM or Municipality and MPW data.

Comparison with Shuwaikh and Shuaiba Readings

This task was performed using GPS due to unavailability of points close to Subbiyah. A point at the coast guard station was established at the pier end where measurements were taken during working periods and used for correction. Values measured were correlated to KTM.

Comparing the Shuwaikh and Shuaiba readings, the Shuwaikh reading was found to be in full agreement with the measurement and used directly for interpretation. This has also been confirmed by KISR measurements taken in 1991, which found that Shuwaikh readings were close to Warbah readings with the same margin of accuracy used in this project.

Geotechnical Results

The island is generally flat to slightly undulated. Elevations vary between zero to +4.00 m, complying with the value obtained by KISR for the highest high water level (HHWL).

Based on the above and with reference to other maps prepared for Boubyan Island, the island border is identified by contour +4.0, which has been verified by measurements surrounding the island and from previous available data. Similarly the +0.0 level, which represents the mean lowest water level, has been verified by measurements surrounding the island and from previous available data, then identified by interpretation during preparation of the contour map.

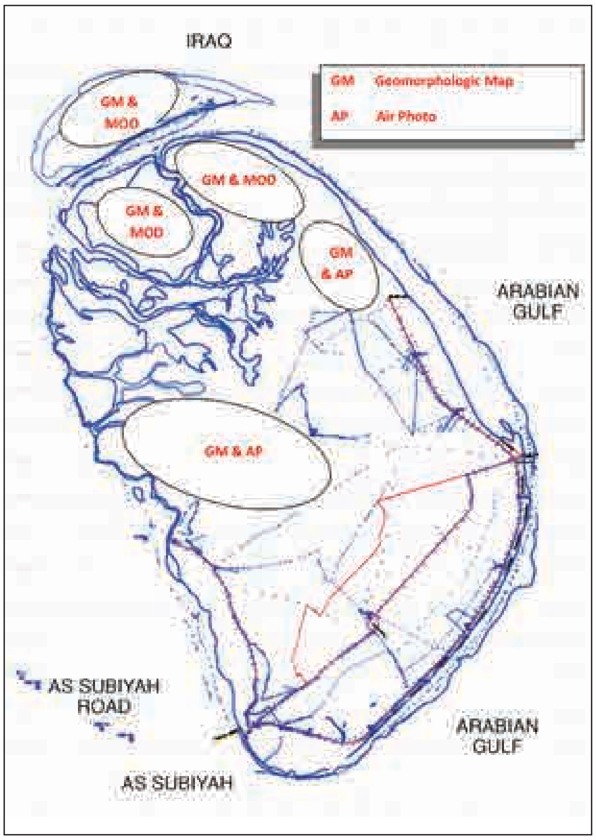

Fig. 40. Composite sources of information for contour map

Fig. 41. Contour map version 5

2

Chapter 3: Soil

3

Abstract

The objectives of this study were to document available information on agricultural and soil factors relating to Boubyan Island; plan and implement a detailed soil survey and characterize soil types; establish a database; develop soil maps; prepare a land use plan and potential use of soils based on soil characterization; delineate suitable agricultural areas and suggest a list of suitable plant species for the island. Three hundred seventy soil samples from 69 soil profile sites (pedons) were completely characterized for physical and chemical properties. A database was established consisting of field and laboratory data. Results revealed that the soils of Boubyan Island fall into two higher levels of classification at the order level: Aridisols (dry soils) and Entisols (little or no soil development); these break down into three great groups: Aquisalids (poorly drained sandy to clayey soils), Haplosalids (deep water table) and Torriorthents (excessively well drained sandy soils). Further breakdowns into lower levels of the classification identified six subgroup levels on Boubyan Island: Aquic Torriorthent, Typic Torriorthent, Typic Aquisalid, Gypsic Aquisalid, Typic Haplosalid, and the Gypsic Haplosalid. Salid indicates salinity levels higher than sea water. Aquic indicates the water table within 1 m of the surface for some times of the year. Gypsic indicates significant gypsum content accumulations. Maps have been prepared indicating location and soil class for each site. Extensive studies on soil and environmental assessment showed several subgroup levels of soils in Boubyan Island with an extremely high salinity, high water table, poor drainage conditions, high gypsum content and frequent inundation with sea water. Therefore, the island is unsuitable for traditional agriculture. Land uses and relevant recommendations were suggested.

Initial Studies

The soil of Boubyan Island was first studied by Yamane and Ueda (1969) and Nishikawa (1969). These were followed by Shimose and Toratani (1970), Al-Zamel (1985a and b) and Al-Zamel (1999). Yamane and Ueda first studied Boubyan Island in 1969 for preliminary soil tests. They discovered that the soil textures were very good for agriculture. Shimose and Toratani (1970) had done a few experiments to plant some vegetation (rice, corn, sunflower, onion, etc.) within Boubyan Island but as these plants were not tolerant to high salt content this experiment was not successful.

The soils of Boubyan Island are saline sandy to clayey soils and a high water table may occur. They are poorly developed and they only support sparse halophytic vegetation.

Previous soil surveys were conducted mainly for soil observations and soil sampling at only a few locations, especially along the island's southern and eastern perimeters where there is vehicle access. Access to the island's interior and northern areas is difficult because of the soft terrain and the risk of encountering unexploded ordnance left behind by the Iraqi military during the invasion of Kuwait in 1990. No soil assessment was conducted in those areas and soil maps were based on interpretations of photographic and remote sensed information. These maps are at a reconnaissance scale with a level of detail to provide an overview of the soil types expected to be found on the island. The island has been relatively undisturbed by human activity as access is restricted to a bridge crossing at Subbiyah and a permit is required to cross into Boubyan Island. Therefore, the existing vegetation and landform patterns are in an undisturbed natural condition and will most likely reflect the types of soils and assist in identifying soil changes.

The initial study of Boubyan soils was performed by Ergun (1969) as part of an FAO study of all of Kuwait to produce a 1:500,000 scale map. He reported 18 detailed soil series descriptions and 18 soil profiles. Percentage characterization of soils was not attempted. Mapping units were mere soil associations and soil series. Yamane and Ueda (1969) made preliminary survey trips to Boubyan Island and collected some soil samples to study the physical and chemical nature of these soils. They discovered that soil texture was suitable for agriculture.

Nishikawa (1969) considered the possibility for agricultural development of the island. He explored distant resources for water extraction and recovery, such as moisture from the sea, wind (humidity changes), tapping soil surface dew production, subterranean less saline water, and improvement of vegetation conditions. He also identified the capillary rise of water in soil and evaporation as moisture. The alluvial soil was posed as a constraint due to its lack of porosity. Plant communities and their soil chemistry were studied. He advocated revegetation of the island with salt-tolerant species only, replacing indigenous species.

Shimose and Toratani (1970) covered nine points on the island and collected samples from four strategic points at a depth of 1 m. The surveyed areas covered one fourth of the total island area. Data were collected on profile characteristics, soil texture, color, hardness, water permeability and content of humus/gravels. Soils of Boubyan Island contained significantly higher amounts of clay and silt fractions than those from the mainland. The textures of Boubyan soils ranged from loam to heavy clay and about 60% of them were light clay. Contents of clay were 7.9 to 13.9% in mainland soils and 10.7 to 67.0% in Boubyan soils. Almost all Boubyan soils contained more than 25% clay. The brown-black color of organic matter was not significantly observed in any soil profile and amounts were negligible. Boubyan soils were found to contain a large amount of soluble salts (i.e., chloride, sulfate, calcium, sodium and magnesium) but potassium was very low. The bicarbonate, sulfate, chloride, sodium reactivity in plants and relative inhibitory effects were assessed. Diluted acid-soluble carbonates were present in large amounts. The main soluble salt is sodium chloride. Soluble calcium salts were 5 to 28 meq/100 g and the pH was 8.05 to 8.75. Calcium levels at the surface were relatively higher. Magnesium compounds were also found in large amounts. Carbon content of surface soils was smaller than that of those under horizons due to the large number of reducing substances in Boubyan soils. Total nitrogen content was 2 to 5 times more than the mainland. They concluded that the soil fertility regime in Boubyan Island was more favorable to agriculture than in the mainland.

Reclamation of soils is a difficult task, as pointed out by Shimose and Toratani (1970). The researchers discussed the reasons for the high salinities, including reduced flow from Shatt Al-Arab and dams in Turkey, Syria and Iraq. Karon River is less saline and accedes into the Shatt Al-Arab. They concluded that the shore-washing effects of the Arabian Gulf waters were minimal since southern Iraq regions are less fertile for agriculture. *Halocnemum strobilaceum* was identified as the dominant native plant species on the island. Salt tolerance tests and chloride accumulation stresses with tobacco indicated 10% chloride in the leaves. Wild saltbush of *Halocnemum* contained up to 13% chloride. Some shoreline plants contained 1.25 to 6.85% chloride. Al-Zamel (1978) conducted preliminary geological and oceanographic investigations on a 40 x 60 km area of Boubyan Island. Geochemistry, sedimentology traits, and genesis of sediments were also studied by Collier (1982) to determine development options.

Omar et al. (2001, 2002) explored the suitability of the soils in the island for agriculture and concluded that some areas can be exploited agriculturally because of the sedimentary formations and the low salinity of waters surrounding them. These include terrain with a low flat surface split into channels and hydrated or dehydrated with the ebb and flow of tidal amplitude. According to the previous soil survey at a reconnaissance scale of 1:100,000, the dominant soil map units of Boubyan and Warbah Islands are chiefly Aquisalids (Sa02 and Sa01), Typic Torriorthents (To01) and to a lesser extent Typic Aquisalids (Sa03) (KISR, 1999a). The Sa02 unit (Typic Aquisalids complex), supratidal flat and nearby level mainly exists in the northern part of Boubyan Island and covers all of Warbah Island. The soils of the Sa02 unit are shallow, poorly drained, sandy Gypsic Aquisalids and Typic Aquisalids. They are widespread on Boubyan and Warbah Islands. Soil texture is predominantly sandy, but in some areas it may be loamy or clayey. The soil profile is moist throughout the year and the water table generally occurs below 1 m but rises above that level in most winters. Perennial vegetation in the Typic Torriorthents (To01) map unit is very rare except for isolated clumps of *Zygophyllum qatarense* (KISR, 1999b). *Seidlitzia rosmarinus* was also prevalent in the less saline areas of the island. The Typic Torriorthents (To01) map

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unit consisted of narrow ridges and elevated broad level coastal plains and formed shell sands. It contains appreciable amounts of gypsum and other salts. Main soil classes within the Sa01 map unit are 90% Aquisalid and 10% Typic Aquisalid. Similarly, Sa02 contained 65% Gypsic Aquisalids and 35% Typic Aquisalids. The families within the Sa03 unit are 50% Typic Aquisalids, 30% Gypsic Aquisalid and 20% Typic Calcigypsid. The To01 map unit consisted of 60% Typic Torriorthent, 30% Torripsamment, and 10% rock outcrop. None of these soil classes are well suited for desert plant habitats with the exception of Sa03 (Typic Calcigypsid) (KISR, 1999b).

Soil Survey Procedures

The detailed procedures followed throughout the survey were as per the *Soil Survey Manual* (Soil Survey Division Staff, 1993) and the *National Soil Survey Handbook* (Soil Conservation Service, 1993). Soils were classified according to Soil Taxonomy, 1994 Revision (Soil Survey Staff, 1975; USDA, 1994). The semi-detailed soil survey was conducted according to the protocols for second-order soil surveys (Soil Survey Division Staff, 1993). This included detailed soil information for making predictions of suitability for use and of treatment needs; the information can be used for planning general agriculture, construction and urban development. Other land uses will require precise knowledge of the soils and their variability. Soil boundaries are plotted by interpretation of remotely sensed data, with boundaries verified from fieldwork in representative areas; map units are consociations and complexes. Undifferentiated groups and associations were also identified wherever applicable. A soil information system was developed for the Soil Survey Project (KISR, 1999a and b), combining spatial information management capabilities of a Geographic Information System (GIS) with the textural information management of a relational database system. The GIS was used for the storage, manipulation, analysis and presentation of spatial data. Details of the soil information system are outlined in the *Soil Survey Report* (KISR, 1999c). All site information relating to soil profiles and the surrounding environment was recorded in the field site cards and later keyed into the project soil information system database.

Three levels of profile descriptions were conducted as follows:

- Detailed: from pit profiles to describe and sample the soil.
- Semi-detailed: from shallow pits combined with auger borings to identify the soil and provide a limited description and information on the range of soil properties.
- Brief: from auger borings to identify the soil and characterize the map units.

Final soil classification, correlation, quality assurance and map production were carried out after all the field and laboratory analyses data became available.

Field Survey, Soil Sampling and Analyses

The project team surveyed and collected soils samples from 69 locations for laboratory analysis and field descriptions of the soil profile. The location of selected sampling points is shown in **Fig. 42**. SEMATCO (a drilling company providing geotechnical information for HOK) provided a further 19 soil samples for analysis from four locations.

Field survey and sampling work was conducted between May and October 2004. The sampling site locations were determined in the field so that site location was representative of the surrounding areas. Using a shovel, pits were excavated to a depth of 1 m; deeper soil samples were collected using a hand auger. The soil profile was described and soil samples were collected from representative depths determined by the surveyor.

Three hundred seventy soil samples from 69 soil profile sites were completely characterized for physical and chemical properties as per the established procedures (USDA, 1996; Munsell, 1998). Soil samples were collected from soil pits at set depths down the profile to enable ease of comparison of results between profiles (rather than sampling by horizon). Depending on the individual soil characteristics of a given site, a number of soil samples from several depths were collected for laboratory analysis.

Soil Morphological Description

Description of soil morphology provides information needed to classify a soil profile formally and enables pedologists to make assessments of the soil's potential for agriculture and other uses. Morphological features such as color, field texture, structure, consistence, segregations, effervescence when treated with hydrochloric acid and coarse fragments all provide valuable information concerning the likely performance of crops and pastures as well as factors affecting other land uses.

The following morphological features and definitions were used to interpret the soil's potential:

Soil Color. Soil color is the most readily identified soil morphological characteristic. It can also provide an indication of the soil's organic matter content and fertility levels, as well as redox condition, which relates to soil aeration (drainage). The Munsell Soil Color Chart system (Munsell, 1998) was used to ascertain soil color.

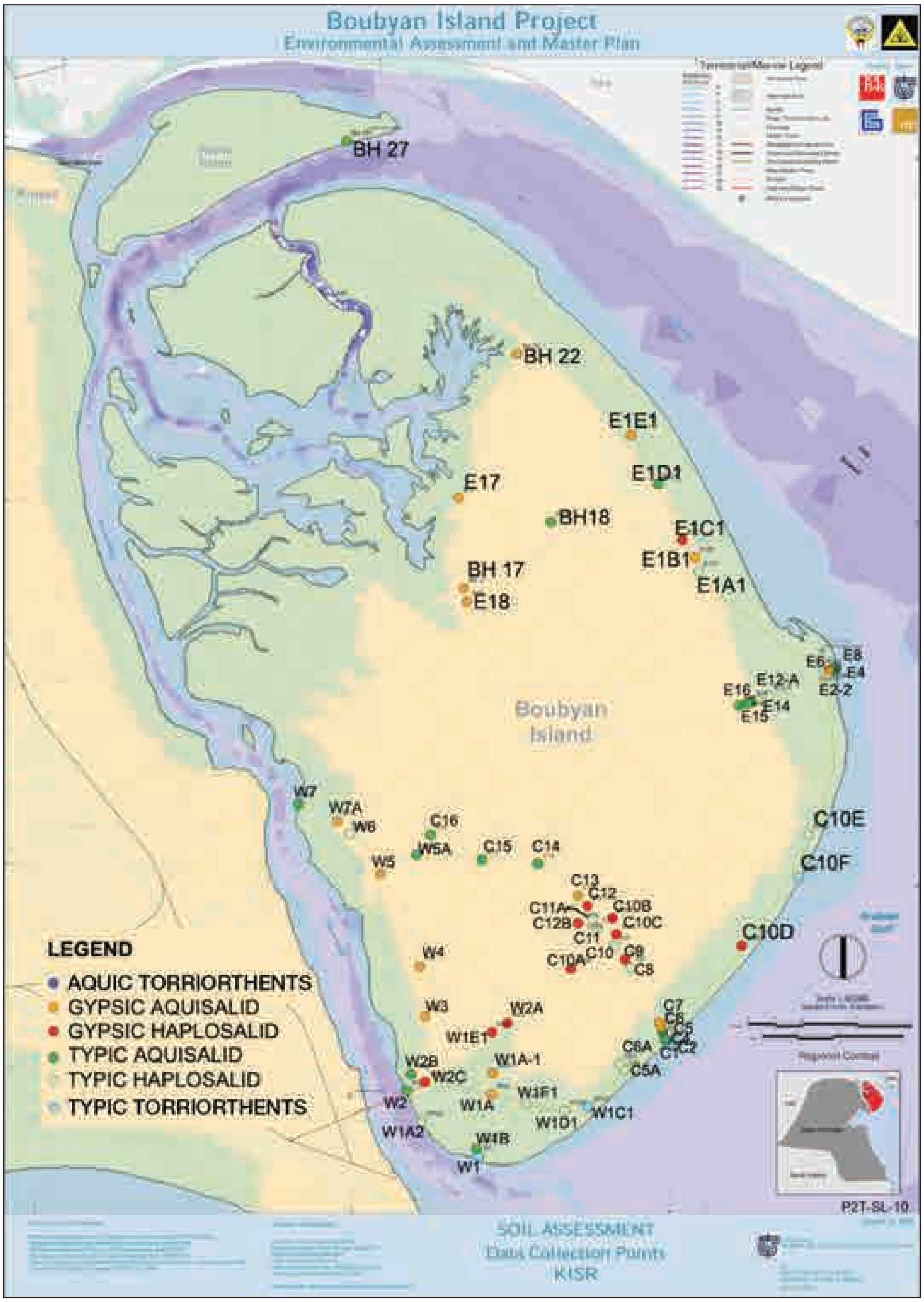

Fig. 42. Location of sampling points in Boubyan Island, Kuwait 2005

Field Texture. Soil texture is a measure of the proportion of sand (2.00 to 0.05 mm), silt (0.05 to 0.002 mm) and clay (<0.002 mm) in soil. The clay content of a soil is closely related to the specific surface area (the total area of all exposed particle sizes), which has a major influence on soil-water relationships and soil physics. The specific surface area also affects many chemical reactions in the soil. As a result, soil texture provides a useful tool for predicting profile water relations, nutrient status, pH buffering capacity, erodibility and the risk of structure decline and subsurface compaction.

Field soil texture (or hand texture) was determined by the behavior of a small handful of soil when moistened and kneaded into a small ball (bolus). Field texture, along with particle-size distribution tests in the laboratory, provided a guide to soil behavior because it is influenced by other factors such as organic matter content, clay mineralogy, the presence of carbonates and the amount of sodium at exchange sites.

Soil Structure. This relates to the way soil particles are arranged and bound together. The size, shape and nature of soil aggregates in playa have a major role in determining profile hydrology and the ease of root penetration. Where soil particles are bound together in natural-forming aggregates (peds) separated by irregular spaces, the soil is described as having structure. The degree and nature of structure development were determined by clay mineralogy and organic matter content, which can be described from the visible appearance of in situ soil in a dry to slightly moist state.

Soil Consistence. This is a measure of the strength and coherence of a soil. Soil consistence or consistency is also called rupture resistance and is very readily observed in the field. In agricultural systems, this morphological attribute gives an indication of root impedance. Factors such as soil texture, mechanical compaction, organic matter content and cementing agents influence consistence. Soil consistence was measured in the field by determining the magnitude of finger, foot or hammer force needed to cause disruption or distortion to a 25 to 30 mm block of soil.

Segregations and Effervescence. Segregations are accumulations of distinct mineral particles such as calcium carbonate, gypsum and iron. They occur in a variety of sizes, shapes and forms and can be either soft or hard. Segregations can have a major influence on soil chemical and physical properties. Effervescence is the reaction, or the amount of fizz witnessed, when 1 M hydrochloric acid (HCl) is applied to the soil. This provides a field test to confirm the presence of calcium carbonate in the soil.

Coarse Fragments. These comprise rock fragments and hard segregations greater than 2.00 mm. They are subdivided into fine gravels (2 to 5 mm), medium gravels (5 to 20 mm), coarse gravels (20 to 75 mm), cobbles (75 to 250 mm), stones (250 to 600 mm) and boulders (>600 mm). High amounts of coarse fragments in the soil may impose severe limitations on the capacity of the soil to supply water and nutrients by reducing the volume of soil available for root activity. They can also have an adverse impact on soil workability, because they are abrasive to tillage implements. On the other hand, surface gravel may reduce erosion and act as a mulch to reduce evaporation from the soil.

Soil Laboratory Procedures

Laboratory analyses were carried out in the Aridland Agriculture and Greenery Department soil laboratories and in the Central Analytical Laboratory (CAL) of KISR. All laboratory procedures and results (physical and chemical) were quality assured by a specialist. The soil analyses and laboratory procedures used include the following:

Particle-Size Distribution (<2 mm). Particle-size distribution analysis (PSDA) is a measure of the size distribution of individual particles in a soil sample. A combination of sieves and pipeting method was used to measure the distribution of clay, silt and sand sized particles in the <2 mm fraction. Samples were washed to remove soluble salts and gypsum, which could interfere with the dispersal of clay sized particles. The sand, silt and clay fractions are reported as a percentage of the <2 mm fraction.

Total Pretreatment Loss (TPL). The loss of carbonate, gypsum and other soluble salts, as prescribed in method 3A1e (USDA, 1996), was determined and reported as a percentage of the <2 mm fraction.

Coarse Fragments (>2 mm). Soil samples were sieved and weighed to separate coarse fragments larger than 2 mm in diameter. Coarse fragments included rock fragments and hard carbonate nodules, excluding gypsum crystals. Coarse fragments were reported as a percentage of the <75 mm fraction.

Fragments (>75 mm). Visual field estimates were used to determine the volume of soil occupied by fragments greater than 75 mm in diameter. They were reported as a percentage of the >2 mm fraction.

Loss on Acid Treatment (LAT). A <2 mm sieved soil sample was treated with hydrochloric acid to dissolve calcium carbonate. Percentage calcium carbonate was determined by comparing weight loss on acid treatment with original sample weight as per method 6E1c (USDA, 1996).

Percent Calcium Carbonate ($CaCO_3$). A <2 mm sieved soil sample was treated with hydrochloric acid in a manometer (calcimeter) and the reaction measured and compared to the reaction of known blanks. Percentage $CaCO_3$ was calculated according to USDA (1996) procedure 6E1g.

Percent Gypsum (Calculated). Gypsum percentage of the <2 mm fraction was assessed by USDA (1996) method 6F1a in which a soil sample was mixed in water and acetone to dissolve and precipitate out the gypsum, which was then redissolved and the electrical conductivity (EC) of the solution measured. The EC reading was used to estimate the gypsum content in meq/100 g, which was then converted to percent gypsum.

Particles Passing Sieves. The proportion of a soil sample passing different sieve sizes was calculated from the particle-size distribution analysis described above. Particles passing sieve numbers 4 (4.75 mm), 10 (2 mm), 40 (0.420 mm) and 200 (0.074 mm) were reported using formulae listed in USDA (1996).

Soil Moisture Content. The amount of water held in a sieved soil sample (<2 mm fraction) was determined at 1/10, 1/3 and 15 bar and reported as a weight percent of the <2 mm sample. The pressure plate extraction method was used on sieved samples, consistent with methods 4B1a and 4B2a (USDA, 1996).

Bulk Density. Bulk density was determined using method 4A3a (USDA, 1996) in which moist soil cores of known volume were taken, weighed with an electronic balance, and then dried in an oven at 105°C at a constant weight. The dry weight was recorded and the bulk density calculated by dividing the oven dry weight with the core volume (reported in g/cm^3).

Porosity. The volume fraction of soil occupied by air or water-filled pores. Percent porosity was calculated from the bulk density and specific gravity of each sample using the formula: Total porosity = (1 – bulk density/particle density).

Water Retention Difference (WRD). A value that denotes the volume fraction of water in the whole soil that is retained between specific suction levels. Method 4C2 (USDA, 1996) was used to calculate the WRD.

Hygroscopic Moisture. The hygroscopic moisture was determined from the weight difference between air drying and oven drying (105°C) in accordance with method 26 (USDA, 1996).

Extractable Cations. The extractable calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) ions were determined with an atomic adsorption spectrophotometer by analyzing the ammonium acetate extraction solution and reported in meq/100 g according to methods 6N2, 602, 6P2 and 602 (USDA, 1996), respectively.

Cation Exchange Capacity (CEC). A measure of the quantity of readily exchangeable cations (such as Ca, Mg, Na, and K) in the soil. Method 5A8c (USDA, 1996) was used with ammonium acetate at pH 7.0 in an automatic extractor to saturate the exchange sites with ammonium. The ammonium adsorbed onto the sites was determined calorimetrically.

Exchangeable Sodium Percentage (ESP). Calculated using exchangeable sodium and CEC data, as prescribed by method 5D2 (USDA, 1996).

Soluble Cations. Water was added to a sieved <2 mm soil sample to produce a saturated paste from which the liquid was extracted under vacuum. This saturated extract was diluted with an ionization suppressant and analyzed with an atomic absorption spectrophotometer to determine the quantity of Ca, Mg, Na, and K, expressed in milliequivalents per liter (meq/L).

Soluble Anions. The above saturated extract was used to determine the quantity of carbonate (CO_3), bicarbonate (HCO_3), chloride (Cl), sulfate (SO_4) and nitrate (NO_3), expressed in milliequivalents per liter (meq/L). Methods 611 and 6J1 (USDA, 1996) were used to determine CO_3 and HCO_3, respectively. Cl was measured by a colorimetric method. SO_4 was analyzed by inductively coupled plasma optical emission spectroscopy (ICP) by method 14F1 (Rayment and Higginson, 1992). NO_3 was analyzed by ion chromatography (USDA, 1996) method 6M1d and by continuous flow autoanalyzer (CFAA) using the cadmium reduction method described in APHA (1992).

Saturation Percentage (SP). The water content percentage was determined by method 8A (USDA, 1996) to find the amount of moisture in the saturated paste.

Total Salts (TS). Calculated according to the formula in USDA (1996) to find a measure of the total salt concentration.

Electrical Conductivity Saturation Extract (ECe). The electrical conductivity of the saturated extract of a sieved soil sample was measured with an electronic probe in accordance with method 8A3a (USDA, 1996).

Soil Reaction. An electronic probe was used to measure the pH of the saturated paste of a sieved <2 mm soil sample, consistent with method 8C1b (USDA, 1996).

Sodium Adsorption Ratio (SAR). An indirect measure of the equilibrium relation between soluble sodium in the salt solution and exchangeable sodium adsorbed by the soil, calculated using the formula outlined in method 5E (USDA, 1996).

Soil Classification

Based on field and laboratory data, soils in Boubyan Island were classified using the international soil survey classification of the United States Department of Agriculture (Soil Survey Staff, 1975, 1993; USDA, 1994; KISR, 1999a and b).

The soil classification name describes the key soil properties. Soils fall into two higher levels of classification at the order level: Aridisols (dry soils that do not have moisture available for plants for long periods) and Entisols (little or no soil development). Further breakdowns into lower levels of classification to subgroup level for each of the sites are shown in **Table 6**. Salid indicates salinity levels higher than sea water. Aquic indicates the water table within 1 m of the surface for some times of the year. Gypsic indicates significant gypsum content accumulations. From the above individual soil classifications six classes of soil have been identified on Boubyan Island and a description for each of these follows. **Table 7** is a generalized summary table of key soil property data interpreted as an aggregated estimate for the first 100 cm of soil. This table has been compiled to show some of the general data trends; however for specific site locations the site data should be referred to.

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Table 6. Soil Classification for Boubyan Island Soil Sampling Sites

Site	Order	Suborder	Great group	Subgroup
C1	Entisol	Orthent	Torriorthent	Aquic Torriorthent
C10	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C10A	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C10B	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C10C	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C10D	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C10E	Aridisol	Salid	Haplosalid	Typic Haplosalid
C10F	Entisol	Orthent	Torriorthent	Typic Torriorthent
C11	Aridisol	Salid	Haplosalid	Typic Haplosalid
C11A	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C12	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C12B	Aridisol	Salid	Haplosalid	Typic Haplosalid
C13	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
C14	Aridisol	Salid	Aquisalid	Typic Aquisalid
C15	Aridisol	Salid	Aquisalid	Typic Aquisalid
C16	Aridisol	Salid	Aquisalid	Typic Aquisalid
C2	Entisol	Orthent	Torriorthent	Aquic Torriorthent
C3	Entisol	Orthent	Torriorthent	Typic Torriorthent
C4	Aridisol	Salid	Aquisalid	Typic Aquisalid
C5	Aridisol	Salid	Aquisalid	Typic Aquisalid
C5A	Aridisol	Salid	Haplosalid	Typic Haplosalid
C6	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
C6A	Aridisol	Salid	Haplosalid	Typic Haplosalid
C7	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
C8	Aridisol	Salid	Haplosalid	Typic Haplosalid
C9	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
E1	Entisol	Orthent	Torriorthent	Typic Torriorthent
E12	Aridisol	Salid	Haplosalid	Typic Haplosalid
E13	Aridisol	Salid	Haplosalid	Typic Haplosalid
E14	Aridisol	Salid	Aquisalid	Typic Aquisalid
E15	Aridisol	Salid	Aquisalid	Typic Aquisalid

Table 6 continued. Soil Classification for Boubyan Island Soil Sampling Sites

Site	Order	Suborder	Great group	Subgroup
E16	Aridisol	Salid	Aquisalid	Typic Aquisalid
E17	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
E18	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
E1A1	Aridisol	Salid	Haplosalid	Typic Haplosalid
E1B1	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
E1C1	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
E1D1	Aridisol	Salid	Aquisalid	Typic Aquisalid
E1E1	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
E2-1	Entisol	Orthent	Torriorthent	Aquic Torriorthent
E2-2	Aridisol	Salid	Aquisalid	Typic Aquisalid
E4	Aridisol	Salid	Aquisalid	Typic Aquisalid
E6	Aridisol	Salid	Aquisalid	Typic Aquisalid
E7	Aridisol	Salid	Aquisalid	Typic Aquisalid
E8	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W1	Entisol	Orthent	Torriorthent	Typic Torriorthent
W1A	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W1A1	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W1A2	Aridisol	Salid	Haplosalid	Typic Haplosalid
W1B	Aridisol	Salid	Aquisalid	Typic Aquisalid
W1C1	Entisol	Orthent	Torriorthent	Typic Torriorthent
W1D1	Aridisol	Salid	Haplosalid	Typic Haplosalid
W1E1	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
W1F1	Aridisol	Salid	Haplosalid	Typic Haplosalid
W2	Aridisol	Salid	Aquisalid	Typic Aquisalid
W2A	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
W2B	Aridisol	Salid	Aquisalid	Typic Aquisalid
W2C	Aridisol	Salid	Haplosalid	Gypsic Haplosalid
W3	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W4	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W5	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
W5A	Aridisol	Salid	Aquisalid	Typic Aquisalid
W6	Aridisol	Salid	Haplosalid	Typic Haplosalid
W7	Aridisol	Salid	Aquisalid	Typic Aquisalid
W7A	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
BH17	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
BH18	Aridisol	Salid	Aquisalid	Typic Aquisalid
BH22	Aridisol	Salid	Aquisalid	Gypsic Aquisalid
BH27	Aridisol	Salid	Aquisalid	Typic Aquisalid

Table 7. Summary of Soil Properties by Soil Class

Soil Property	Soil Class					
	Aquic Torriorthent	Typic Torriorthent	Gypsic Haplosalid	Typic Haplosalid	Gypsic Aquisalid	Gypsic Aquisalid
Soil development present	No	No	Yes	Yes	Yes	Yes
Shell fragment content <35%	Yes	Yes	No	No	No	No
Salt content within upper 100 cm is more salty than sea water	No	No	Yes	Yes	Yes	Yes
Water table occurs within upper 100 cm for some times of the year	Yes	No	No	No	Yes	Yes
Significant gypsum accumulation in subsoil	No	No	Yes	No	Yes	No
Salt crust may be present on soil surface	No	No	Yes	Yes	Yes	Yes
Soil Property Data (upper 1 m)						
Total clay (%)	10-30	5-20	0-30	5-35	5-45	10-50
Total silt (%)	0-35	0-20	30-95	45-85	40-85	40-90
Total sand (%)	40-95	40-95	5-55	5-50	5-35	0-45
Bulk density (g/cm^3)	1.2-1.4	1.3-1.6	0.8-1.3	1.0-1.4	1.1-1.4	1.1-1.4
Soil reaction (pH)	8.0-8.4	8.1-8.8	7.1-8.1	7.4-8.1	7.6-8.0	7.3-7.9
Electrical conductivity (dS/m)	10-60	10-60	110-200	120-180	130-200	90-185
Cation exchange capacity (meq/100 g)	0-5	0-10	10-40	10-40	5-20	0-20
Exchangeable sodium (%)	30-40	15-45	50-75	55-70	60-80	50-75
Gypsum (%)	0-1	0-1	1-12	0-4	1-10	0-4
Calcium carbonate (%)	40-80	30-90	5-40	10-45	5-40	10-40
Plant root depth (cm)	25-50	75-100	75-100	100-150	0-25	25-50
Drainage	Very poor	Somewhat excessive	Somewhat excessive	Somewhat excessive	Very poor	Very poor

1. Typic Torriorthents (Site Numbers: C10F, C3, E1, W1, and W1C1). These soils are somewhat excessively drained due to the shelly and sandy nature of the soil, with moderate to deep plant rooting depth. Calcium carbonate content is high due to seashells, which appear in bands forming layers throughout the profile. The soils occur on gentle slopes (less than 5% slope) and offer very little resistance to excavation. The water table appears at depths varying from 50 to 200 cm. The soil texture is mainly sandy and ECe values range from 10 to 136 dS/m. **Plate 3** illustrates this soil subgroup.

Plate 3. Seashells are observed in bands in alternate layers throughout the profile Typic Torriorthent (Site W1C1)

2. Typic Aquisalids (Site Numbers: C4, C5, C14, C15, C16, E1D1, E2-2, E4, E6, E7, E14, E15, E16, W1B, W2, W5A BH18, BH27, W7, and W2B). These soils are very poorly drained, with a shallow plant rooting depth and the water table occurring within 100 cm of the soil surface for most of the year. The soils are highly saline, gypsum content is low, and calcium carbonate content is moderate. The soil texture is dominantly silt loam to silty clay, ECe values ranges from 90 to 185 dS/m. Native vegetation is present in some areas. **Plate 4** illustrates this soil subgroup.

Plate 4. No vegetation; salt layers are white patches on loose and soft surface soil, sticky at subsurface layers (Typic Aquisalid, Site C5)

3. Gypsic Aquisalids (Site Numbers: C6, C7, C13, E1B1, E1E1, E8, E18, W1A, W1A1, W3, W4, W5, W7A, BH17, and BH22). These soils are very poorly drained, with a very shallow plant rooting depth and the water table occurring within 100 cm of the soil surface for most of the year. They are highly saline, highly gypsic, and calcium carbonate content is moderate. The soil texture is predominantly silt loam to silty clay loam and in some sites more sandy. ECe values range from 130 to more than 200 dS/m. Native vegetation exists in some areas within this soil type. **Plate 5** illustrates this soil subgroup.

Plate 5. Green vegetation is seen on small heaps of soil; surface soil is white in color with salt crystallization and clayey texture (Gypsic Aquisalid, Site C13)

4. Gypsic Haplosalids (Site Numbers: C9, C10A, C10B, C10C, C10D, C11A, C12, E17, E1C1, W1E1, W2A, and W2C). These soils are very deep and somewhat excessively drained, with a moderately shallow plant rooting depth. The soils are highly saline with high gypsum (75%) and the water table occurs at a depth of 130 to 210 cm from the surface. The surface layers have a loose, dry consistence, often with a salt crust. Structure varies from blocky to platy at lower layers, and shining fine crystals of gypsum are present. Calcium carbonate content is moderate. The soil texture is dominated by silts and clays and ECe values range from 110 to more than 200 dS/m. **Plate 6** illustrates this soil subgroup.

Plate 6. Flat land, weak salt encrustation in white to dark brown color occurs on the surface of soil (Gypsic Haplodsalid, Site E17)

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5. Typic Haplosalids (Site Numbers: C5A, C6A, C8, C10, C10E, C11, E1A1, E12, E13, W1A2, W1D1, W1F1, W6, and C12B). These soils are somewhat excessively drained, with a deep plant rooting depth, and the water table occurs at a depth of 150 to 200 cm from the surface. They are highly saline with low gypsum content. Calcium carbonate content is moderate. The soil texture is silt loam to silty clay loam and ECe values range from 120 to 180 dS/m. These sites have native vegetation growing on them. **Plate 7** illustrates this soil subgroup.

Plate 7. No vegetation; platy surface structure observed in lower layers with brown coloration (Typic Haplosalid, Site W1D1)

6. Aquic Torriorthents (Site Numbers: C1, C2, and E2-1). These soils are well drained, with a shallow to moderately deep plant rooting depth, and occur on gentle slopes to the sea (approximately less than 5% slope). Aquic conditions prevail throughout the year, with the water table at depths between 25 and 100 cm. Soils have high calcium carbonate content due to seashell deposits in the profile. The soil has a coarse sandy texture and ECe values range from 10 to 91.3 dS/m. **Plate 8** illustrates this soil subgroup.

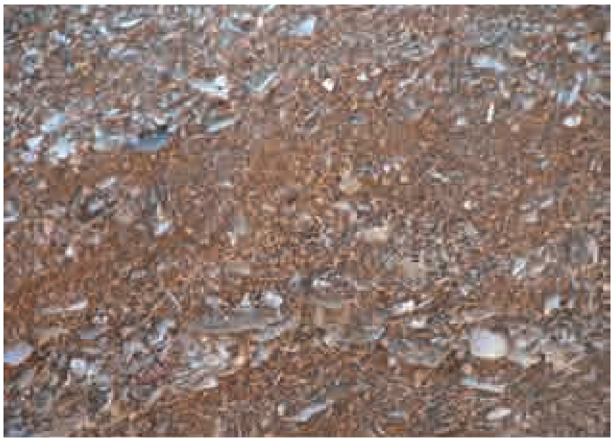

Plate 8. Close-up of seashells seen on surface (Aquic Torriorthents, Site E2-1)

Soil Map and Map Units

The soil map is a representation of the general soil distribution and within each map unit the aim is to group similar soil classes. The difficult access around Boubyan Island meant that comprehensive routine field verification of map unit boundaries was not possible. Therefore drafting of the soil map relied on the previous map drawings from work of the Soil Survey for the State of Kuwait (KISR, 1999b) and refinement of these boundary placements by pattern recognition using newer remote sensed imagery (Landsat 2001), honoring the data collected in this survey and field observations conducted during the survey. The classifications are shown in Table 6. In general there was little modification made to the previous placement of the map unit boundaries or delineation of any new map units. However, the current survey provided additional site classification and characterization information that confirmed the type of soils found on Boubyan Island and supplied information that could be used to refine and improve the map unit descriptions in the Soil Survey for the State of Kuwait, which was based on a very limited data set.

The soil map is shown in **Fig. 43**. Five map units have been identified and these are described in **Table 8**. **Table 9** identifies the sites that occur in each of the five map units. Note that some of these map units contain more than one soil type because the scale of mapping does not allow individual soil areas to be delineated. However, for this data set the agreement between the map unit classification and the soils that occur in it is very good; rarely are there any other classified soils different from the named map unit. The soil descriptions do provide information that allows predictions of where these soils occur within the map unit. A constraints map is presented in **Fig. 44**.

Land Suitability Interpretations

Soil suitability interpretations were conducted for irrigated agriculture. In addition, interpretations were made for restrictive features or soil properties that restrict or limit the use of a soil for generalized land uses for recreation, construction material, sanitary facilities, and range management.

For each land use, there is a criteria table for the soil properties that will rank the soil. It should be noted that the suitability interpretations presented here will be based on soil properties only; this will then need to be integrated with other relevant environmental and physical factors to be used in management planning. These interpretations are useful for regional assessment and planning. They provide a regional perspective on restrictions or suitability for the particular land uses. They are by no means site-specific and do not eliminate the need for detailed on-site investigation.

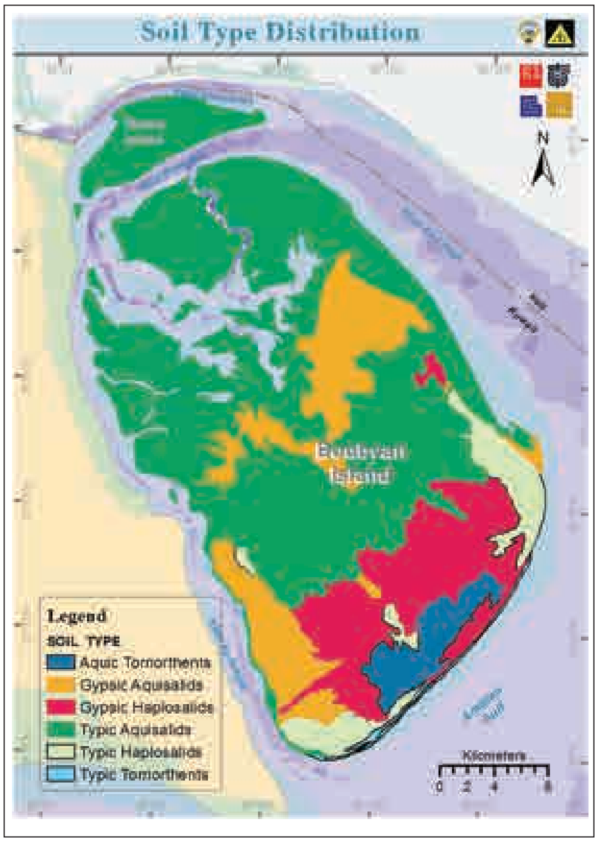

Fig. 43. Soil map units and classification of Boubyan Island

Fig. 44. Constraints map for agricultural land use planning of Boubyan Island

Table 8. Map Unit Descriptions

Map Symbol	Map Unit Name	Description
A	Gypsic Aquisalids, playa, nearly level	**Playas and coastal flats.** Moderately deep, poorly drained, sandy Gypsic Aquisalids are dominant, and in some areas the soils may contain loamy or clayey layers. The soils are characterized by the presence of gypsum and a water table above 100 cm. In the southern portion, self-mulching, saline soils have been deflated, forming round closed depressions that are 10 to 50 m wide and up to 50 cm deep. Perennial vegetation is rare.
B	Typic Aquisalids, supratidal flat, nearly level	**Supratidal flats and associated drainage channels, plus some narrow intertidal areas.** Shallow or moderately deep, poorly drained, sandy Aquisalids occur throughout, and in some areas the soils may contain loamy or clayey layers. Near margins and on elevated areas where the water table remains below 100 cm there may be other similar soils such as Haplosalids. The soil surface varies from hard-set to prominent salt crusting. Perennial vegetation is rare except for some areas of *Halocnemum strobilaceum* and *Seidlitzia rosmarinus*.
C	Gypsic Haplosalid, flat, nearly level	**Flats.** Shallow or moderately deep, poorly drained, sandy Gypsic Haplosalids occur throughout, and in some areas the soils may contain loamy or clayey layers. Soils are characterized by the presence of gypsum, mainly occurring in the upper part of the profile. The soil surface varies from hard-set to prominent salt crusting. Perennial vegetation is rare.
D	Typic Haplosalid, flat, nearly level	**Flats down to sandy beaches.** Shallow or moderately deep, poorly drained, sandy Haplosalids occur throughout, and in some areas the soils may contain loamy or clayey layers. The soil surface varies from hard-set to prominent salt crusting. Perennial vegetation occurs in sheltered areas.
E	Typic Torriorthents-Aquic Torriorthents complex, shelly, gently sloping	**A series of narrow ridges and elevated broad level coastal plains.** Very deep, somewhat excessively drained, sandy Typic Torriorthents occur on the slopes and on the low lying flats Aquic Torriorthents occur. Rock outcrops are dominant on the crests and upper slopes of the ridges. The Torriorthents are formed in shelly sand and contain appreciable amounts of gypsum and other salts. Perennial vegetation is rare except for isolated clumps.

Table 9. Map Unit Distribution

Map Symbol	Site	Subgroup
A	C6	Gypsic Aquisalid
A	C7	Gypsic Aquisalid
A	E18	Gypsic Aquisalid
A	E1E1	Gypsic Aquisalid
A	W1A	Gypsic Aquisalid
A	W1A1	Gypsic Aquisalid
A	W3	Gypsic Aquisalid
A	W4	Gypsic Aquisalid
A	W5	Gypsic Aquisalid
A	W7A	Gypsic Aquisalid
A	BH17	Gypsic Aquisalid
A	E17	Gypsic Aquisalid
A	BH22	Gypsic Aquisalid
B	E8	Gypsic Aquisalid
B	C14	Typic Aquisalid
B	C15	Typic Aquisalid
B	C16	Typic Aquisalid
B	E14	Typic Aquisalid
B	E15	Typic Aquisalid
B	E16	Typic Aquisalid
B	E1D1	Typic Aquisalid
B	E2-2	Typic Aquisalid
B	E4	Typic Aquisalid
B	E6	Typic Aquisalid
B	E7	Typic Aquisalid
B	W1B	Typic Aquisalid
B	W2	Typic Aquisalid
B	W2B	Typic Aquisalid
B	W5A	Typic Aquisalid
B	W7	Typic Aquisalid
B	BH18	Typic Aquisalid
B	BH27	Typic Aquisalid
C	E1B1	Gypsic Aquisalid
C	C10A	Gypsic Haplosalid
C	C10B	Gypsic Haplosalid
C	C10C	Gypsic Haplosalid
C	C10D	Gypsic Haplosalid
C	C11A	Gypsic Haplosalid
C	C12	Gypsic Haplosalid
C	C9	Gypsic Haplosalid
C	E1C1	Gypsic Haplosalid
C	W1E1	Gypsic Haplosalid
C	W2A	Gypsic Haplosalid
C	W2C	Gypsic Haplosalid
C	C10	Gypsic Haplosalid
D	C13	Gypsic Haplosalid
D	C10E	Typic Haplosalid
D	C11	Typic Haplosalid
D	C12B	Typic Haplosalid
D	C5A	Typic Haplosalid
D	C6A	Typic Haplosalid
D	C8	Typic Haplosalid
D	E12	Typic Haplosalid
D	E13	Typic Haplosalid
D	E1A1	Typic Haplosalid
D	W1A2	Typic Haplosalid
D	W1D1	Typic Haplosalid
D	W1F1	Typic Haplosalid
D	W6	Typic Haplosalid
E	E2-1	Aquic Torriorthent
E	C1	Aquic Torriorthent
E	C2	Aquic Torriorthent
E	C4	Typic Aquisalid
E	C5	Typic Aquisalid
E	C10F	Typic Torriorthent
E	C3	Typic Torriorthent
E	E1	Typic Torriorthent
E	W1	Typic Torriorthent
E	W1C1	Typic Torriorthent

Soils were first assessed as to their suitability for irrigated agriculture and it was found that none of the soils on Boubyan Island were suitable; this conclusion is discussed in more detail below. Alternative land uses were then considered.

Irrigated Agriculture

In general land suitability classification schemes apply the concepts developed by the FAO in its Framework for Land Evaluation (FAO, 1976). The framework does not in itself constitute an evaluation system, but is a set of principles and concepts on which the basis of the evaluation system can be constructed.

Important factors to consider in selecting land for irrigated agriculture in Kuwait based on the experience from the Soil Survey for the State of Kuwait (KISR, 1999a) include:

- Emphasis should be placed on profile depth and deep drainage, because of the brackish nature of the bulk of the irrigation water available.
- Areas having a limited capacity to dispose of excess irrigation water should be avoided.
- It is likely that the quality of water used will require a leaching fraction of between 20 and 25%. Therefore, suitable soils should have a profile permeability class of at least “moderate” (K_{sat} 20 to 65 mm/hr) and deep, free-draining subsoil material.
- The depth to a root-restricting layer for crops such as barley, alfalfa or vegetables should be at least 60 cm.
- Salinity values in the root zone should be below 4 dS/m ECe or have the potential, via leaching, to be reduced to this level.
- Sodicity is not considered critical in most soils as they contain high amounts of free calcium carbonate.
- Alkalinity, although a problem, is not prohibitive and can be overcome with irrigation and soil management techniques and appropriate crop selection.
- Highly gypsic soils should be avoided.
- Sandy soils require careful water management because of low water-holding capacity. The loose sandy surface may be susceptible to wind erosion; therefore wind breaks, mulches and vegetative ground covers should be encouraged.

The criteria used to assess soils suitable for irrigated agriculture in Kuwait were based on the experience from the Soil Survey for the State of Kuwait and are presented in **Table 10**. **Table 11** shows the soil class suitability rating for irrigated agriculture, where the properties for each class are compared against the criteria table.

Based on this set of criteria the interpretation for all soil classes is rated as not suitable for developing any large-scale irrigated agriculture operations. The main constraint for all soil classes is the high soil salinity. In addition other limiting factors for some of the soil classes include shallow plant rooting depth, poor drainage, high sodium adsorption ratio, and high calcium carbonate content.

Other Land Use Interpretations

Assessments have also been made of the features or soil properties that restrict or limit the use of a soil for the generalized land uses of recreation, construction materials, sanitary facilities, and range management. These restrictive features, defined in Part 620.04, Soil Conservation Service (1993), are intended to assist users in identifying soil features important for use and management. The suitability assessments also provide a tool for management. Criteria used to make these assessments come from Part 620, Soil Conservation Service (1993).

Based on the land use criteria, the soil classes are rated and assigned to one of three groups as suitable for that land use. The limitation rating is expressed as being slight, moderate, or severe. Soils with slight limitations require no additional measures other than the normal local procedures used in site development and maintenance. Soils with moderate limitations require changes to the original design or the application of corresponding conservation practices, or both, to overcome the limitations. Severe limitations are found where soil properties are unfavorable and those limitations can be offset only by costly soil reclamation, special design, intensive maintenance, limited use or a combination of these measures.

This information is intended as a guide to land users. The information presented, in its own right, does not restrict or control the development or use of land. It is intended as an input to the land use planning process and therefore can contribute to decisions on zoning and land use policy that lead to legislation on land use.

Although the soil being assessed may have severe limitations or be poorly suited to a particular land use, this does not necessarily mean that it cannot successfully be put to that use. The restrictive features may be overcome by costly and difficult corrective measures such as engineering design or intensive maintenance.

A summary of the rating for other land use for each of the soil classes is presented in **Table 12**. It is clear from the table that for all of the six major soil classes identified on Boubyan Island the constraints due to soil properties are severe limitations for all of the mentioned land uses.

Table 10. Criteria for Assessing Soil Suitability for Irrigated Agriculture in Kuwait

Soil Characteristic	Rating (suitability class)				
	S1	S2	S3	N1	N2
	(Nil..................Degree of Limitation.....................Severe)				
Rooting depth (cm)	>150	100-150	50-100	25-50	<25
Site drainage	Moderately well to well	Somewhat excessively to excessively	Somewhat poorly	Poorly	Very poorly
Profile coarse fragments (%)	0	<15	15-35	35-60	>60
Slope (%)	0-1	1-3	3-5	5-10	>10
Microrelief	Smooth, small hummocks	Medium hummocks	Large hummocks		
Surface stone (%)	0.01-0.1	0.1-3	5-15	15-50	50-90
Salinity (ECe, dS/m)	0-2	2-4	4-8		>8
	Non-saline	Very slightly saline	Slightly saline		Moderately saline to strongly saline
Sodicity (SAR)	0-5	5-10	10-15	15-30	>30
Soil reaction (pH)	6.6-7.3	7.4-8.4	8.5-9.0	>9.0	
Gypsum (%)	0-1	1-5	5-15	15-40	>40
$CaCO_3$ (%)	0-5	5-15	15-40	>40	

Table 11. Irrigated Agriculture Soil Suitability Ranking Based on Criteria

Soil Characteristic	Aquic Torriorthent	Typic Torriorthent	Gypsic Haplosalid	Typic Haplosalid	Gypsic Aquisalid	Typic Aquisalid
	Soil Class					
Rooting depth (cm)	N1	S3	S3	S2	N2	N1
Site drainage	N2	S2	S2	S2	N2	N2
Profile coarse fragments (%)	S3	S3	S2	S2	S2	S2
Slope (%)	S3	S3	S1	S1	S1	S1
Microrelief	S2	S2	S2	S2	S2	S2
Surface stone (%)	S2	S2	S1	S1	S1	S1
Salinity (ECe, dS/m)	N2	N2	N2	N2	N2	N2
Sodicity (SAR)	N2	N2	N2	N2	N2	N2
Soil reaction (pH)	S2	S3	S2	S2	S2	S2
Gypsum (%)	S1	S1	S3	S2	S3	S2
$CaCO_3$ (%)	N1	N1	S3	S3	S3	S3
Overall rating (based on most limiting factor)	N2	N2	N2	N2	N2	N2

Key: Suitability class = S1: highly suitable land with no significant limitation to the specified use; S2: moderately suitable land with moderate limitations to the specified use; S3: marginally suitable land with severe limitations to the specified use; N1: currently unsuitable land with severe limitations which cannot be corrected with existing technology; N2: permanently unsuitable land with severe limitations which cannot be corrected.

Table 12. Ratings for Other Land Uses

Soil Characteristic	Aquic Torriorthent	Typic Torriorthent	Gypsic Haplosalid	Typic Haplosalid	Gypsic Aquisalid	Typic Aquisalid
Camp Areas	*Severe* Ponding, wetness, excess sodium, excess salt	*Severe* Excess sodium, excess salt	*Severe* Excess sodium, excess salt	*Severe* Excess sodium, excess salt	Severe Ponding, wetness, excess sodium, excess salt	*Severe* Ponding, wetness, excess sodium, excess salt
Shallow Excavations	*Severe* Wetness	*Severe* Cutbanks cave	*Severe* Cutbanks cave	*Severe* Cutbanks cave	*Severe* Wetness	*Severe* Wetness
Sand Sources	*Improbable* Excess fines	*Improbable* Excess fines, excess gypsum	*Improbable* Excess fines	*Improbable* Excess fines	*Improbable* Excess gypsum	*Improbable* Excess fines
Gravel Source	*Improbable* Excess fines	*Improbable* Excess fines	*Improbable* Excess fines	*Improbable* Excess fines	*Improbable* Too sandy	*Improbable* Excess fines
Septic Tank Adsorption	*Severe* Ponding, wetness	*Severe* Poor filter	*Severe* Poor filter	*Severe* Poor filter	*Severe* Ponding, wetness, poor filter	*Severe* Ponding, wetness
Sewage Lagoons	*Severe* Seepage, ponding, wetness	*Severe* Seepage	*Severe* Seepage	*Severe* Seepage	*Severe* Seepage, ponding, wetness	*Severe* Seepage, ponding, wetness
Sanitary Landfill (trench)	*Severe* Seepage, ponding, wetness, too sandy, excess salt	*Severe* Too sandy, excess salt	*Severe* Too sandy, excess salt	*Severe* Too sandy, excess salt	*Severe* Seepage, ponding, wetness, too sandy, excess salt	*Severe* Seepage, ponding, wetness, too sandy, excess salt
Sanitary Landfill (area)	*Severe* Ponding, wetness	*Slight*	*Slight*	*Slight*	*Severe* Ponding, wetness	*Severe* Ponding, wetness
Seedling Mortality	*Severe* Wetness	*Severe* Drought	*Severe* Drought	*Severe* Drought	*Severe* Wetness	*Severe* Wetness
Desert Plant Habitat	*Poorly suited* Excess salt	*Poorly suited* Excess salt	*Poorly suited* Excess salt	*Poorly suited* Excess salt	*Poorly suited* Excess salt	*Poorly suited* Excess salt
Resort	*Severe* Wetness	*Slight*	*Severe* Excess salt	*Severe* Excess salt	*Severe* Wetness, excess salt	*Severe* Wetness, excess salt
Wetlands Habitat	*Slight*	*Moderate*	*Moderate* Excess salt	*Moderate* Excess salt	*Moderate* Excess salt	*Moderate* Excess salt
Golf Course	*Severe* Wetness	*Slight*	*Severe* Excess salt	*Severe* Excess salt	*Severe* Excess salt, wetness	*Severe* Excess salt, wetness
Building Construction	*Severe*	*Moderate*	*Severe* Excess salt	*Severe* Excess salt	*Severe* Wetness, excess salt	*Severe* Wetness, excess salt

Alternative Agriculture and Suggestions

- Based on results obtained in the soil assessment of Boubyan Island, it is not recommended that halophytes should be used as forage as most open area soils of the island have ECe above 50 dS/m and are too heavy (silty) for considerable periods. With such high salinity levels along with other limiting factors mentioned above, productivity should be expected to be very low and uneconomical.
- Since halophytic plant species can tolerate high salinity concentrations in both water and soil and can occur over a wide range of salinities, many halophytes (some native plant species) could be used as ornamentals and landscape plants. These include shrubs, succulents and semi-succulents, biennial and perennial groundcover plants, and grasses. They can tolerate irrigation water with ECe of 15 to almost 50 dS/m. A suggested plant list is provided in **Table 13**. However, the performance of some of these plants under Kuwait's harsh environmental conditions (high salinity coupled with extended summer) should be evaluated prior to large-scale planting.

Table 13. Suggested Plant List

Plant Name	Remarks
Salicornia spp.	Can be grown with sea water
Sporobola	Can be grown with sea water
Crithmum maritimum	Can tolerate up to 31 dS/m salinity
Sesuvium portulacastrum	Can tolerate up to 47 dS/m salinity
Aster tripolium	Can be grown with sea water
Borrichia frutescens	Can tolerate up to 31 dS/m salinity
Nitraria retusa	A native halophyte that can be grown in salt marshes
Limoniastrum monopetalum	
Maireana sedifolia	This plant is suitable for elevated locations
Distichlis sp.	Highly salt-tolerant grass; may be used in the proposed golf course
Phragmatis	Can be grown in poorly drained soils along the shoreline
Atriplex spp.	A number of species in this genus can be grown in soils with salinity as high as 62 dS/m
Avicennia marina	Can be grown in intertidal mudflats with soil salinity as high as 90 dS/m

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- Protected agriculture (PA) is a recommended option for growing ornamental plants using soilless culture and closed production systems, as this operation is not dependent on soil types. Selected elevated inlands of open space zone (yellow-Option 3) can be appropriate for this purpose, where nurseries and greenhouses may be built to supply desired seedlings/plants to either proposed resorts/hotels along the southern seashore of Boubyan or even to the newly developed Subbiyah township. The location of Boubyan Island is favorable for such a PA development as it is somewhat remote from the established northern agricultural production area of Abdaly.
- Landscape plants may be grown in closed subirrigated growing systems. Such systems can be very simple and thus inexpensive, with many recycled components. In such a case, use of resource inputs is minimized and options for choosing plants are much greater as choice is no longer dependent on being salt-tolerant. Furthermore, use of halophytic plants (native or otherwise) may be complemented with plants grown in closed systems.
- Correcting soil conditions by transporting non-saline soils from the mainland is not an economically feasible option if done for large-scale agricultural uses. However, this may be a practical option in a few small and localized neighborhoods intended to offer a high aesthetic value, such as along entrance roads to a recreation club, hotels/resorts or along the rail/road corridor, provided drainage is established. If this option is adopted, deep-rooted plants and particularly deep-rooted trees should be avoided. Furthermore, continual maintenance will be necessary.
- Certain areas may be identified for establishment of mangrove (*Avicennia marina*) plantations to protect and enhance the coastline environment and increase marine productivity (e.g., shrimp production). However, site selection is crucial for establishing mangrove plantations. For proper growth and development, mangrove plants require a muddy (silty) surface layer (0 to 5 cm), underlain by a fine sandy aerobic layer (5 to 30 cm) and a silty or clayey anaerobic layer below 30 cm. The selected sites should be flooded by high tides at least once a day.
- Native halophytes that may be considered for Boubyan Island include: *Arthrocnemum glaucum, Halopeplis perfoliata, Anabasis setifera, Seidlitzia setifera, Cyperus conglomeratus, Limonium axillare, Suaeda vermiculata, Heliotropium bacciferum, Salsola tetrandra, Zygophyllum simplex* and *Cornulaca monacantha*.
- Some exotic halophytes that could be considered (but need to be tested prior to their use) include: *Acrostichum aureum* L., *Alhagi maurorum* Medik., *Artemisia maritima* L., *Aster tripolium* L.., *Avicennia germinans* (L.) Stearn., *Baccharis halimifolia* L., *Bassia hirsuta* (L.) Aschers., *Batis maritima* L.., *Clerodendrum inerme, Eucalyptus sargentii, Limoniastrum monopetalum* (L.) Boiss., *Limonium vulgare* Miller, *Lycium barbarum* L., *Melaleuca halmaturorum, Mesembryanthemum crystallinum* L., *Pandanus utilis* Bory, *Pandanus veitchii* Hort., *Phoenix canariensis* Chab., *Phyla nodiflora* (L.) Greene, *Salsola kali* L., *S. longiflora* Forsk., *S. soda* L., *Sesuvium portulacastrum* L., *Spartina alterniflora* Loisel., *Sergularia marina* (L.) Griseb., and *Suaeda maritima* (L.) Dum.

Chapter 4: Geomorphology

Abstract

In Boubyan and Warbah Islands, a complex assembly of landforms occurs. The complexity is related to the interference of a wide variety of geomorphologic processes including marine, coastal, fluvial and aeolian. In general, the landscape of Boubyan and Warbah Islands is seasonally changeable due to alternations of wetting and drying cycles, groundwater fluctuations, terrestrial runoff and aeolian dynamics. Geographically, the area of Boubyan and Warbah Islands is subdivided into three major units: northern, central and southern. Each of these has its own morphologic, topographic and geologic characteristics.

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Boubyan and Warbah Islands constitute a kidney-like land feature surrounded by seawater. The islands are separated from each other by a water channel named Khor Boubyan. Both islands exhibit a wide variety of marine, coastal and terrestrial landforms. Marine and coastal land features include mud flats, beaches, beach ridges, strand lines, rocky islands, tidal channels, coastal sabkha, near-shore nabkha and salt marshes. Terrestrial features include inland sabkha, intermittent water ponds, fluvial features and aeolian forms (mainly inland nabkha). In addition to these macro and meso land features a set of micro landforms can be observed in the study area. These include patterned ground phenomena (mainly polygons and circles) composed of elements from only a few centimeters across to more than 50 m.

In previous studies, the landforms of Boubyan Island have been grouped into three land features: tidal flats, sabkha, and beach deposit (Dar Al Handasah Consultants, 1983). This study was based on an examination of existing topographic maps and aerial photography taken in 1969. Khalaf and Al-Ajmi (1993) prepared a geomorphologic map for the State of Kuwait where Boubyan and Warbah Islands are shown as one geomorphologic unit (coastal flat) with no detailed landforms shown.

In the *Atlas of the State of Kuwait* derived from satellite images, two satellite images for Boubyan and Warbah Islands are shown (as of 1991). No details or explanations for the features of these two images are given. In the text, brief reference is made to the main characteristics of coastal and inland sabkha and aeolian forms.

Methodology

Remote Sensing

The subset of the area of interest (AOI) covering Boubyan and Warbah Islands was taken with outer boundaries extending to the marine area with a buffer zone to avoid the confusion of uncertain shoreline or land-sea boundary. The subset gives the advantage of enhancing the satellite data in a more specific manner.

This study used Landsat Thematic Mapper (TM) images taken on March 6, 2001. Bands 2, 4 and 7 with resolution of 30 m and a panchromatic (PAN) band with resolution of 15 m were used for generating the final output for the geomorphology (landform) study. The data represent 8-bit pixel values (i.e., 256 levels of radiance for each band). The various bands illustrate the following properties:

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- Band 2: corresponds to the green reflectance of healthy vegetation.
- Band 4: is especially responsive to the amount of vegetation biomass present.
- Band 7: discriminates the geologic rock types and soil boundaries, and also responds to the soil and vegetation moisture content.

Hence the combination of bands 2, 4 and 7 helps identify vegetation cover, barren dry loose soil, cultural areas, exposed rocky areas and soil moisture content in Boubyan Island, which are some of the factors governing identification of geomorphologic landforms.

The image was geo-corrected and projected to UTM projection. Bands 2, 4 and 7 were co-registered with the PAN band prior to processing. Multispectral bands 2 (0.52-0.60 µm), 4 (0.76-0.90 µm), and 7 (2.08-2.35 µm) were fused with the panchromatic band. The processing creates an output RGB color image by fusing an input RGB (2, 4 and 7) with another input black and white intensity image using HIS transform. Though it is not strictly accurate to fuse the panchromatic with band 7 (2.08-2.35 µm), as it falls outside the spectral range of PAN (0.05-0.90 µm), the fusion proved practically useful in extracting geomorphologic landform information. The result is an output RGB color image with the same resolution as the original B/W intensity image (15 m), but where the color (hue and saturation) was derived from the resampled input RGB image. The output data are also rich with 8-bit of radiometric information (i.e., 256 levels of radiance in each channel). The image was enhanced based on a histogram of image data sampled from the currently selected image planes. **Fig. 45A** shows the “raw” unenhanced image data prior to fusion. The fusion product was subjected to an infrequency brightening (or histogram inversion) algorithm for enhancing it to create a better output image as shown in

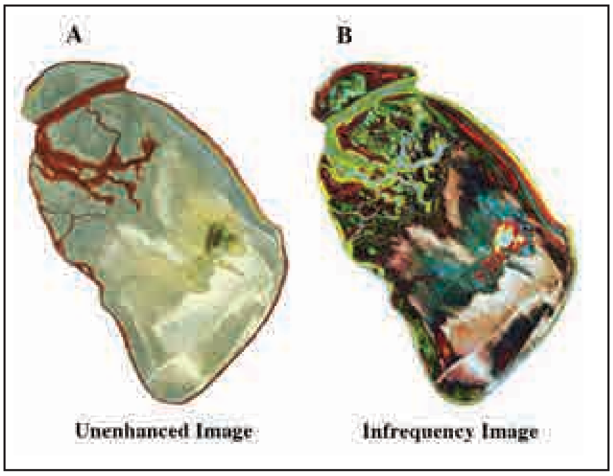

Fig. 45. Infrequency image (B) generated from unenhanced image (A)

Fig. 45B. Bands 7, 4 and 2 were filtered through blue, green and red channels. The function produces an output image where infrequenly occurring gray levels are assigned an inverted (upside down) histogram of the input image data. The final output map for geomorphology landform studies was generated at a scale of 1:125,000. The multi-histogram panel is scaled to gray level values from 0-255 and displays three histograms for each image. The horizontal dimension represents the gray level values from 0 on the left to 255 on the right. The tick marks along the bottom show the 64, 128, and 192 points on the histogram.

The vertical dimension is a representation of the percentage of pixels in the sample area that have the indicated gray level value. Labels on the left side of the histogram show the maximum percentage representable on the graph. The top label is “5%” and a spike on the histogram rises to half the height of the graph; then the gray level at that spike represents about 2 1/2% of the sampled area of the image.

The capabilities of such a map generated from optical Landsat TM satellite images showed more reliability for mapping geomorphology. The derivation of land was based on the physical surfaces present in a pixel, distinguished from each other via their characteristic shape and structure, into a description closer to the human view. Therefore it is important to extract features that are able to describe relevant "textural" properties of various landforms. Preprocessing of the raw image of Kuwait was carried out to correct non-systematic or random (image restoration and rectification) error prior to the actual image processing. The preprocessing operation served to correct both radiometric and geometric distortion within the image.

This image restoration and enhanced processing utilize computers to provide corrected and improved images for study by human interpreters. The computer makes no decisions in these procedures. However, the processes that comprise information extraction do utilize the computer's decision-making capability to identify and extract specific pieces of information. A human operator must instruct the computer and must evaluate the significance of the extracted information.

Ground Truthing

Ground truthing was conducted at both the terrestrial and marine parts of the island. On land, 45 ground truthing stations were selected along three transects (eastern, central and western). In the marine area, a total of 10 ground truthing stations (M1-M10) were selected in three cruises (24-8-2003,13-10-2003 and 1-8-2004). In addition, nine ground truthing stations in the northeastern part of Boubyan Island were selected using hovercraft in May 2004 (HI-H9). In the ground truthing stations, field observations of the local features were collected and photographs taken. **Fig. 46** shows the location of the terrestrial and marine ground truthing stations. **Tables 14-18** show the data from the ground truthing stations. In addition, field onsite remarks on the local geomorphologic characteristics and surface sediments were collected at the sites of environmental monitoring (dust collectors and traps, passive samplers and piezometers).

During the ground truthing program,10 classes were identified from the unsupervised Landsat image of March 6, 2001 (**Fig. 47**):

Class 1: Water bodies including inland terrestrial lakes and ponds.

Class 2: Drift sands rich in salt crystals (covering coastal and inland sabkhas) forming stabilized, active and deflated nabkhas and sandy sheets. Dense vegetation along coastal area, moderate to slight in inland areas.

Class 3: Rough sabkhas with wide patches of salt crusts, cut by shallow terrestrial drainage (depressions and wadis).

Class 4: Wet mud and sands forming tidal flats, sandy beaches, and floors of tidal channels and peripheries of inland water bodies.

Class 5: Relatively high patches of compact clay drained by a net of tidal channels.

Class 6: Moderately drained sabkha (clay, silt and sand) surrounding the low-lying very poorly drained sabkhas (class 8). Parts of this class are influenced by hollows formed by runoff water.

Class 7: Elevated mud flats cut by shallow tidal channels (made up mainly of compact clay and silt).

Class 8: Very poorly drained sabkha (moist silt and clay) affected by high tide water and terrestrial runoff.

Class 9: Expanses of fairly well drained sabkhas cut by shallow hollows filled with fine outwashed materials (carried by runoff water), influenced by drift sands in the form of active nabkhas. This class also includes isolated flanks and low cliffs of compact clay.

Class 10: Expanses of poorly drained sabkhas (moist silt and clay) with almost no vegetation (paleodrainage).

Landform Classification

The landforms represented in the three main geographic units of the study area and surrounding low-lying coastal plains are discussed below.

Landforms of the Northern Geographic Unit

The northern geographic unit represents about 30% of the study area. It includes the marine portion of Boubyan Island, Khor Boubyan and Warbah Island. This unit is separated from its southern periphery by an erosional cliff, which acts as a rim separating the marine northern part of Boubyan Island from its central terrestrial part. The ground elevation of the northern geographic unit is relatively higher (mainly between 3-4 m above sea level). This affects the morphology of the existing two main tidal channels, i.e., Khors Al Milh and Al Thaalib, where meandering occurs to match with the relief of the surrounding banks. Khor Al Milh (*milh* in Arabic means salt) cuts its course between very closely spaced banks so it is narrow (500 m on average) and steeply meandered, while Khor Al Thaalib cuts its way between widely spaced banks, making it wider (1000 m on average) and gently meandered. In the northern geographic unit the following landforms are observable:

Tidal Channels. Tidal channels (streams) constitute a highly complex net of water streams in which the seawater alternately flows seaward and landward. Based on their hydrologic and geomorphologic characteristics, tidal channels are subdivided into permanent and intermittent. In the case of the former type the water is permanent, although it fluctuates during high and low water tides. In the latter case, the streams are filled with water only during flooding and high tides. Geographically, the permanent tidal channels are subdivided into northern and western sets. The northern set, which is connected with Khor Boubyan, consists of large channels including Khor Al Milh, Khor Al Thaalib and Khor Al Mughwi. The width of these khors near their inlets ranges between 1000-1500 m and their length varies between 9 and 18 km. A western set of narrow tidal channels is connected with Khor Al Subbiyah. Both

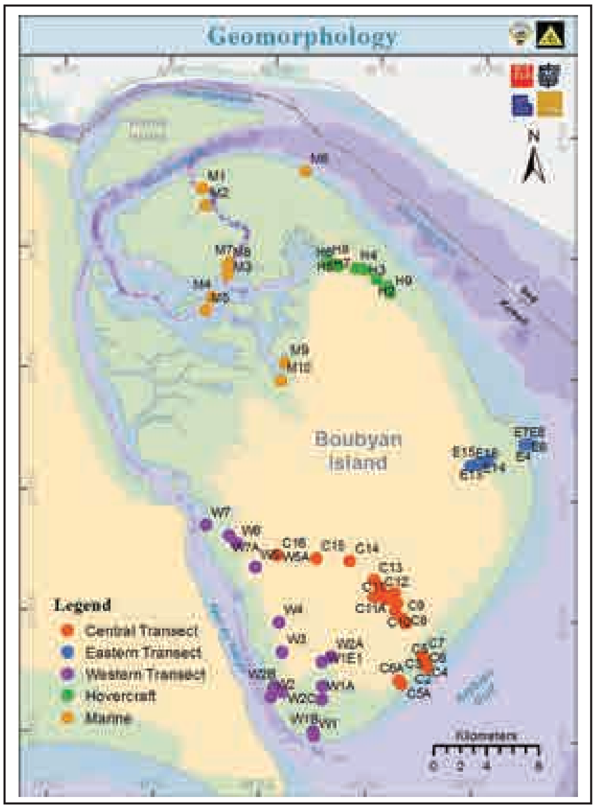

Fig. 46. Image showing the locations of ground truthing stations (see text for details)

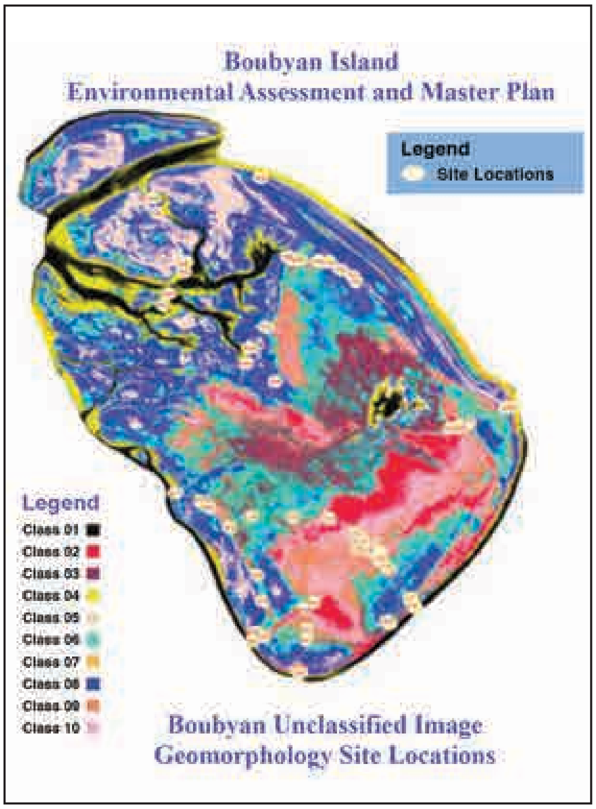

Fig. 47. Unsupervised Landsat image of March 6, 2001

Table 14. Data from the Eastern Transect (E1-E15)

Station No.	GPS-N	GPS-E	Landform	Class No. of Unsupervised Image	Date
E1	29.78886	48.37281	Beach (seaward side)	4	29-03-2004
E2	29.78883	48.37267	Tidal channel	4	29-03-2004
E3	29.78881	48.37258	Beach (inland-ward side)	4	29-03-2004
E4	29.78878	48.37242	Beach berm	4	29-03-2004
E5	29.78867	48.37189	Transitional zone (beach/sabkha)	7	29-03-2004
E6	29.7885	48.37108	Near-shore vegetated sabkha	8	29-03-2004
E7	29.78828	48.37011	Tidal channel	8	29-03-2004
E8	29.78817	48.36964	Inland-ward of near-shore sabkha	8	29-03-2004
E9	29.78617	48.36694	Bare sabkha with recent alluvium	6	29-03-2004
E10	29.78344	48.36583	Bare sabkha dotted with closed drainage basins	6	29-03-2004
E11	29.77953	48.35117	Bare sabkha (no visible drainage)	8	29-03-2004
E12	29.77689	48.34106	Inland sabkha with minor nabkha	8	29-03-2004
E13	29.77536	48.33625	More wet terrain close to the main water pond (lake)	2	29-03-2004
E14	29.77444	48.33336	Closed hollows some with water remnants	2	29-03-2004
E15	29.77375	48.33169	Very poorly drained sabkha and thick salt crusts	2	29-03-2004

Table 15. Data from the Central Transect (C1-C16)

Station No.	GPS-N	GPS-E	Landform	Class No. of Unsupervised Image	Date
C1	29.633767	48.2965	Seaward side of sandy beach	4	29-3-2004
C2	29.63375	48.2965	Inland-ward side of sandy beach	4	29-3-2004
C3	29.63390	48.29649	Beach berm	4	29-3-2004
C4	29.63389	48.29647	Inland-ward side of foreshore nabkha cut by tidal channels	6	29-3-2004
C5	29.63453	48.29617	Inland vegetated sabkha (inundated with rainwater)	8	29-3-2004
C6	29.63714	48.29481	Central part of inland vegetated sabkha, remnants of rainwater bodies	8	29-3-2004
C7	29.63906	48.29411	Northern periphery of sabkha	6	29-3-2004
C8	29.64128	48.29322	Bare sabkha with local circular hollows	6	29-3-2004
C9	29.66356	48.27906	Bare sabkha with dense circular basins filled with recent outwashed silt and clay	9	29-3-2004
C10	29.66681	48.27644	Clayey materials in drainage channels	9	29-3-2004
C11	29.67228	48.27094	Outwashed clayey deposits	9	29-3-2004
C12	29.67944	48.26306	End of outwashed clayey deposits	10	29-3-2004
C13	29.69272	48.25339	Poorly drained, wet terrain, dense vegetation	10	29-3-2004
C14	29.70547	48.23414	Water body of main water pond (lake)	2	29-3-2004
C15	29.70656	48.20756	Poorly drained sabkha and thick salt crusts	6	29-3-2004
C16	29.7081	48.17658	Thick salt crusts	6	29-3-2004

Table 16. Data from the Western Transect (W1-W7)

Station No.	GPS-N	GPS-E	Landform	Class No. of Unsupervised Image	Date
W1A	29.60992	48.21481	Bare sabkha	6	9-6-2004
W1B	29.58736	48.20839	Bare sabkha	8	9-6-2004
W1	29.58436	48.20928	Tidal channel	4	9-6-2004
W2	29.61061	48.17456	Coastal strip cut by minor tidal channels	8	9-6-2004
W2A	29.63939	48.22131	Nabkha over sabkha with polygons	2	9-6-2004
W2B	29.62231	48.19578	Bare sabkha, polygons	8	9-6-2004
W2C	29.61425	48.18342	Densely vegetated sabkha	6	9-6-2004
W3	29.64136	48.1825	Inland side of wet coastal flat, oil pollution	6	9-6-2004
W4	29.66189	48.17942	Sabkha with dead nabkha	6	9-6-2004
W5	29.69953	48.15981	Sabkha scarce vegetation	6	9-6-2004
W5A	29.70811	48.17658		4	9-6-2004
W7	29.72769	48.12033	Coastal strip cut by major tidal channels	4	9-6-2004
W6	29.71603	48.14483	Sabkha	10	9-6-2004
W7A	29.72103	48.13867	Wet sabkha	8	9-6-2004

4

Table 17. Data from Marine Ground Truthing Stations (M1-M10)

Station No.	GPS-N	GPS-E	Landform	Class of Unsupervised Image	Date
M1	29 57 32	48 06 39	Inlet of Khor Al Milh	4	24-8-2003
M2	29 56 51	48 06 48	Secondary channel	8	24-8-2003
M3	29 54 02	48 07 57	Khor Al Milh-south	4	24-8-2003
M4	29 53 03	48 07 13	Rocky island	4	24-8-2003
M5	29 52 31	48 06 57	Strand line	4	24-8-2003
M6	29 58 22	48 11 30	Beach	4	1-8-2004
M7	29 54 31	48 08 02	Salt marsh	5	1-8-2004
M8	29 54 24	48 07 55	Small island	4	1-8-2004
M9	29 50 24	48 10 46	Cliff	8	1-8-2004
M10	29 49 41	48 10 35	Cliff	8	1-8-2004

Table 18. Data from Hovercraft Ground Truthing Stations (H1-H9)

Station No.	GPS-N	GPS-E	Landform	Class of Unsupervised Image	Date
H1	29 53 40	48 15 30	Mud flat, polygons	8	26-5-2004
H2	29 53 58	48 15 00	Mud flat	8	26-5-2004
H3	29 54 20	48 14 23	Mud flat	8	26-5-2004
H4	29 54 24	48 13 58	Dissected sabkha, nabkha, high vegetation	9	26-5-2004
H5	29 54 29	48 13 10	Dissected sabkha, nabkha, high vegetation	9	26-5-2004
H6	29 54 31	48 13 01	Dissected sabkha, nabkha, high vegetation	9	26-5-2004
H7	29 54 34	48 12 42	Dissected sabkha, nabkha, high vegetation	9	26-5-2004
H8	29 54 38	48 12 38	Inland fringes of tidal channels	8	26-5-2004
H9	29 53 24	48 15 38	Mud flat, high tide, organic remains	8	26-5-2004

the northern and western channels are connected during high tide through a narrow meandering channel, which stretches in an almost east-northeast trend for about 4 km.

Shallow Deflation Hollows (Dissected Salt Marshes). Shallow deflation hollows (dissected salt marshes) constitute low-lying wet terrain on both sides of Khor Al Milh and the central part of Warbah Island. These marshes, which are surrounded by a narrow strip of halophytic vegetation, are dissected by a set of shallow drainage basins. Occasionally the marshes are dotted with flat shallow hollows trending in a northwest–southeast direction, i.e., parallel to the prevailing winds.

Rocky Islands. Rocky remnants of lithified shells (oyster banks) survive in the main course of the tidal channels (mainly the upper reaches of Khor Al Milh). During high tide conditions some of these islands disappear, causing hazards to sailing and fishing activities. Locally the rocky islands are called Al Baqr (which means cows in English).

Residual Muddy Hills. These are relatively high areas (around 4 m above sea level) surviving in the western part of Warbah Island and both sides of Khor Al Milh. During high tide these features act as islands.

Southern Erosional Cliff. The most picturesque land feature in the area. The cliffs are higher than the surrounding terrain, reaching about 4 m above sea level (about 1.5 m high from the surrounding features). The middle part is sculptured by a huge northwest-southeast hollow. It seems that this hollow was formed and enlarged by the mechanical action of the prevailing northwesterly winds mainly during low tide conditions. The hollow acts as a gate, allowing the passage of high tide water from the northern marine part of Boubyan Island to the central terrestrial part of the island. Minor gaps in the erosional cliff are observed at both sides of the main one. Occasionally these gaps allow the flow of high tide water from north to south. Due to the persistent nature of the erosional cliff, it acts as a barrier for the upper reaches of the Khor Al Thaalib tidal channel, which consequently changes its direction. The upper reaches of Khor Al Thaalib change direction from northwest-southeast to north (for the southeastern reaches) and south (for the southwestern reaches), forming a frog leg landscape.

Landforms of the Central Geographic Unit

The central geographic unit is very poorly drained, receiving tidal water from the north, west and east. It is dotted by a huge inland hollow, which represents the most significant landform in this geographic unit. This hollow is filled with water during winter and spring and evaporated into dry salt flats during summer. From the south, the central geographic unit is limited by patches of drift sands. The ground elevation ranges from 2-3.5 m above sea level. The following landforms are found:

Sabkha-Salina Complex. Occasional inundation of seawater on the sabkha surface results in the development of the so-called sabkha-salina complex. This landform is influenced by shallow puddles or ponds of saline water. The water evaporates, leaving salt crusts of varying characteristics. The sabkha-salina complex covers the majority of the central part of Boubyan Island.

Poorly Drained Northeast Sabkha-Nabkha Complex. Poorly drained sabkha (silt and clay) cut by shallow channels with fields of nabkhas, and dense vegetation in channels.

Intermittent Central Water Ponds. These constitute shallow closed to semi-closed hollows filled with saline water (maximum depth 50 cm). They have different sizes and occupy the lowest portions of the central geographic unit. The ground elevation of the water ponds varies between 2-2.75 m above sea level. The water bodies persist only during fall, winter and early spring. They disappear during summer, leaving extensive salt crusts. The sources of water for these bodies are seepage from the underlying shallow groundwater, surface runoff and high water tides.

Landforms of the Southern Geographic Unit

The southern part of the island is dominated by aeolian features including fields of active nabkhas, dead nabkhas and sand sheets on wet terrain. The extreme southern periphery is influenced by coastal sabkhas. The area is dissected by several roads running west-east and south-north, which have a direct impact on current geomorphologic processes, e.g., coastal flooding, fluvial processes and aeolian activities. Some of the roads are about 1.5 m higher than ground level, so they act as barriers for high tide water. Under conditions of strong coastal flooding, segments of the roads have been washed out, e.g., the western road parallel to Khor Sabbiyah. At the same time these raised roads (8-10 m wide) act as artificial watersheds, resulting in changes in the local hydrological conditions. From a dynamic point of view the raised roads act as barriers for shifting sands, which accumulate around plant species at the upwind side of the roads crossing the southern fringes of Boubyan Island. The ground elevation of the southern geographic unit ranges between 2.5 m and about 4 m above sea level.

4

Geomorphologic Mapping

A geomorphologic map for Boubyan Island was prepared (Fig. 7), based on interpretation of an infrequency image generated from Landsat 7 imagery (recorded on March 6, 2001) at a scale of 1:125,000. The infrequency image enhances some parallel running non-linear features of topographic importance in a particular direction as shown.

The three main units presented are the northern, central and southern units. The northern unit consists of five landforms (landforms no. 1-5 on the map): tidal channels, shallow deflation hollows, dissected muddy banks, mud flats and muddy floors. The central unit consists of six landforms (no. 6-11 on the map): intermittent water ponds, wet salt flats, sabkha-salinas complex, hummocky sabkha, notched rim and a series of gentle low cliffs. The southern unit consists of 11 landforms (no. 12-22 on the map): sabkha, rugged sabkha, salt flats, low-lying sabkha, highly vegetated sabkha and tidal channels, rough sabkha, near-shore nabkha, scattered strips of vegetation, smooth hard sabkha, submerged mud flats and tidal salt flats. Detailed description for the different landforms is given in the following pages:

A: Northern Geomorphologic Unit (Tidal Channels, Salt Marshes and Mud Flats Complex System). Consists of gray sticky clays to soft unconsolidated mud, which are very loosely packed and have a low allowable bearing pressure. The following landforms are observable in this unit:

1. Tidal channels: 1a. northern set (connected with Khor Boubyan) and 1b. western set (connected with Khor Al Sabbiyah) (**Plates 9-10**).

2. Shallow deflation hollows (dissected salt marshes): Flat expanses of wet terrain cut by deflational hollows mostly oval in shape with an almost northwest-south-

east trend. Patches of high vegetation are found between and around the depressions.

3. Dissected muddy banks cut by shallow dendritic tidal creeks, sometimes with rocky cliffs (**Plate 11**).

4. Mud flats and tidal inlet zone with strips of vegetation along the seaward margins (**Plate 12**).

5. Muddy floors where expanses of soft clay constitute the floors of tidal channels. Parts of the floors are exposed during low tide conditions.

B: Central Geomorphologic Unit (A Series of Sabkhas, Intermittent Water Ponds, Dissected Rims and Cliffs). This unit consists of the following landforms:

6. Intermittent water ponds (shallow closed hollows filled with saline water): Ultra-saline, very poorly drained, void of vegetation.

7. Wet salt flats: Damp, dark brown to gray, void of vegetation.

8. Sabkha-salinas complex system: Sabkha inundated by seawater during high tides, ultra-saline, very poorly drained, void of vegetation. Patches of hard evaporates, and polygonal cracks persist between inundations and salt crusts. There are man-made piles of fine sediments (silt and clay) (**Plate 13**).

9. Hummocky sabkha: Sabkha cut with moist channels bounded by vegetated sand accumulations (2-3 m high). Dead nabkhas are observable.

10. Notched rim: Dissected V-shaped rim bounding the extreme southern fringes of the northern geomorphologic unit (about 3 m high from the low-lying terrain).

11. Series of gentle low soft cliffs (foot slopes).

C: Southern Geomorphologic Unit (Varied Area Consisting Mainly of Sabkas, Nabkas and Salt Flats). The following features can be seen:

12. Moist sabkha: Very poorly drained, made up of silt and clay, thin salt crusts, void of vegetation.

13. Rugged sabkha: Moderately drained, affected by terrestrial fluvial and aeolian processes, moderate to dense vegetation mainly in local hollows, patches of dead nabkha. This landform is partially flooded by high tide, e.g., October 2003. It is dissected by a raised

Plate 9. Aerial photograph showing the main trunk of a tidal channel cutting the central western part of Boubyan Island (low tide, July 2002)

Plate 10. Aerial photograph showing the upper reaches of tidal channel, western part of Boubyan Island (low tide, July 2003)

Plate 11. Muddy bank limiting the course of a meandering tidal channel connected with Khor Al Milh (low tide, October 2003)

east-west road (no. 2) and a raised north-south road (no. 3).

14. Salt flats: Inundated by sea waters, often moist, strips of dense vegetation along the seaward side and in inland hollows and channels, made up of clayey and silty soils covered with thin veneer of salts. A raised road (no. 4) runs parallel to this landform; at the southern part the road acts as a barrier, controlling the high water tide of Khor Al Sabbiyah, and further to the north the road is cut by tidal channels, allowing the flow of water inland.

15. Low-lying sabkha: Poorly drained, almost flat, made up of silt and clay, void of vegetation, cut by tracks of light vehicles and buggies.

16. Highly vegetated sabkha: Runs parallel to the extreme southwestern coast of Boubyan Island (in the Ras Al Barshah area), stretches inland from a sandy beach, influenced by permanent shallow tidal channels, with a high vegetation density and diversity.

17. Rough sabkha: Flat to slightly undulated surface of wet silt and clay, partially covered with thin sheets of fine outwashed sediments (carried by runoff), windblown sands in the form of thin sheets and nabkhas and patches of vegetation in low areas especially at the southern fringes. It is influenced by water ponds (runoff water), which persist for 6-10 weeks at the southern part, e.g., January-March 2004, limited at the extreme southern side by a tidal channel. It is rarely influenced by high water tide, which is blocked by the main raised road to the south. A north-south raised road dissects the surface of this landform, causing some changes on both sides of the road.

18. Near-shore nabkha: Windblown sands (drift sands) trapped by dense vegetation, e.g., *Halocnemum strobilaceum, Seidlitzia rosmarinus, Zygophyllum* sp. The morphology of the nabkhas is disturbed by high water tide, and a considerable amount of rainwater infiltrates in the highly porous accumulated sands.

19. Scattered strips of vegetation: Vegetation growing in hollows and channels and at irregular sand accumulation apart from the near-shore nabkhas **(Plates 14-15**).

20. Smooth hard sabkha: Almost flat surfaces of hard clay and silt covered in parts with a thin veneer of fine outwashed sediments (carried by runoff water), which form circular to oval bodies. There is scarce vegetation, rarely influenced by high water tide, and deep ponds of rainwater that survive from 8-12 weeks, e.g., January-March 2004.

Plate 12. Mud flat, southwestern coast of Boubyan Island, north of Boubyan Bridge; note the white salt flat on the right (low tide, July 2004)

Plate 13. Aerial photo showing sabkha dotted with circular and oval hollows (saline puddles and ponds), western Boubyan Island (July 2002)

21. Submerged mud flats: Coastal strip stretching parallel to Khor Abdullah at the eastern side of Boubyan Island, covered with high water tide. The water persists for hours during the summer (leaving extensive salt flats) and may persist for days during the winter. The water also invades parts of the road, and the surface is very rich in organic materials including *Phragmites* and date palm trees derived from the salt marshes of southern Iraq.

22. Tidal salt flat (Khor Abdalah mud flats): Coastal strip stretching parallel to Khor Abdullah, almost moist because inundated by seawater, cut by tracks, rich in organic remains including dead date palms. Its seaward side is at the extreme north.

Plate 14. Aerial photo showing part of the southern coastal zone of Boubyan Island with strips of vegetation (dark patches); note the V-shaped tidal channel and the ground fortifications between the two tidal branches (high water tide, July 2002)

Plate 15. Dense vegetation covering beach ridge, southern coastal plain of Boubyan Island (October 2003)

4

Erosion Map

An erosion map for Boubyan Island was established (**Fig. 48**). This map was produced on the basis of both field observations and remote sensing information. The map shows the following items:

Deflational Areas. Deflational areas are relatively higher sites which are subjected to wind erosion. These areas are not affected by high water tide at any time of the year and therefore are considered as active sand/silt supply areas. Six deflational areas are identified (no. 1-6 on the erosion map). Deflational areas no. 1-4 are located near the contact between the northern marine and central terrestrial sectors of Boubyan Island. Deflational area no. 5 is located at the western fringes of the central sector of the island, whereas deflational area no. 6 is located at the eastern parts of the central sector of the island. Erodible materials from these six deflational areas are transported by wind towards the central and southern sectors of the island.

Deflational-Depositional Areas. Deflational-depositional areas exhibit different topographic and ecological conditions. These areas act as deflational areas during summertime when a drop in the water table takes place. At the same time they act as depositional areas for sands blown from other deflational areas in the upwind side. Four deflational-depositional areas are identified (no. 7-10 on the erosion map). Deflational-depositional area no. 7 occupies the southern fringes of the central sector of Boubyan Island. This area is cut by a set of terrestrial drainage channels which act as sources for fine sand and silt, while deflational-depositional areas no. 8-9 are located at the northern fringes of the southern sector of Boubyan Island. As parts of these two deflational-depositional areas are covered by plant species, they act as depositional rather than deflational. The last deflational-depositional area (No. 10) is represented by the near-shore zone at the extreme southern part of Boubyan Island. It includes a complex of nabkhas of different characteristics. This deflational-depositional area is highly affected by erosional processes of high tide water.

Divide Line Between Severe (S) and Moderate (M) Sand Encroachment. The divide line between severe and moderate sand encroachment is marked by northwest-southeast hollows (grooved features) developed by wind deflation processes. This line divides the island into two different parts in terms of the severity of sand encroachment: a western (severe sand encroachment) part and an eastern (moderate sand encroachment) part. Results of field monitoring of sand accumulation support the demarcation of the two parts as severe and moderate sand encroachment.

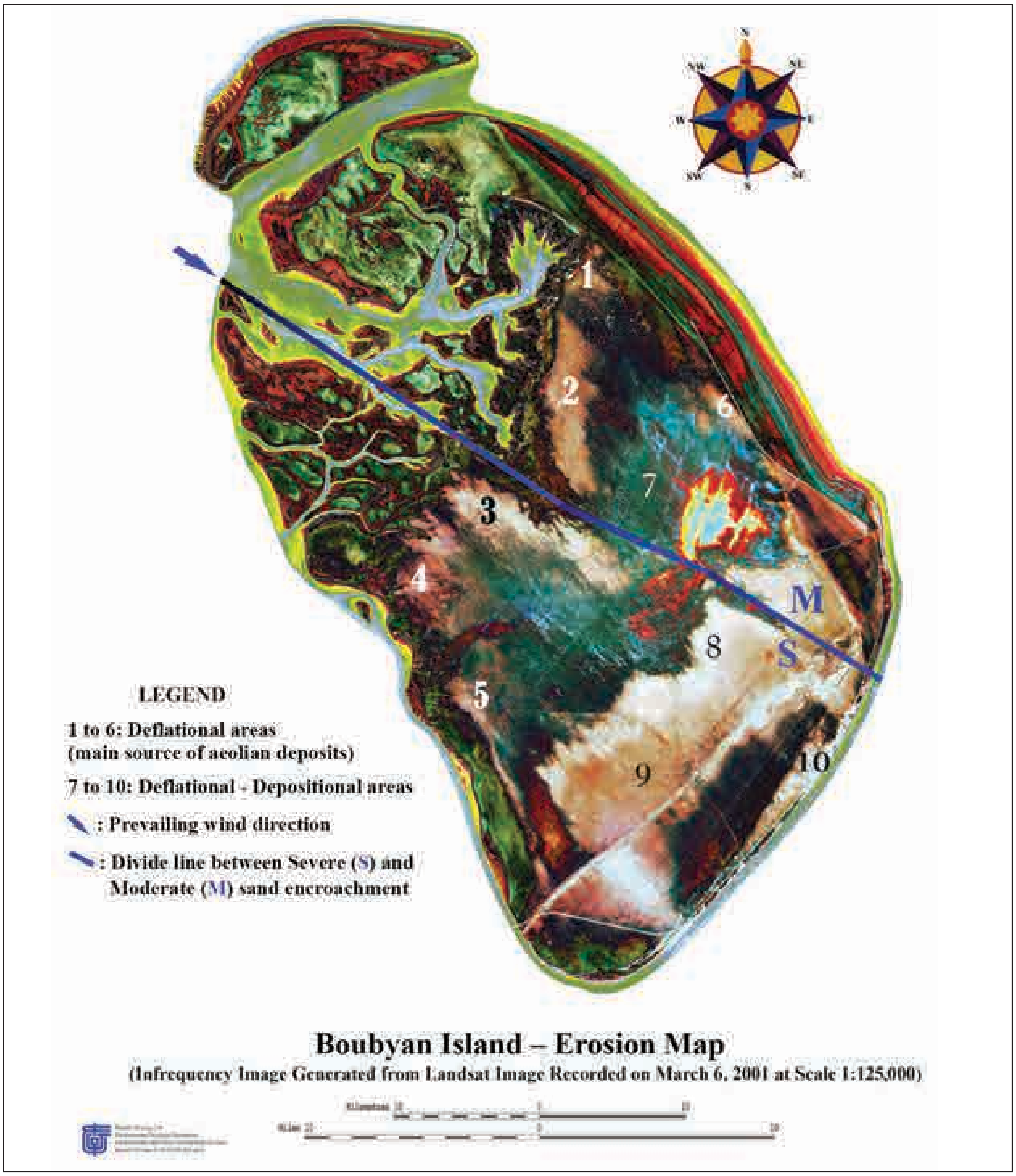

Fig. 48. Erosion map of Boubyan Island

4

Chapter 5: Summary of Main Features and Landforms of Boubyan Island

5

Abstract

Boubyan Island exhibits a wide variety of marine, coastal and terrestrial land features. Marine coastal features include beaches, beach ridges, strand lines, tidal channels, mud flats, coastal sabkha, near-shore sabkha and salt marshes. Terrestrial land features include inland sabkha and ephemeral saline lakes, fluvial features (drainage systems and abrasion surfaces) and aeolian forms of both deflation and deposition. In addition to these macro and meso landforms, a set of micro land forms are observable in the island. These include patterned ground phenomena, which vary widely in scale from patterns composed of elements only a few centimeters across to those with dimensions of 50 m or more. Examples of patterned ground features are polygons, circles, nets, steps and stripes, thaw lakes and others. For a better understanding of the land features of Boubyan Island, and for consistency, a list of definitions is introduced.

Marine and Coastal Features

Shoreline and Shore Zone

The shoreline is the line of contact of water with the land. The shore zone is the entire surface over which the water line sweeps. In the case of Boubyan and Warbah Islands the shore zones have a fairly smooth sloping bottom extending offshore into deeper water.

Coast

The coast is the zone that includes not only the shore but also a shallow water zone adjoining it and a belt of land above the limit of water action that is influenced by marine processes. Consequently, cliffs and dunes bordering the shore are part of the coast. On Boubyan Island the width of the coast varies between about 100 m at the southern coast to several kilometers along the eastern coast (**Plates 16 and 17**).

Marine Spit

A marine spit forms an elongated depositional feature attached at one end to the mainland and usually developed where the coast changes its direction. In Boubyan Island, the marine spit is well developed at Ras Al Qaid (south-eastern part of the island).

Beaches

In Boubyan Island, beaches are geographically differentiated into southern (composed of shells and deposits) and eastern and western (buildup of silt, clay and sand with a variety of organic materials particularly on the eastern side). The beach profiles are variable. They are controlled by size, shape and composition of beach materials; the tidal range; and the type and characteristics of incoming waves.

Along the southern shoreline of Boubyan Island, the beach varies between 30-70 m wide and is defined at its highest point either by near-shore nabkha (vegetated sand accumulation, 50-150 cm high), beach ridge or berm. The upper section of Boubyan southern beach in some stretches consists of a horizontal to slightly landward sloping surface called a berm (a zone of vertical accretion formed by the backwash deposition). The elevation of the berm is limited by the upper limit of swash and rarely exceeds 50 cm. Submerged longshore bars run parallel to the southern beach and are separated from it by troughs near Ras Al Qaid (**Plate 18**). Other minor features include beach cusps, which are crescent shaped indentations lying parallel with the shore on the upper beach face and along the seaward margin of the berm.

Khors

This local term describes permanent water channels surrounding Boubyan Island from the east (Khor Abdalla), north (Khor Boubyan) and west (Khor Al Subbiyah). Besides these three khors there are other khors to the north including Khor Shatyanah (north of Warbah Island) and Khor Zubeir to the northwest. The sediments constituting the bottoms of these khors are composed of sandy mud and mud. Oil contamination is detected at the shore of some khors.

Tides

Tide effects along the western coast of the island are more significant in comparison to those on the eastern and southern coasts. Waters of the high tide can extend more than 10 km inland, e.g., June 9, 2004, 10 a.m. spring and neap tides involve deviations of about 20% above and below normal tide ranges. The tidal amplitude for the water surrounding Boubyan Island is large (about 3.5-4 m). Several factors complicate the simple mechanism of tidal behavior, including size, depth, geomorphology and topography of tidal channels; shoreline configuration; meteorological conditions; and current land use (mainly raised roads).

Tidal Flats

If the coastal sediments are fine grained (such as those extending along the northern, western and eastern coasts of Boubyan Island), a tidal mud flat or mud coastline is developed instead of beach or sandy coastline (as in the case of the southern coast). The tidal mud flats are wider (more than 5 km) than the sandy ones (maximum 100 m or even less). Mud flats consist of very plastic grey clays mixed with minor quantities of silt and sand.

Tidal Channels (Streams)

Tidal channels (streams) constitute a highly complex net of water streams in which the seawater alternately flows seaward and landward. Based on their hydrologic and geomorphologic characteristics, tidal channels are subdivided into the following:

Permanent Tidal Channels. Geographically the permanent tidal channels are subdivided into northern and western sets. The northern set is large and is connected with Khor Boubyan and includes Khor Al Milh, Khor Al Thaalib and Khor Al Mughwi. The width of these khors near their inlets ranges between 1000-1500 m. The length varies between about 9 km (Khor Al Milh) to 18 km (Khor Al Thaalib). The western set of permanent tidal channels are narrow (width at inlets ranges between 300-500 m) and the length rarely exceeds 7 km. They are connected with Khor Al Subbiyah. There is a connection between the northern and western sets of permanent tidal channels through a narrow meandering channel which stretches in an almost east-northeast trend for about 4 km. In addition,

Plate 16. Ras Al Qaid coast; note sandy beach, high water mark and submerged mud flat

Plate 17. Southwestern coast, under Boubyan bridge, beach cusp at low tide (July 2004)

Plate 18. Ras Al Qaid coast, longshore bar (March 2004)

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Plate 19. Ras Al Barshah tidal channel

Plate 20. Khor Al Thaalib Al Mughwi, tidal channels (July 2002)

Plate 21. Ras Al Barshah, southern Boubyan tidal channels (July 2002)

permanent tidal channels (1.5-2 km long) are also observed in the Ras Al Barshah area (southwestern part of Boubyan). Typically a single tidal channel is characterized by an inlet with a width rarely exceeding 1000 m. Each single channel is bounded from both sides by muddy or rocky banks of different morphologic features (**Plates 19-22**).

Plate 22. Khor Al Thaalib Al Mughwi, tidal channels (July 2002)

Intermittent Tidal Channels. There are small channels influencing the southern and parts of the eastern and western shores of Boubyan Island. These are more prominent at the southwestern stretch of the island (along the eastern side of Khor Al Subbiyah for about 18 km). During high tide they are filled with water.

Coastal Sabkha

Sabkha (Arabic name for salt flats) is used to describe both coastal and inland saline depressions in North Africa and the Middle East, such as the salt encrusted supra tidal flats of Abu Dhabi along the Arabian Gulf (Briere, 2000). Sabkha is a geomorphologic surface, the level of which is dictated by the water table. At the sabkha surface, displacive and replacive evaporate minerals form in the capillary zone above the saline water table (Briere, 2000).

Coastal sabkha is composed of a variety of surface forms including marine features (such as beach ridges, strand lines and tidal channels) and aeolian features of deflation and deposition (such as salt streaks and nabhkas). Generally the sabkha sediments are dominated by carbonates, evaporates, fluviatiles, and aeolian and marine debris. On the sea side of the sabka there are characteristically intertidal flats, lagoons and offshore bars, and islands and beach ridges may separate the two zones. Coastal sabkha development results from the intersection of several critical components: a porous, plastic framework; a shallow water table; potential evaporation exceeding precipitation; and a source of aeolian material and wind of high enough strength to transport materials. The latter two requirements are critical to maintain a dynamic equilibrium between the elevation of the top of the capillary zone and the elevation of the sabkha surface.

In Boubyan Island, the oldest and largest sabkhas (inland) occur in the central part of the island and the most recent lagoon sabkha are along the coast (Dar Al Handasah Consultants Company, 1983) (**Plates 23-28**).

Plate 23 and 24. Northwestern Boubyan Island intermittent tidal channels (aerial photo)

Plate 25. Intermittent channels, July 2002 (aerial photo)

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In Boubyan, coastal sabkha are broad flats of extensive salt accumulation, chiefly as a result of seawater being drawn to the surface by capillary action. They run approximately parallel to the coast, with a slope that averages 1:300, and lie above the high tide level. Extensive flooding occurs when offshore winds (mainly from the northwest) combine with high spring tides and during sporadic torrential rainfall. After the floods, the pools on the sabkha evaporate and leave salt crusts several centimeters thick. These crusts are later dissolved when the surface is flooded or washed by rain.

Salt Marshes (Tidal Marshes)

Salt marshes are coastal wetlands which are frequently or continually inundated with water. This feature covers the majority of the northern parts of Boubyan Island and parts of Warbah Island. They are an extremely productive ecosystem characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions. Plants include rushes, sedges and grasses, generally with an extensive root system to withstand storm tides. Diversity within the salt marsh communities tends to increase with distance from the open sea areas. As some salt marsh plants die and decompose they create organic detritus, another source of food for many marsh dwellers. The salt marsh system is dynamic and constantly changing as tidal waters move up into the marsh and then retreat.

Plate 26. Intermittent channels, July 2002 (aerial photo)

Near-shore Nabkha (Coastal Impeded Aeolian Accumulations)

Nabkha or nebkha is an Arabic term that describes sand drifts building in the lee of shrubs. The near-shore nabkhas (aeolian sands accumulated around halophytes such as *Halocnemum strobilaceum, Seidlitzia rosmarinus, Zygophyllum* spp. and other species) constitute one of the most significant land features, especially along the southern coast of Boubyan Island. They are composed of a mixture of sands and salts. Their height ranges between a few centimeters to 150 cm. The length rarely exceeds 2 m. During high tides the extreme seaward nabkhas are cut and deformed by the mechanical action of waves in some tidal channels. Occasionally the nabkhas at the extreme inland side of the coastal strip are covered by high water tide and are fully saturated with saline water (stabilization).

Plate 27. Western Boubyan, intermittent channel (aerial photo)

Plate 28. Intermittent channels, July 2002 (aerial photo)

Rocky Islands (Oyster Banks)

These are hard lithified shells that limit the banks of some tidal channels in Khor Al Milh.

Strand Line Deposits

These are unconsolidated sand formed of shingle deposits of marine shells. These materials originate as offshore bars and are deposited at the high water mark by wave action.

Terrestrial Features

Inland Sabkha (Playa)

Inland sabkhas cover wide stretches in the southern and central parts of Boubyan Island. These land features are highly dynamic, controlled by several conditions including deflation (particularly during summer), sabkha composition, rate of inundation by high tide water, sand supply, depth of groundwater and accumulation of outwashed materials by terrestrial runoff. Evaporation at the surface of the sabkhas results in the development of thick salt crusts in dry seasons (10-20 cm thick in some areas in the central portion of Boubyan Island). Underneath the crust, a salty mush exists in which vehicles may get stuck if they break the protective salt crust.

Generally, the groundwater depth plays a crucial role in salt distribution, geomorphology and surface geology of the inland sabkhas. Under environmental conditions in Boubyan Island, the groundwater depth (0.5-2 m) is a dynamic feature. In certain areas where the water table is close to the sabkha floor it is exposed as standing ephemeral water bodies, while in areas where the water table is relatively deeper, moist flats dominate the sabkha floors.

During rainy seasons, e.g., January-February 2004, rainwater and runoff water accumulate, forming ephemeral water ponds at lower parts of the sabkha.

Intermittent Water Ponds (Ephemeral Saline Lakes)

Intermittent water ponds are shallow closed hollows filled with saline water (maximum 50 cm depth). They are of different sizes, occupying the extreme lowest portions of the inland sabkha in the central portion of Boubyan Island. These water bodies persist only during fall, winter, and early spring. They evaporate during summertime, leaving extensive salt crusts. The water sources are seepage of the shallow groundwater, surface runoff and occasionally high tides.

The most significant ephemeral saline water body exists in the central part of Boubyan Island about 6 km west of Ras Al Qaid. The size of this water body varies during different seasons: during spring it covers an area of roughly 8 km^2 with a water depth of 20-40 cm. To the west of this water body a number of smaller water bodies are also found.

Salinas

Salinas occur in sabkhas as a result of occasional inundation of seawater on the sabkhas' surface during high tide conditions, leaving shallow ephemeral saline puddles or ponds. This later evaporates, leaving salt crusts of different characteristics depending on local conditions. In Boubyan Island salinas are observed at the western and central fringes. During summertime, the saline water of the salinas quickly evaporates to precipitate halite (rock salt) and is then desiccated and subject to subaerial processes.

Evaporates

These sediments result from the evaporation of saline water. The minerals are formed in the reverse order of their solubility, i.e., the least soluble first: calcite and dolomite, gypsum and anhydrite, halite and potash, and then magnesium salts. In a depositional environment like Boubyan Island, where sabkhas undergo strong evaporation, the pore waters become highly concentrated and are drawn towards the surface, causing the precipitation of evaporates (halite, gypsum and anhydrite), together with some authigenic minerals (aragonite, calcite, dolomite, celestite and magnetite).

Salt Crusts and Salt Films

Based on the occurrence of salt crusts and films in the land and coastal areas of Boubyan Island, the following features are observed:

In Situ Salt Crusts and Films. Mainly from the evaporation of the shallow groundwater underneath the sabkha (capillary migration).

Ex Situ Salt Crusts and Films. Due to the evaporation of surface water (mainly high tide water), which is trapped (reserved) in low areas of the main courses of the tidal channels. In this case, the salt crusts are thick (more than 15 cm thick on average), fractured by wide polygons. Generally, crusts have different sizes and shapes depending on the local topography and geomorphology of the tidal channels and are composed of pure snow white salts (mainly sodium chlorides).

In summer increased evaporate growth induces lateral and upward buckling of the slightly hardened salt encrusted surfaces. Thin films of salt crusts (a few centimeters thick) result from the evaporation of thin sheets of high tide water at the higher areas of the tidal channels (flanks and cliffs of tidal channels).

Aeolian

Geographically the aeolian landforms are differentiated into nabkha, blowouts, and sands sheets. Aeolian geomorphologic processes include dust and sand storms. Each is discussed below:

Nabkha. Near-shore (coastal) and inland nabkhas (sand accumulation around plant species) have different morphologic features depending on plant species and geographic location.

Blowouts. These are circular to elliptical shallow hollows only a few meters across formed by deflation of sand accumulations which have been stabilized by vegetation.

Sand Sheets. Carpets of drift sands, mainly in the southern parts of Boubyan Island.

Dust Storms. These phenomena are observable in Boubyan Island particularly during summertime, when strong turbulent winds lift fine dust into the air from the dry silt and clayey soils, forming a dense cloud of fine particulates. Dust refers to mineral particles ranging in size from 0.001-0.03 mm, which spans the range from medium clay to medium silt. A decrease of groundwater and the dryness of natural vegetation accelerate deflation and, in turn, the occurrence of dust storms. On August 29, 2003, Boubyan Island experienced a severe dust storm. Darkness prevailed from 12-3 pm and visibility was almost zero. Between 6-8 pm north-south dust corridors crossed the main road of the island during this event. Other dust events took place on October 29, 2003, February 11, 2004 and June 21, 2004. Generally, the island experiences between 15-20 dust storms/year.

Sand Storms and Sand Encroachment. Sand storms constitute a low cloud of moving sands that usually rise only a few inches and at most 2 m above the ground. Storms consist of sand particles driven by strong winds. As a result of sand storms, drift sands accumulate around roads and infrastructures particularly in the southern parts of Boubyan Island. The inland nabkhas, especially where the vegetation is dry, present a significant source of sand during sand storms.

Dead (Deflated) Nabkha. Piles of elongated sand bodies with dead vegetation materials, which are a source of sand and dust.

Fluvial Features

Terrestrial Drainage

Terrestrial drainage constitutes a set of short dendritic basins (maximum 1.5 km in length) occurring mainly at the extreme northeastern portion of Boubyan Island (about 5 km to the northwest of Ras Al Qaid and about 0.5 km inland from the mudflats stretching parallel to the Khor Abdalah shoreline at the eastern side of Boubyan Island. They drain low ridges and rims.

Patterned Ground (Micro Land Features)

In Boubyan Island, patterned ground is one of the most conspicuous features in several parts of the island. It constitutes a great variety of micro land features, which vary widely in scale from patterns composed of elements only a few centimeters across (such as polygons) to those with dimensions of 50 m or more (such as circles and patches of dead vegetation). The following forms of patterned ground are observable:

Polygons. Polygons are a form of patterned ground in which initial cracking of the surface is essential and are found on sabkha surfaces. In addition, the smooth surfaces of the clay and silt saturated with salt in the eastern and western mud flats have polygonal patterns of desiccation cracks, and solution pits are common at crack junctions. There are numerous causes of cracking, the most significant being contraction of sabkha and mud flat surfaces on drying (desiccation cracking). Wetting and drying, and solution and recrystallization of salts, are the main processes controlling the occurrence and characteristics of polygons. When saline solutions in pores of the sabkha and other salty surfaces become saturated as a result of temperature change or evaporation, salt crystals begin to form and considerable pressure is generated. Salt crystal growth in pores of the sabkha can cause considerable ground heave. When salt solutions enter desiccation cracks various types of polygons are developed. Generally, the patterned ground is ephemeral and reflects the local hydrological conditions. When a salty water body

Plate 29. Central Boubyan polygonal cracking in salt crust (June 2004)

Plate 30. Sand encroachment on ground fortification (June 2003)

Plate 31. Demolition pits, southwestern Boubyan (July 2003)

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evaporates a salt crust develops, and polygonal cracking is ultimately created by contraction. The cracks narrow downward and a wedge of salt grows within each crack, usually fed by evaporation from shallow groundwater. The salt wedges may widen the cracks and grow to produce ramparts around the polygons. The ramparted polygons sometimes become miniature salt pans when flooding next occurs. In addition, groundwater evaporation between the surface crust and the underlying mud can cause salt crystal growth that imposes blisters on the polygonal surface. Open pools are formed where salt layers in mud have been dissolved and the surface has collapsed (**Plate 29**).

Circles (Ring Fissures). Circles (ring fissures) are produced around clusters of halophytic plants that lower the shallow saline groundwater and capillary fringe as they grow, dry out surface materials of the sabkha and cause shrinkage and cracking. These features suffer deflation and the accumulated aeoilan sands around the plants are blown up. In most cases the cracks are completely eliminated and their only trace may be lines of bushes or slight surface discolorations. Circles occur singly or in groups.

Puddles and Bogs. Small water bodies in sabkhas representing relics of high tide waters (trapped in local hollows).

Man-made Land Features. These include ground fortifications, mainly concrete from the Iraq-Iran War, 1980-1988, and earthen from the Iraqi occupation, August 1990-February 1991 (**Plate 30**).

Demolition Hollows. Demolition hollows constitute circular excavations dug in the topsoil of Boubyan Island in numerous sites, especially on the western fringes of the island. They were used mainly for demolition of unexploded ordnance. The diameter of these hollows ranges between 4-5 m and the depth ranges between 1-2 m. In the majority of the hollows the highly saline shallow groundwater is exposed at the bottom. A ring of vegetation grows around the rim of these hollows (**Plate 31**).

Raised Roads. Boubyan Island is dissected by several raised roads (0.3-1.5 m above ground level). Four main raised roads were established at the southern part of the island. These influence the environmental conditions of the island in several ways, including:

- Blocking the high water tide especially along the western and southern coasts of Boubyan Island.
- Trapping drift sands carried out by northwest winds.
- Blocking runoff waters.

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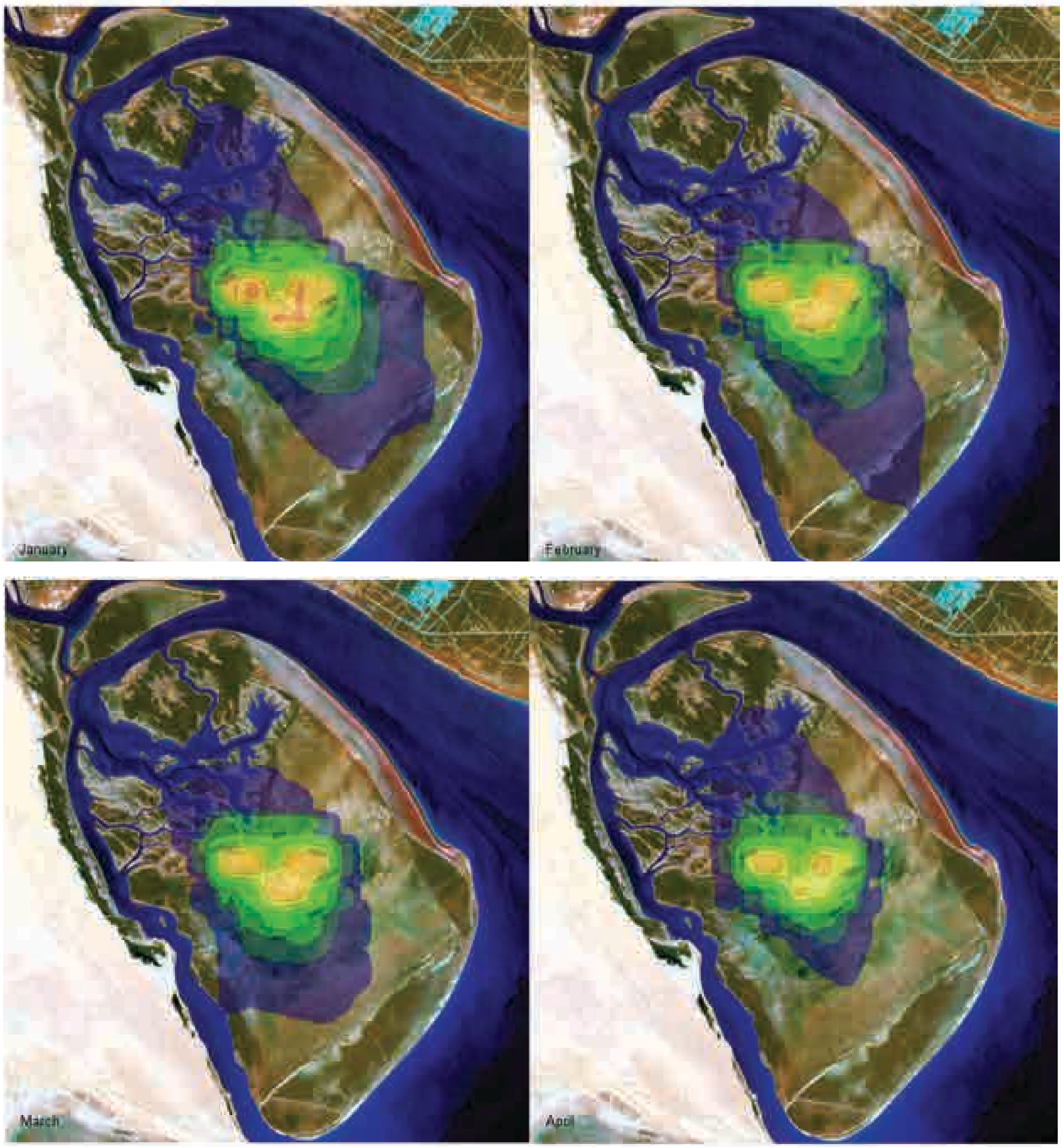
Section 2

Environmental Monitoring and Environmental Impact Assessment

Chapter 6: Aeolian Conditions and Air Quality

Chapter 7: Environmental Impact Assessment



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Chapter 7: Environmental Impact Assessement

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Section 2

Chapter 6: Aeolian Conditions and Air Quality

Abstract

During the project period, a reconnaissance field survey was conducted. This survey covered the terrestrial parts of both Boubyan and Warbah Islands and some tidal channels dissecting both islands. The main objectives were to identify the major landforms and types of surface sediments, to monitor safe traveling routes and to select the appropriate sites for monitoring stations for dust, sand, groundwater level, air pollutants and weather conditions. A recent geomorphologic map at a scale of 1:25,000 was prepared. The dust deposition rates measured at Boubyan and Warbah Islands during the period from November 2003 to January 2005 reflect the mixing of dust from three sources. The main sources are: long-distance dust deposition producing fine deposits mainly less than 5 µm in diameter; dust deposition from regional sources, mainly from the Mesopotamian Floodplain, producing 20-40 µm range size fractions; and local dust deposition producing relatively coarse dust material in the 50-70 µm range grain size fraction. This theory was supported by the Brunauer-Emmett-Teller (BET) surface area, which illustrates the variation of the surface area with time in both Boubyan and Warbah Islands. The interrelationship of the variations in dust fallout, groundwater level and trapped sand with time clearly shows a close relationship between the dust fallout with the drop in the groundwater level, while there is no relation with the amount of trapped sand.

This study concentrates more on the environmental conditions of the two islands (Boubyan and Warbah) through continuous monitoring of mobile sand movements, dust fallout, groundwater level and air pollution. Mobile sand movements and air pollution in Boubyan Island are at the lowest levels in Kuwait. The weather data from Ras Al-Subbiyah show close similarities to those from the Boubyan meteorological station.

Introduction

Mecall (1952) and Hunziker and Mecall (1952) conducted an early reconnaissance field survey on Boubyan Island. They reported a cliff of beach deposits at the southwestern part of the island. This cliff was formed by sea storms and may represent a paleo shoreline.

Al-Asfour (1982) discussed the development of Boubyan Island. According to this study the age of the shells collected from the island ranges between 2240-3520 years B.P. (before the present). Age determination was based on carbon 14 dating.

Boubyan Island consists of different types of sabkhas. The interior sabkha depends largely on rainfall, which settles and slowly penetrates about 1 m. During winter rainstorms a network of shallow ephemeral channel-bar drainage systems may develop after heavy runoffs (Al-Zamel, 2000).

Al-Hasem (2001) studied the morphodynamics of the open-ended tidal channel in the arid and mesotidal environment at Subbiyah tidal channel and included some samples from the western coast of Boubyan Island.

Tectonically, Kuwait occupies the eastern extremity of the Arabian shelf; it is located southwest of the active collisional plate boundary between the Arabian and Eurasian (Iranian) plates. Boubyan Island lies northeast of Kuwait (northwestern end of the Arabian Gulf). The eastern margin of the Arabian shelf (Gulf region) has experienced a complex structural evolution starting from the late Triassic to the Palaeogene, followed by the movements associated with Neogene Arabian plate motion (Al-Sulaimi and El-Rabaa, 1994). The pre-Neogene structure in Kuwait comprises: 1) Kuwait Arch, which includes the Wafra, Burgan and Zubair oil fields in the eastern part of Kuwait and Um Gudair-Al-Minagish structures in the western part of Kuwait as offshoots of the Kuwait Arch, and 2) Safaniya Arch at the eastern offshore area of Kuwait (**Fig. 1**).

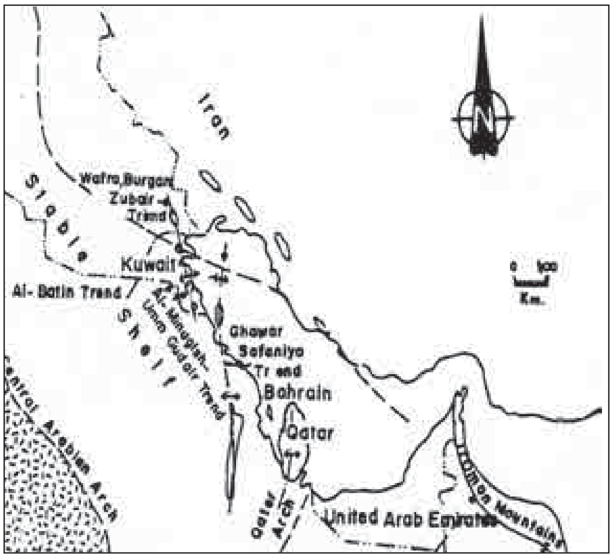

Fig. 1. Major tectonic units of the Arabian Gulf region (after Clarke, 1988)

These pre-Neogene structures are thought to occur as a result of vertical stresses caused by deep-seated block faulting along activation zones and in some cases are due to the intrusion of salt plugs (Lees, 1950).

Boubyan Island is located close to the Jal Az-Zor escarpment, Zagros Mountain belt and three oil fields (Bahra, Sabbriyah and Rawdatain). Kuwait Oil Company (K.O.C.) geophysical surveys (1956-1974) for Bahra oil field wells (southwest Boubyan Island) revealed two faults under Kuwait Bay running parallel to the orientation of the Jal Az-Zor (northeast-southwest) escarpment (Davies, 1965; Al-Sarawi, 1982). These faults show a 50-70 m downward movement. Movements along these faults were occurring during the Eocene period (Al-Sarawi, 1982).

The extreme southern part of Boubyan Island (sandy beaches) and the muddy banks of the northern tidal channels are covered by grasses, shrubs and reeds. These serve as breeding ground for birds.

Based on recent field investigation and visual analysis of a Landsat 7 enhanced Thematic Mapper Plus (ETM+) color composite image recorded on March 6, 2001, three main geomorphologic units are identified. These are:

Northern Geomorphologic Unit: Consists of a flat muddy terrain covered with grasses and shrubs. This unit is dissected by two systems of tidal channels. The first, which is the major system, is connected to the Khor Boubyan water body to the north of Boubyan Island, while the second, which is a minor system, is connected to the Khor Al-Subbiyah water body to the west of Boubyan Island. In the course and banks of the tidal channels rocky patches (consolidated shell fragments) are exposed. These bodies are locally called Al Baqr (caws in Arabic).

Central Geomorphologic Unit: Consists of sabkhas and water ponds. This unit is limited by a soft low cliff (2-3 m height) separating it from the northern geomorphologic unit. At its middle portion this cliff is cut by an almost north-south channel which under high water tide connects both geomorphologic units.

Southern Geomorphologic Unit: An area dominated by sabkhas and recent bodies of drift sands. A number of west-east and north-south roads dissect this unit.

Aeolian Condition Methodology

Research on aeolian conditions was based around piezometers for monitoring the groundwater level, dust collectors for monitoring dust fallout, sand traps for monitoring the mobile sand activities, and ground level monitoring sticks. The locations of the equipment are shown in **Table 1**. One of the main targets of this study was to establish a database containing all information regarding the aeolian activities of the island in relation to weather data.

Table 1. Site Number and Location of Each Monitoring Station

Site No.	North	East	Dust Collector	Sand Trap	Piezometer	Erosion Sticks	Weather Station
(P01)	29° 40' 42.4"	48° 16' 16.9"	x		x		x
(P02)	29° 38' 24.6"	48° 13' 14.6"	x	x	x	x	
(P03)	29° 37' 52.1"	48° 12' 20.1"			x		
(P04)	29° 36' 51.3"	48° 11' 04.1"			x		
(P05)	29° 53' 01.9"	48° 16' 27.5"	xx		x		
(P06)	29° 50' 55.7"	48° 17' 43.5"			x		
(P07)	29° 48' 45.3"	48° 19' 29.7"			x		
(P08)	29° 47' 53.4"	48° 22' 04.5"	x		x		
(P09)	29° 46' 02.3"	48° 46' 02.3"			x		
(P10)	29° 36' 20.1"	48° 15' 34.4"	x	x	x		
(P11)	29° 37' 23.7"	48° 16' 49.1"			x		
(P12)	29° 38' 13.6"	48° 17' 43.6"			x		
(P13)	29° 39' 07.8"	48° 18' 43.2"	x	x	x		
(P14)	29° 38' 51.8"	48° 11' 0.1"			x		
(P15)	29° 40' 04.2"	48° 19' 40.7"		x	x		
(P16)	29° 41' 10.3"	48° 20' 35.3"	x	x	x	x	
(P17)	29° 42' 15.6"	48° 21' 18.4"		x	x		
(P18)	29° 42' 58.3"	48° 21' 40.5"			x		
(P19)	30° 00' 11.5"	48° 08' 11.7"	xx		x		
(P20)	29° 44' 0.6"	48° 22' 5.5"			x		

Key: x = number of pieces of monitoring equipment installed.

6

Monitoring Groundwater Levels

The capillary moisture from the shallow groundwater table in Boubyan Island, which is about 1-2 m from ground level, keeps the loose sediments damp and firm, thus preventing deflation by prevailing winds. In dry seasons the groundwater table drops, a process that accelerates deflation of the higher dry sediments. To monitor the fluctuations of the shallow groundwater table a set of piezometers was established.

Twenty piezometers were located in Boubyan Island and one in Warbah. The design is shown in **Fig. 2**. The methodology for installing the piezometers is described below:

1. Multiple field visits to pick the best locations for the piezometers, which were then detected by GPS and tabulated and located in the base map.
2. The piezometer location was chosen to be higher than the water level. This restricted possible locations within the central and southern units. Only one piezometer was installed within the northern unit in Warbah Island.
3. Each piezometer was drilled 2 cm in diameter to 5 m depth using a Geoprope (GH-40) (**Plate 1)**.
4. A 3 m PVC pipe was installed with 20 cm screen intervals and 20 cm casing 1.5 cm in diameter.
5. Groundwater level was measured from ground level.

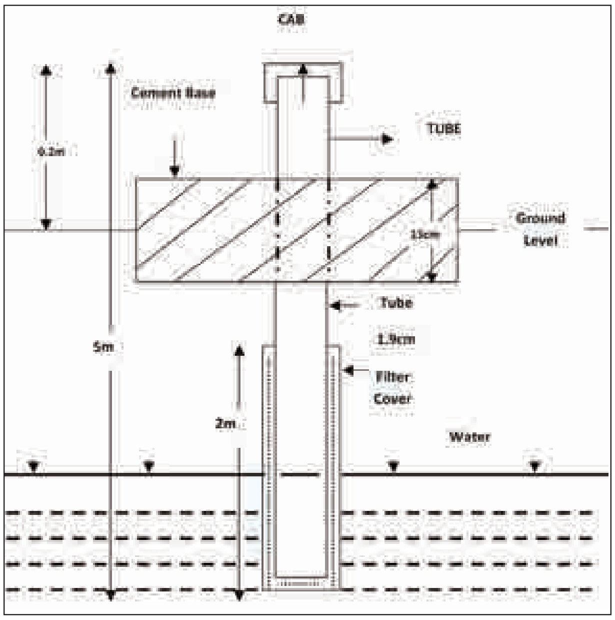

Fig. 2. A sketch of the piezometer design for Boubyan and Warbah Islands

Plate 1. Drilling a piezometer 2 cm in diameter to 5 m deep by using a Geoprope

Compilation of Existing Data and Information for Groundwater Resources

Groundwater Review: In 1969, the Agricultural Division of the Kuwait Institute for Scientific Research (KISR) suggested a detailed investigation of the possibility and feasibility of obtaining and utilizing the moisture from underground for sustaining plants in Boubyan Island. It was assumed that the moisture from underground could be continuously supplied from the shallow water table to the soil surface through capillarity. It was further assumed that the moisture supply from the underground water would be sufficient to sustain this kind of planting, taking into consideration the alluvial soil of Boubyan Island.

However, in reality, due to the high water table there is constant upward seepage of groundwater, which evaporates on the surface, leaving an accumulation of salts. Considerable work has been carried out elsewhere on the evaporation of saline water and it has been demonstrated that the rate of evaporation can be considerably less than that of freshwater under the same meteorological conditions. The rate of evaporation decreases as the salt concentration increases and may almost cease where a continuous surface layer of salt forms a physical barrier to gaseous water molecule movement.

Aquifer Condition in Boubyan Island: Three Kuwait Group wells (Boubyan 1, 2 and 3) were drilled in Boubyan Island in 1984 by Bouygues Co. (MEW, 1984), to a depth ranging from 50-100 m. Wells Boubyan 2 and 3 were abandoned due to clayey and silty formation and heaving of sand respectively. Water samples were collected from wells Boubyan 1 and 2. The total dissolved solids contents (TDS) of the samples for two wells were 86,989 and 84,280 mg/l respectively.

The most effective part of the natural recharge of the island occurs as a sluggish lateral flow coming from the northeast part of Kuwait with a water salinity (TDS) value of more than 30,000 mg/l in the uppermost Kuwait Group and more than about 100,000 mg/l in the deeper part of the Kuwait Group and Dammam Limestone Aquifers.

The other parts of the recharge which are not considered to be effective, at least in forming a producible brackish groundwater potential in the island, are:

- The local infiltration of rainwater;
- The surface flow drained through the Khor Az-Zubair; and
- The possible lateral flow coming through shallow aquifers from Iraq.

Previous studies (Shimose and Toratani, 1970) revealed extremely saline groundwater on Boubyan Island. The results of these data (six sites with chloride % ranging from 11.25-14.27) indicate the groundwater is much more saline than seawater. The Ministry of Planning (1983) concludes that a heavy accumulation of salts occurs due to the existing high water table and resulting upward seepage of groundwater that subsequently evaporates on the surface. The rate of evaporation decreases with salt accumulation, which can eventually form a physical barrier to gaseous water molecule movement.

Groundwater Monitoring Work Plan Elements (Hypothetical): Guidelines for a groundwater field survey program and testing for the Boubyan project were prepared by KISR but executed under the scope of the geotechnical investigation by another Boubyan team consultant. Supplemental tests of groundwater samples for pollution were assessed and reported under the KISR Boubyan Environmental Measurement project from designated piezometer test sites.

Conclusion

The evaluation of the existing data does not suggest that the brackish water available would be usable for agriculture.

Establishing Dust Collectors

The dust collectors were designed as shown in **Fig. 3** and a few modifications in the design were made. These design modifications were concentrated in the dust containers, where they were sealed to prevent high rates of evaporation. Distilled water was put in these containers to capture all fallen dust. Ten dust collectors were installed in the field.

Dust Collector Site Selection

Ten sites for dust collectors were selected based on reconnaissance field survey and on analyses of satellite images for 2001 and 2002: two on the eastern part of Warbah Island and eight in the southern, western and central parts of Boubyan Island (**Plate 2**). During selection of these sites the following criteria were considered:

- The selected sites were at least 100 m away from desert roads (to avoid sources of dust raised by vehicles).
- Appropriate geographical distribution for dust collectors.
- Avoidance of the impact of obstacles, such as buildings (at least 100 m away from existing facilities).
- Reasonable access to the sites.

After selecting the sites of the dust collectors and recording their coordinates using GPS, the collectors were installed on a concrete base. The design is shown in Fig. 3. Afterwards, the ground was leveled and water with a stabilizer was showered on the area around the collectors

Plate 2. Dust collector (DC-10) installed in the southern part of Boubyan Island

to minimize the effect of soil disturbance during installation. The containers were periodically filled with distilled water to increase efficiency in capturing the dust particles. The dust samples were monitored on a monthly basis for one year.

Sand Traps

Transportation and deposition of sand by winds (sandstorms) is an active geomorphologic process on the island. An understanding of the relationship between the rate of sand transport, wind speed, surface roughness, local sources of sands and other environmental conditions is essential for future planning to control mobile sand.

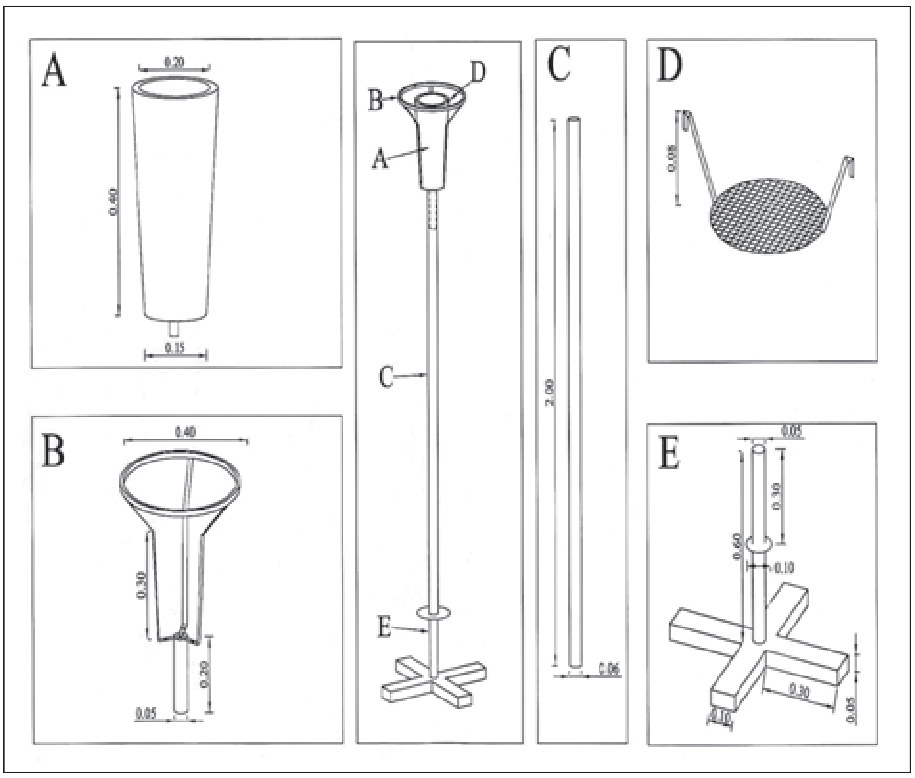

Fig. 3. Parts of a dust collector (dimensions in meters)

Plate 3. Leveling and directing the sand traps using a Brunton compass

Plate 4. Leveling the ground surrounding the sand traps

Plate 5. Sand trap installation (station 1)

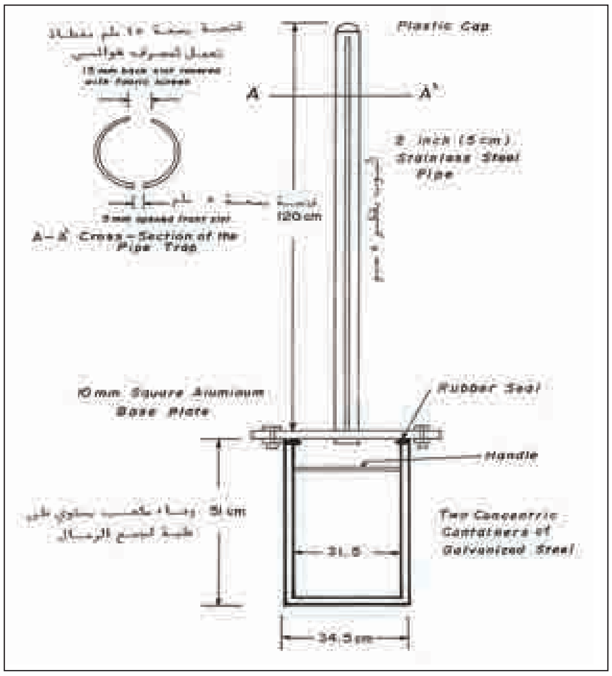

Fig. 4. Sand trap design

In order to monitor sand transport, a number of sand traps were erected in several parts of the island. The availability of suitable sites was a major problem. There are few sites where mobile sand is represented by small wind corridors due to the effect of certain natural and/or artificial morphological features within the island. The artificial features are mainly off-road vehicle tracks, berms and human settlements.

Twenty sand traps were installed in Boubyan Island at six sites: two of these sites contained eight sand traps (directional sand traps) for the major eight directions (north, northeast, east, northwest, west, south, southwest and southeast). The installation of sand traps was as follows:

- The installation of the directional sand traps was done in a circle of 10 m radius.
- The center of the circle was used to identify the location and direction of each sand trap.
- Eight pits were dug to 52 cm depth and 40 cm width.
- Each sand trap was then leveled and directed using a Brunton compass to get greater accuracy with respect to one of the main directions mentioned above (**Plate 3**).
- The ground was leveled around the sand trap (**Plate 4**).
- The surrounding sediments were then fixed using water and a stabilizer to minimize the effect of soil disturbance during installation.

Twenty unidirectional sand traps were manufactured at the KISR workshop; the design is shown in **Fig. 4** and **Plate 5**. The sand traps consist of 120 cm stainless steel pipe with two openings: one is covered by 0.095 mm mesh. All parts of the sand trap were locally manufactured. The dust and sand were collected monthly from the sand traps and dust collectors.

Monitoring Ground Level (Deflation and Deposition Rates)

Boubyan Island is characterized by active aeolian processes particularly during summer. Deflation of dry soils is driven by the prevailing winds. Deposition of fresh sands takes place in certain areas. Monitoring of this process is significant for better understanding of aeolian activities of the island.

Two main areas were found to be suitable for ground level monitoring. Both monitoring stations have eight directional sand traps, one dust collector, and one piezometer for correlating the data. The area of each station is 9000 m^2 (100 m x 90 m). There are 90 posts of 40 cm in length for monitoring the erosion level in each station. The distance between one stick and another is 10 m to increase the accuracy level.

Aeolian Condition Results

Monitoring Dust

The data show that the southeastern and the eastern parts of Boubyan have the highest quantities of deposited dust compared to other sites on Boubyan and Warbah Islands (**Fig. 5**), and Warbah has the lowest quantities. Preliminary results also show lower quantities of dust toward the north and northwestern parts of the island. Both islands show higher quantities of dust in the southeastern and eastern sides during the summer compared to the Ras Al-Subbiyah area. The western coast of Boubyan shows slightly higher quantities of dust compared to the Ras Al-Subbiyah area. **Fig. 6** illustrates the variability between Ras Al-Subbiyah, Warbah and Boubyan and also illustrates the higher quantities of dust in Ras Al-Subbiyah from September to December 2002 due to huge military maneuvers in preparation for the Iraq Liberation War. **Table 2** shows that dust fallout is higher than the global average, but less than North Africa. The higher concentration of dust in the eastern and southeastern parts of Boubyan Island can be attributed to the large contribution of local rather than regional sources and to local geomorphology, where many dry wadis feed the predominant northwesterly wind with dust particles.

The characteristics of dust have been analyzed. Useful information was drawn largely from the surface area of the grain particles. Average rates of dust deposition are also valuable indicators of potential source areas and transport distances of windblown dust.

The rate of dust fallout in Warbah Island is lower than Boubyan Island for all months of collection except November 2004, averaging almost half that of Boubyan Island. This study clarified that dust is dominantly from local sources, with the highest dust deposition rates measured in the southern and eastern sides of Boubyan Island.

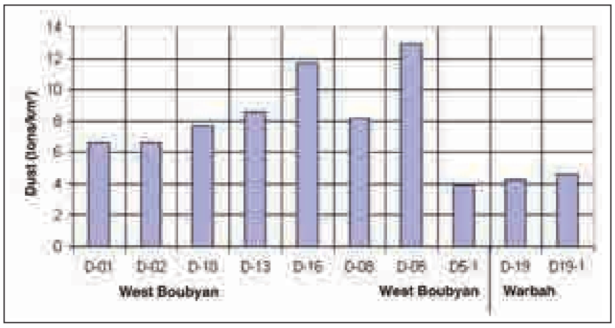

Fig. 5. The dust fallout variations in tons/km²

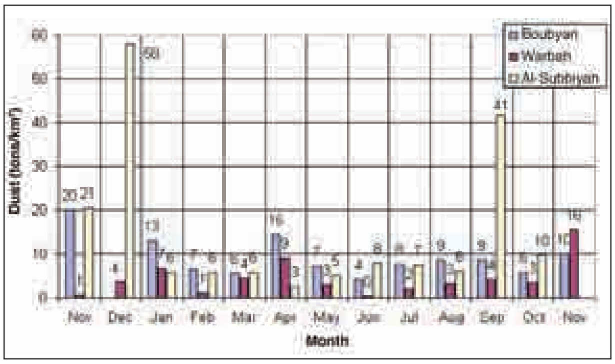

Fig. 6. Dust fallout comparison between Boubyan, Warbah (2003/2004) and Ras Al-Subbiyah (2002/2003)

Drilling Observation Wells (Piezometers)

To identify the relation between soil moisture, sand movement and dust fallout, 20 piezometers were drilled in the southern fringes of Boubyan Island. The diameter of these piezometers is 5 cm. The depth of groundwater varies between 1.5 to about 3 m from ground surface depending on the local topographic, geographic and lithologic conditions. Selection of the sites of these piezometers was based on field investigations and remote sensing information and the measurements were taken from the lowest astronomical tide (LAT).

Variation of water level from November 2003 to November 2004 is obvious from one month to another. It shows deeper values from LAT in the period from February to June 2004 and shallow values during the rest of this period. The shallowest water level was noted in November, October and December.

The results from the two groundwater monitoring stations described above show much higher average erosion rates compared to average depositional rates (**Fig. 7a and b**). The erosion rates were 126 and 143 m^3 respectively, while depositional rates were only 53 and 34 m^3 respectively. This might be attributed to the high content of clay and silt size fractions. The depositional rates within the southern coastal areas which are represented by station 16 show continuous growth in depositional rates and variable erosional rates. This might indicate that the southern coastal

Table 2. The Average Amount of Dust in Boubyan and Warbah in Comparison to Regional and Global Site Samples

Political Region	Location	Reference	Tons/km²/month	Tons/km²/year
Kuwait	Boubyan Island	Present study	9.4	112.3
Kuwait	Warbah Island	Present study	4.4	57.8
Kuwait	Ras Al-Subbiyah	Al-Awadhi (2003)	6.2	74.8
Kuwait	Kuwait	Safar (1980)*	4.6	55.0
Palestine	Negev Desert	Yaalon and Ganor (1975)*	4.8-18.1	57-217
Mali	Along Niger River	McTainsh et al. (1997)*	75-858	913-10,446
Chad	Northern Diarnena	Maley (1982)*	11.8	142.0
Nigeria	Kano	McTainsh and Walker (1982)	11.4-15.1	137-181
Greece	Crete	Pye (1992)*	0.83-8.33	10-100
U.S.A.	Arizona	Pewe (1981)*	4.5	54.0
U.S.A.	Between Rocky Mts & Mississippi	Simonson (1995)*	0.003	0.03
U.S.A.	S Nevada & SE California	Reheis and Kihl (1995)*	0.36-1.31	4.3-15.7
U.S.A.	SW California	Reheis and Kihl (1995)*	0.52-2.82	6.8-33.9
Morocco	Agadir	Rott (2001)	9.4	114.4
Morocco	Sidi Ifni	Rott (2001)	11.9	144.5
Morocco	Tan Tan	Rott (2001)	14.4	175.0
Western Sahara	Smara	Rott (2001)	9.1	110.8
Western Sahara	Itguity	Rott (2001)	3.3	40.2
Western Sahara	Laayoune	Rott (2001)	4.3	51.8
Western Sahara	Boujdour	Rott (2001)	18.0	218.8
Mauritania	Dakhla	Rott (2001)	15.7	191.4
Mauritania	Nouadhibou	Rott (2001)	6.5	79.5
*Also Rott (2001)				

line is a depositional area and as we get to the northern direction the erosional rates will be higher.

Lab Analysis: Surface Area

The Brunauer-Emmett-Teller (BET) surface area is expressed as values for a certain weight of loose sand in terms of m^2g^{-1} measured by using isotherm plot diagrams of volume against pressure and using the BET equation devised by Brunauer et al. (1938). Al-Dousari (2003) was the first to use this technique to characterize the three-dimensional surface texture of aeolian quartz sand grains within the Kuwait aeolian environment. Monthly collections of dust fallout were analyzed and compared to identify the main source of dust. Al-Dibdibba formation sediments were picked from the Al-Mutlaa area, which represents the main geological formation exposed in the surface within Kuwait, but not in Boubyan Island. Also, comparison was extended to regional and global aeolian samples.

The surface area values of the Boubyan dust samples obtained were quite similar to the surrounding sand samples. However, there was variability in the surface area compared with Warbah samples (**Fig. 8a** and **b**). The surface area of the dust samples over time illustrates the trend of similarities between both Boubyan and Warbah. When comparing the dust samples with the medium sand fractions of the trapped sand collected from sand traps they are quite similar; the variability with time is less within sand fractions **(Fig. 9**). Furthermore, comparison of these values with regional and global aeolian sediments illustrates higher variability. The dust samples show much higher values than regional and global averages (**Fig. 10**). In addition, dust samples are quite different than those from the Al-Dibdibba formation. These results lead to several conclusions:

- The Al-Dibdibba formation is the dominant source of aeolian sand within terrestrial Kuwait, the only exception being Warbah and Boubyan Islands since here this formation is not exposed to the surface, as in other Kuwaiti terrestrial areas.

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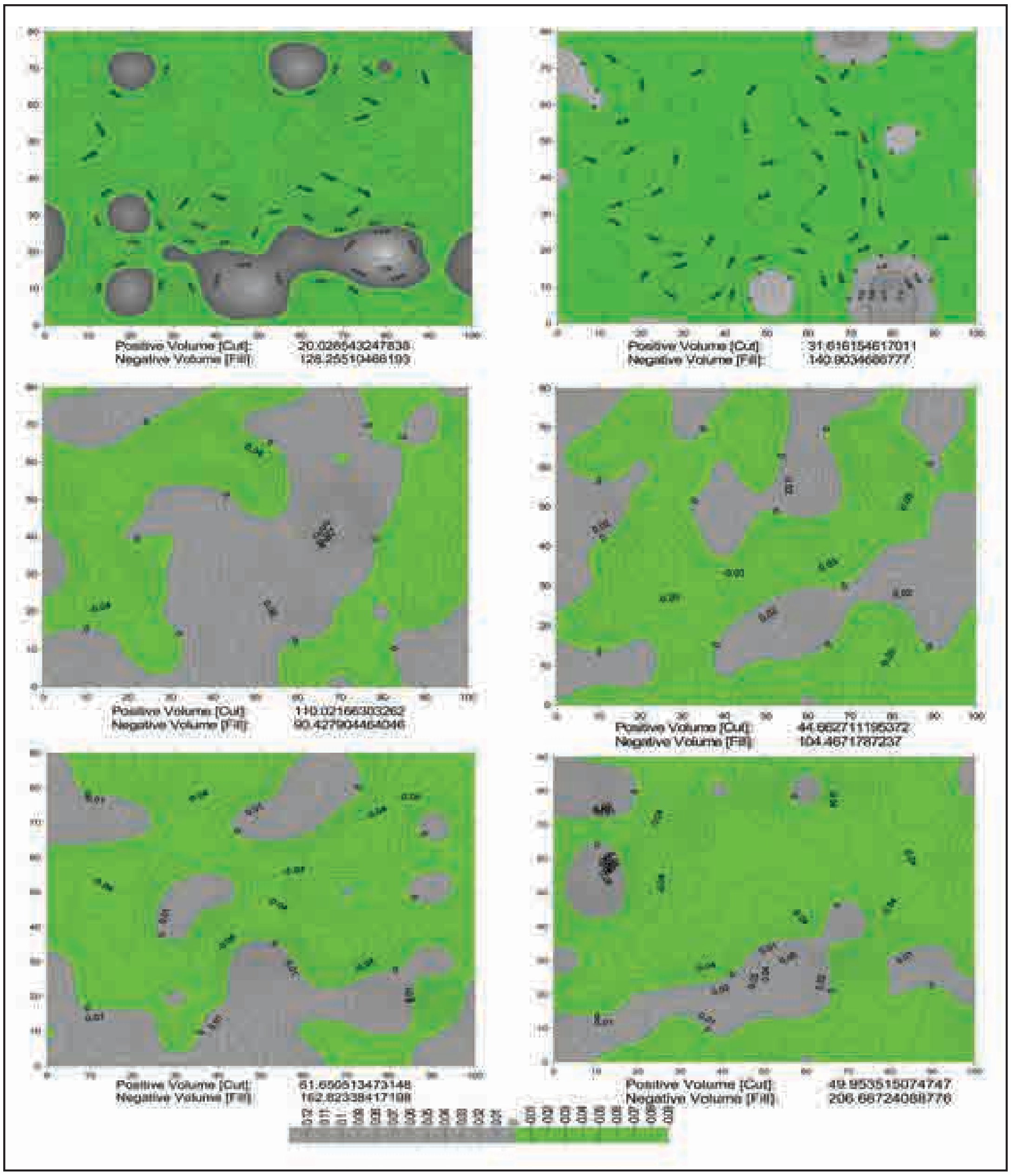

Fig. 7a and b. Contour maps and values of deposition and erosion at monitoring stations 12 (left) and 16 (right) on March 30, July 7, and Dec 13, 2004 respectively (vertical and horizontal scales are in meters)

- Variability of the surface area of dust fallout over time, which was observed in both islands, indicates multiple dust sources, with at least three main sources identified (local, regional and global). The high surface area values represent the regional and global sources, while low surface area values represent local sources.
- Warbah Island dust fallout is predominantly from regional sources and the contribution of local sources is very limited; conversely, contribution of local sources to Boubyan dust fallout is much higher. Although current trend in dust surface area is quite similar between the two locations, they nonetheless show slight differences.
- Boubyan and Warbah sediments are dominantly from the Mesopotamian Floodplain, which might explain the broad similarity in the surface area of the dust fallout in relation to time.

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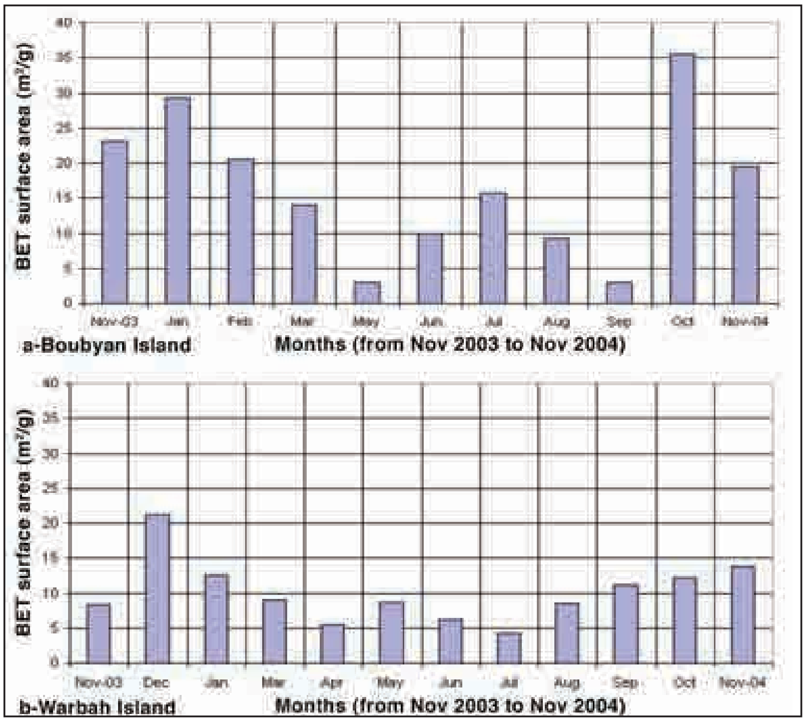

Fig. 8. BET surface area of dust fallout for November 2003 through November 2004 for (a) Boubyan Island and (b) Warbah Island

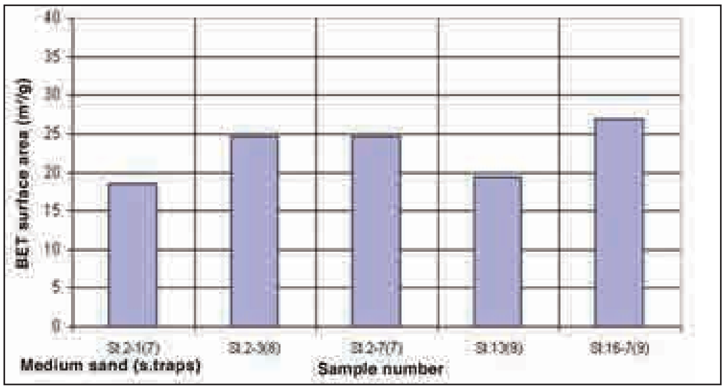

Fig. 9. BET surface area in m^2/g for the medium sand fractions collected from sand traps in Boubyan Island in June, August and September 2004

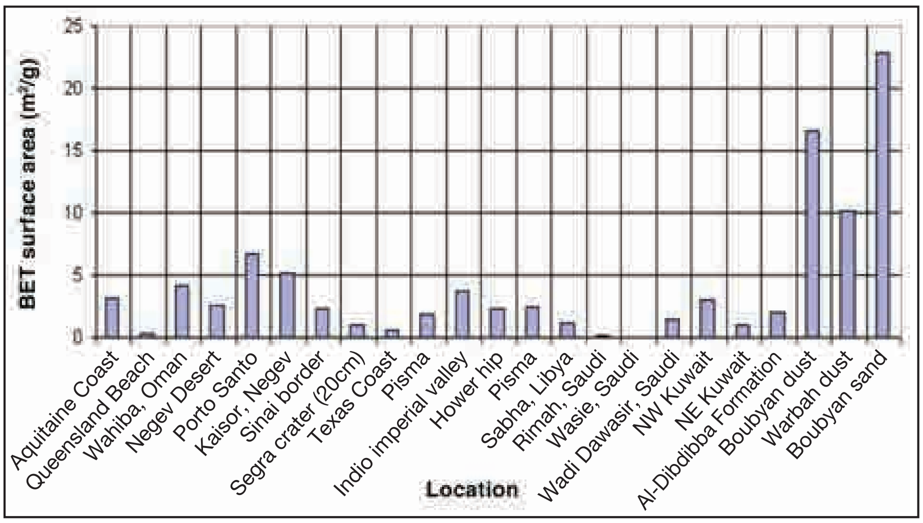

Fig. 10. BET surface area of Boubyan and Warbah dust and medium sand samples in comparison to aeolian sand (medium sand fractions) from regional and global areas

Grain Size Analysis

All sand trap samples that exceed 100 g in all months were subjected to grain size analysis, with averages illustrated in histograms. Statistical parameters were also calculated. These statistical parameters are:

Mean grain size:

$M_z = 1/3\ (\phi 16 + \phi 50 + \phi 84)$

Sorting or standard deviation:

$\sigma_1 = (\phi 84 - \phi 16)/2 + (\phi 95 - \phi 5)/3.3$

Skewness:

$SK_1 = [\phi 16 + \phi 84 - \phi 50/2(\phi 84 - \phi 16)] + [\phi 5 + \phi 95 - 2\phi 50/2(\phi 95 - \phi 5)]$

Kurtosis: $K_G = \phi 95 - \phi 5/2.44(\phi 75 - \phi 25)$

Interrelationship plot diagrams between statistical para-meters were also prepared to identify dominant sources of sand.

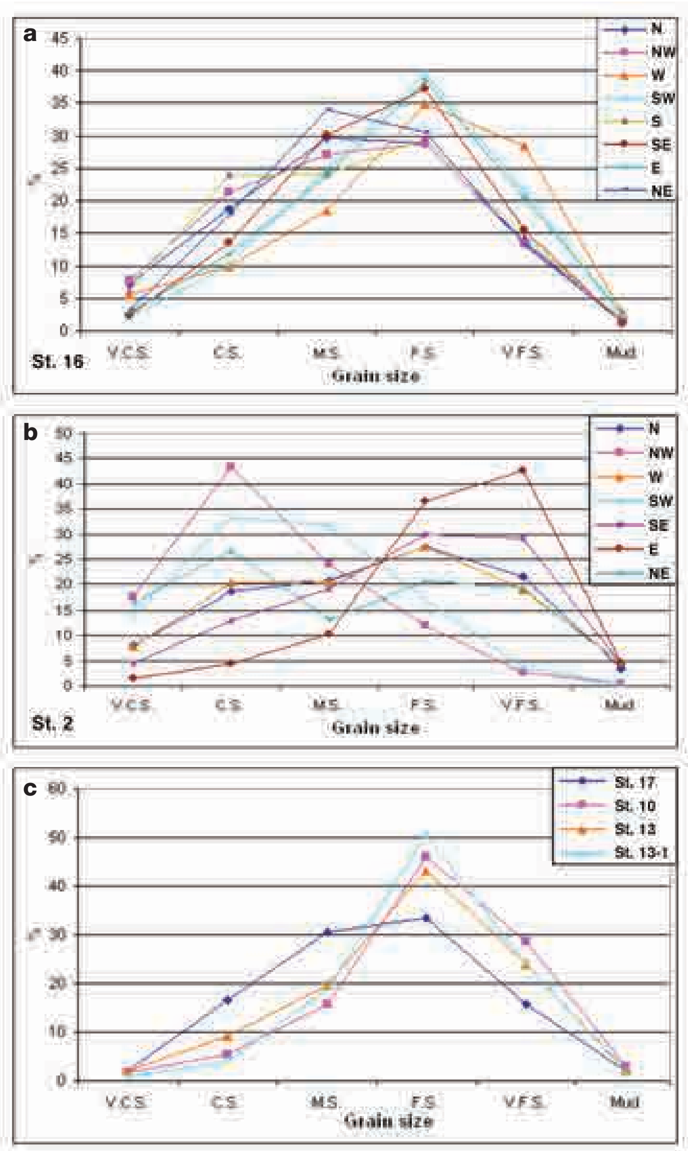

Fig. 11a, b, c Grain size percentages in all directions at stations 16, 2, and other sand traps

Grain Size and Statistical Parameters of Sand Trap Sediments

The results clearly illustrate no variability of dominant size fractions with location and direction of the dust collectors. The eight sand traps at station 16, for example, in the southeastern part of Boubyan, show dominantly fine sand in all directions except for the northeast where medium sand is dominant (**Fig. 11a**). At station 16, coarse sand is dominant in the northwest, southwest, and northeast directions, while very fine sand is dominant in the rest. At station 2, the particle size distribution is variable, but coarser size particles are dominant (**Fig. 11b**). Sand traps in the coastal line, which are all directed towards the northwest (e.g., stations 17, 13, 13-1, and 10) collected predominantly fine sand (**Fig. 11c**).

The directional sand traps show that the dominant trapped sands are coming from the northwest, north, and east respectively at station 2 (**Fig. 12a**) and from the west, north, and northwest respectively at station 16 (**Fig. 12b**). The slight variation between the two sites is due to the effect of the windblown sand from the sea.

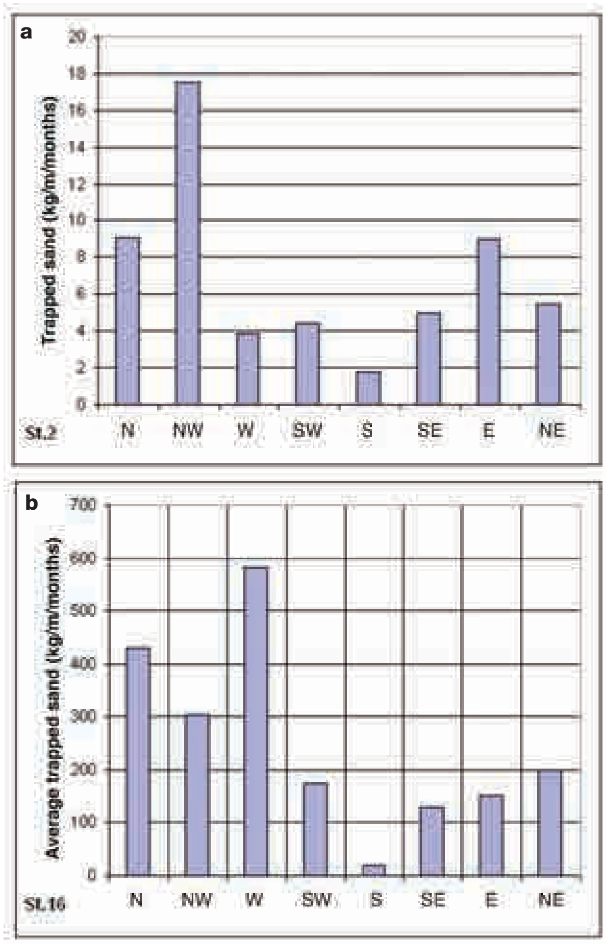

Fig. 12a and b. Average trapped sand in stations 2 and 16 from eight directions

Table 3. Grain Size Percentages and Statistical Parameters of Dust Fallout at Site 4 from January to October 2004

Sample	Mean	Sorting	Skewness	Kurtosis	C.S.	M.S.	F.S.	V.F.S.	Silt	Clay
S.4-Jan	7.851	2.336	0.094	1.052	0	0.4	1.4	1.5	55.8	40.8
S.4-Feb	7.801	2.817	-0.029	1.153	0	3.1	3.1	0.7	51.1	41.9
S.4-Mar	7.965	2.834	0.005	1.267	0.2	3.9	2.3	0.6	51.1	41.8
S.4-Apr	7.212	2.849	0.069	1.209	0	4.5	4.3	1.4	58.6	31.3
S.4-May	7.293	2.575	0.08	1.006	0	0.2	3.5	5	56.4	34.9
S.4-Jun	6.682	2.676	0.26	1.096	0	0.7	5.8	4.4	63.2	25.9
S.4-Jul	7.502	2.9	0.005	1.222	0	4.8	4.4	0.2	53.8	36.7
S.4-Aug	7.648	2.528	0.15	0.931	0	0.4	2.7	0.9	58.1	37.9
S.4-Sep	7.51	2.647	0.004	1.249	0	2.7	4.6	0.2	56.5	36
S.4-Oct	7.395	2.658	0.063	1.231	0	2.7	3.3	0.2	58.1	35.7

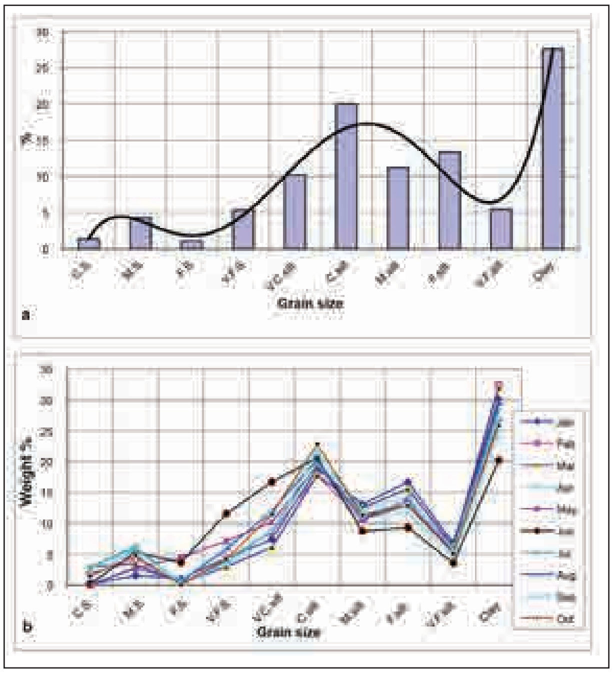

Fig. 13. Average grain size percentages of dust fallout in site 4 (a) and variation with time within the same site (b)

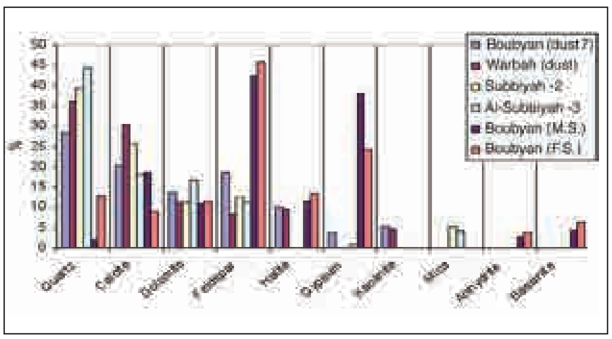

Fig. 14. Mineralogy percentages for dust and sand samples

Dust Collector Sediments

The histogram clearly illustrates no variability of dominant size fractions with location and direction of the dust collectors. The average histogram for station 4 shows a trimodal type of size population which might indicate three different origins (**Fig. 13a**). The smaller the size fraction, the longer the distance the sand was transported. There were no variations observed in grain size with time (**Fig. 13b** and **Table 3**).

Mineralogy of Aeolian Sediments

The mineralogical analysis of sediments from Boubyan and Warbah Islands found two size fractions of sand collected from the sand traps at Boubyan Island: medium sand, which is the dominant size fraction within collected sediments in sand traps, and fine sand. Dust samples from two different locations from the Subbiyah area were analyzed as comparable samples.

Variation between analyzed sand and dust samples is illustrated in **Fig. 14**, which shows that quartz content in all analyzed dust samples is much higher than those collected from sand traps (both size fractions). The two size fractions show higher content of feldspar and gypsum, with appreciable amounts of bassinite and anhydrite. Although the dust and sand samples are highly variable, they are similar in halite content; the similarity of halite indicates that the salt marshes in Iraq play a major role as a dust source.

Conclusions

The dust deposition rates measured in Boubyan and Warbah Islands from November 2003 to November 2004 reflect the mixing from three sources: long-distance dust deposition produces fine deposits mainly less than 5 µm in diameter; dust deposition from regional sources, mainly the Mesopotamian Floodplain, produces 20-40 µm range size fractions; and local dust deposition from natural, human, vehicle and livestock activities produces relatively coarse dust in 50-70 µm grain size fractions. This

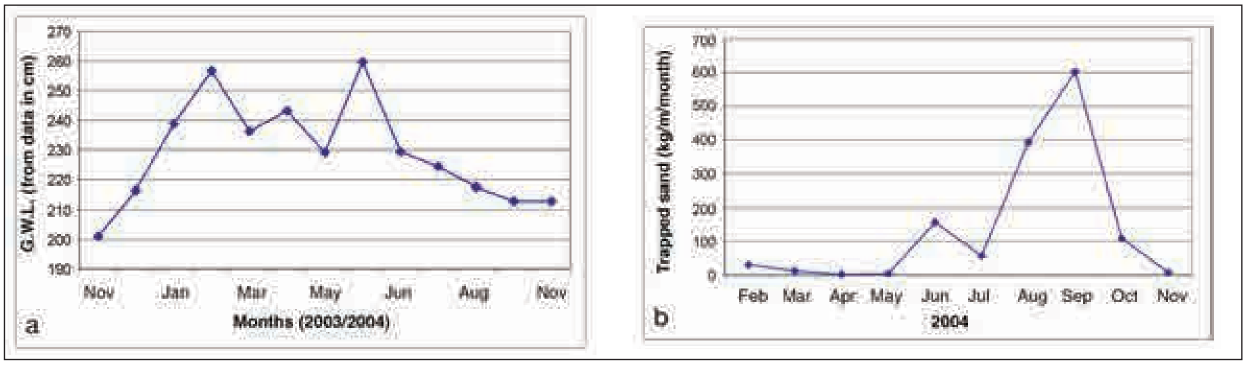

Fig. 15. The groundwater level (a) and trapped sand variation (b) with time

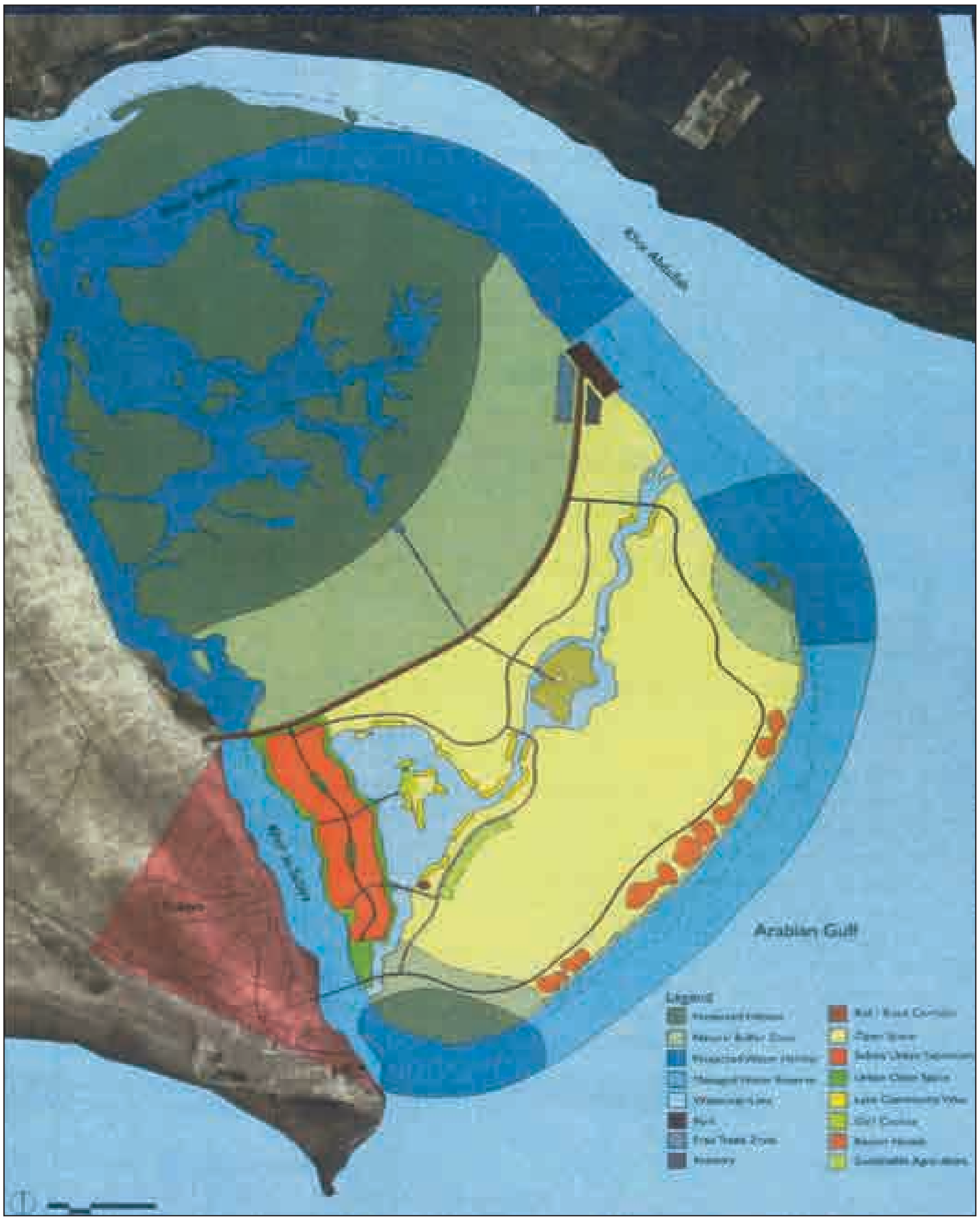

Fig. 16. Environmental assessment master map of Boubyan and Warbah Islands

theory was supported by the BET surface area, which illustrates the variation of surface area with time in both Boubyan and Warbah Islands.

The interrelationship of the variations over time of groundwater level (**Fig. 15a**) and trapped sand (**Fig. 15b**) shows a close relationship between dust fallout and drop in the groundwater level, while there is no relation with the amount of trapped sand. The amount of dust fallout increases with drop in water level. The trapped sand map is closely related to the local sources in the island; for this reason the aeolian source map is in the chapter on geomorphology. Dust fallout was highest in the east of Boubyan Island, medium towards the south and low on Warbah Island.

Aeolian Impact

The environmental assessment master plan (**Fig. 16**) shows proposed resort hotels within the southern coastal line of Boubyan Island. Although the sand measurements here are much lower than those in the rest of Kuwait, the southern coast of Boubyan nonetheless shows high reading values during summer, as evident from sand trap collections and the rate of deposition.The proposed hotels will therefore still suffer from sand encroachment problems. Multiple lines of trees planted as shelter belts upwind should be sufficient to reduce sand encroachment.

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The eastern hotels, and the proposed port, are both within the high dust zone area (>8 tons/km^2). The dominant size of the dust particles is 7.5 μm on average, which means that the island will be dustier at mid-day, since this size fraction is likely to demonstrate long-term suspension or non-settling.

The planned Subbiyah Urban Expansion will increase human activities on the island. Many studies show that increase in aeolian activities is related to increase in human activities (e.g., off-road vehicles, overgrazing, maneuvers, etc.). It is recommended that the expansion be completely isolated from the rest of the island in order to minimize human interference. Furthermore, the island is characterized by very shallow average groundwater levels ranging from 66-101 cm, which means any buildings may suffer from high salinity water due to the shallow water level.

Air Pollution Condition Methodology

Following extensive research, described earlier, the weather station site was selected about 5 km to the north of the middle part of the southern coast of Boubyan Island. In addition, the locations of about 16 weather-passive air sample systems and a mobile lab were also selected.

Passive Sampler Assembly and Use

Each passive sampler contains one of the following: sampler body, diffusion barrier, sampling medium, support ring, and cover cap. They are assembled in a glove box or a clean room, which is always purged with purified air to avoid cross contamination. After assembly, the passive sampler is sealed in a small resealable plastic bag, which is itself put into a protective container, with a cap sealed with Teflon tape. Four passive sampler containers (or fewer) are sealed in a large resealable plastic bag to further prevent contamination. The plastic bags are put into a safe container and shipped as non-hazardous goods.

Unexposed and exposed passive samplers are kept at 4°C, which gives a life of three months. If there is no cooler available, they would be stored in a place where the temperature is relatively low. At room temperature, a shelf life of one month is recommended.

Field Sampling

For credible results, at least duplicate passive samplers are used for each monitoring location. To validate results, traveling blanks are included, the number depending on the number of passive samplers used. Two traveling blanks are needed for up to ten passive samplers, with one blank added for each additional one to ten passive samplers. A traveling blank should never be opened. During exposure, traveling blanks are kept in a large glass bottle with the cap sealed with Teflon tape.

The passive samplers are installed facing downwind in a rain shelter manufactured by Maxxam. Each passive sampler is installed in the rain shelter face down as recommended. Care must be taken not to touch diffusion barriers or let passive samplers fall to the ground.

The installation height of the rain shelter follows the standard site criteria:

- 1-3 m above ground;
- Election angle <30° from the diffusion barrier surface of the passive sampler to the top of any obstacle; or
- The distance from the obstacle is >10 times the obstacle height.

In general, the rain shelter is installed to prevent passive samplers from being reached by animals or humans. If there are several rain shelters in one location, they should be kept separate to avoid air movement interference.

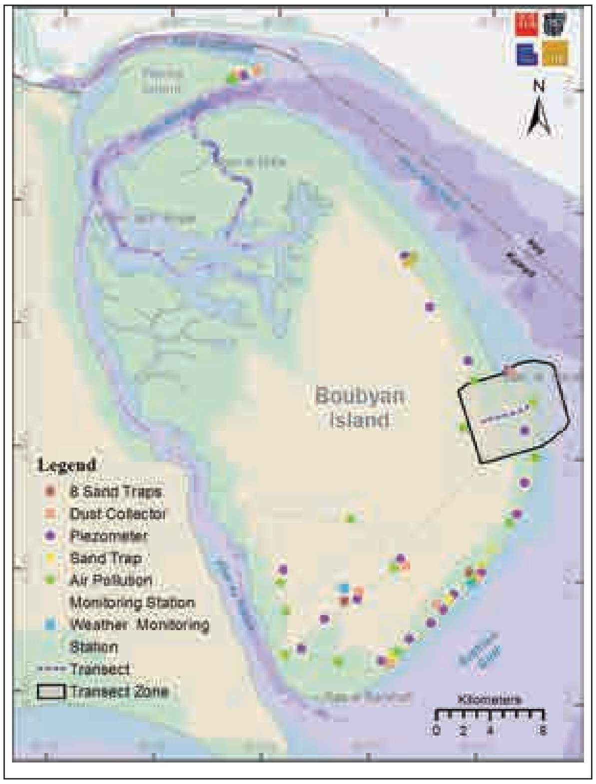

Fig. 17. Passive air monitoring network in Boubyan

Plate 6. Passive station 11 in Boubyan

Plate 7. Passive station 15 in Warbah

Table 4. Locations of the Passive Stations in Boubyan

Station	N	E
1	29° 36’ 46.1”	48° 11’ 00.0”
2	29° 36’ 30.7”	48° 13’ 29.5”
3	29° 37’ 00.5”	48° 16’ 14.9”
4	29° 42’ 21.5”	48° 21’ 20.6”
5	29° 45’ 03.2”	48° 22’ 27.0”
6	29° 40’ 05.3”	48° 19’ 39.2”
7	29° 46’ 11.2”	48° 19’ 05.1”
8	29° 47’ 19.3”	48° 22’ 18.9”
9	29° 52’ 56.9”	48° 16’ 25”
10	29° 48’ 5”	48° 19’ 29.1”
11	29° 40’ 25.7”	48° 15’ 59.7”
12	29° 42’ 20.5”	48° 13’ 53.6”
13	29° 39’ 43.2”	48° 10’ 42.6”
14	29° 38’ 31.5”	48° 11’ 01.5”
15	30° 00’ 06.3”	48° 08’ 00.7”
16	30° 00’ 06.3”	48° 07’ 46.1”

Passive samplers’ starting and end times and date are recorded on a field sampling sheet. Average temperature, average relative humidity, and average wind speed during the exposure period can be obtained from the local weather station or from nearby monitoring stations. After exposure, the samplers are removed from the rain shelter, sealed in the resealable bags, put back into the protective bottle with the cap sealed using Teflon tape and returned to the lab for analysis.

Air Pollution Results

As per the proposal, an all-season passive air sample system (ASPASS) (stations 1-4) was used in the network. SO_2, H_2S, NO_x and O_3 were monitored by the ASPASS. The sampling rates of the passive samplers are calculated taking into account their dependence on associated meteorological factors.

Boubyan Air Monitoring Network

An air monitoring network can create same-period air pollution concentrations for different locations over a large area and thus provide useful information for air quality management.

The Air Pollution Monitoring Network in Boubyan was designed to determine the background air quality levels in given locations. A combination of grid and radial locations was used in the Boubyan network, although due to the geographical conditions, it is not easy to reach some areas.

Passive Sampling Site Selection: A total of 16 passive sampling stations were selected **(Fig. 17)**: 14 in Boubyan and 2 in Warbah. The distance between stations was about 5 km. Uniform siting criteria are necessary to ensure the collection of compatible and comparable data:

- Monitoring sites should not be located near pollution sources.
- Monitoring sites should not be close to roadways. The distance between the site and the roadway should be more than 10 m.
- The preferred site is a flat, valley location and siting at the top or the base of a hill is not recommended unless special studies are needed for these locations and weather information can be obtained.

The 16 passive station locations are listed in **Table 4**. **Plates 6 and 7** show stations 11 and 15.

After exposure, the collection media in the passive samplers were analyzed in a laboratory equipped with ion chromatography, fluorometry, and colorimetric devices.

6

Discussion

The measurement results for August, September, October and November 2004 are shown in **Tables 5-8**. The SO_2 and H_2S concentrations in September 2004 were higher than those in August 2004, due to there being more western winds in September, which blew pollution from the thermal power station onto the island.

The air pollution concentration distribution maps for Boubyan Island in August and September 2004 are shown in **Figs. 18 and 19**. Since stations 1, 12 and 13 are relatively close to the thermal power plant, the SO_2 concentrations in these stations were higher in September.

Figs. 20-23 show the comparison of four air pollutants (SO_2, H_2S, NO_x and O_3) in the four months studied. From August to November, the SO_2, NO_2 and H_2S concentrations increased, but the ozone concentrations decreased. **Figure 24** shows the four-month average concentrations, demonstrating that over a longer period, the concentration distributions are relatively smooth.

In order to compare air pollution levels in a Kuwait industrial area and Boubyan Island, a passive sampler station was also installed at an industrial area (named STN 4), i.e., station 4. **Figure 25** shows the comparison between results of a station in Warbah Island (station 15) and the station in the industrial area. The industrial area air pollution levels are, except for ozone, very high compared to Warbah Island. Generally, ozone concentration is controlled by NO. High NO concentrations normally result in lower ozone concentrations. Since there is not a lot of NO in Boubyan Island, it is not surprising to see that the ozone concentrations there are higher than in the industrial area.

Conclusion

Based on the four months studied, it is concluded that although Boubyan Island's air quality is slightly affected by local pollution sources, compared to industrial areas in Kuwait, the air pollution levels are very low.

Air Quality Impact

Studies have shown that when population is increased in any developing areas, the air quality will eventually be affected. Exposure to air pollution is now an almost inescapable part of urban life throughout the world and World Health Organization (WHO) guidelines are regularly being exceeded in many major urban centers, in some cases to a great extent. Given the rate at which these cities are growing, the quality of life of many urban residents will continue to deteriorate without proper air pollution control strategies.

The potential air pollutants are NO_x, PM10, PM2.5, total hydrocarbon (THC), and H_2S. In the atmosphere, NO_x and THC are precursors for the formation of the secondary pollutants ozone, formaldehyde, and PAN. NO_x is the only gas that can cause visibility problems. Particles less than 10 μm (PM10 and PM2.5) in diameter have very low sedimentation speeds under gravity, and may remain in the air for days before eventually being washed out by rain or impacted out onto vegetation or buildings. PM10 is a very important environmental pollutant, which can reduce visibility, soil surfaces, and create health problems. Many volatile organic compounds in the atmosphere such as benzene are harmful to human health.

The possible sources of air pollution are mainly from traffic, human intervention, and construction. Automobile emissions include NO_x, PM10, PM2.5, and THC. Construction can contribute to PM10, PM2.5, etc. H_2S is a problem in Kuwait. In many cases, the H_2S is from underground water. Construction might disturb underground water in some cases and cause the release of H_2S. It is not so easy to estimate the air pollution levels without a proper risk assessment. Here, only the potential risk of air pollution is discussed.

Modeling of Dust Distribution

The main objective of this model is to study dust distribution from local sources, looking at overall dust patterns based on measurements or modeling. Site selection for measurements followed recommendation from the USEPA):

Table 5. Air Pollution Concentrations of August 2004 in Boubyan Network

Station No.	SO_2 ppb	H_2S ppb	NO_x ppb	Ozone ppb
1	2.3	0.79	NA	49.3
2	1.5	0.69	2.8	50.9
3	1.4	NA	3.0	49.1
4	2.1	0.38	NA	NA
5	2.0	0.31	1.9	53.3
6	1.5	0.57	2.0	45.0
7	2.0	1.42	2.7	59.5
8	2.1	0.53	NA	53.7
9	2.4	0.85	1.5	52.1
10	2.0	0.61	1.4	54.1
11	1.7	0.53	1.7	47.8
12	2.0	0.63	1.6	51.3
13	1.9	0.32	2.0	50.8
14	1.5	NA	0.8	52.6
15	2.1	0.51	3.0	50.8
16	3.1	0.64	3.2	48.3

Table 6. Air Pollution Concentrations of September 2004 in Boubyan Network

Station No.	SO_2 ppb	H_2S ppb	NO_x ppb	Ozone ppb
1	12.6	1.86	4.9	52.4
2	6.8	1.46	4.6	62.6
3	3.3	1.66	4.6	52.2
4	5.8	1.46	4.6	58.6
5	2.5	6.17	3.9	49.5
6	4.5	3.16	3.3	65.9
7	4.0	3.43	4.9	57.8
8	7.4	4.41	3.4	85.7
9	5.2	3.95	2.6	46.8
10	9.4	5.39	3.4	49.7
11	6.3	5.52	3.6	40.7
12	10.2	4.34	3.3	55.9
13	12.4	4.54	3.6	52.3
14	8.2	NA	2.9	42.2
15	4.5	6.48	4.1	48.7
16	9.1	6.99	8.4	42.1

Table 7. Air Pollution Concentrations of October 2004 in Boubyan Network

Station No.	SO_2 ppb	H_2S ppb	NO_x ppb	Ozone ppb
1	6.1	NA	2.9	46.0
2	5.0	NA	3.1	50.0
3	2.4	NA	2.9	45.3
4	2.8	NA	2.5	53.0
5	3.8	NA	2.3	44.6
6	2.5	NA	2.8	47.0
7	2.7	NA	3.6	50.8
8	4.5	NA	2.2	42.9
9	4.4	NA	2.8	47.9
10	3.8	NA	2.1	44.3
11	5.1	NA	2.4	49.9
12	4.6	NA	2.4	39.3
13	5.1	NA	2.5	44.0
14	5.6	NA	2.7	43.1
15	3.2	NA	4.0	46.0
16	8.8	NA	13.2	50.7

Table 8. Air Pollution Concentrations of November 2004 in Boubyan Network

Station No.	SO_2 ppb	H_2S ppb	NO_x ppb	Ozone ppb
1	13.5	0.40	4.6	46.5
2	13.0	0.94	4.0	40.8
3	10.1	1.34	4.7	44.1
4	12.2	1.09	3.8	48.5
5	8.9	0.90	4.1	44.1
6	12.8	1.74	4.1	45.9
7	11.0	0.90	5.0	43.0
8	11.8	0.92	3.8	41.8
9	12.0	1.28	3.6	41.8
10	13.5	0.62	3.8	40.4
11	13.0	1.15	3.8	38.6
12	12.5	0.60	3.8	49.6
13	11.7	0.62	4.2	40.7
14	13.2	0.19	4.7	41.2
15	9.0	0.80	5.0	49.0
16	12.9	1.0	NA	45.5

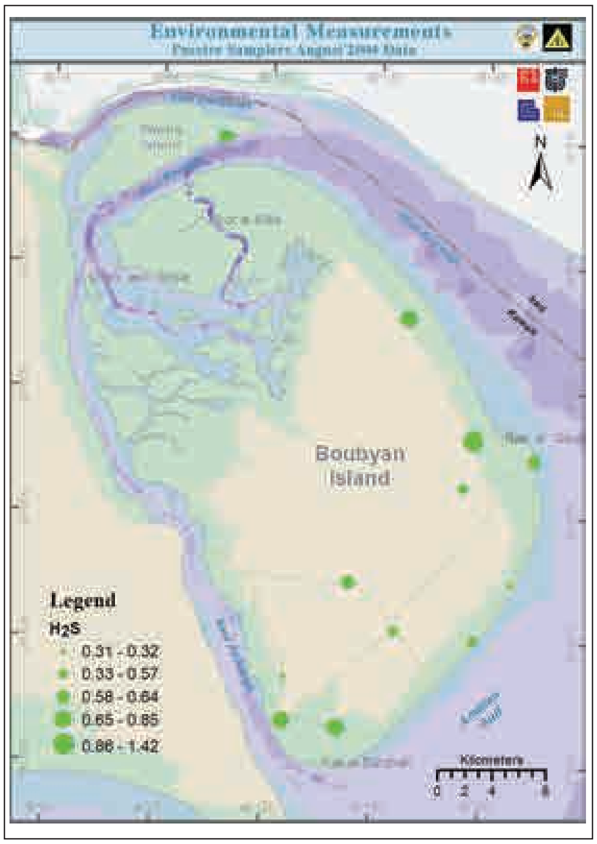

Fig. 18. Air pollution concentration distribution map for August 2004 (H_2S)

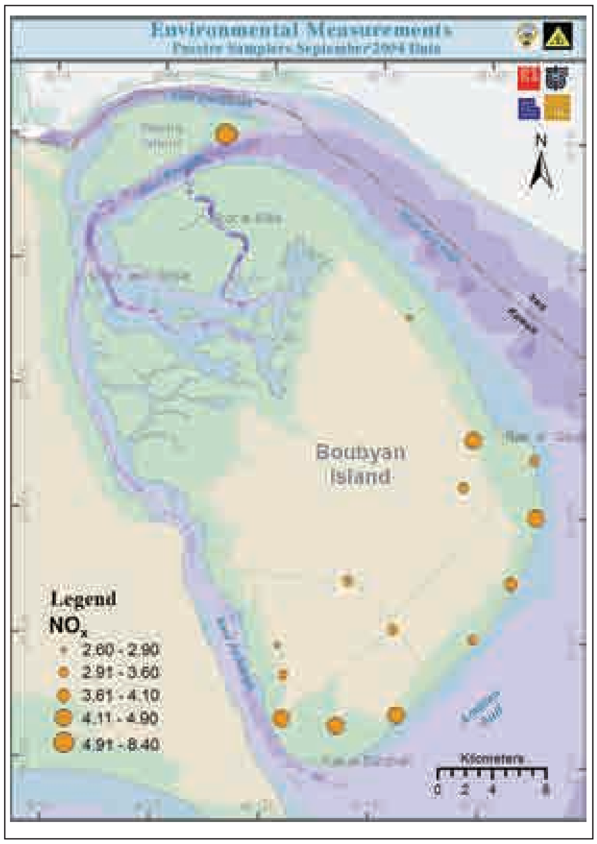

Fig. 19.2. Air pollution concentration distribution map for September 2004 (NO_x)

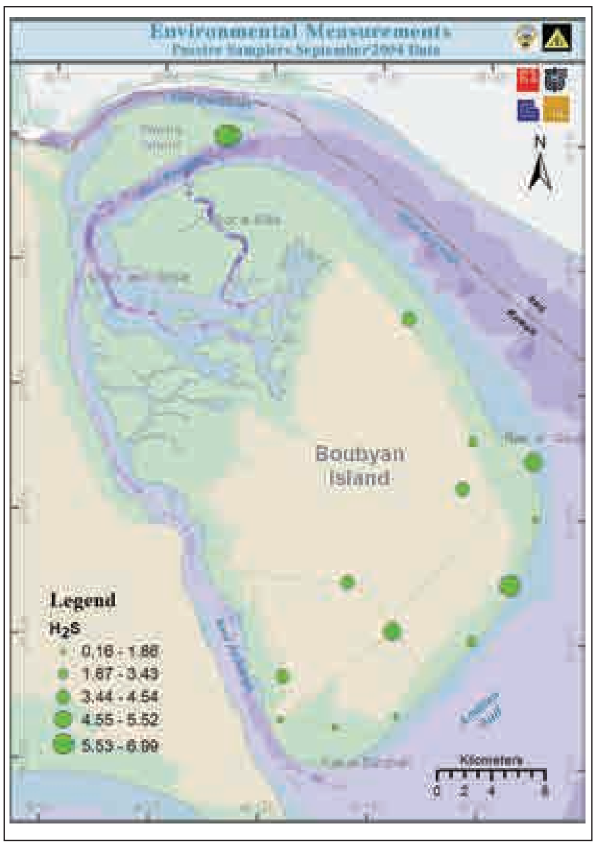

Fig. 19.1. Air pollution concentration distribution map for September 2004 (H_2S)

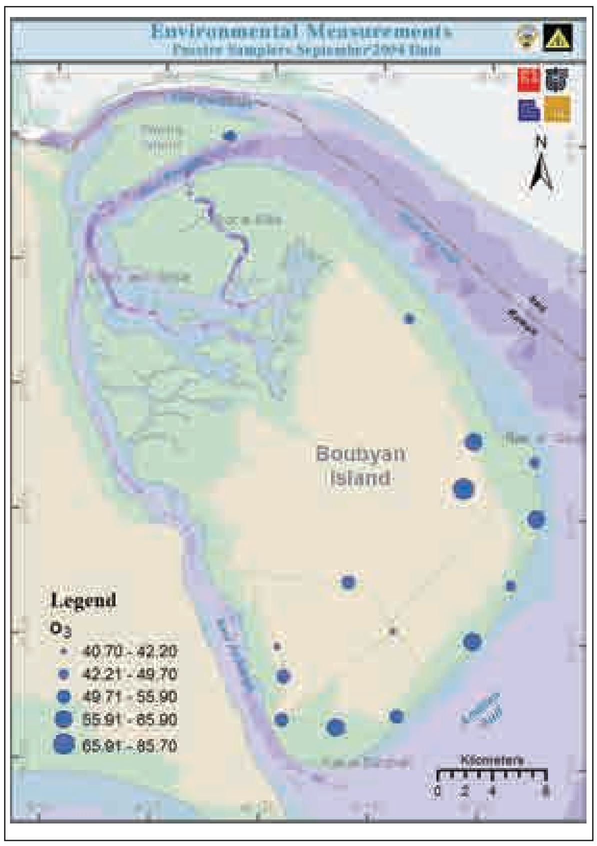

Fig. 19.3. Air pollution concentration distribution map for September 2004 (O_3)

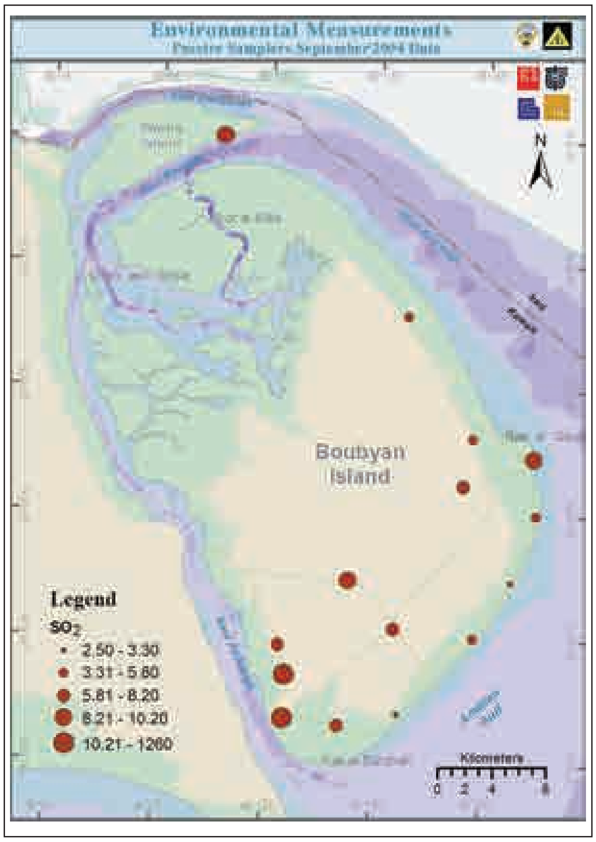

Fig. 19.4. Air pollution concentration distribution map for September 2004 (SO_2)

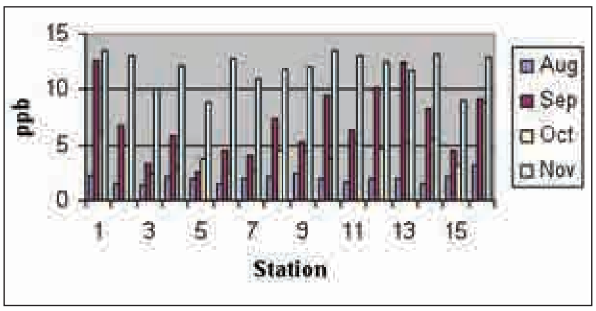

Fig. 20. Four-month SO_2 concentration comparison

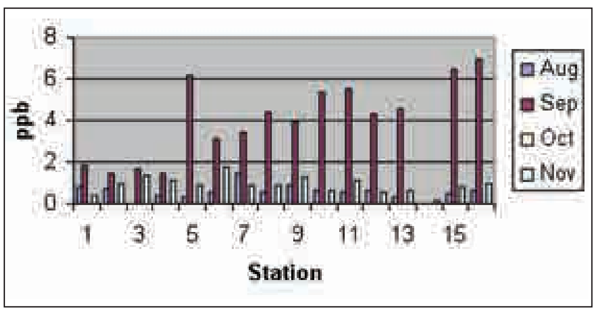

Fig. 21. Four-month H_2S concentration comparison

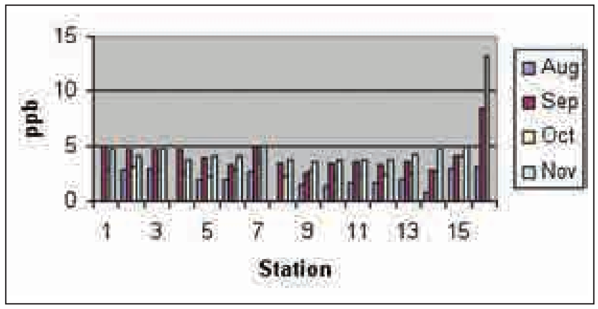

Fig. 22. Four-month NO_x concentration comparison

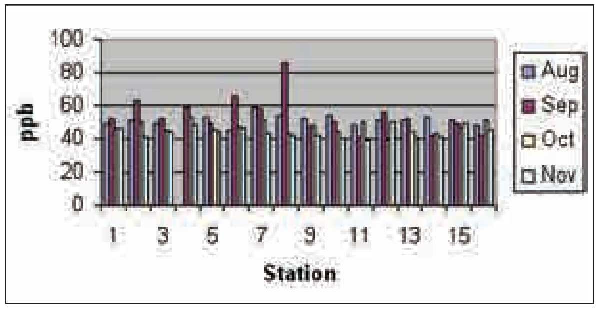

Fig. 23. Four-month O_3 concentration comparison

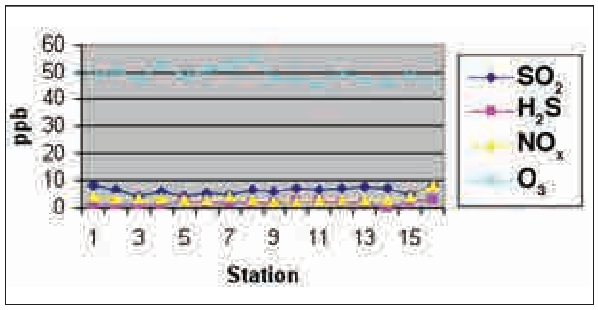

Fig. 24. Four-month average concentration of the four pollutants (SO_2, H_2S, NO_x and O_3)

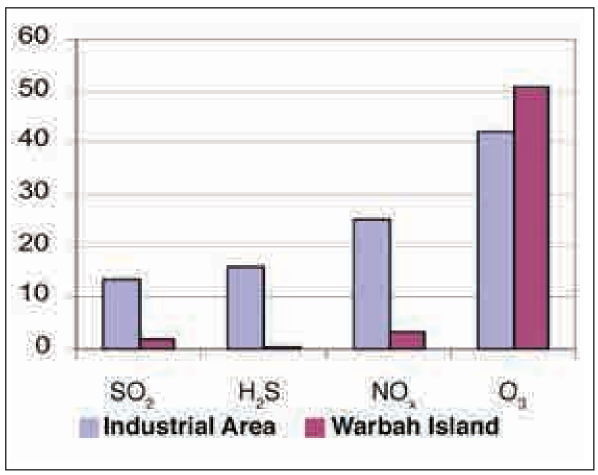

Fig. 25. Air pollution concentration comparison for the industrial area and Warbah Island

Table 9. Meteorological Sample Input File

Surface Station Number	Day	Month	Year	Hour	Ceiling Height (100 ft)	Wind Direction (10°)	Wind Speed (m/s)	Dry Bulb Temperature (°C)	Total Cloud Cover	Opaque Cloud Cover
15000	1	1	2003	0	40	34	4	13.6	10	6
15000	1	1	2003	1	40	36	3	13.3	7	5
15000	1	1	2003	2	40	36	6	13.1	7	5
15000	1	1	2003	3	40	34	8	12.8	7	5
15000	1	1	2003	4	25	34	8	12.1	7	5
15000	1	1	2003	5	25	35	4	12.3	7	7
15000	1	1	2003	6	25	34	5	13	6	6
15000	1	1	2003	14	100	2	6	15.8	7	3

Fig. 26. Receptor grid and major source points used for the ISCST3 model

- Uniformity in height above ground level is desirable for sampler location.
- Constraints to airflow from any direction should be avoided by placing inlet probes at least 3 m from buildings or other obstructions.
- An elevation of 3-6 m is suggested for sampling.

The model chosen to calculate time-averaged ground level concentrations in the proposed source area is the Industrial Source Complex Short Term 3 (ISCST3) dispersion model, modified by the United States Environmental Protection Agency (US EPA) in 1999. The ISCST3 is an air quality model based on the Gaussian plume simplification of the diffusion equation that assumes time independence in the input meteorology and source concentration. The ISCST3 algorithm is a Gaussian plume dispersion model (solving the steady-state Gaussian plume equation) that calculates short-term pollutant concentrations from multiple point sources at a specified receptor grid on level or gently rolling terrain. The ISCST3 model includes a wide range of options for modeling the air quality impacts of pollution sources, making it a popular choice among the modeling community for a variety of applications. The main features of the model are described below:

Dispersion Options: Since the ISCST3 model is specially designed to support the US EPA's regulatory modeling programs, specifications in the revised guidelines for air quality models (US EPA, 1999) are the default mode of operation. These include: the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise, a routine for processing averages when calm winds prevail, default values for wind profile exponents and for the vertical potential temperature gradients, and the use of upper bound estimates for super-squat buildings that have an influence on the lateral dispersion of the plume.

Source Options: The model is capable of handling multiple sources, including point, volume, area and open pit source types. Line sources may also be modeled as a string of volume sources or as elongated area sources. Several source groups may be specified in a single run, with the source contributions combined for each group. In this study, area source is used to specify the dust emission from potential locations within the island.

Source Parameters: The source parameters required for the ISCST3 numerical model are pollutant emission rates (g/s), location coordinates (UTM), source height (m), exit inner diameter (m), exit gas speed (m/s), and exit gas temperature (°C). All of the required information on the location coordinates emission rates; heights of releases from the ground are specified based on field measurements.

Meteorological Data: The model requires anemometer height (m), wind speed (m/s), wind direction (degree) clockwise from the north, air temperature, total and opaque cloud cover (%), Pasquill stability class at the hour of measurement (dimensionless) and rural and urban mixing height (m). Hourly sequential data for the entire duration is required for the model to calculate concentrations for the required averaging periods. The anemometer height, wind speed, wind direction, air temperature and cloud cover are usually obtained from direct measurements. For the present study, the meteorological data used is from the Subbiyah meteorological station for 2003 and assumed to be valid for the periods and location of the study. **Table 9** presents an example of the meteorological data inserted into the model. The stability class was defined on the basis of Pasquill categories, which are mainly a function of the hour of measurement, wind speed and sky cover (i.e., the amount of clouds). The mixing height was estimated by the model based on temperature profile measurements.

Output Options: The basic types of printed outputs available with the model are as follows:

- Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination.
- Summaries of overall maximum values for each averaging period and source group combination.
- Tables of concurrent values summarized by receptor for each averaging period and source-group combination for each day of data processed. These "raw" concentration values may also be output to unformatted (binary) files.
- Graphic outputs presented as contours and isopleths.

Receptors: The ISCST3 models have considerable flexibility in the specification of receptor locations. The user has the capability of specifying multiple receptor networks in a single run and may also mix Cartesian grid receptor networks and polar grid receptor networks in the same run.

Results and Discussion

The dispersion model ISCST3 was used to predict the ground level concentration of dust particulates. Several runs were performed in order to investigate the impact of weather conditions on the ground level concentration for every month of the year.

After several numerical experiments, a grid sensitive-free model was set up based on two uniform grids (**Fig. 26**). The UTM location coordinates were taken from a registered map of a Boubyan satellite image. The first uniform grid covered an area of 39 km x 50 km to study the whole

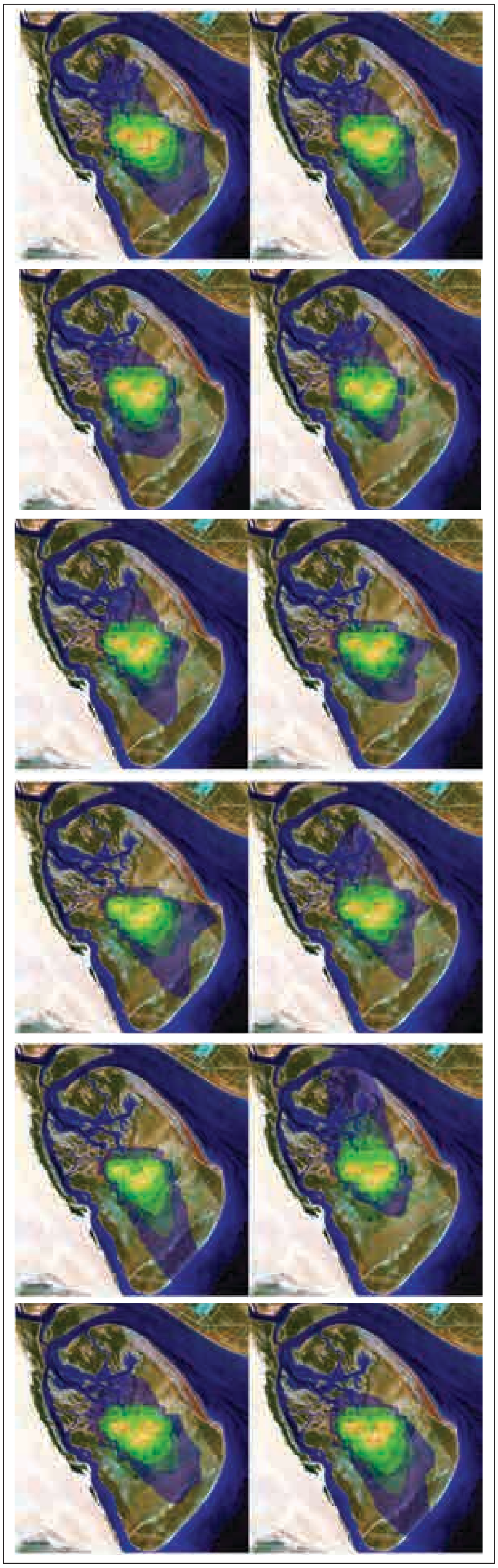

Fig. 27. Modeling of dust from January to December 2004

island, with 0.09 km x 0.11 km grid spacing. The grid included 441 receptor locations at each grid intersection and 9 discrete receptors at sampling points. A second, finer grid was superimposed on top of the coarse grid for precise evaluation of results close to the emission area, with grid spacing equal to 0.05 km. The maximum predicted concentration of dust and averaging period of hourly, daily and monthly values were reported. The predicted ground level concentrations are shown in **Fig. 27** for the months of January to December. This shows clearly that the highest concentration above 5000 μg/m^3 is always located close to the source area, while concentration decreases as the distance from the source increases. According to the wind speed and direction, the extent of the high concentration zones is expanded to the southeastern corner of the island in January and July. The high concentration zones also extend to cover the southwestern part during February, September and December, while the northern island is covered by the high dust concentration during January, August and October. In most cases, the majority of the central part of the island is under high dust concentration, especially during seasons when the soil and mud moisture is very low.

Chapter 7: Environmental Impact Assessment

Abstract

The study reported here carried out an Environmental Impact Assessment (EIA) on Boubyan Island, based on the environmental measurements carried out during Phase-I, Phase-II and Phase-III studies, through Rapid Impact Assessment Matrix (RIAM) and Strategic Environmental Assessment Matrix (SEAM) for the proposed major land uses covered under the preferred Master Plan Concept.

The main objective of this report is to assess and evaluate the various impacts to the natural environment of Boubyan Island of implementing the developmental activities based on the Master Plan Concept (as of August 2005) of Boubyan Island Master Plan Development.

This chapter gives a summary of an initial EIA and subsequent evaluation based on the two models (RIAM and SEAM). From the results it can be concluded that the construction and operation phases of the Master Plan Concept will result in a range of major, significant, moderate and slightly negative impacts on the existing ecosystem of Boubyan Island and significant positive changes to some biological components. The environmental components affected by the Master Plan Concept are of immense importance as far as the biodiversity of Kuwait is concerned. Recommendations and follow-up actions to maintain the ecological integrity of Boubyan Island, to be implemented during construction and operation activities, are also included.

Introduction

Kuwait Institute for Scientific Research (KISR) conducted an environmental assessment valuation matrix study for the proposed major land uses based on KISR field investigation project results, with expert input and interpretation from each appropriate KISR project leader. The roles of KISR were:

- To assess the potential impacts during construction and to study the severity of proposed uses in the allocated area (i.e., worse case scenarios).
- To identify mitigation options to reduce expected problems.
- To identify the long-term impacts, temporary impacts, and activities that will have no impact at the local or regional level.

Initial Environmental Evaluation and Strategic Environmental Assessment

The Initial Environmental Evaluation (IEE) is an integrative and systematic decision-making tool, used to identify the environmental, social and economic impacts of development projects. The purpose of an IEE is to give the environment its due place in the decision-making process by clearly evaluating the environmental consequences of any proposed activity *before* action is taken. It makes sure that environmental issues are raised when a project or plan is first discussed and that all concerns are addressed as a project is implemented. To be of most benefit it is carried out early in the project cycle (i.e., before and during construction). The IEE should lead to a mechanism whereby adequate monitoring is undertaken to realize environmental management. This helps to identify the most environmentally suitable option at an early stage, the best practicable environmental option and alternative processes. The IEE process is often described as an assessment of how, negatively or positively, a project affects various impact indicators.

Some of the objectives of IEE according to UNDP (2003) are:

- Make decision makers aware of the significant environmental effects of the proposed project.
- Outline alternatives with different environmental impacts.
- Identify approaches for how to avoid or reduce environmental damage and other impacts on proposed regions.
- Disclose to the public the reason for approval of a project with significant environmental effects.
- Foster coordination among stakeholders.
- Enhance public participation in decision-making processes.

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An impact indicator is an element or parameter that provides some measure of the magnitude of environmental impact. Examples of different indicators are loss of recreational activities, changes in water quality parameters such as pH and turbidity, and loss of bird communities and vegetation. The measurement may be qualitative or quantitative, depending on the parameter and the means of evaluation, and is usually subject to expert opinions (Al-Ghadban and Al-Ajmi, 1993). In cases where there is a lack of detailed information about the above-mentioned indicators, environmental studies are categorized as environmental assessment.

Strategic Environmental Assessment (SEA) is a high-level procedure that extends the concept and principle underlying IEE, but is normally applied to policies, plans, programs and groups of projects. It is a process designed to ensure that significant environmental effects arising from proposed plans and programs are identified, assessed, subjected to public participation, taken into account by decision makers, and monitored. SEA provides the potential to avoid the preparation and implementation of inappropriate plans, programs, and projects and assists in the identification of environmentally feasible development. It includes an evaluation of project alternatives and identification of cumulative effects. SEA falls into two main types: sectoral SEA (applied when many projects fall within one sector) and regional SEA (applied when broad economic development is planned within one region) (UNDP, 2003). SEA sets the framework for future assessment of development projects, some of which require a preliminary/IEE assessment.

Project Importance

Boubyan and Warbah Islands are located at the far north–west of the country at the head of the Arabian Gulf and have been isolated from Kuwait's fast-developing population centers. This strategic location has been vital to Kuwait's national security due to its proximity to Iraq and Iran.

Boubyan and Warbah Islands clearly have enormous potential for conservation of Kuwait's main natural biodiversity, along with public education and promotion of ecotourism. This is considered fundamental to the future increase of the economy of Kuwait. Their importance is not only seen as a site of scientific interest but also as a source of enrichment of life for Kuwait's population. They will provide a quality destination where national and international tourists can appreciate natural heritage. It is also necessary to establish Kuwait's legitimate ownership of Boubyan Island and this can be achieved more adequately by establishing responsible stewardship. This will also help in promoting international recognition of Kuwait's achievements.

Several proposals and plans have in the past addressed a variety of uses and developments on Boubyan Island including holiday villages and leisure activities in the 3rd Kuwait Master Plan, 1997. In the National Physical Plan for the State of Kuwait and Master Plan for Urban Areas prepared by Colin Buchanan and partners in 1970, Boubyan Island was designated as a high-potential area for forestry and recreation. The National Greenery Plan of Kuwait (KISR, 1996) suggested appropriate sites on the south Boubyan shoreline for a coastal park and recreation area, as well as sites of high national and environmental value.

The Kuwait Master Plan Review-2 recommends a satellite urban center including Subbiyah new town. If the new town project is implemented, it is bound to have an impact on the natural environment as well as future development of Boubyan as a whole. This master plan was reviewed periodically and has identified sites for recreational development, water resource areas, future oil exploration and urban development outside the metropolitan areas. In view of this Master Plan development, the Government of Kuwait entered into an agreement with HOK Planning Group (HOK), Gulf Consult Architect and Planners (GC), MGP Information Systems Ltd. (MGP), and KISR to prepare a detailed report on *Boubyan Island—Initial Environmental Evaluation and Master Plan Project.* After completing a preliminary study and through detailed survey and investigation, the team drew up four preliminary development scenarios designating different areas for the development of Boubyan Island (KISR, 2004a, b).

This report deals with the assessment of various environmental impacts that will be encountered while implementing the preferred alternative. Baseline data is from the preliminary reports (Environmental Baseline Assessment—KISR, Interim and Final Reports, Technical Report—Phase-I and Phase-II) combined with personal consultations with professionals involved in the strategy study and sourcing of available documents containing the components of environment-related details on the project.

The baseline data is summarized in brief. The project has been classified into different zones based on biodiversity and the environmental constraints highlighted. Evaluation of the different features (general and specific) was done by formulating the Rapid Impact Assessment Matrix (RIAM) and Strategic Environmental Assessment Matrix (SEAM) for the preferred alternative master plan. The task of fulfilling the IEE (which includes identification, measurement and interpretation of impacts) for the selected alternative was achieved by assigning different degrees of impact to different environmental components. By integrating the results of the two matrices (which provides a comparison in a very transparent way), recommendations were formulated, and the report concluded with an eco-conservative and environmentally sound master plan.

Archaeological Potential of Boubyan Island

Despite the important strategic position of Boubyan Island, it has not in the past received sufficient attention by archaeologists and no previous surveys were carried out. However, its location has placed it in the path of ancient navigators following trade routes for hundreds of centuries. Lorimer (1910) mentioned the presence of a Turkish military base consisting of 20 soldiers and the remains of human-built structures on the island. Due to its geographic location near the mouth of the Shatt Al Arab River, and the civilization that existed in the south of Al Rafidayn country (Iraq), Boubyan Island played a vital role in sea transportation from 3000-1000 B.C., because of active commercial movement to the Gulf area during this period. Lorimer also mentioned that there is a route from Kuwait going to Al Basrah and passing through Al Jahara, Umm Deira, Subbiyah Palace (Qasr Al Subbiyah), Araifjiyah, Al Sabriya, Umm Qasr and then to Safwan. It is also believed that Boubyan Island shared historical relationships with the other islands in Kuwait Bay. The British Archaeological Expedition team recorded that there was no significant indication of archaeological remains on Boubyan Island. However, any archaeological discoveries during development should be reported to the Kuwait Museum Authority and preserved in consultation with the National Council for Culture, Arts and Literature.

Alternatives for the Development of Boubyan Island

During the development process for drafting different alternatives in the Boubyan Island Master Plan, four alternatives were sketched. These land use alternatives were:

Alternative I: Nature preserve, with low-impact development restricted to education and ecotourism development only. This alternative can be considered as the most eco-friendly low-impact developmental option. A managed development is also proposed in this option, thereby improving the aesthetic value of the island and helping to promote a highly natural tourist spot, which will attract national and international visitors. This development will not only increase the economic value of Kuwait but will preserve the unique natural ecosystem of Kuwait to its fullest extent. The output of the managed development will comply with the ecology of the island.

Alternative II: Nature preserve and port-nature preserve, accommodating the proposed port on the island and locating the free trade zone and industrial estate on the mainland near the proposed Subbiyah new town. In this alternative a port project is included in the middle part of the eastern coast of Boubyan Island. The port will be linked to the proposed Subbiyah new town project via a railway/road bridge line, incorporating the free trade zone and port-related industries north of Subbiyah new town in addition to the developmental activities proposed in Alternative I (the area which is in between Ras Al Qaid and Ras Al Barshah).

Alternative III: Nature preserve, port development and recreational development. Preservation of critical environmental areas with a full port, associated free trade zone, and industrial estate development on Boubyan Island. Urban development on the island is proposed at Subbiyah new town across Khor Subbiyah. Recreational development of lakes and beachfront will be within Boubyan Island.

Alternative IV: New town development similar to Alternative III with more intensive development around the lakes and beachfront. Increased road development and a new urban community (population 30,000) adjacent to the port and the free trade zone/industrial estate facility are proposed. This may also include other increased economic opportunities and potential development.

After several workshops regarding selecting the best alternative, it was decided to select Alternative III, with some modifications, as the Master Plan Concept. The following section describes the Master Plan Concept for the development of Boubyan Island.

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Master Plan Concept (August 2005)

The Master Plan Concept takes a more pro-development attitude toward Boubyan Island compared to the limited development elements of Alternatives I and II, by adding a community of permanent residents. The various types of development involved in this concept are shown in **Fig. 28.**

The location of the project is proposed to be towards the middle part of the eastern coast of Boubyan Island. The port will be linked to the proposed Subbiyah new town project through a railway/road bridge line, accommodating the free trade zone on the western side of the rail bridge and port-related industries on the eastern side of the rail bridge (near the port). The location of the proposed connecting bridge is southwest of the northern buffer zone. The disturbance to the northern buffer zone can be quantified as low, but land use will require more engineered infrastructural facilities and economic investments. The island-oriented urban developments are proposed along the eastern shoreline of Khor Subbiyah extending about 10 km from the shore. A new town is proposed across Khor Subbiyah (outside Boubyan at Subbiyah), while recreational development of inland lakes and creation of lakefront lots are proposed within the island. This urban development across the river contributes to the quality of urban life.

Output of Master Plan Concept: The output envisaged by this development alternative can be expected as follows:

a. Development of second-home villages
b. Clustered lodges for short-term rentals (economic value)
c. Youth education/adventure camps
d. Small recreation businesses including a golf club (economic value and recreation)
e. Small retail food and shopping (economic value)
f. Light agribusiness, sourced from island agriculture (economic value)
g. Light nurseries (economic value)
h. Island administration (offices and accommodations)
i. Research facilities (enhances monitoring to improve the natural biodiversity)
j. Visitor center
k. Cultural and historic center
l. Roads, utilities and car parking
m. Mosques and banks
n. Boating and beach activities (economic value)
o. Employment facilities

Additional Output from Alternatives I and II:

1. Link bridge connecting Subbiyah town and port area
2. Port-related buildings
3. Port container area
4. Port anchorage and transportation area
5. Introduction of navigation channels
6. Creation of dredging infrastructure
7. Employment (economic value)
8. Island security
9. Introduction and scope of new industries
10. Introduction of free trade zone
11. Implementation of inland lake system
12. Enhanced recreational development
13. Subbiyah urban expansion
14. Increased roads due to enhanced recreational, industrial and port activities

Impact Evaluation for the Master Plan Concept

The IEE for any project should secure long-term benefits for the project concerned. The IEE of projects has traditionally relied on subjective conclusions from data analysis of primary field data and secondary data sources. The sources of data may be poor, particularly in areas peripheral to project sites. It is important that any IEE be objective, subjective, and descriptive and rely on an integrated approach. In order to conduct the Strategic Environmental

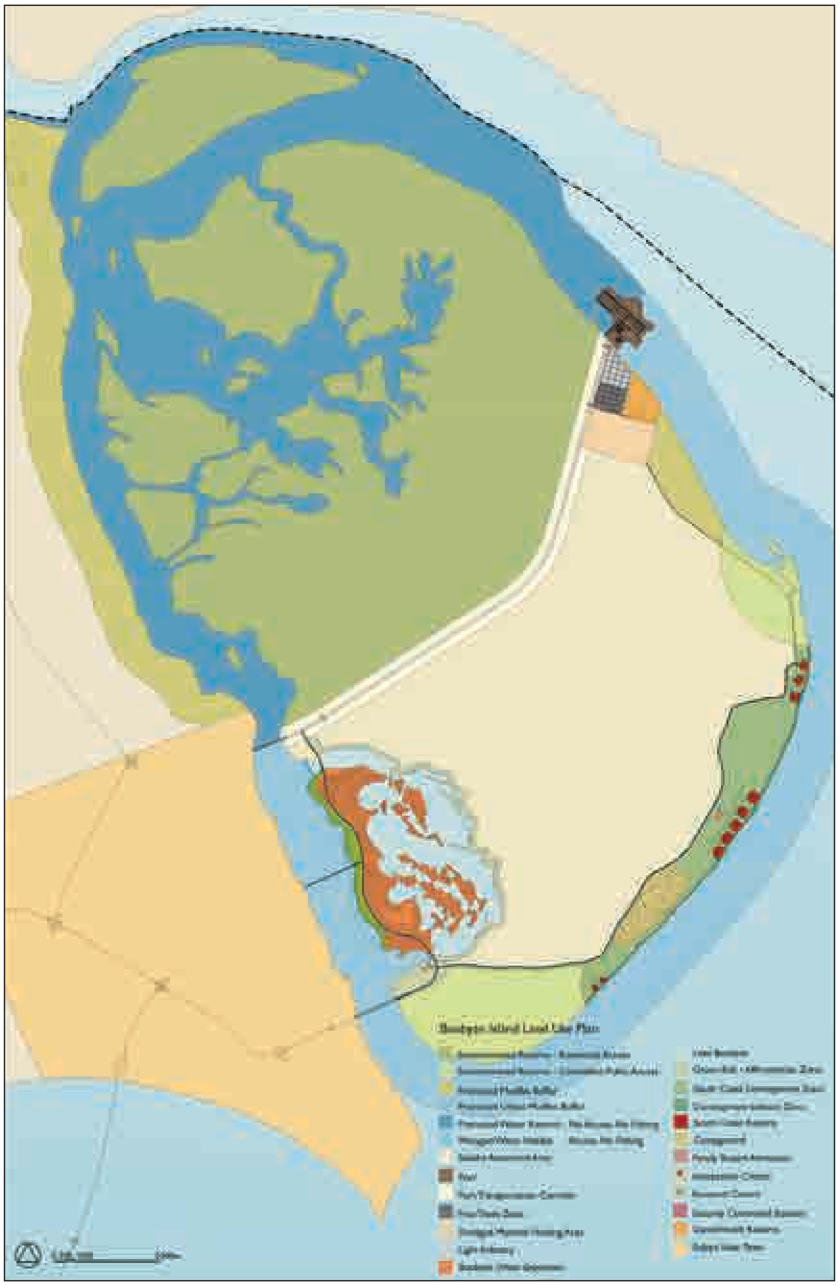

Fig. 28. Land use activities for Master Plan Concept

Assessment, two matrixes were designed and structured as follows:

1. Strategic Environmental Assessment Matrix (SEAM)
2. Rapid Impact Assessment Matrix (RIAM)

The first matrix is to assess the impacts of different environmental elements on the different land use activities for the Master Plan Concept. The second matrix is designed for the RIAM model to study the impact of different environmental elements from proposed activities of the preferred concept.

Strategic Environmental Assessment Matrix (SEAM)

Matrix methods incorporate a list of project activities or actions with a checklist of environmental conditions or characteristics that might be affected. Combining these lists as horizontal and vertical axes on a matrix allows the identification of cause-effect relationships between activities and impacts. The entries in the cells of the matrix can be either qualitative or quantitative estimates of these cause-effect relationships. The latter are often combined into a weighting scheme to create a total "impact score."

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Table 10. Matrix for the Different Land Use Activities

Activities for Preferred Concept	Reserve (RA)	Reserve	Reserve (CPA)	Habitat	Afforestation	Buffer	Port	Industry Zone	Holding Area	Corridor	Access	Expansion	Lake Boubyan	Resorts	Subbiyah New Town
Air pollution	1	3	1	4	4	4	4	4	4	4	4	4	4	4	4
Groundwater	1	4				5	4	4	4	3	4	5	5	5	5
Sand accumulation	1	3	1	0	0	4	1	0	0	4	1	1	1	4	4
Tidal processes	2	4	1	4	4	5	4	4	4	0	4	5	5	5	5
Inland terrestrial processes	1	3	1	2	2	4	2	2	2	3	3	1	1	4	4
Dust fallout	1	5	1	5	5	3	5	5	5	5	5	1	2	4	5
Coastal geomorphology	1	3	1	4	4	5	4	4	4	0	2	5	5	5	5
Coastal erosion	1	3	1	5	5	3	5	5	5	0	2	5	5	3	3
Coastal sediment transport	1	3	1	5	5	5	5	5	5	0	2	5	5	5	5
Soil erosion (terrestrial)	2	2	1	5	1	5	5	1	3	3	4	3	3	1	1
Soil deposition (terrestrial)	4	5	1	5	1	5	5	5	3	4	2	3	3	1	1
Plant cover	4	2	4	3	4	4	3	3	3	3	2	3	3	3	3
Microbiology	4	2	4	3	4	4	3	3	3	3	2	3	3	3	3
Terrestrial wildlife	5	5	3	5	2	1	1	1	1	1	1	2	2	3	1
Coastal wildlife	5	5	4	5	3	1	1	1	1	1	1	2	2	1	1
Bird migratory path	5	5	5	5	3	2	3	2	2	4	2	2	3	2	2
Bird nesting	5	5	5	5	4	5	4	1	2	4	1	2	2	3	1
Hydrodynamic regime	3	1	5	5	5	5	5	2	5	4	1	4	3	2	4
Bathymetry	3	1	5	5	5	5	5	4	5	4	1	4	1	1	4
Flood pattern	5	1	5	5	5	5	5	4	5	4	1	3	1	1	4
Sediment quality	5	1	5	4	4	4	4	2	5	4	1	3	1	1	3
Fisheries	5	1	5	5	5	5	5	2	5	3	1	4	1	1	4
Shrimps	5	1	5	5	5	5	5	2	5	3	3	4	1	1	4
Plankton	5	1	5	5	5	5	5	2	5	3	3	3	1	1	3
Marine mammals and reptiles	5	1	5	5	5	5	5	2	5	3	3	4	1	3	4
Eutrophication	5	1	5	5	5	5	5	3	5	3	3	5	5	3	4
Productivity	5	1	5	5	5	5	5	3	5	3	3	4	3	2	4
Water quality	5	1	5	5	5	5	5	3	5	3	3	4	4	3	4
Salinity	4	1	4	3	3	3	3	2	3	2	2	1	1	1	1
Gypsic Aquisalid	5	5	1	1	2	1	1	1	1	5	3	5	5	4	5
Typic Aquisalid	5	5	1	1	2	1	1	1	1	5	3	5	5	4	5
Typic Torriorthent	5	5	1	1	2	1	1	1	1	3	3	3	5	4	5
Historical elements	1	1	1	1	1	2	2	2	2	1	1	2	1	2	1
Landscape setting	5	3	1	1	1	5	3	3	3	3	1	5	4	5	2
Visual quality	5	3	2	2	2	5	4	4	4	4	3	5	5	5	2
Noise pollution	5	5	4	4	2	4	1	1	1	1	2	3	4	5	2
Military activities	5	5	3	3	3	5	2	2	2	3	3	5	5	5	3

Key: 1 = low importance to 5 = high importance, RA = restricted access, CPA = controlled public access

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During the present study, a matrix table was developed with a quantitative scoring scheme. The matrix sheet assesses the different environmental impacts from a range of activities associated with the selected alternative concept. This simple matrix was organized to cross-reference the different land uses of the selected master plan against major environmental impacts or sensitive receptors. Numerical scores were used to show the approximate scale or magnitude of the impact: each project leader involved in the assessment was asked to give a score between 1 (low importance) and 5 (high importance), with 3 used for average importance. By introducing weighting into the matrix, impacts can be rated in a qualitative way. It also provides a tool for assessing complex effects. A weight is assigned to each environmental component, indicating its importance. The weighting of the impacts will be calculated for each impact area. The following equation was used to calculate the weight of each environmental component on the land use activities:

Weight % of the component = [Weight/Total weight]/100

The matrix is shown in **Table 10**. The weights of the impact of different environmental components on each of the major land use activities are shown.

Results of SEAM

Most of the environmental components related to ecological issues (wildlife, vegetation, birds and marine life) are the main controlling issues for Environmental Reserve (Restricted Access), Managed Water Habitat, Environmental Reserve (Controlled Public Access) and Green Belt Afforestation. On the other hand, issues such as air pollution, dust fallout, coastal dynamics and site planning issues are considered as the controlling factors for the land use activities such as port, Boubyan urban expansion, sabkhas restricted access and Subbiyah New Town.

Statistical Analysis of the Matrix Data

Statistical discrimination is a powerful technique to present the relationship between a set of variables and cases. The role of statistical analysis in general is to measure the similarity and dissimilarity between multivariate objects. Similarity between objects, in this case land use activities (Q-mode) or variables and environmental parameters (R-mode), can be expressed by a wide variety of statistical analyses (factor analysis). The aim of the statistical analysis during the present study is to extract the common factors between the land uses and identify the key environmental elements that should be taken into account during specific IEE analysis for different single uses.

A dendrogram is a representation of the degrees of similarity between multivariate objects. The samples

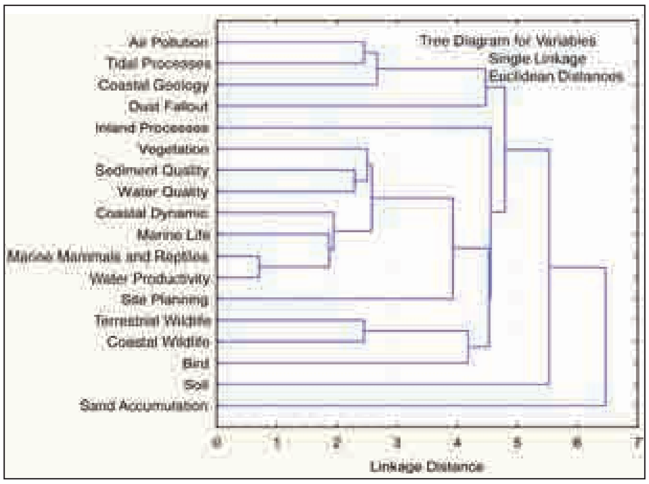

Fig. 29. Cluster analysis for environmental parameters

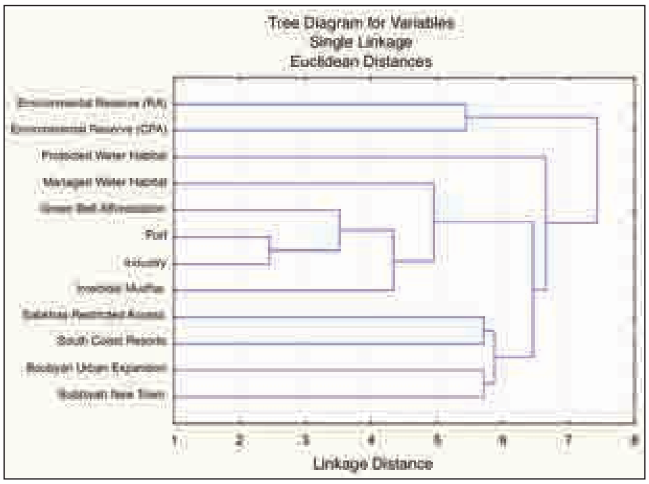

Fig. 30. Cluster analysis for land use activities

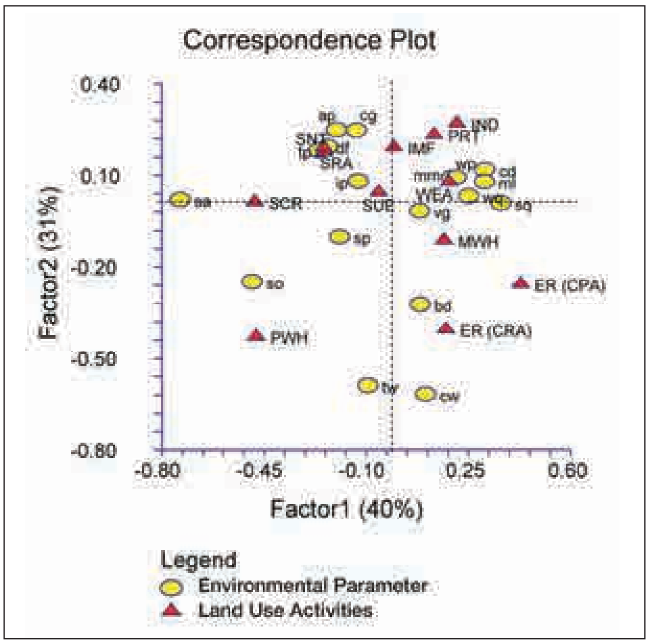

Fig. 31. Correspondence factor analysis based on matrix values

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that share the closest similarity are set nearest together (Rock, 1988). In the present study, Q-mode single-linkage cluster analysis was performed via a data matrix comprising 18 variables (environmental parameters). The Q-mode and R-mode single-linkage cluster analyses represent the similarity between different land uses as well as the linkage between different parameters. The environmental elements are: air pollution (ap), dust fallout (df), sand accumulation (sa), inland processes (ip), tidal processes (tp), coastal geology (cg), vegetation (vg), terrestrial wildlife (tw), marine wildlife (mw), birds (bd), coastal dynamic (cd), sediment quality (sq), marine life (ml), marine mammals and reptiles (mm), water productivity (wp) water quality (wq), soil (sl) and site planning (sp). **Figure 29** represents the resulting tree diagram showing the relationship between different environmental parameters. Similar parameters clearly cluster together within different groups. The marine and oceanographic parameters cluster in one group, and the ecological parameters (including wildlife, birds and soil) cluster together, while the other parameters cluster in small groups.

The land uses are: Environmental Reserve-Restricted Access (ER-RA), Environmental Reserve-Controlled Public Access (ER-CPA), Protected Water Habitat (PWH), Managed Water Habitat (MWH), Green Belt Afforestation (GBA), Port (PRT), Free Trade/Light Industry Zone (IND), Intertidal Mudflats (IMF), Sabkhas Restricted Access (SRA), South Coast Resorts (SCR), Boubyan Urban Expansion (BUE) and Subbiyah New Town (SNT). The resulting tree diagram (**Fig. 30**) shows that similar land use activities are clustered into three groups. Protected environments (ERs RA and CPA) comprise the first group; MWH, GBA, PRT, IND, and IMF form the second group, while SRA, SCR, BUE and SNT are the constituents of group 3.

Correspondence factor analysis was used to confirm the statistical discrimination results of the cluster analyses, as well as to define the controlling variables (environmental parameters) of each land use activity. This method is analogous to a combination of Q- and R-mode factor analysis (Rock, 1988). Correspondence factor analysis was performed using a data matrix comprising the land uses and the environmental parameters from the same matrix used for the cluster analysis. Factor 1 and factor 2 accounted for 71% of the total variance. Hence, we can rely on these results as a reasonable summary of the raw data. Factor 1 was responsible for 40% of the variance, while factor 2 accounted for 31% of the total variance (**Fig. 31**). The factor 1 space was divided into four areas based on the positive and negative values of the factor weight. In the first area, where factor 1 is positive and factor 2 is negative, ER-CPA, MWH and ER-RA are separated. The controlling environmental factors are the birds, coastal wildlife, terrestrial wildlife and vegetation. The Protected Water Reserve (PWH) was discriminated on the negative side of both factors. Soil was discriminated on PWH. Subbiyah New Town (SNT) and Sabkhas (SRA) were located in the third quarter (positive factor 2 and negative factor 1). Inland processes, tidal processes, air pollution, dust fallout and coastal geology discriminate these activities. In the last quarter (positive values for both factor weights), Industry, Port and Green Belt Afforestation were located. They are discriminated by the coastal dynamics, water productivity, marine life and water quality. Boubyan Urban Expansion is discriminated by inland processes and site planning. Sand accumulation discriminates South Coast Resorts.

Rapid Impact Assessment Matrix (RIAM)

A key problem that may cause a significant impact is the indirect and cumulative impacts as well as impact interactions from different sources. In order to have an integrated approach for the impact assessment, the RIAM methodology was used. RIAM is ideally suited to IEE, where a multi-disciplinary team approach is used, as it allows for data from different sectors to be analyzed against common impact criteria within a common matrix, thus providing a rapid clear assessment of the major impacts (Pastakia and Jensen, 1998). RIAM also provides a transparent and permanent record of the analysis process while at the same time organizing the IEE procedure, which in turn considerably reduces the time it takes to execute impact assessment (Pastakia and Jensen, 1998). The method is based on a standard definition of the important assessment criteria, as well as the means by which semi-quantitative values for each of these criteria can be collated, to provide an accurate and independent score for each condition. The impacts of the project activities are evaluated against the environmental components, and for each component a score is determined using the defined criteria, which provides a measure of the impact expected from the component.

The Holistic Approach of RIAM: The RIAM is an analysis and presentation tool for Environmental Impact Assessment (EIA) and Initial Environmental Evaluation (IEE), which allows the EIA or IEE reports to be completely transparent and easily understood. In the execution of these impact assessments, a general routine may be followed which contains individual elements recognized by most forms of traditional EIAs and many national and international regulations. The RIAM program incorporates these elements while undertaking the analysis and presentation of results. For an IEE to be of full value it should be possible to evaluate impacts across a wide range of disciplines. Accordingly, the holistic approach allows an IEE to consider impacts not merely to the ecology of an area, but to the totality of the environment of the area. This totality requires consideration of natural, developmental and human factors.

The RIAM requires that the assessor define components that are important insofar as they are indicators of change (either positive or negative). These components are selected from four main categories:

1. **Physical/Chemical:** Represents the natural, non-organic environment and changes therein
2. **Biological/Ecological:** Contains the habitats, food chain, and species that make up the natural and domesticated flora and fauna that may be impacted
3. **Social/Cultural:** Represents the human environment and the cultural heritage of the societies in the study area
4. **Economic/Operational:** Contains the economic aspects of development and the operational complexities that will guarantee, or hinder, sustainability of development in the future

These components are evaluated against defined criteria that are universal to all impact assessments. The subjective judgments of the assessor are converted into a figure on defined scales, and in turn, the RIAM matrix formula converts these into values within a series of ranges. These scores allow the RIAM easily to display the results of the assessment and record them with full transparency.

Scoring of the RIAM: The criteria used in RIAM fall into two groups:

Group (A): Criteria that are of importance to the condition, that can individually change the score obtained.

Group (B): Criteria that are of value to the situation, but should not individually be capable of changing the score obtained.

Group (A) Criteria

Importance of condition (A1): A measure of the importance of the condition, which is assessed against the spatial boundaries or human interests it will affect. The scales are defined as follows:

4 = important to national/international interests
3 = important to regional/national interests
2 = important to areas immediately outside the local condition
1 = important only to the local condition
0 = no importance

Magnitude of change/effect (A2): According to Pastakia and Jensen (1998), magnitude is defined as a measure of the scale of benefit/dis-benefit of an impact or a condition:

+3 = major positive benefit
+2 = significant improvement in status quo
+1 = improvement in status quo
0 = no change/status quo
-1 = negative change to status quo
-2 = significant negative dis-benefit or change
-3 = major dis-benefit or change

Group (B) Criteria

Permanence (B1): This defines permanence in terms of whether a condition is temporary or permanent and should be seen only as a measure of the temporal status of the condition (e.g., a power station is a permanent condition for many years, but a leased summer house is a temporary condition, as it will be removed).

1 = no change/not applicable
2 = temporary
3 = permanent

Reversibility (B2): This defines whether the condition can be changed and is a measure of control over the effect of the condition. It should not be confused or equated with permanence. For example, an accidental toxic spill into the sea is a temporary condition (B1) but its effect (death of fish) is irreversible (B2) if it is a closed embayment; a town's sewage treatment works is a permanent condition (B1), but the effect of its effluent can be changed (reversible condition) (B2).

1 = no change/not applicable
2 = reversible
3 = irreversible

Cumulative (B3): This is a measure of whether the effect will have a single direct impact or whether there will be a cumulative effect over time or a synergistic effect with other conditions. The cumulative criterion is a means of judging the sustainability of a condition and is not to be confused with a permanent/irreversible situation. For instance, the death of an old animal is both permanent and irreversible, but non-cumulative as the animal can be considered to be past its breeding capability. The loss of post-larval shrimp in the wild is also permanent and irreversible, but in this case cumulative, as all subsequent generations that the larvae (as adults) may have initiated will also have been lost.

1 = no change/not applicable
2 = non-cumulative/single
3 = cumulative/synergistic

The process for RIAM can be expressed in the following equations:

Table 11. Conversion of Environmental Scores into Range Bands

RIAM Environmental Score (ES)	Range Value (RV) (Alphabetic)	Range Value (RV) (Numeric)	Description of Range Band
108 to 72	E	5	Major positive change/impact
71 to 36	D	4	Significant positive change/impact
35 to 19	C	3	Moderate positive change/impact
18 to 10	B	2	Positive change/impact
9 to 1	A	1	Slight positive change/impact
0	N	0	No change/status quo/not applicable
-1 to -9	-A	-1	Slight negative change/impact
-10 to -18	-B	-2	Negative change/impact
-19 to -35	-C	-3	Moderate negative change/impact
-36 to -71	-D	-4	Significant negative change/impact
-72 to -108	-E	-5	Major negative change/impact

(a1) x (a2) = aT
(b1) + (b2) + (b3) = bT
(aT) x (bT) = ES

where (a1) and (a2) are the individual criteria scores for group (A); (b1), (b2) and (b3) are the individual criteria scores for group (B); aT is the result of multiplication of all (A) scores, bT is the result of summation of all (B) scores; and ES is the environmental score for the condition (Pastakia and Jensen, 1998). **Table 11** gives the ES values and range bands currently used in RIAM. The final assessment of each component is evaluated according to these range bands.

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The RIAM program utilized in this study incorporates all the above elements while undertaking the analysis and presentation of results in accordance with the principles of the RIAM concept.

The RIAM method (formulated by Pastakia, 1998) is based on a standard definition of the important assessment criteria, as well as the means of semi-quantitative values for each of these criteria. It can be collated to provide an accurate and independent score for each condition. The different components and criteria that were considered during the construction and operation phases were formulated on the basis of expert discussion and review. In order to avoid bias in scoring, several experts from KISR involved in different disciplines of the Boubyan Master Plan Project were requested to give a score to the impact of different activities expected during construction and operation for the selected Master Plan Concept option.

Integrated EIA and Evaluation

In this section, the impact of project activities is evaluated against the environmental components, and for each component a score (using the defined criteria) is determined which provides a measure of the impact expected from each component. The assessment criteria formulated in this RIAM include two groups:

(A). Criteria that are of importance to the condition, that individually can change the score obtained (importance and magnitude).

(B). Criteria that are of value to the situation, but should not individually be capable of changing the score obtained (permanence, reversibility and cumulative).

In this option, the physical/chemical and biological/ecological environmental components are only taken into consideration for the initial environmental evaluation. The different components selected are as follows:

Components: PC1: Air pollution, PC2: Noise pollution, PC3: Groundwater, PC4: Sand accumulation, PC5: Tidal processes, PC6: Inland terrestrial processes, PC7: Dust fallout, PC8: Military activities, PC9: Coastal geomorphology, PC10: Coastal erosion, PC11: Coastal sediment transport, PC12: Hydrodynamic regime, PC13: Bathymetry, PC14: Flood pattern, PC15: Sediment quality, PC16: Water quality, PC17: Salinity, PC18: Gypsic Aquisalid, PC19: Typic Aquisalid, PC20: Typic Torriorthent, PC21: Historical elements, PC22: Landscape setting, PC23: Visual quality, PC24: Soil erosion (terrestrial), PC25: Soil deposition (terrestrial), BE1: Plant cover, BE2: Microbiology, BE3: Terrestrial wildlife, BE4: Coastal wildlife, BE5: Bird migratory path, BE6: Bird nesting, BE7: Fisheries, BE8: Shrimps, BE9: Plankton, BE10: Eutrophication, and BE11: Productivity.

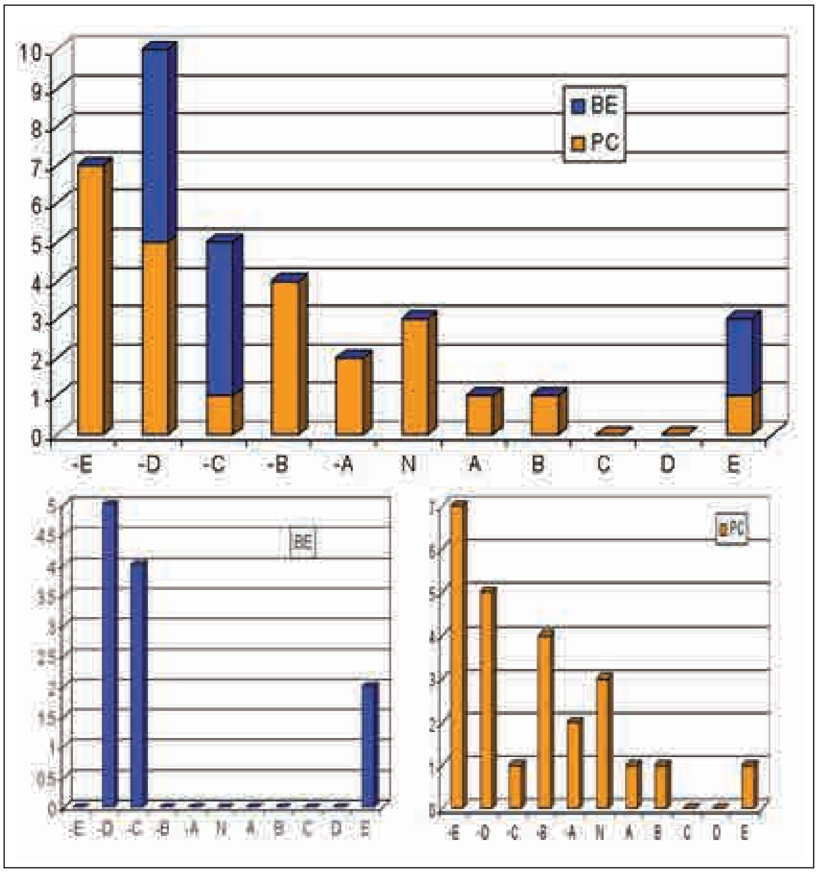

Fig. 32. Graphical presentation of RIAM results during the construction phase

Results of RIAM

Scenario 1. Construction Phase: **Table 12** gives the Environmental Score values and range bands currently used in RIAM. The final assessment of each component is evaluated according to these range bands. The graphical representation of the output of the RIAM matrix results with the integrated impact of the components selected is shown in **Fig. 32**. The actual RIAM matrix with selected components and weighting value assigned is illustrated in Table 12. **Table 13** represents the RIAM output results for the present environmental evaluation for scenario 1 (during the construction phase). Out of a total of about 36 criteria selected in this phase (physical/chemical and biological/ecological), the following conclusions were drawn:

Negative Changes/Impacts

A magnitude of **2** falls in -A (slight negative change/impact)
3 falls in N (no change/impact)
4 falls in -B (negative change/impact)
5 falls in -C (moderate negative change/impact)
7 falls in -E (major negative change/impact)
10 falls in -D (significant negative change/impact)

Positive Changes/Impacts

A magnitude of **1** falls in **A** (slight positive change/impact)
A magnitude of **2** falls in **B** (positive change/impact)
A magnitude of **3** falls in **E** (major positive change/impact)

Out of a total magnitude of 28 negative impacts, environmental scores (ES) range between a minimum of -72 and a maximum ES of 108. The criteria which have major negative impacts are those of physical and chemical components. Biological components also have significant and moderate negative impacts during the construction phase. It can be concluded from Table 12 and Fig. 32 that during construction phase activities in Boubyan Island the following issues are to be given priority with due consideration to the magnitude of negative impacts:

Major Negative Impact (-108 to -72): Noise pollution, hydrodynamic regime, coastal geomorphology, coastal erosion, coastal sediment transport, soil erosion (terrestrial) and soil deposition (terrestrial).

Significant Negative Impact (-71 to -36): Groundwater, military activities, flood patterns, water quality, salinity, terrestrial wildlife, coastal wildlife, bird nesting, fisheries and shrimps.

Other Negative Impact which Falls in the Range of Moderate to Slight Impact (-31 to -1): Air pollution, inland terrestrial processes, Gypsic Aquisalid, Typic Aquisalid, Typic Torriorthent, landscape setting, visual quality, plankton, eutrophication and productivity.

Table 12. Environmental Components for the EIA of the Master Plan (as of August 2005)

Components		ES	RB	A1	A2	B1	B2	B3
PC1	Air pollution	-14	-B	1	-2	3	2	2
PC2	Noise pollution	-72	-E	4	-3	2	2	2
PC3	Groundwater	-54	-D	3	-3	2	2	2
PC4	Sand accumulation	6	A	1	1	2	2	2
PC5	Tidal processes	18	B	3	1	2	2	2
PC6	Inland terrestrial processes	-18	-B	2	-1	3	3	3
PC7	Dust fallout	108	E	4	3	3	3	3
PC8	Military activities	-54	-D	3	-3	2	2	2
PC9	Coastal geomorphology	-108	-E	4	-3	3	3	3
PC10	Coastal erosion	-108	-E	4	-3	3	3	3
PC11	Coastal sediment transport	-108	-E	4	-3	3	3	3
PC12	Hydrodynamic regime	-81	-E	3	-3	3	3	3
PC13	Bathymetry	0	N	3	0	3	3	3
PC14	Flood pattern	-36	-D	4	-1	3	3	3
PC15	Sediment quality	0	N	3	0	2	2	2
PC16	Water quality	-36	-D	4	-1	3	3	3
PC17	Salinity	-54	-D	3	-2	3	3	3
PC18	Gypsic Aquisalid	-16	-B	1	-2	3	3	2
PC19	Typic Aquisalid	-16	-B	1	-2	3	3	2
PC20	Typic Torriorthent	-24	-C	1	-3	3	3	2
PC21	Historical elements	0	N	3	0	1	1	1
PC22	Landscape setting	-8	-A	1	-1	3	3	2
PC23	Visual quality	-8	-A	1	-1	3	3	2
PC24	Soil erosion (terrestrial)	-108	-E	4	-3	3	3	3
PC25	Soil deposition (terrestrial)	-81	-E	3	-3	3	3	3
BE1	Plant cover	72	E	3	3	3	2	3
BE2	Microbiology	72	E	3	3	3	2	3
BE3	Terrestrial wildlife	-54	-D	2	-3	3	3	3
BE4	Coastal wildlife	-54	-D	3	-2	3	3	3
BE5	Bird migratory path	-32	-C	4	-1	2	3	3
BE6	Bird nesting	-48	-D	3	-2	2	3	3
BE7	Fisheries	-48	-D	3	-2	3	2	3
BE8	Shrimps	-48	-D	3	-2	3	2	3
BE9	Plankton	-24	-C	3	-1	3	2	3
BE10	Eutrophication	-24	-C	3	-1	3	2	3
BE11	Productivity	-24	-C	3	-1	3	2	3

Table 13. Summary of Scores (during Construction)

Range	-108	-71	-35	-18	-9	0	1	10	19	36	72
	-72	**-36**	**-19**	**-10**	**-1**	**0**	**9**	**18**	**35**	**71**	**108**
Class	-E	-D	-C	-B	-A	N	A	B	C	D	E
PC	7	5	1	4	2	3	1	1	0	0	1
BE	0	5	4	0	0	0	0	0	0	0	2
SC	0	0	0	0	0	0	0	0	0	0	0
EO	0	0	0	0	0	0	0	0	0	0	0
Total	7	10	5	4	2	3	1	1	0	0	3

Apart from the above negative impacts, a total magnitude of 5 scores were expected during the construction phase, which includes a magnitude of 3 for physical components with significant positive change (a magnitude of 1 for E) as well as slight and positive impacts (a magnitude of 1 each for A and B) and a magnitude of 2 for biological/ecological components with significant positive change. The different environmental components which have a positive impact during construction are the following:

Major Positive Impact (72 to 108): Dust fallout, plant cover and microbiology.
Significant/Moderate Positive Impact (19 to 71): Sand accumulation and tidal process.
No Impact Components: Bathymetry, sediment quality and historical elements.

A comparison of the RIAM results during the construction and operation phases (summary) clearly indicates the changeover of environmental components to different range bands. It can be expected that during the operation phase of selected activities, particularly construction, groundwater quality in particular will experience major negative impacts. The effect of sand accumulation and tidal process can have a moderate and significant positive impact during the operation compared to the construction phase, where these components indicated a slight positive impact.

In general, the construction and operation phases of activities involved in the Master Plan Concept will result in major, significant, moderate and slight negative impacts on the existing ecosystem of Boubyan Island and significant positive changes/improvement to biological components as highlighted above.

Zonal EIA for the Master Plan Concept during Construction

Based on the integration of the SEAM and RIAM results, the impact of land use activities responsible for major, significant environmental impact has only been considered in order to arrive at the zonal and activity-based impact evaluation. The possible measures to mitigate these impacts (which are to be strictly followed during both the construction and operation phases), and the residual impact are discussed in the final section.

Environmental Evaluation Results

1. Environmental Reserve (Restricted Access): Significant impact on birds and wildlife is expected due to noise emerging from dredging, excavation and construction of the connecting rail/road corridor, port, free trade zone and industrial area. The area is a major resident bird protection zone and has scope as an Important Bird Area if properly designed, managed, controlled and conserved.

The effect will be greatest during construction. Detailed sound pressure analysis is necessary to mitigate the impact. Control of traffic speed and constructing noise barriers along rail and road corridors are advisable. A sustainable green belt (as proposed in the Master Plan) will double as a buffer zone between the railway line and the northern part of the island, thus minimizing noise.

2. Environmental Reserve (Controlled Public Access): This area is highly sensitive, rich in habitat, and unique in natural vegetation with high native plant density compared to other parts of the island. In this area, several micro-landforms were identified such as sabkhas, flood patches, drainage basins and eolian land forms. The area will suffer from noise, air pollution and human disturbance due to the construction of eco resorts, family resorts, etc. along the southern part of the island. Strict restrictions on human disturbance should be enforced. Construction activities in the neighborhood should be avoided during nesting and migration seasons.

3. Protected Intertidal Mudflats and Buffer: Minor impacts are expected during construction due to the wind-driven transport of dredged material from the north (dredged material holding area) during the summer. This area should be properly fenced with restricted access.

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4. Protected Water Reserve: Restricted access to the public will be imposed in this area, which should be demarcated with a sufficient buffer area and the development of a mangrove plantation along the coast to support marine shrimps and other vertebrates (with a positive impact on coastal habitats). Some impact is expected on coastal water quality due to the discharge of waste produced from rail/road corridors. Some impact on high and unique coastal vegetation, birds and wildlife which normally utilize the area near the port and rail/road crossway can be anticipated. Noise from construction will affect breeding and nesting birds. Impact on terrestrial wildlife can be expected. Impact will be greatest during construction. Frequent monitoring of coastal water quality and marine population survey is essential.

5. Managed Water Habitat: All the construction activities should be restricted for 200 m from the high tide line. Impact can be expected on marine water quality and marine population due to port construction and operation (e.g., navigation channel, marine transportation and many engineering structures). Marine species may avoid the area due to disturbance and stress. Changes in coastal erosion and deposition processes are expected. Effect of tidal floods has to be taken care of while planning the different kinds of resorts near the southern beach area.

6. Sabkhas Restrictive Access: Less impact is expected. Minor noise disturbance may be expected due to construction in the nearby area.

7. South Coast Resorts and Family Resort Attraction: Impact can be expected to marine water quality and marine population due to discharge of wastewater during construction and solid waste produced during operation. Increased freshwater demand has to be considered. If resorts are set back adequately, no change in coastal erosion and deposition processes should occur. Effect of tidal floods has to be taken care of while planning the different kinds of resorts near the southern beach area. Some impact to the nearby environmental reserve (Ras Al Gaid and Ras Al Barshah) can be expected due to noise and air pollution from vehicular transport during construction. There will be some impact on existing salt-encrusted nabkah land which serves to stabilize the land and provide a microhabitat for invertebrates, small mammals and birds. The Master Plan design is thus designated to preserve the integrity of east-west coastal vegetation/animal corridor during resort construction and operation.

8. Free Trade/Light Industry Zone: In the case of Boubyan Island, inclusion of any industrial activity requires advanced technology, which leads to increased land and water pollution loads, and noise pollution from vehicles and construction activities. The raw industrial wastes contain many contaminants which when discharged into the sea/land are hazardous to the surrounding environment. Impact on coastal water quality and sediment toxicity can be expected during both construction and operation.

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9. Dredged Material Holding Area: This area should be provided with storm water control to protect the storm water drainage of dredged material to nearby areas, particularly towards the coast and to the intertidal mudflats. Alteration in soil characteristics can be expected. Proper covering of dredged material is necessary to reduce wind-driven transport of dredged materials. Open water discharge of dredged material should be avoided as it releases ammonia and manganese to the water column, which can cause deterioration in quality of coastal water and sediment. A proper management plan is necessary to control any contamination of the surrounding soil and coastal waters.

10. Port Transportation Corridors: Major impact on birds, other terrestrial wildlife and coastal habitat is expected. Heavy noise pollution due to the construction of railway track and port road is anticipated. High vibration can be expected from railway and road transport. Reducing automobile traffic to the greatest extent possible and restricting vehicle horns can minimize the noise pollution. Construction of noise barriers and establishing noise emission standards are the other mitigation measures that can be used to control noise.

11. Boubyan Urban Expansion Area: This part of Boubyan lies near Khor Al Subbiyah, extending from the end of the highly vegetative Ras Al Barshah spit to the limit of the rail/road connection. Based on the wildlife survey, this area seems to be highly productive for both terrestrial and coastal habitats. Most of the bird species were observed in this part, as the area supports an excellent breeding ground, in addition to pristine scenic beach views. Boubyan urban expansion activities will have a major impact on coastal and terrestrial habitats for breeding birds and on marine habitats and will also destroy the high-density vegetation area close to the coast. Changes to the marine water quality by discharge of wastewater during construction and urban waste during operation, can impose heavy stress on existing marine biota. Urban growth influences runoff from the area and alters the natural drainage pattern. There will be an increased water demand to meet the need of the urban community. Storm water from urban areas may add a significant pollution load to the receiving stream (dust and chemicals deposited on the ground will be transported by storm water runoff), while increased urbanization and associated industrialization will result in rapid accumulation of pollutants such as total solids, COD, phosphate and Kjeldahl nitrogen. The urban development will also increase invasive terrestrial species such as cats, rats, etc. Some impact on marine biota and sediment quality also can be expected.

12. Subbiyah New Town: Major impacts from constructional and operational wastes can be expected on coastal water quality. This part of Boubyan lies near Khor Al Subbiyah, extending from the end of the highly vegetative Ras Al Barshah to the limit of the rail/road connection. Based on the wildlife survey, this area seems to be highly productive for both terrestrial and coastal habitats. Most of the bird species were observed in this part, as the area supports an excellent breeding ground, along with a pristine scenic beach view. Urban activities will impact coastal and terrestrial habitats including breeding birds and marine shrimps. This may destroy the high-density vegetation area and related habitats close to the coast. Changes in the marine water quality are likely due to the discharge of construction waste and urban waste. Storm water from urban areas may add up to a significant pollution load to the receiving stream. Some impact on marine biota and sediment quality also can be expected.

13. Port: Major impact on coastal habitats due to port construction, which includes dredging of navigation channels, excavation, erection of pillars and engineering activities. The anticipated impact on water quality is an increase in turbidity, freshwater influx from Shatt Al Arab, impact on sand drainage from Shatt Al Arab, disturbance due to sand transport, and increased water and sediment toxicity from oil spillage due to dredging and ship transport. Bottom sediment quality also affects biological activities and marine production. Changes in bird foraging and migratory grounds can also be expected. The port will import invasive species such as crows and mongooses that are predators of ground nesting birds.

Table 14 illustrates the zonal assessment of the Impact Assessment and Evaluation based on various land use activities of the Master Plan Concept (as of August 2005). The expected impact without mitigation and with mitigation measures and the residual impact are also detailed in this table. **Table 15** deals with the activity-based impact of different environmental components and the relative mitigations to be taken care of for each land use development.

Conclusion

In conclusion, the construction and operation phases of activities involved in Alternative III will result in a range of major, significant, moderate and slight negative impacts on the existing ecosystem of Boubyan Island and significant positive changes to biological components. The environmental components affected due to the activities of the selected Master Plan Concept are of immense importance as far as the biodiversity of Kuwait is concerned.

The RIAM analysis also indicates that some physical components (noise pollution, groundwater, sand accumulation, tidal processes, sediment quality, military activities, etc.) will be temporary during construction (short term on a regional basis). However, many of the components selected may have a permanent, long-term impact during both the construction and operation phases. Some of the important permanent impact components will be on coastal geomorphology and sediment transport, visual quality, coastal water quality, coastal wildlife, bird migration and fisheries. Though there are significant positive impacts due to the construction and operation phases of Alternative 3 for vegetation, care should be taken to avoid dumping excavated sand and other waste material near the high-density vegetation areas. It is important to consider that any further archaeological findings uncovered during the Boubyan development should be reported to the Kuwait Museum Authority and preserved for the public in consultation with the National Council for Culture, Arts, and Literature.

Recommendations

The following important recommendations are to be included in the detailed EIA.

- A detailed description of project structures such as chalets, service and main buildings, roads and other infrastructure is needed to cover all possible discharges and impacts.
- A separate authority should be set up to handle responsibility for the entire Conservation Management Plan and the statutory guidelines therein.
- Set up a separate protective area for birds (near the northern island), especially rare birds, thereby promoting a bird sanctuary, because Boubyan Island provides a critical habitat for birds such as the swift tern (*Sterna bergii*), slender-billed gull (*Larus genei*) and great knot (*Calidiris tenuirostris*), which are of international and national importance. Conservation may provide an opportunity for the site to be recognized as a Ramsar Site and an Important Bird Area. This can also support the breeding population of crab plover (*Dromas ardeola*) and other foraging birds, which will otherwise be at risk due to the development of Boubyan Urban Expansion and port transportation activities. Some selected mitigation and habitat measures may be required.
- A detailed groundwater study to determine the level of the water table and other groundwater contamination that may occur due to construction, dumping, and spillage of wastes emerging from construction and development operations.
- An extensive engineering study is required for all types of building and construction networks, as the island geology is uniform and overlain by soft clays and marine deposits which cannot easily support piling and heavy foundation structures.
- An engineering study and detailed development plan are needed to address the need for a proper sanitary network and treatment of wastes.
- Development of a sustainable green belt for sand stabilization, to separate the northern intertidal area from the cross rail/road bridge and southern development area.
- Creation of recreational parks and chalets should be prohibited within a 300-m zone from the high tide line in the beach area.
- Detailed study (modeling) on wave and tidal characteristics is needed to investigate the impact on the beach shore and future infrastructure.
- The eastern and western beach areas, Ras Al Barshah and Ras Al Qyad, are also important sites for migratory and breeding birds and these areas are to be separated by adequate fencing to avoid disturbing breeding and migratory birds and other wildlife.
- Introduction of mangrove plantations (supplemented with a freshwater supply for long-term sustenance as

the coastal waters of Boubyan are highly saline) can be developed near the coastal belt by incorporating extensive research activities, as they promote nursing grounds for juvenile finfish, shrimp, and breeding and nesting birds. An assessment of environmental impacts carried out by KISR suggested a positive impact of mangroves on marine and coastal environment (Bhat et al., 2002).
- A detailed sewage treatment network study should be incorporated for different infrastructures.
- A study of a storm water network to drain runoff from reclaimed areas to the sea may be included.
- An effective monitoring program is necessary to monitor groundwater quality, coastal water and sediment quality, terrestrial and coastal habitat population, and air and noise pollution loads during construction and operation.
- Public access should be controlled to protect the pristine ecosystem of Boubyan, especially towards the interior of the northern part of the island. This also ensures public safety and welfare.
- Oil pollution on the western shore (from the extreme end of high tide) was reported during the KISR survey. This site should be shielded from pollution in order to protect the intertidal mudflats from oil contamination while developing Boubyan Urban Expansion.
- Injection of limewater for the development of a dredging channel for Boubyan port (which increases the bottom temperature by 300°C) should be carried out without any potential hazards to the bottom biota. All coastal and offshore construction work related to Boubyan port should be avoided during the spawning season of marine species.
- It is important to develop ground vegetation (with supportive habitat for birds) surrounding the proposed lake system near the Boubyan Urban Expansion as a mitigation factor to development.

Follow-up Actions

Though the evaluation is based on environmental measurements, predictions of environmental impacts may not be as anticipated since development is changing the natural ecosystem and firm projections are difficult. A proper monitoring mechanism, in accordance with environmental regulations and implementations, to the maximum extent possible, is the key for all future follow-up actions. This is to ensure that the terms and conditions of approval are met (once a project/program is approved for implementation) to monitor the impacts of development and the effectiveness of mitigation measures. The technique also strengthens future impact applications and mitigation measures and helps to undertake environmental audit and process evaluations to optimize environmental management and sustainable development. An environmental assessment can be effective and measurable only with the help of good monitoring practices, coupled with the identification and implementation of corrective measures.

In the case of Boubyan Island, by implementing the land use activities of the selected Master Plan Concept, monitoring the following can help to ensure sustainable development, which will also help conserve and protect biodiversity to the maximum extent possible:

1. The three critical areas (Northern Island, Ras Al Qayd and Ras Al Barshah) should be conserved with supportive research and monitoring to provide a high-quality environment by increasing the naturalness of the area.
2. Groundwater monitoring should be carried out to ascertain that changes do not affect the long-term survival of new settlements.
3. Strict restriction on minor construction and encroachment in the eastern and western beach areas, i.e., Ras Al Barshah and Ras Al Qayd.
4. Restriction should be imposed on any kind of fishing activities throughout the Boubyan coastal waters within 200 m of shore.
5. A detailed monitoring program has to be set up to study the coastal water and sediment quality in order to meet the Kuwait Environment Public Authority's quality criteria during the construction and operation phases.
6. An effective monitoring network for bird community and terrestrial habitats must be developed to ensure the continued existence of the whole range of species and proper protection for the rare species. Warning boards should be maintained during the construction and operation phases to protect birds from human disturbance.
7. Monitoring of coastal and marine habitat populations can help to understand the degree of impact due to development activities, in order to develop proper mitigation of potential future impacts.
8. The pollution load on air quality can be expected to increase from the various land use activities and hence monitoring of these parameters is also key to reducing pollution; this should conform to the regulative standards of Kuwait's EPA.
9. Involvement of military security is necessary but activities such as training, live-fire weapon exercises, and ordinance dumping should be restricted since they conflict with the island's ecological processes.
10. The level of noise will be mostly due to development activities especially during dredging, excavation, and transportation associated with construction of the port, rail/road corridors, and industrial network. The noise level should be maintained below the EPA limits during the development phase.

Table 14. Zonal Assessment of Environmental Impacts for the Activities Based on the Master Plan Concept

Area	Importance of Area	Type of Activities	Expected Impacts	Magnitude without Mitigation	Mitigation Measures	Residual Impacts
Northern Boubyan	Ecologically very sensitive. Breeding and nesting area of internationally important birds.	No direct activity. Indirect activities like dredging and excavation works for port construction.	Impact on birds and wildlife due to noise and vibration from nearby areas.	Negative change (-B).	Avoid work involving high noise levels at night. Continuous noise monitoring is recommended during construction and operation of dredging, excavation, transportation, and other port activities.	Slight negative impact (-A) may remain.
Boubyan Urban Expansion	Connecting site for Subbiyah new town and port. Presence of khor habitats and bird breeding.	Link bridge excavation, dredging, erection of pillars. Road construction. Dumping of waste and sands. Construction of Subbiyah urban township.	Disappearance of breeding birds and marine shrimp. Changes to the marine water quality and sediment quality. Disturbance to marine biota. Attracts terrestrial animals like rats, mice, etc., which are predators of ground nesting birds.	Significant negative change (-C).	Development of alternate area for birds with the same natural environment. Introduction of a mangrove plantation in the alternate site to benefit birds and marine habitat. Proper plan for dumping and disposal of waste materials. Strict control on human access to sensitive bird migration and nesting areas.	Slight negative impact (-A) will remain on marine water quality.
Port and industrial zone	Easy access to nearby countries for trade. Bird nesting and migratory route.	Construction activities: Dredging of navigation channels, excavation and erection of engineering structures. Marine transportation.	Increase in economic levels and employment. Affects freshwater influx. Disturbance to bird migratory routes and nesting grounds. Change in marine water and sediment quality. Reduces marine population. Changes in soil characteristics. Increase in noise and vibration.	Significant positive change (C). Significant negative change (-C).	Sensitive coastal area in the northern island and Ras Al Gaid should be protected from fishing and boating. Proper plan for minimizing the impact on coastal flora, fauna and endangered marine species. Proper plan for disposal/re-use of dredged material. Monitoring of coastal water quality is essential.	Slight negative impact (-A) will remain.
Southern coast	Recreation and tourism	Construction of hotels, chalets, roads and other amenities.	Eliminates vegetative and productive areas for terrestrial habitats to some extent. Changes in the long shore drifts. Eliminates bird migratory routes.	Negative change (-A).	Proper screening with native greenery can mitigate this loss.	No impact (N) will remain.

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Area	Importance of Area	Type of Activities	Expected Impacts	Magnitude without Mitigation	Mitigation Measures	Residual Impacts
Ras Al Qyad and Ras Al Barshah	No direct activity is involved.	Construction activities in nearby areas.	Noise pollution, air pollution and human disturbance affect birds' migration and nesting.	Negative change (-A).	Activities involving high noise levels and other disturbances are suitably planned, considering the migratory path and nesting season of birds. The protected area should be separated by proper fencing to protect from encroachment of other predators.	Birds may adapt to the new environment after construction, but slight negative impact may remain.
Port transportation	Protects from encroachment to the northern island.	Introduction of a new bridge.	Slight negative change.	Disturbance to birds and other coastal wildlife.	Avoid traffic sounds at night and during nesting seasons. Proper conservation measures to minimize sound and air pollution.	Slight negative impact (-A) may remain.

Table 15. Activity-based Impact of the Selected Master Plan Concept

Activity	Major Impact Components	Type of Impact	Recommended Mitigation
Environmental reserves, managed water habitats, protected water reserves	Vegetation, terrestrial and coastal wildlife, birds, coastal water and sediment quality, fisheries and marine production, visual quality, noise pollution, and soil deposition.	Positive impacts: development in this part would significantly hinder the birds' life.	If properly protected, these areas can have positive impacts on the environment; however care should be taken to avoid destruction of vegetation. Precaution to minimize noise at night.
Boubyan Urban Expansion	Groundwater, tidal processes, coastal geomorphology, erosion and sediment transport. Bird foraging and migration. Eutrophication, water quality, soil characteristics, visual quality and noise.	Major impact on bird population due to increase in rats and mice (predators of bird), hunting by residents. Negative effect on community health can also be expected.	Groundwater monitoring, preventing coastal erosion, water quality monitoring in lake and beach area, arrangement for soil drainage system, proper wastewater treatment and provision for proper medical facilities (hospitals) within the island. Enforcing regulations for private bird hunting; disposal and treatment of garbage from residential areas should be effective to avoid pest problems.
Port transportation corridor	Air pollution, dust fallout, bird migration and nesting, soil characteristics, and noise pollution.	Significant impact on birds. Noise pollution will increase.	Proper control of traffic and noise. Development of buffer zone and monitoring of sound pressure.
South coast resorts	Coastal erosion, bathymetry and flood pattern, eutrophication.	Significant impact	Preventing coastal erosion by ground greenery and water quality monitoring.

Table 15 continued. Activity-based Impact of the Selected Master Plan Concept

Activity	Major Impact Components	Type of Impact	Recommended Mitigation
Port	Air pollution, noise pollution, dust fallout, bird migration and nesting, soil characteristics, coastal erosion and sediment transport, coastal hydrodynamics, flood patterns, coastal water quality, and fisheries.	Natural and anthropogenic waste disposal, oil spillage, discharge of ballast water, use of anti-fouling material, sewage-contaminated water, increase in air pollution from industrial stacks and traffic movement.	Sensitive coastal area in the northern island and Ras Al Gaid should be protected from fishing and boating; proper plan for minimizing the impact on coastal flora, fauna and endangered marine species. Advance identification of locations for stationary installations such as underwater cables, pipelines, and outfalls to avoid navigation channels. Use of efficient dredging equipment to reduce water turbidity, physical and chemical analysis of water and sediment before and during construction to design proper monitoring mechanisms to minimize impact, limit dredging activity during critical spawning and pre-spawning periods and a detailed management plan for dredging and disposal of dredged materials. Emergency contingency plans to minimize accidents during transport.
Subbiyah new town	Air pollution, groundwater, soil characteristics, dust fallout, coastal geomorphology and sediment transport and coastal water quality.	Significant impact	Prevent coastal erosion through proper conservation methods and water and sediment quality monitoring. Groundwater monitoring, arrangement for soil drainage system, proper wastewater treatment and provision for proper medical facilities (hospitals) to be planned.
Free trade zone/light industry	Air pollution, groundwater, dust fallout, coastal processes and bird migration to some extent due to noise from increased traffic and industrial works.	Significant impact	Proper air quality monitors and groundwater monitoring, avoid major noise-producing work at night. Proper management of industrial wastes.
Dredged material holding area	Transportation and storage of dredged materials. Air pollution in summer; changes soil characteristics.	Moderate impact	Proper conservation methods for disposal/reuse of dredged material. Monitoring the quality of dredged material.
Intertidal mudflats and buffer	Impact on intertidal biota (oysters reef, snails, and fiddler crabs) and vegetation due to construction activities in the nearby area.	Negative impact	All the construction activities (excavation, dumping, and vehicular transport) should be planned away from the intertidal zones. The area should be free from oil contamination. Fencing and restricted access should be enforced.

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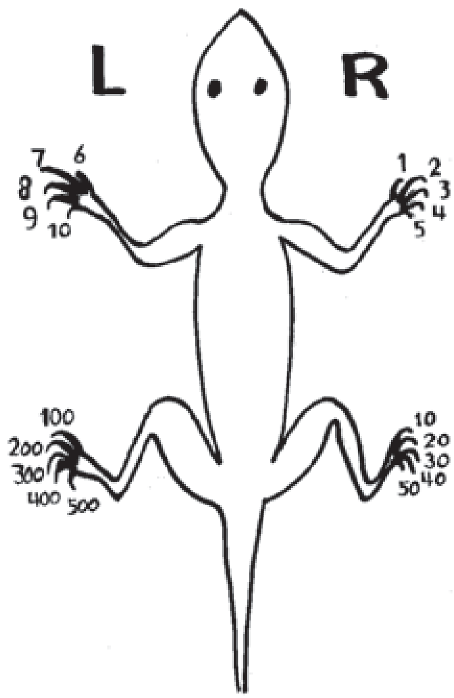
Section 3

Terrestrial and Marine Environments



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Section 3

Chapter 8: Vegetation

Abstract

The vegetation survey classified the vegetation community type of Boubyan and Warbah Islands as *Halocnemum strobilaceum* and other halophytic species. The vegetation is rich on the shoreline and poor inland. It is also characterized by simple zones or belts that run more or less parallel with the shoreline. These are directly influenced by the tidal action and the high saline water table. The zonational sequence varied by site and is frequently modified by local topography, such as sand accumulation. Four types of habitats were identified and the dominant plant species with vegetation coverage and herbage production were estimated. The dominant plant species in the four recorded habitats were as follows: 1) tidal channel habitat: *Halocnemum strobilaceum*, *Salicornia europaea*, and *Bienertia cycloptera*; 2) aeolian drift habitat: *Seidlitzia rosmarinus* and *Halocnemum strobilaceum*; 3) inland sabkha habitat: *Halocnemum strobilaceum*; and 4) muddy soil along tidal flats habitat: *Halocnemum strobilaceum*.

A record of 52 plant species, belonging to 18 families, was prepared together with a photographic record for some of the plant species observed on the islands. Three line transects were also established at three sites and the different vegetation zonations were delineated.

Two vegetation constraint maps were produced at the end of the project, which helped in the environmental assessment and planning activities. For sustained development of both Boubyan and Warbah Islands recommendations were made relating to the protection of the areas of high vegetative cover, herbage production and floral species diversity. Northern khors of Boubyan and Warbah Islands, Ras Al Barshah and Ras Al Qayed were the recommended areas for protection.

Introduction

The State of Kuwait ratified the Convention on Biological Diversity (CBD) in 2002 and prepared and adopted a national strategy for conservation of biodiversity. The primary elements of this national strategy are to identify important areas of biological diversity, establish methods to conserve biodiversity at the site of origin, regulate access to genetic resources and to transfer relevant technology. This project will lead to the actual implementation of important elements of this national strategy.

This project started in September 2003 and ended in January 2004. The overall objectives were to establish an in-depth, interactive digital database of the existing literature and maps on the vegetation of the study area and to conduct a preliminary vegetation survey to identify the major halophytic communities of the salt marshes and salines on Boubyan and Warbah Islands. The outputs from the project are summarized here.

Literature Review

A general description of the physical and biological environment of Kuwait was given by Halwagy and Halwagy (1974). Native plant classification and distribution in Kuwait have received attention from many investigators (Dickson, 1955; Kernick, 1966; Ergun, 1969; Halwagy and Halwagy, 1974; Omar, 1985; Omar et al., 2000). Several authors conducted plant classification with specific reference to Boubyan Island. Kernick (1966), Macksad (1969), Halwagy and Halwagy (1974) and Omar (1995) described the vegetation as *Zygophyllum coccineum*, with a major portion of the island being bare (Kernick, 1966; Ergun, 1969; Omar, 1995). Omar (1985) conducted a survey of Boubyan Island on two selected sites and recorded the following plant species:

Site I (29° 36N and 48° 11E): *Atriplex leucoclada, Bassia eriophora, Cistanche tubulosa, Cressa cretica, Halocnemum strobilaceum, Launaea mucronata, Launaea nudicaulis, Stipagrostis plumosa, Reseda arabica, Rumex vesicarius, Salsola baryosma, Salicornia herbacea, Schismus barbatus, Scrophularia deserti, Seidlitzia rosmarinus, Senecio desfontainei, Silene salsa, Stipa capensis, Suaeda maritima, Zygophyllum coccineum.*

Site II (29° 35N and 48° 13E): *Atriplex leucoclada, Halocnemum strobilaceum, Salicornia herbacea, Seidlitzia rosmarinus, Scrophularia deserti, Stipagrostis plumosa, Suaeda maritima, Zygophyllum coccineum.*

Many of the native plants listed by Omar (1985) are now thought to be extinct on the island. A more recent vegetation survey (Omar et al., 2000, 2001) shows that Boubyan Island is more than 80% bare of vegetation. However, in the lower coastal areas where Typic Torriorthents is the main soil type, *Halophyletum* is the dominating map unit. This area is dominated by halophytic species such as *Zygophyllum qatarense*, *Nitraria retusa, Tamarix aucheriana* and other species.

There was only minimal plant life on most of Boubyan and large parts of the sabkha areas and the tidal flat areas were completely barren (Anon., 1983). This lack of diversity in plant life is due to the harsh climatic conditions combined with very high soil salinities. Only plant species with special halophytic characteristics can survive in such an environment. Sabkha plant communities in Kuwait were identified by Omar et al. (2000). Five major plant communities were reported: *Nitraria retusa, Tamarix aucheriana, Zygophyllum qatarense, Halocnemum strobilaceum* and *Seidlitzia rosmarinus*. Associated species were also identified, such as *Aeluropus lagopoides, A. littoralis, Frankenia pulverulenta, Bienertia cycloptera, Cressa cretica, Aizoon canariense, A. hispanicum* and *Mesembryanthemum nodiflorum*. Some rare flowering plants were identified in Failaka Island (Shuaib, 1995). *Ixiolirion tataricum*, an exquisite amaryllis, was found. Two main perennial species of plants were widespread on Boubyan and grew in environments which no other indigenous plants appear able to tolerate. The distribution of these two species was reported (Anon., 1983), quoted as follows:

Halocnemum strobilaceum: This appeared in many areas just above the high tide level throughout the island. In the tidal inlet zone, it occurred along the leaves of the inlets. This plant was also found extensively on the fringes of mudflats in other coastal areas, but was rare on the sandy beach strandlines, such as those along the southern and eastern coasts of the island. Usually the species occurred in fairly dense communities.

Zygophyllum qatarense: This plant was widely distributed in the better drained central part of Boubyan, where salinity levels were high. Plants were scattered and the species cover was generally associated with small patches of windblown sand, either on hummocks or in depressions. The distribution of this plant was somewhat puzzling since there were significant barren areas where conditions appeared to be quite similar to those areas where the plant was widespread.

The small areas of coastal beach ridges carried the largest variety of flora on the island. At least 14 species of plants had been positively identified on Boubyan in the last 14 years. Unfortunately, there was no location record for these species, but observations carried out during the course of this study suggest that they were almost certainly restricted to the beach ridge areas. The species are: *Aeluropus lagopoides, Anabasis setifera, Arnebia sp., Atriplex leucoclada, Bienertia cycloptera, Cistanche lutea, Cynomorium coccineum, Salicornia herbacea, Salsola subaphylla, Scrophularia deserti, Seidlitzia rosmarinus, Senecio desfontainei, Senecio cornopifolins* and *Halocnemum strobilaceum*.

Recent information on the vegetation cover in areas near Boubyan Island was reported in Omar et al. (2001). The study compares percent cover of vegetation in protected and grazed areas at Al Subbiyah. Results showed a significant difference between the two: 9.5 and 12.9% vegetation cover for grazed and ungrazed areas, respectively. A list of 22 plant species was provided in this study.

Preliminary Vegetation Survey

The vegetation survey conducted by the Kuwait Institute for Scientific Research (KISR) from September 2003 to January 2004 classified the vegetation types of the islands as *Halophyletum* map unit, mainly of *Halocnemum strobilaceum* community and other halophytic species. A characteristic feature of the coastal salt marsh vegetation is its organization into zones or belts more or less parallel with the shoreline. The width and sequence of zones differ from one site to another. The zonational sequence also varies according to site characteristics and is frequently modified by local topography, such as sand accumulation or shallow depression.

The following is a preliminary zonation of vegetation that appeared in Boubyan and Warbah salt marshes starting from the shoreline towards inland areas.

Community type of *Salicornia europaea:* During October the community type of *Salicornia europaea* usually occupies the low waterlogged mud banks along the open water edge or along banks of creeks. The annual halophyte *Bienertia cycloptera* shows lush growth and it is associated with *Salicornia* communities.

Community type of *Halocnemum strobilaceum:* This community type usually occupies the shoreline, unless preceded shoreward by *Salicornia europaea*. *Halocnemum strobilaceum* shows lush growth and is flowering in October when it occupies a major area of Boubyan Island.

Community type of *Seidlitzia rosmarinus:* This plant is fairly luxuriant. It flowers in October and forms small sand mounds. This community provides shelter for a number of perennials, which are mostly halophytic, such as *Suaeda vermiculata, Zygophyllum qatarense, Atriplex leucoclada and Scrophularia deserti.*

Vegetation Assessment and Database

The project started in January 2004 and was completed in January 2005. Its overall objective was to conduct a detailed vegetation field investigation at representative selected sites and to develop a comprehensive updated database of the flora of the islands.

Methodology

A detailed qualitative and quantitative investigation was conducted of the vegetation of the coastal salt marshes of the islands. The major halophytic communities were surveyed where possible in relation to soil characteristics, particularly soil salinity, soil texture and waterlogging. The plants were used as indicators of soil type and conditions.

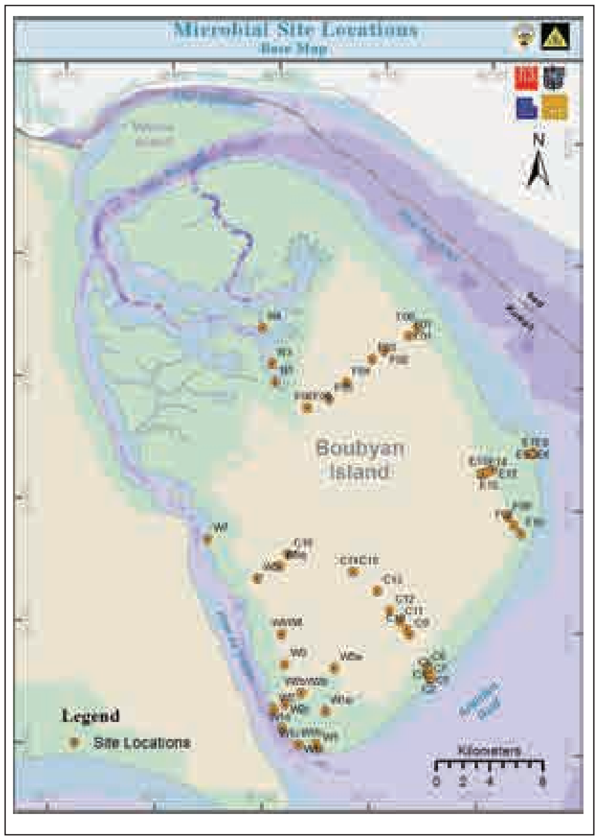

Fig. 1. Sites selected during the field visit for vegetation survey

1. Study site selection: Sixteen field trips were conducted on Boubyan Island between January and October 2004. Fifty-nine sites were selected during the field trips as shown in **Fig. 1**. The global positioning points of the selected sites and habitat types are shown in **Table 1,** which also shows the herbage production (kg/ha) and seasonal variation of vegetation percent cover at the selected study sites.

2. Vegetation assessment and monitoring:

- **Qualitative vegetation assessment methodology:** All the existing perennial and annual plant species during the 2003-2004 growing season in Boubyan have been recorded and photographed by field observations.
- **Quantitative vegetation assessment methodology:** For quantitative evaluation of the vegetation in the field, the following parameters were measured in selected study sites as shown in Fig. 1 and Table 1.

a. Herbage production: Herbage production data are one of the best quantitative measures for the response of vegetation to environmental and man-made stresses. Vegetation in the study areas was divided into five major categories: annual forbs, annual grasses, perennial shrubs, perennial forbs, and perennial grasses. The first two were measured on 15 quadrats (30 x 60 cm) randomly located within each site. The sampling was carried out during April

Table 1. Global Positioning Points, Habitat, Herbage Production (kg/ha), and Seasonal Variation of Vegetation Percent Cover at Selected Study Sites at Boubyan Island

Site No.	Global Positioning Points			Herbage Production (kg/ha)					Percent Cover (Summer)	Percent Cover (Spring)
	North D M S	East D M S	Habitat	Shrub	Annual Forb	Annual Grass	Perennial Grass	Total		
E1	29 47 19.9	48 22 22.1	Beach seaward side	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E2	29 47 19.8	48 22 21.6	Aeolian drift habitat	82.70	54.44	25.56	0.00	162.70	6.67	27.73
E3	29 47 19.7	48 22 21.3	Tidal channel habitat	962.73	0.00	0.00	0.00	962.73	51.6	51.6
E4	29 47 19.6	48 22 20.7	Tidal channel habitat	193.47	0.00	0.00	0.00	193.47	18.93	18.93
E5	29 47 19.2	48 22 18.8	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E6	29 47 18.6	48 22 15.9	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E7	29 47 17.8	48 22 12.4	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E8	29 47 17.4	48 22 10.7	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E12	29 46 36.8	48 20 27.8	Low vegetation sabkha	1.60	14.29	0.00	0.00	15.89	1.8	2.93
E13	29 46 31.3	48 20 10.5	Low vegetation sabkha	144.03	0.00	0.00	0.00	144.03	3.33	3.33
E14	29 46 28.0	48 20 00.1	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
E15	29 46 25.5	48 19 54.1	Low vegetation sabkha	178.43	10.74	0.00	0.00	189.17	3.07	4.0
E16	29 38 1.679	48 17 47.5493	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C1	29 38 01.5	48 17 47.4	Beach seaward side	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C2	29 38 01.7	48 17 47.5	Beach seaward side	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C3	29 38 02.0	48 17 47.3	Aeolian drift habitat	752.80	47.04	0.00	0.00	799.84	32.67	35.47
C4	29 38 02.0	48 17 47.3	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C5	29 38 04.3	48 17 46.2	Low vegetation sabkha	29.00	0.00	0.00	0.00	29.00	0.33	0.33
C6	29 38 13.7	48 17 41.3	Low vegetation sabkha	188.33	0.00	0.00	0.00	188.33	7.47	7.47
C7	29.38 20.6	48 17 38.8	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C8	29 38 28.6	48 17 35.6	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C9	29 39 48.8	48 16 44.6	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C10	29 40 00.5	48 16 35.2	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C11	29 40 20.2	48 16 15.4	Low vegetation sabkha	6.27	10.00	0.00	0.00	16.27	1.0	2.33
C12	29 40 46.0	48 15 47.0	Low vegetation sabkha	9.33	48.15	9.26	0.00	66.16	0.73	5.73
C13	29 41 33.8	48 15 12.2	Low vegetation sabkha	18.37	12.96	0.00	0.00	31.33	2.33	2.8
C14	29 42 19.7	48 14 02.9	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C15	29 42 23.6	48 12 27.2	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
C16	29 42 58.6	48 10 59.4	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W1	29 35 03.7	48 12 33.4	Tidal channel habitat	296.73	2304.81	0.00	0.00	2601.54	57.2	9.87

Site No.	Global Positioning Points		Habitat	Herbage Production (kg/ha)					Percent Cover (Summer)	Percent Cover (Spring)
	North D M S	East D M S		Shrub	Annual Forb	Annual Grass	Perennial Grass	Total		
W1a	29 36 35.7	48 12 53.3	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W1b	29 35 14.5	48 12 30.2	Bare vegetation sabkha	0.00	0.00	0.00	00.00	0.00	0.0	0.0
W1c	29 35 12.9	48 11 42.1	Aeolian drift habitat	447.13	56.3	195.56	3.4	702.39	16.03	46.73
W1d	29 35 51.9	48 10 54.5	Low vegetation sabkha	128.57	6.3	1.11	0.00	135.98	9.0	9.67
W2	29 36 38.2	48 10 28.4	Muddy soil along tidal flat habitat	227.27	111.11	0.00	0.00	338.38	20.87	16.47
W2a	29 38 21.8	48 13 16.7	Low vegetation sabkha	30.67	0.00	0.00	0.00	30.67	4.47	4.47
W2b	29 37 20.3	29 37 20.3	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W2c	29 36 51.3	48 11 00.3	Low vegetation sabkha	104.63	16.67	0.00	0.00	121.3	6.8	7.8
W3	29 38 28.9	48 10 57.0	Low vegetation sabkha	73.40	0.00	0.00	0.00	73.40	8.0	8.0
W4	29 39 42.8	48 10 45.9	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W5	29 41 58.3	48 09 35.29	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W5a	29 42 57.7	48 10 35.7	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
W7	29 43 31.08	48 7 11.4599	Muddy soil along tidal flat habitat	150.77	56.67	0.00	0.00	207.44	10.67	0.00
N1	29 49 51.6	48 10 11.856	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2	29 50 18.4199	48 10 37.8480	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N3	29 50 43.80	48 9 57.5280	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N4	29 52 5.52	48 9 26.64	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N5	29 52 34.3559	48 7 45.66	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N6	29 54 17.1359	48 1 27.048	Tidal channel habitat	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F00	29 52 19.7	48 16 46.2	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0
F01	29 52 01.1	48 16 22.9	Low vegetation sabkha	40.2	0.00	0.00	0.00	40.2	1.0	1.0
F02	29 51 22.6	48 15 15.3	Low vegetation sabkha	29.73	0.00	0.00	0.00	29.73	0.5	0.5
F03	29 51 01.4	48 14 42.2	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F04	29 50 00.3	48 13 30.3	Low vegetation sabkha	29.9	0.00	0.00	0.00	29.9	0.8	0.8
F05	29 49 21.0	48 12 44.0	Low vegetation sabkha	15.77	0.00	0.00	0.00	15.77	0.3	0.3
F06	29 48 58.1	48 11 44.2	Low vegetation sabkha	31.6	0.00	0.00	0.00	31.6	1.0	1.0
F07	29 44 21.3	48 21 29.1	Aeolian drift habitat	108.9	0.00	0.00	0.00	108.9	11.3	11.3
F09	29 44 42.2	48 21 12.2	Aeolian drift habitat	115.17	0.00	0.00	0.00	115.17	13.0	13.0
F10	29 44 01.4	48 21 49.0	Bare vegetation sabkha	0.00	0.00	0.00	0.00	0.00	0.0	0.0

and July-October, as these times are considered to represent peak biomass production of these species. All annual grasses and forb species were clipped at ground level, dried at 70°C for 24 hours and weighed. Perennial shrub, forb and grass clippings were also taken from 15 (1 x 2 m) quadrats randomly located within each site. The current year's growth was clipped, bagged, dried at 80°C for 72 hours, and weighed.

b. Ground cover: Ground cover, or percent cover, is a parameter used to evaluate range condition and abundance of plant species (Schimwell, 1971; Brown, 2001a). Percent cover composition was determined by using the quadrat-placement method (Canfield, 1941; Brown, 1954, 2001a; Abbadi and El-Sheikh, 2002). Three temporary 50 m transects were used in each site, and on each transect line, five (30 x 60 cm) quadrats were located at random. The percent cover composition of bare ground, litter and total vegetation by species was determined.

c. Species frequency: The determination of this quantitative measure is important as it provides information on species distribution (Brown, 1954, 2001a). The quadrat method was used to estimate the presence or absence of individual species. Three 50 m temporary transect lines were located at each site, and on each transect line, five (30 x 60 cm) quadrats were located randomly. The presence and absence of each individual perennial and annual species were recorded (Brown, 2001b).

d. Density: Density is a parameter used for studying species' dispersal mechanisms (Schimwell, 1971; Brown, 2001). The number of plants per unit area (density) was estimated by the quadrat method. Three temporary 50 m transects were located in each site and on each transect line, five (30 x 60 cm) quadrats were located at random on each transect. The number of plants of each species was recorded and an estimate was made of the number of species per unit area.

e. Zonation along transect line: Three line transects were taken at three sites, with different zonations. The transects ran perpendicular to the shoreline and to the vegetation belts, their length varying according to the sites. The vegetation communities were analyzed along the transect lines.

To quantify the vegetative cover, the vegetation base image of the islands was prepared by using a vegetative index value calculated from remotely sensed Landsat data of Boubyan Island collected on March 6, 2001. The processing was done with dedicated remote sensing Geomatica software.

Results and Discussion

Qualitative assessment: A record of all the existing and identified perennial and annual plant species during the first growing season was prepared, as well as a photographic record for some of the plant species found on the island (see section: Boubyan Island: Perennial and Annual Plant Species). Qualitative evaluation was prepared from field records of all existing perennial and annual plant species for each of the selected study sites within Boubyan Island during the 2003-2004 growing season. Locations of study sites are shown in Fig. 1. Most of the species reported in Omar (1985) were found on the island with the exception of *Silene salsa*. This species is very rare and difficult to find. It is possible that this species disappeared from the island due to human activities. A total of 52 plant species belonging to 18 families were identified on the island. The highest score was recorded in sites Ras Al Qayd (E2) and Ras Al Barshah (W1C) (29 and 42 respectively).

Quantitative evaluation of vegetation: The average biomass of shrub, perennial grass, annual forbs and annual grasses at Boubyan Island in the different study sites is shown in Table 1. **Table 2** shows the percent cover, species frequency and density in the different study sites within Boubyan Island.

From the data collected and recorded in the tables, figures, plates, and from data analysis, the following is a general account of habitat and vegetation that appeared in Boubyan and Warbah Islands.

A. Type of Habitats

1. Tidal channel habitat: In this habitat *Halocnemum strobilaceum* is the dominant perennial species, with coverage from 19-57% in winter. The herbage production of this habitat varies between 200-2600 kg/ha. The width of this zone varies from a few meters to about 600 m. During summer, the mud bank is covered with the annual halophytic species *Salicornia europaea* and *Bienertia cycloptera*, in addition to *Halocnemum strobilaceum* with a coverage up to 100%. Sites E3, E4, W1, N1, N2, N3, N4, N5 and N6 represent the tidal channel habitat (Fig. 1). In this habitat, for example W1, the plant cover is higher in summer than in spring (Table 1). It is dominated by the perennial species *Halocnemum strobilaceum* all year. In summer (June-October) the annual species *Salicornia europaea* and *Bienertia cycloptera* show lush growth in the low water-logged mud banks, with the perennial species *Halocnemum strobilaceum* giving higher plant coverage in summer.

2. Aeolian drift habitat: The vegetation of this habitat is characterized by its organization into zones, which are

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parallel with the shoreline. The width and the sequence of zones differ from one site to another. The zonational sequence also varies according to site and is frequently modified by local topography and sand accumulation. The first zone in this habitat is always dominated by a *Seidlitzia rosmarinus* community, which form small sand mounds. The vegetation coverage in the community varies between 11-46%, and herbage production varies between 109-800 kg/ha. In some sites, such as C3 (Fig. 1 and **Plate 1**), which is an aeolian drift habitat, the *Seidlitzia rosmarinus* community is found in pure stands to form the first zone.

The halophytic annual species recorded in winter is *Frankenia pulverulenta*. The *Seidlitzia* community is then followed by a zone of a *Halocnemum strobilaceum* community in the saline soil (sabkha). In other sites (Sites E2 and W1C, Fig. 1 and **Plate 2**) a *Seidlitzia rosmarinus* zone shelters a number of halophytic perennial species: *Zygophyllum qatarense, Anabasis setifera, Suaeda vermiculata, Scrophularia deserti, Atriplex leucoclada,* and *Erodium glaucophyllum*. The halophytic annual species recorded are *Frankenia pulverulenta, Sphenopus divaricatus, Bassia eriophora, Bassia muricata* and *Herniaria hemistemon*.

The non-halophytic perennial species recorded in this community are *Fagonia bruguieri, Helianthemum lippii,* and *Stipagrostis plumosa*. The non-halophytic annual species recorded in this community are *Launaea capitata, Launaea mucronata, Paronychia arabica, Senecio glaucus, Reichardia tingitana, Rostraria pumila, Rumex vesicarius, Erodium laciniatum, Cutandia memphitica, Emex spinosa, Trigonella stellata, Ifloga spicata, Oligomeris linifolia, Spergularia diandra, Stipa capensis, Hordeum marinum, Schismus barbatus, Arnebia decumbens, Asphodelus tenuifolius, Cakile arabica, Erodium laciniatum, Filago pyramidata, Picris babylonica, Plantago ovata* and *Stipa capensis*.

In depressions (low ground affected by tidal action) within the *Seidlitzia* zone, *Halocnemum strobilaceum* communities appear in pure stands or associated with other halophytic perennial species such as *Zygophyllum qatarense, Atriplex leucoclada, Aeluropus lagopoides* and *Phragmites australis*. The annual halophytic species recorded in this community are *Trachynia distachya, Bromus madritensis, Astragalus corrugatus, Astragalus tribuloides, Frankenia pulverulenta, Sphenopus divaricatus* and *Parapholis incurva*. When the ground level rises from the adjacent community of *Halocnemum strobilaceum*, there is a narrow pure community of *Zygophyllum qatarense*, forming small mounds because of wind action.

In this habitat the plant cover is higher in spring than in summer, for example Sites E2, C3, and W1C. Because of the topography and sand accumulation, the habitat is always dominated by a *Seidlitzia rosmarinus* community, sometimes in a pure stand and in others it shelters a number of halophytic perennial species. The difference between spring and summer vegetation cover is due to the growth of the non-halophytic annual species which depend on the rain water and grow in the higher ground, avoiding the high soil salinity.

3. Inland sabkha habitat: This habitat is characterized by its highly saline soil. Areas include sabkha without any vegetation cover (Sites E5, E6, E7, E8, E14, E16, C4, C7, C8, C9, C10, C14, C15, C16, W1a, W1b, W2b, W4, W5, W5a, F00, F03 and F10 in Fig. 1, **Plates 3 and 4**) and sabkha with low vegetation cover ranging from between 0.5-9%. In the latter, herbage production varies between 29-190 kg/ha and is dominated by the perennial *Halocnemum strobilaceum*. The halophytic annual species recorded in winter are *Frankenia pulverulenta* and *Sphenopus divaricatus* (Sites E12, E13, E15, C5, C6, C11, C12, C13, W1D, W2A, W2C, W3, F01, F02, F04, F04, F05 and F06 in Fig. 1).

In most of Boubyan Island, there was only minimal plant life on the bare ground and on the low vegetation sabkha (80% of the island). The low vegetation sabkha did not show an obvious variation in vegetation cover between seasons. It was dominated by the perennial species *Halocnemum strobilaceum*, which is an evergreen plant and shows lush growth and flowers in October. Inland, in a sabkha habitat this species looked unhealthy and was clearly suffering from the high salinity. The small differences in plant cover between summer and spring in the low vegetation sabkha sites such as E12, E15, C11, C12, C13, W1d and W2c (Table 1) are related to the two annual halophytic forbs *Frankenia pulverulenta* and *Sphenopus divaricatus*, which bloom in spring.

4. Muddy boil along tidal flats habitat: *Halocnemum strobilaceum* is the dominant perennial species with 10-21% cover here. Herbage production varies between 200-340 kg/ha. In this habitat the plant cover is higher in summer than in spring, for example Sites W2 and W7. The habitat usually occupies the muddy shoreline. It is dominated by the perennial species *Halocnemum strobilaceum* all year. In summer (June-October) the annual species *Salicornia europaea* and *Bienertia cycloptera* show lush growth in the low waterlogged mud banks recorded (Sites W2 and W7 in Fig. 1 and **Plate 5**).

B. Zonations

Three line transects were taken at Sites W1D, W1C, and E2. These sites have different zonations. Transects ran perpendicular to the shoreline and vegetation belts. The length of transect varied according to the site, i.e., Site

Table 2. Percent Cover, Species Frequency and Density at Sites E1-E53 during the 2003/2004 Growing Season in Boubyan Island, Kuwait

Site No.	Parameter	Cover (%)	Frequency (%)	Density (m²)
E1	Bare	100	-	-
	Total vegetation	0	-	-
E2	Bare	72.27	-	-
	Total vegetation	27.73	-	-
	Shrub			
	Atriplex leucoclada	0.33	6.67	0.37
	Scrophularia deserti	1.67	13.33	1.85
	Seidlitzia rosmarinus	0.20	6.67	0.37
	Zygophyllum qatarense	4.47	40.00	2.22
	Annual grass			
	Cutandia memphitica	1.67	26.67	41.85
	Rostraria pumila	2.00	53.33	48.89
	Stipa capensis	1.13	20.00	14.07
	Annual forb			
	Erodium laciniatum	1.00	26.67	5.56
	Filago pyramidata	3.47	46.67	172.22
	Frankenia pulverulenta	1.46	26.67	79.63
	Ifloga spicata	0.60	20.00	22.59
	Launaea mucronata	0.07	6.67	0.74
	Picris babylonica	0.73	40.00	2.59
	Senecio glaucus	8.33	86.67	69.26
	Trigonella stellata	0.60	13.33	2.96
E3	Bare	48.40	-	-
	Total vegetation	51.60	-	-
	Shrub			
	Halocnemum strobilaceum	51.60	100.00	53.33
E4	Bare	81.07	-	-
	Total vegetation	18.93	-	-
	Shrub			
	Halocnemum strobilaceum	18.93	100.00	9.63
E5	Bare	100	-	-
	Total vegetation	0	-	-
E6	Bare	100	-	-
	Total vegetation	0	-	-
E7	Bare	100	-	-
	Total vegetation	0	-	-
E8	Bare	100	-	-
	Total vegetation	0	-	-
E9	Bare	97.07	-	-
	Total vegetation	2.93	-	-
	Shrub			
	Halocnemum strobilaceum	1.80	20.00	0.54
	Annual forb			
	Frankenia pulverulenta	1.13	20.00	14.07
E10	Bare	96.67	-	-
	Total vegetation	3.33	-	-
	Shrub			
	Halocnemum strobilaceum	3.33	6.67	1.48
E11	Bare	100	-	-
	Total vegetation	0	-	-

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Site No.	Parameter	Cover (%)	Frequency (%)	Density (m²)
E12	Bare	96.00	-	-
	Total vegetation	4.00	-	-
	Shrub			
	Halocnemum strobilaceum	3.07	20.00	1.11
	Annual forb			
	Frankenia pulverulenta	0.93	20.00	3.33
E13	Bare	100	-	-
	Total vegetation	0	-	-
E14	Bare	100	-	-
	Total vegetation	0	-	-
E15	Bare	100	-	-
	Total vegetation	0	-	-
E16	Bare	64.53	-	-
	Total vegetation	35.47	-	-
	Shrub			
	Halocnemum strobilaceum	30.67	80.00	14.44
	Seidlitzia rosmarinus	2.00	6.67	0.37
	Annual forb			
	Frankenia pulverulenta	2.67	33.33	13.33
	Oligomeris linifolia	0.13	6.67	0.37
E17	Bare	100	-	-
	Total vegetation	0	-	-
E18	Bare (sabkha)	99.67	-	-
	Total vegetation	0.33	-	-
	Shrub			
	Halocnemum strobilaceum	0.33	6.67	0.74
E19	Bare	92.53	-	-
	Total vegetation	7.47	-	-
	Shrub			
	Halocnemum strobilaceum	7.47	53.33	10.00
E20	Bare	100	-	-
	Total vegetation	0	-	-
E21	Bare	100	-	-
	Total vegetation	0	-	-
E22	Bare	100	-	-
	Total vegetation	0	-	-
E23	Bare	100	-	-
	Total vegetation	0	-	-
E24	Bare	97.67	-	-
	Total vegetation	2.33	-	-
	Shrub			
	Halocnemum strobilaceum	1.00	6.67	0.37
	Annual forb			
	Frankenia pulverulenta	1.33	13.33	112.22
E25	Bare	94.27	-	-
	Total vegetation	5.73	-	-
	Shrub			
	Halocnemum strobilaceum	0.73	13.33	0.74
	Annual grass			
	Sphenopus divaricatus	1.13	13.33	57.41
	Annual forb			
	Frankenia pulverulenta	3.87	33.33	331.48

Site No.	Parameter	Cover (%)	Frequency (%)	Density (m²)
E26	Bare	97.20	-	-
	Total vegetation	2.80	-	-
	Shrub			
	Halocnemum strobilaceum	2.33	6.67	0.37
	Annual forb			
	Frankenia pulverulenta	0.47	20.00	24.81
E27	Bare	100	-	-
	Total vegetation	0	-	-
E28	Bare	100	-	-
	Total vegetation	0	-	-
E29	Bare	100	-	-
	Total vegetation	0	-	-
E30	Bare	42.80	-	-
	Total vegetation	57.20	-	-
	Shrub			
	Halocnemum strobilaceum	9.87	20	1.11
	Annual forb			
	Bienertia cycloptera	2.00	20	4.07
	Salicornia europaea	45.33	66.67	229.63
E31	Bare	100	-	-
	Total vegetation	0	-	-
E32	Bare	100	-	-
	Total vegetation	0	-	-
E33	Bare	53.27	-	-
	Total vegetation	46.73	-	-
	Shrub			
	Erodium glaucophyllum	2.20	13.33	0.74
	Halocnemum strobilaceum	3.33	46.67	3.33
	Helianthemum lippii	2.00	20.00	6.67
	Seidlitzia rosmarinus	5.30	13.33	0.74
	Zygophyllum qatarense	1.20	13.33	0.74
	Annual grass			
	Parapholis incurva	6.73	20.00	31.48
	Rostraria pumila	6.33	46.67	195.93
	Sphenopus divaricatus	3.27	53.33	103.70
	Stipa capensis	0.27	26.67	1.48
	Annual forb			
	Asphodelus tenuifolius	0.13	6.67	0.37
	Astragalus tribuloides	0.33	6.67	1.85
	Filago pyramidata	0.53	6.67	4.07
	Frankenia pulverulenta	3.80	46.67	115.18
	Ifloga spicata	0.06	6.67	0.74
	Launaea capitata	0.47	20.00	1.85
	Launaea mucronata	0.80	13.33	3.33
	Oligomeris linifolia	1.08	20.00	3.33
	Plantago ovata	1.33	13.33	12.96
	Reichardia tingitana	0.67	20.00	1.11
	Rumex vesicarius	0.67	6.67	0.74
	Senecio glaucus	5.00	53.33	25.19
	Spergularia diandra	0.20	20.00	1.11
	Trigonella stellata	0.33	6.67	1.11
	Perennial grass			
	Aeluropus lagopoides	0.67	6.67	0.37

Site No.	Parameter	Cover (%)	Frequency (%)	Density (m²)
E34	Bare	90.33	-	-
	Total vegetation	9.67	-	-
	Shrub			
	Halocnemum strobilaceum	9.00	53.33	5.56
	Annual forb			
	Sphenopus divaricatus	0.53	13.33	4.44
	Annual grass			
	Frankenia pulverulenta	0.13	6.67	2.96
E35	Bare	79.13	-	-
	Total vegetation	20.87	-	-
	Shrub			
	Halocnemum strobilaceum	14.47	46.67	17.04
	Salsola imbricata	2.00	6.67	0.37
	Annual forb			
	Bienertia cycloptera	2.00	6.67	0.37
	Salicornia europaea	2.40	6.67	4.44
E36	Bare	95.53	-	-
	Total vegetation	4.47	-	-
	Shrub			
	Halocnemum strobilaceum	4.47	20.00	1.11
E37	Bare	100	-	-
	Total vegetation	0	-	-
E38	Bare	92.20	-	-
	Total vegetation	7.80	-	-
	Shrub			
	Halocnemum strobilaceum	6.80	26.67	2.20
	Annual forb			
	Frankenia pulverulenta	1.00	13.33	2.20
E39	Bare	92.00	-	-
	Total vegetation	8.00	-	-
	Shrub			
	Halocnemum strobilaceum	8.00	20.00	1.11
E40	Bare	100	-	-
	Total vegetation	0	-	-
E41	Bare	100	-	-
	Total vegetation	0	-	-
E42	Bare	100	-	-
	Total vegetation	0	-	-
E43	Bare	89.33	-	-
	Total vegetation	10.67	-	-
	Shrub			
	Halocnemum strobilaceum	9.00	26.67	1.85
	Annual forb			
	Salicornia europaea	1.67	13.33	3.33
E44	Bare	100	-	-
	Total vegetation	0	-	-
E45	Bare	99.00	-	-
	Total vegetation	1.00	-	-
	Shrub			
	Halocnemum strobilaceum	1.00	6.66	0.33

Site No.	Parameter	Cover (%)	Frequency (%)	Density (m²)
E46	Bare	99.46	-	-
	Total vegetation	0.5	-	-
	Shrub			
	Halocnemum strobilaceum	0.5	6.66	0.33
E47	Bare	100	-	-
	Total vegetation	0	-	-
E48	Bare	99.2	-	-
	Total vegetation	0.8	-	-
	Shrub			
	Halocnemum strobilaceum	0.8	6.66	0.74
E49	Bare	99.7	-	-
	Total vegetation	0.3	-	-
	Shrub			
	Halocnemum strobilaceum	0.3	6.66	0.33
E50	Bare	99.00	-	-
	Total vegetation	1.0	-	-
	Shrub			
	Halocnemum strobilaceum	1.0	6.66	0.33
E51	Bare	75.03	-	-
	Total vegetation	11.3	-	-
	Shrub			
	Halocnemum strobilaceum	11.3	66.66	6.27
E52	Bare	87.00	-	-
	Total vegetation	13.00	-	-
	Shrub			
	Halocnemum strobilaceum	10.7	53.3	5.55
	Seidlitzia rosmarinus	1.6	6.66	0.37
	Zygophyllum qatarense	0.7	6.66	0.37
E53	Bare	100	-	-
	Total vegetation	0	-	-

W1D = 165 m, Site W1C = 331 m and Site E2 = 539 m. The different zonations along these transect lines were identified.

Site W1D: The results of the vegetation analysis along this transect line are shown in **Fig. 2**, which represents the soil profile transect and the different zonations. The communities along the transect are:

1. Bare ground (the first 15 m is a disturbed area): The soil is shelly sand.
2. Community of *Halocnemum strobilaceum*: This community is about 50 m in width. *Halocnemum strobilaceum* is the dominant, sole, perennial species with coverage of 9%. Two annual halophytic species appeared, *Frankenia pulverulenta* and *Sphenopus divaricatus*, with coverage of 0.5 and 0.1% respectively. The soil is wet Aquisalids.
3. Bare ground (no vegetation recorded): The soil is Aquisalids.

Site W1C (Ras Al Barshah): The results of the vegetation analysis along the transect line are shown in **Fig. 3**, which represents the profile transect and the different zonations. The communities along the transect are:

1. Bare ground (the first 25 m disturbed area).
2. Community of *Seidlitzia rosmarinus*: This community forms small sand mounds and is about 58 m in width. The soil is shelly sand, whitish in color (Typic Torriorthents). This community shelters a number of perennials which are mostly halophytic, such as *Suaeda vermiculata, Zygophyllum qatarense, Atriplex leucoclada, Scrophularia deserti, Erodium glaucophyllum, Helianthemum lippii* and *Stipagrostis plumosa*. The community is also characterized by the appearance of several halophytic (*Frankenia pulverulenta and Spheno-*

Plate 1. Site C3, which represents aeolian drift habitat with *Seidlitzia rosmarinus* community type

Plate 2. Site E2, which represents aeolian drift habitat

Plate 3. Site C16, which represents a bare vegetation sabkha

Plate 4. Site C15, which represent a bare vegetation sabkha

Plate 5. Site W7, which represents a muddy soil along tidal flat habitat

pus divaricatus) and non-halophytic annual species (*Launaea capitata, Launaea mucronata, Paronychia arabica, Senecio glaucus, Picris babylonica, Filago pyramidata, Cistanche tubulosa, Cakile arabica, Schismus barbatus, Plantago ovata, Reichardia tingitana, Rostraria pumila, Rumex vesicarius, Erodium laciniatum, Cutandia memphitica, Emex spinosa, Trigonella stellata, Ifloga spicata, Oligomeris linifolia, Spergularia diandra, Stipa capensis, Hordeum marinum and Herniaria hemistemon*).

3. Community of *Halocnemum strobilaceum*: This community is about 13 m in width. The ground is a little low (depression) and soil is slightly moist, which is suitable for *Halocnemum* growth. *Zygophyllum qatarense* and *Atriplex leucoclada* occurred in this zone with some annuals such as *Frankenia pulverulenta, Sphenopus divaricatus, Bromus madritensis, Trachynia distachya, Stipa capensis, Rumex vesicarius* and *Senecio glaucus*.
4. Community of *Zygophyllum qatarense*: This community is about 8 m in width; the ground level rises from the

adjacent community of *Halocnemum strobilaceum* and supports a pure *Zygophyllum* community.

5. Community of *Halocnemum strobilaceum*: This community is about 14 m in width. The ground is a little low (depression) and the soil is a moist aquisalids. The associated perennial species are *Atriplex leucoclada and Aeluropus lagopoides*; also present are halophytic annuals, such as *Frankenia pulverulenta, Parapholis incurva and Sphenopus divaricatus*. The non-halophytic annuals are *Senecio glaucus, Rumex vesicarius, Oligomeris linifolia, Astragalus corrugatus, Astragalus tribuloides, Reichardia tingitana, Filago pyramidata, Trigonella stellata, Stipa capensis* and *Rostraria pumila.*
6. Community of *Halocnemum strobilaceum*: The ground level rises a little in this community and its width is 47 m. The perennial *Fagonia bruguieri*, which grows in saline soil, was recorded here. The annuals that grow in this community are *Senecio glaucus, Frankenia pulverulenta, Oligomeris linifolia, Spergularia diandra* and *Rostraria pumila*.
7. Community of *Zygophyllum qatarense*: This community is about 66 m in width. The soil is shelly sand, whitish in color (Typic Torriorthents), and the ground level rises a little from the adjacent community. The *Zygophyllum* plants form small sand mounds because of the wind action. The perennial *Anabasis setifera* also grows in this community.
8. Community of *Halocnemon strobilaceum*: This community occupies most of the landward side. It is characterized by a poor cover of *Halocnemum strobilaceum*, which is the dominant species; the soil is an Aquisalids.

Site E2 (Ras Al Qayd): The results of the vegetation analysis along the transect line are shown in **Fig. 4**, which represents the profile transect and the different zonations. The communities along the transect are:

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1. Bare ground for the first 20 m to the sea: Characterized as disturbed area with no vegetation cover.
2. Community of *Seidlitzia rosmarinus* and *Zygophyllum qatarense*: This community forms small sand mounds and is about 34 m in width. The soil is a shelly sand and whitish in color (Typic Torriorthents). The community shelters a number of halophytic perennial species: *Suaeda vermiculata, Atriplex leucoclada, Scrophularia deserti,* and *Phragmites australis.* The non-halophytic annual species are *Launaea capitata, Launaea mucronata, Paronychia arabica, Senecio glaucus, Reichardia tingitana, Rostraria pumila, Rumex vesicarius, Erodium laciniatum, Cutandia memphitica, Emex spinosa, Trigonella stellata, Ifloga spicata, Oligomeris linifolia, Spergularia diandra, Stipa capensis* and *Hordeum marinum*. The halophytic annual species recorded are *Frankenia pulverulenta* and *Sphenopus divaricatus*. The parasitic plant *Cistanche tubulosa* has been recorded.
3. Community of *Halocnemum strobilaceum*: This community is about 15 m in width. The ground is slightly low (depression), moist and salty, which is suitable for *Halocnemum strobilaceum* growth. The associated perennial halophytic species are *Suaeda vermiculata* and *Atriplex leucoclada*.
4. Community of *Zygophyllum qatarense*: This community is about 21 m in width. The ground level is a little higher than the adjacent community of *Halocnemum strobilaceum*. The annual species *Senecio glaucus, Frankenia puverulenta* and *Sphenopus divaricatus* were recorded.
5. Bare ground 14.5 m in width: The ground is low and the soil is a muddy Aquisalids without any vegetation.
6. Community of *Halocnemum strobilaceum*: In this community the ground starts to rise gradually. *Halocnemum strobilaceum* started to appear again in association with other halophytic perennial species, like *Zygophyllum qatarense, Suaeda vermiculata* and *Atriplex leucoclada*. The width of this community is 102 m.
7. Community of *Halocnemum strobilaceum*: This community is about 56 m in width. The ground is a little low (depression) and the soil is a moist Aquisalids. *Halocnemum strobilaceum* is the sole perennial species; the halophytic annual species recorded is *Parapholis incurva*.
8. Community of *Halocnemum strobilaceum*: The ground level rises gradually in this community and its width is about 26 m. The associated halophytic species are *Zygophyllum qatarense* and *Suaeda vermiculata*.
9. Community of *Halocnemum strobilaceum*: This community is about 24.5 m in width. The ground is a little low (depression) and the soil is a moist Aquisalids. The perennial grass *Aeluropus lagopoides* was recorded in addition to the halophytic annuals *Frankenia pulverulenta, Sphenopus divaricatus* and *Parapholis incurva*.
10. Community of *Zygophyllum qatarense*: This community is about 26 m in width. The ground level is higher than the adjacent community. The perennial shrub *Suaeda vermiculata* was recorded here.
11. Community of *Halocnemum strobilaceum*: The ground level is a little low (depression) and the soil is a very Aquisalids because it is adjacent to a tidal channel. *Halocnemum strobilaceum* is the only species and covers about 50% of the ground. The width of this community is about 54.5 m.
12. Bare ground 20 m in width: This ground represents a tidal channel; the ground is muddy Aquisalids without any vegetation cover.
13. Community of *Halocnemum strobilaceum*: The width of this community is about 17 m; the ground starts to rise gradually. *Halocnemum strobilaceum* started to appear again in association with the perennial shrub *Suaeda vermiculata.* The halophytic annual *Sphenopus divaricatus* and the non-halophytic annual *Senecio glaucus* were present.

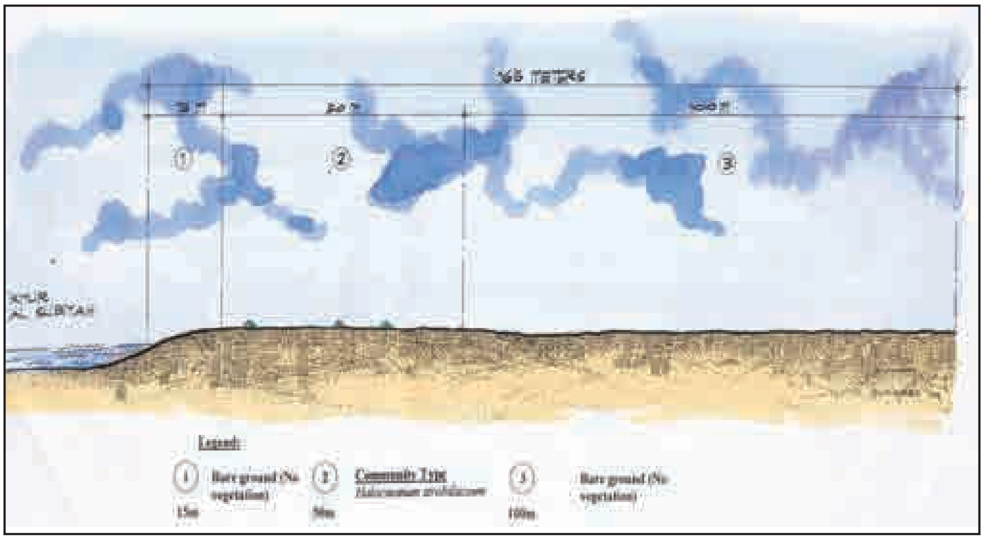

Fig. 2. Vegetation communities along 165 m transect line (W1D)

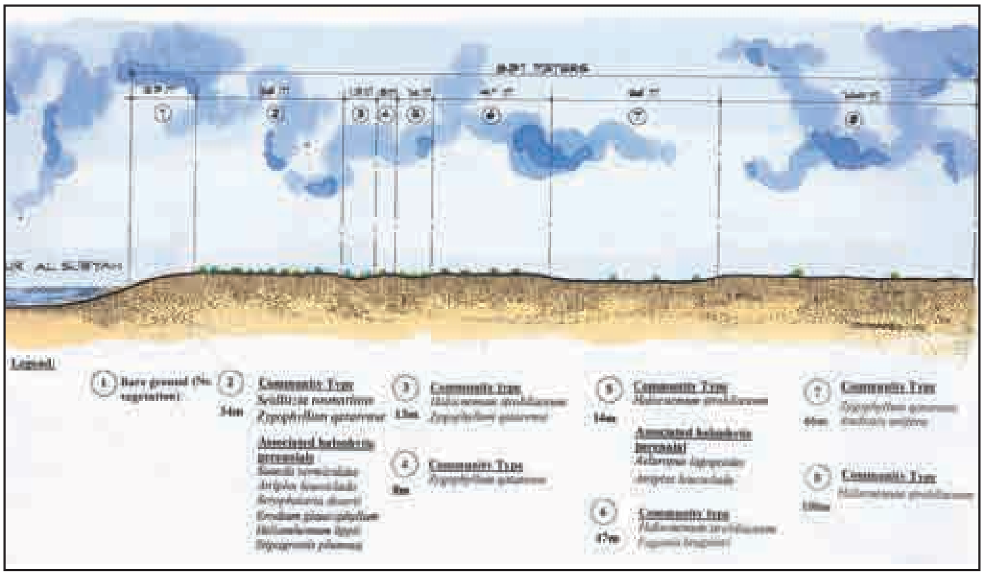

Fig. 3. Vegetation communities along 331 m transect line (W1C)

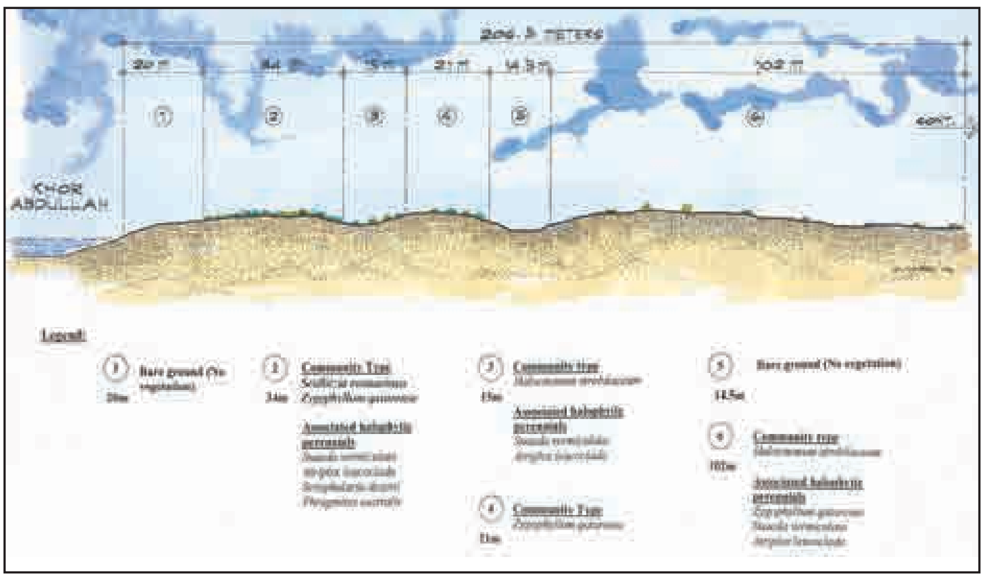

Fig. 4. Vegetation communities along 539 m transect line (E2)

8

Fig. 5. Surface coverage and productivity constraint map

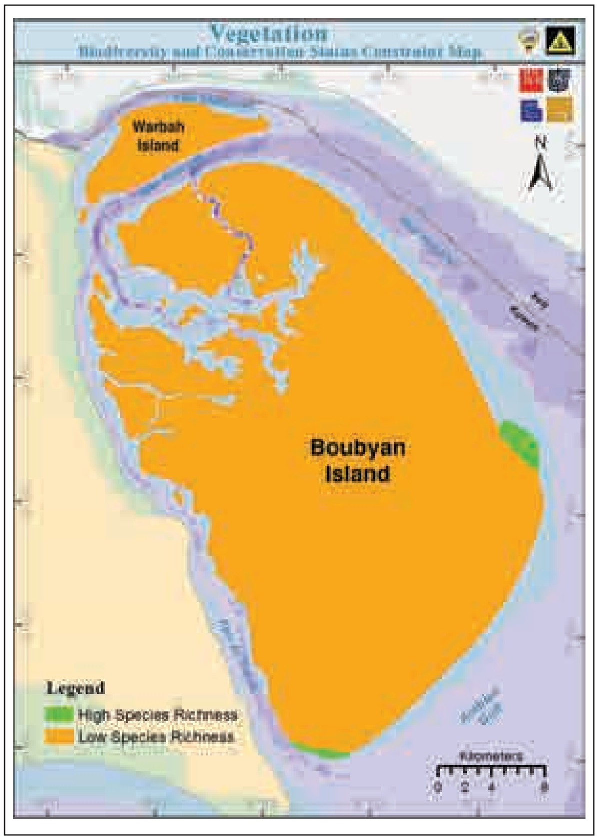

Fig. 6. Biodiversity and conservation status constraint map

14. Community of *Halocnemum strobilaceum*: This community occupies the most landward side. It is characterized by poor vegetation cover. *Halocnemum strobilaceum* is the pure dominant species. The soil is an Aquisalids.

Mapping the Vegetation of Boubyan and Warbah Islands

The normalized difference vegetation index (NDVI) is an index that provides a standardized method of judging vegetation greenness in satellite images. It is created by transforming raw image data into an entirely new image using algorithms to calculate the color value of pixels. NDVI is used as an indicator of relative biomass and greenness. Higher index values are associated with higher levels of healthy vegetation. The red areas in the image represent those with relatively high vegetation in Boubyan Island. Thus, KISR was able to produce images showing the vegetation matched with the actual ground status.

The vegetation is not continuous and background reflection from the soil was also a limiting factor in assessing the vegetation cover for Boubyan Island. The accuracy and reliability of the vegetation assessment image were achieved by means of proper ground truthing using field data and GIS application. Refer to the section on NDVI vegetation mapping in Chapter 1 for more image processing details.

Two vegetation constraint maps were produced at the end of the project, which helped in the environmental assessment and planning activities. The first map was a surface coverage and productivity constraint map (**Fig. 5**). The field data for percentage surface cover and production data (kg/ha) were used to categorize the vegetation in this map as high (over 25% cover and 500 kg/ha or greater biomass), medium (10-24% cover and 190-499 kg/ha biomass), low (1-10% cover and 14-189 kg/ha biomass) and bare (0% cover and less than 13 kg/ha biomass).

The second map was a biodiversity and conservation status constraint map (**Fig. 6**). The qualitative field data (plant species richness) was used to categorize the vegetation into high species richness and low species richness in this map. Results show that the dominant plant community (*Halocnemum strobilaceum*) is mainly distributed on the coastal line, with higher density in the extreme southwest, southeast, and the northern shores. The plant community in the northern shores of both Boubyan and Warbah Islands is dominated by *Halocnemum strobilaceum* and *Salicornia europaea*. Vegetation is scarce or non-existent in the inland island surface areas, creating large bare open areas, void of vegetation. The water channels and lagoons on the northern shores of Boubyan Island indicate favorable conditions for luxurious growth of *Halocnemum strobilaceum* and *Salicornia europaea*. The high tide and low tide action reduces the effects of salt

Table 3. List of Native Plant Species Which Can Be Used in Rehabilitation and Planting on Boubyan Island

Sl. No.	Scientific Name	Life Form	Growth Form	Propagation	Value
1.	*Aeluropus lagopoides*	p	g	r, s	f
2.	*Anabasis setifera*	p	s	s	f
3.	*Atriplex leucoclada*	p	s	s	f
4.	*Fagonia bruguieri*	p	s	s	m, f
5.	*Halocnemum strobilaceum*	p	s	s	f, n, s
6.	*Helianthemum lippii*	p	s	s	f
7.	*Phragmites australis*	p	g	r, s	f
8.	*Salicornia europaea*	a	f	s	f
9.	*Scrophularia deserti*	p	s	s	m, f, o
10.	*Stipagrostis plumosa*	p	g	s	f
11.	*Tamarix aucheriana*	p	s	s, c	s, f, o
12.	*Lycium shawii*	p	s	c, s	s, f, o
13.	*Nitraria retusa*	p	s	s, c	s, f, o

Key: Life form: p = perennial, a = annual. **Growth form:** f = forb, s = shrub, g = grass. **Propagation:** s = seed, r = rhizome, c = cutting. **Value:** f = fodder, s = shelter, m = medicinal, o = ornamental, n = nesting.

accumulation on plant tissues, reducing salinity stress on plants. Species richness in Ras Al Barshah and Ras Al Qayd is well recorded in the qualitative vegetation assessment reported in this document.

Recommendations for Flora Protection of the Islands

Vegetation communities on Boubyan and Warbah Islands are important for many reasons. They serve as food and habitat for fish and wildlife, act as a filter by removing pollutants from the water, slow erosion by establishing roots that anchor the soil and provide a recreational and educational opportunity for local residents.

Recommendations have been made for the protection of areas of high vegetation cover and herbage production, such as the northern khors of Boubyan and Warbah Islands. Also, areas that have the highest level of floral species diversity, like Ras Al Barshah and Ras Al Qayed, were recommended for protection.

To minimize the negative environmental impact on the vegetation and natural habitat, all the roads and infrastructure (resorts, campground, chalets) must be located at least 700 m inland or away from the shoreline (buffer zone).

To rehabilitate the disturbed areas and to green the urban area and resorts, some native plant species can be introduced to the islands. Other existing species can be propagated and multiplied, especially those that have limited distribution in Kuwait and on the islands. Some of these species are listed in **Table 3**.

Conclusion

A characteristic feature of the coastal salt marsh vegetation is its organization into zones or belts, which are more or less parallel with the shore. They are directly influenced by tidal action and also by the high saline water table. Accordingly, they correspond to both the inundation salines and the high water table saline (**Plate 6**). It is also suggested that ground level, in relation to tide or to water table, plays a role in determining plant distribution, possibly through affecting soil water and salt content.

The survey conducted by KISR (September 2003-October 2004) described the island's vegetation as uniform and of simple structure and mostly dominated by *Halocenemum strobilaceum*. Fifty-two native plant species belonging to 18 plant families were recorded in the island. The vegetation often shows a simple zonation along the coastal beach (on the low ridges), the width and sequence of which vary from site to site and appear to be related to microtopography. The low central mudflats of Boubyan are more or less permanently affected by the high water table and are bare of vegetation. The vegetation is rich on the shoreline and poor inland.

Plate 6. The vegetation of Boubyan is directly influenced by inundation salines and the high water table saline

Plate 7. Saltwater inundation is a primary factor determining the growth of *Halocnemum strobilaceum*

Plate 8. In summer the mud banks are covered with the annual halophytic species *Salicornia europaea* and *Bienertia cycloptera*

The occurrence of *Halocnemum strobilaceum* on the coastline of Boubyan may suggest that saltwater inundation is the primary factor determining its growth (**Plate 7**). Inundation seems to act mainly through increasing soil moisture and affects the soluble salt content to a level suitable for the germination and establishment of *Halocnemum*. The rainfall may also help in decreasing the salt content. The vertical elevation above the saline water table, aided by a large portion of coarse and fine sand, all contribute to produce a slightly saline, coarse-textured soil suitable for the growth of *Seidlitzia rosmarinus* and *Zygophyllum qatarense*. Luxuriant growth appears to be further associated with the accumulation of deep layers of different sand.

The following is a general account of habitat and vegetation occurring in Boubyan and Warbah salt marshes:

- **Tidal channel habitat:** In this habitat *Halocnemum strobilaceum* is the dominant perennial species, with coverage from 19-57% in winter. The herbage production of this habitat varies between 200-2600 kg/ha. During summer, the mud bank is covered with the annual halophytic species *Salicornia europaea* and *Bienertia cycloptera* (**Plate 8**).
- **Aeolian drift habitat:** The vegetation of this habitat is characterized by its organization into zones which are parallel with the shore. The first zone in this habitat is always dominated by a *Seidlitzia rosmarinus* community, which forms small sand mounds, and is then followed by a *Halocnemum strobilaceum* community. The vegetation coverage in the community varies between 11-46% and herbage production between 109-800 kg/ha.
- **Inland sabkha habitat:** This habitat is characterized by its highly saline soil and it is divided into bare vegetation sabkha without any vegetation cover and low vegetation sabkha with low vegetation cover ranging between 0.5-9%. Herbage production varies between 29-190 kg/ha and is dominated by the perennial *Halocnemum strobilaceum*.
- **Muddy soil along tidal flats habitat:** In this habitat *Halocnemum strobilaceum* is the dominant perennial species, covering from 10-21% of the area. Herbage production varies between 200-340 kg/ha.

The plant cover showed a seasonal variation in the tidal channel habitat; it was higher in summer than in spring because of the blooming of *Salicornia europaea* and *Bienertia cycloptera*. In the aeolian drift habitat the plant cover was higher in spring than summer due to the growth of the non-halophytic annual species.

Two vegetation constraint maps were produced at the end of the project, which helped in the environmental assessment and planning activities. For sustained development of both Boubyan and Warbah Islands, recommendations have been made for the protection of the areas of high vegetation cover, herbage production and floral species diversity. The northern khors of Boubyan and Warbah Islands, Ras Al Barshah and Ras Al Qayed, are recommended areas for protection. To rehabilitate disturbed areas and to green the urban area and resorts during the process of island development, some native plant species were recommended for planting.

Boubyan Island: Perennial and Annual Plant Species

The following plant descriptions were prepared using a range of source literature, the most recent of which was Omar et al. (2000). The plants are categorized according to the following sequence: genus and species, name, family and local name.

Aeluropus lagopoides (L.) Trin. ex Thwaites
GRAMINEAE
Ikrish
This perennial is a pubescent grass that sometimes has densely tufted culms and at other times has widely spreading prostrate stems. It has stolons or rhizomes covered with overlapping scales and inflorescence with a terminal head of hairy spikelets. It is a halophyte and grows on saline ground around cultivated areas and salt marshes. It is propagated by rhizomes and seeds. The plant is used as fodder.

Anabasis setifera Moq.
CHENOPODIACEAE
Sharan
This is a glabrous perennial succulent shrublet (above), about 60 cm tall, with numerous erect stems and fleshy cylindrical, club-shaped, horizontal leaves, 8-10 mm long and 4-6 mm wide, ending in a deciduous bristle. The flower cluster is in the upper axils. The fruiting perianth has five wings, which are often compressed laterally due to crowding of the fruits. The plant is commonly found in hot deserts, moist saline regions and wadi beds, often on gypsaceous ground. The plant is used as fodder. It flowers between August and November.

Arnebia decumbens (Vent.) Coss and Kralik
BORAGINACEAE
Kahil
An annual herb (above), this is one of the most common of the desert flowers and blooms early in spring. It is a narrow-leafed herb with yellow flowers arranged densely on a V-shaped cyme. Later in the season, the curving stems elongate and bear more yellow flowers. It will reach 20 cm in height if there is sufficient moisture. The leaves are stiff alternate and lanceolate and have bristles along the stem. The roots produce a red dye that can be rubbed off with the fingers and applied to the skin as rouge. The plant flowers in February.

Asphodelus tenuifolius (Cav.) Baker
LILIACEAE
Barwaq
This annual, elegant lily (above) is about 30 cm high. It has bright green, grass-like leaves arising from the base. The flowers are white and bell-shaped with a brownish midrib down each petal. The seeds are formed in a globular capsule about 3 mm across. The plant has fibrous roots rather than a bulb, as typically seen in lilies, and it is used as an ornamental plant. It flowers in February.

Astragalus corrugatus Bertol.
LEGUMINOSAE
Abou Qurainah
This annual forb (above) is a glabrous to sparingly appressed hairy plant with densely branched stems. Its leaves are made up of 11-17 leaflets, with their tips cut straight across. The flowers are white to pinkish in short racemes. It has erect, almost cylindrical, semicircular smooth pods 3-4 cm long. It grows in fine shallow soils and the plant is used as fodder. It flowers from March to April.

Atriplex leucoclada Boiss.
CHENOPODIACEAE
Al Rughl
This is a woody perennial shrub (above), about 40 cm tall, with silvery twigs that branch in a prostrate fashion. The silvery leaves are alternate, triangular and undulate. Bud-like clusters of flowers appear in the axils and on terminal clusters. It is commonly found on sandy calcareous soil, such as the type found in Ad-Dhubaiyah and Al Khiran. The plant is used as fodder.

Astragalus tribuloides Delile
LEGUMINOSAE
Rukhami, Qafaa
This is a small, silvery, hairy, annual herb with numerous prostrate stems (above) with 15-19 small, pointed, furry leaflets to a leaf. The flowers are pale purple with tubular, glabrous or white hairy calyxes and a whitish corolla. The pods are stellately divergent, 5-12 mm long, slightly curved with acute tips, and the seeds are quadrangular, nearly smooth and yellow. It likes a sandy soil habitat and is used as fodder. It flowers from March to April.

Bassia eriophora (Schrad.) Asch.
CHENOPODIACEAE
Qittaina
This annual herb (above) is commonly found in disturbed areas or in areas irrigated by brackish water. It is about 15 cm tall, identified by the cotton-like appearance of its fruit that is enclosed in balls of dense white hairs. It is used as an ornamental plant and flowers during February to April.

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Bassia muricata (L.) Asch.
CHENOPODIACEAE
Haitham, Qutaynah
An annual herb, this densely tomentose plant (above) reaches 30 cm in height with many erect to decumbent stems branching from the base. The stem is reddish and pubescent. The leaves are linear, alternate, densely hairy and sessile. The flowers are solitary or clustered in the axils. The fruit is a perigonium, star-shaped and yellow with five spines twice the length of the disc. The plant is used as an ornamental plant and as fodder. It is found on sandy and stony ground and flowers between February and March.

Bienertia cycloptera Bunge ex Boiss.
CHENOPODIACEAE
Golleman
This halophytic, salt-loving annual plant (above) grows in salt marsh areas and on sabkhas. It is about 60 cm high and has apple green, glabrous, succulent, linear leaves. It has minute flowers, about 2 mm in diameter, loosely arranged on a receme, followed by a fruit embedded in a disc-shaped wing. The plant is used as fodder. It flowers in November.

Bromus madritensis L.
GRAMINEAE
Sabel Abu Al Hassin
An annual grass (above) with solitary, erect or ascending glabrous culms and an erect or slightly noded panicle. The spikelets are green or purple, wedge-shaped with an awned lemma about 12-19 mm long and 3 mm wide. In dry specimens, the panicle is fan-shaped. The plant grows on stony ground and sandy gravel areas. This grass is used as fodder. It flowers between March and April.

Cakile arabica Velen. & Bornm.
CRUCIFERAE
Slaih
This annual herb (above) covers the desert with a splash of lilac color. The multi-branched plant has deeply lobed leaves, cross-shaped lilac flowers, and beak-shaped seed pods. This plant is used as an ornamental plant and also as fodder. It flowers from February to March.

Cistanche tubulosa (Schrenk) Wight
OROBANCHACEAE
Halook, Dhunun
This sturdy-looking root parasite (above) has a thick, fleshy, aerial stem approximately 30-40 cm high and an elongate, bulb-shaped underground stem, which, in turn, has long thread-like roots that attach themselves to the roots of the host. The funnel-shaped flowers are bright yellow with purple tips, usually seen between February and May.

Emex spinosa (L.) Campd.
POLYGONACEAE
Hembizan
This is a prostrate, leafy, annual herb (above) about 60 cm long with a reddish stem and a basal rosette of leaves. Basal and cauline leaves are large, deep green, ovate to oblong and truncate at the base. The flowers are tiny and appear in clusters on the leaf nodes. The white fleshly taproot is edible. This plant often appears as a weed in disturbed areas and it is used as fodder. It flowers in March.

Cutandia memphitica (Spreng.) Benth.
GRAMINEAE
Khafoor
This annual grass (above) has numerous fascicled, purple-noded, ascending, smooth, glabrous culms branched in tufts. It grows up to 30 cm tall with conspicuously dilated sheaths at the nodes. The leaf blades are narrower than the sheath, and the inflorescence is forked and branching with a 5-10 cm long panicle. Each branch is divided into a short, pedicelled spikelet. The lemma ends in an awn-like, short, pungent mucro. The plant grows in sandy habitats and on sand hills. The plant is used as fodder. It flowers from March to April.

Erodium glaucophyllum (L.) Ait.
GERANIACEAE
Dabgha
This branched perennial herb (above) has leaves that ovate or subcordate to oblong. Petals are bright purple. Fruit beaks extend up to 7 cm long. It grows on rocky terrain in shallow sandy and calcareous soil. It flowers from March to April.

Erodium laciniatum (Cav.) Willd.
GERANIACEAE
Humbaz
This slender annual herb (above) is procumbent to ascending. It grows in sandy soil and even in the cracks of paved traffic medians. It is about 10 cm high and up to 30 cm across. It has mauve flowers, about 5 mm across with purple venation. The leaves are oval to heart-shaped, pinnately divided nearly to the base, and slightly hairy. It has a distinctive seedpod, which looks like a beak, about 12 cm long and rigid. The plant is used as fodder. It flowers in March and April.

Fagonia bruguieri DC.
ZYGOPHYLLACEAE
Janbah
This small branching spiny perennial herb (above) is about 15 cm high and 10-40 cm across. It has many stems that grow laterally and horizontally. The leaves are trifoliate and lanceolate. The flowers have five petals and are pale pink. The plant has medicinal value.

Filago pyramidata L.
COMPOSITAE
Quttaynah
A small, furry annual herb (above) up to 15 cm high, this plant is common on compact, gravelly and sandy desert soils, especially after rain. It is a semi-prostrate, narrow-stemmed herb with grayish-white leaves. The florets are small and yellow, appearing between February and April. The plant is used as fodder.

Frankenia pulverulenta L.
FRANKENIACEAE
Mulaih, Abu thurayb
This branching, prostrate mat-forming annual herb (above) is about 15 cm across. The stems are trailing, slender and reddish in color. The leaves are very small, about 4 mm, fleshy, deep green, and spathulate to obovate. The flowers that appear in March are papery-pink, and many seeds are formed in capsules. The plant is used as fodder.

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Halocnemum strobilaceum (Pall.) M. Beib.
CHENOPODIACEAE
Theluth, Thullayth

This is a halophytic perennial shrub (above) that is easily recognized by its numerous, small decussate, green tubercles along the branches. The leaves are minute, connate, opposite and have rudimentary lamina. The flowers grow in a cluster of three, forming lateral and terminal spikes. The plant grows in littoral salt marshes, which are usually inundated by seawater. It flowers in October to November. The plant is used as fodder.

Helianthemum lippii (L.) Dum. Cours.
CISTACEAE
Rag-Rug

A small woody perennial shrub (above), this plant is between 10-45 cm high with white stems. The leaves are small, grayish-green and pubescent. The flowers are yellow and about 5 mm wide. The mycelium of the desert truffles *Tirmania* and *Terfezia* is associated with the roots of *Helianthemum lippii*. It is a symbiotic relationship, and when the plant is absent, so is the truffle.

Herniaria hemistemon J. Gay
CARYOPHYLLACEAE
Esh Shawla

This very small perennial neat plant (above) is often found on limestone rock as well as on sandy soil. It reaches heights of 3-10 cm. The leaves are grayish-green, 2-6 mm long, opposite, elliptic-oblong, ciliate at the margins and sessile. The flowers are minute axillary clusters that bud and bloom from February to April. It has no petals, just yellow stamens peeping out of a green calyx that looks like the open beak of a baby bird. It has been reported to have medicinal properties, especially for curing diuretic and astringent ailments.

Hordeum marinum Huds. subsp. *gussoneanum* (Parl.) Thell.
GRAMINEAE
Shaeer

This annual grass has solitary or loosely tufted culms about 30 cm tall. It has linear, acuminate, flat, hairy leaf blades and cylindrical spikes; spikelets are in threes with lanceolate glumes that are ciliate at the base, tapering into awns that are broadly winged at the base. It is locally distributed along the seacoast and flowers from March to June. The plant is used as fodder.

Ifloga spicata (Forssk.) Sch. Bip.
COMPOSITAE
Neayma, Tarabah
An erect herb (above) around 5 or 6 cm tall, its leaves are small and slender, and densely arranged spirally on the stem. It is a widespread annual herb often found on gravel grounds and is used as fodder. Its tiny yellow flowers, only 1 mm across, are produced in leaf axils between February and March.

Launaea capitata (Spreng.) Dandy
COMPOSITAE
Huwaa
A prostrate, biennial herb, this plant is about 15 cm high. Leaves form a dense rosette around the base. The flower heads, about 1 cm wide, are pale yellow and almost sessile. It flowers in April. The plant is used as fodder.

Launaea mucronata (Forssk.) Muschl.
COMPOSITAE
Adhid
This plant is an almost leafless, multi-branched annual herb (above) that grows up to 40 cm high. The leaves are deeply lobed, mucronate, and form rosettes around the base of the stem. Stem leaves are smaller and toothed. Flower heads are about 2.5 cm wide, yellow and appear between March and April. The plant is used as fodder.

Oligomeris linifolia (Hornem.) J.F. Macbr. syn. *Reseda linifolia* Hornem.
RESEDACEAE
Thenban
These annual, erect-standing herbs (above) are about 25 cm high. They have slender linear, blue-gray lanceolate leaves. The flowers are minute, appearing on a spike-like raceme between March and April. The plants have conspicuous seed capsules that are attached on an elongated stem. The plant is used as fodder.

Parapholis incurva (L.) C.E. Hubbard
GRAMINEAE
Oaija
This is a somewhat glaucous annual grass (above), 10-15 cm high, with many erect stems often arched above. The spikes are up to 10 cm long, straight or incurved to form a semicircle or almost a circle, with the basal part usually enclosed in the uppermost leaf sheath. It grows in dry and moist steppe on limestone or alluvium and flowers from March to May. The plant is used as fodder.

8

Paronychia arabica (L.) DC.
CARYOPHYLLACEAE
Rig-Raga
This low-growing annual herb has a hairy, branching stem and elliptical to linear leaves, around 10 mm long and 2 mm wide. It is recognizable by its bracts and stipules, which are silvery-white. The flowers are tissue-like and greenish-white. It grows on sandy soil and it is used as fodder. It flowers between March and April.

Phragmites australis (Cav.) Trin. ex Steud.
GRAMINEAE
Bous, Qasba
This tall perennial reed swamp grass (above) grows up to 3-4 m high. The roots are rigid, creeping rhizomes. The leaves are lanceolate, flat, acuminate, and rough. It has branched panicles that are brown and silvery-white when it matures. Its spikelets have 3-6 flowers with unequal-keeled glumes. It grows in marshes and near water. The plant is used as fodder and has medicinal value as an anti-emetic and coolant. It flowers in April.

Picris babylonica Hand. Mazz.
COMPOSITAE
Howaithan
An erect branching herb, this plant is 10-20 cm high and covered with soft fine hairs. It has a basal rosette of lobed leaves that are coarsely toothed. The flowers are about 4.5 cm wide with dentate tipped ray florets with a black center. This desert daisy covers sandy and gravelly soil during the spring. It is used as fodder.

Plantago ovata Forssk.
PLANTAGINACEAE
Lugmat Al Naaja
This annual plant has long, slender, strap-like leaves that taper towards both ends. It has fine hairs on the leaves and a leafless flower stalk arising from the basal rosette. The flowers are borne on an oval flower spike. The seeds are pink or gray-brown in color and contain a significant amount of mucilage. The seeds are used as a medicine for gonorrhea and as a diuretic.

Reichardia tingitana (L.) Roth.
COMPOSITAE
Murrar
This small compact herb (above), just a few centimeters high, has a leafy, basal rosette that may or may not be deeply lobed. The flower heads, which are large and thick, are deep yellow with a darker center. The seedpods are fat and have large bracts. The plant is used as fodder.

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Rostraria pumila (Desf.) Tzvelev. syn. *Lophochloa pumila* (Desf.) Bor.

GRAMINEAE

Abu Sunbulah

This small annual grass (above) with erect, fascicled, smooth, glabrous culms has deep green, shortly ciliated leaf blades up to 6 cm long and a dense panicled inflorescence, often somewhat lobed, up to 4 cm long. The glumes are equal and dark green with scarious margins. The green part is covered with hairs, and the rachilla is also furnished with long hairs. This is a sandy desert grass that is used as fodder and flowers from February to May.

Rumex vesicarius L.

POLYGONACEAE

Humaith

A leafy, erect, succulent annual herb (above), its leaves are triangular in shape and truncate at the base. The flowers are small and clustered on the stem. The fruit is more conspicuous than the flower. Each fruit has three deep pink tissue-like membranous wings with red venation. It is commonly found in sandy soils and sometimes in pavement cracks. The plant is used as fodder and also as a medicine for diarrhea and scorpion stings.

Salsola imbricata Forssk. syn. *Salsola baryosma* (Roem. & Schult.)

CHENOPODIACEAE

Muliah, Gaghraf

This low-growing, halophytic shrub (above) smells like rotting fish when crushed. It has ascending branches, and the leaves are ascending and wide spreading from the base. New shoots are bright and red in color. The leaves are clusters of small balls that are followed by the appearance of conspicuous winged fruit. The plants flower between June and September. It has medicinal value.

Salsola jordanicola Eig.

CHENOPODIACEAE

Homaidh

An annual, yellowish, papillose-mealy and petulous-villous plant (above), its stem is erect, greatly and divaricately branched from the base, and whitish in color. The leaves are linear or oblong linear, 10-20 mm long, and 1.5-2 mm wide, and dilated at the base, but soon deciduous. The flowers are solitary in the axils and distant or sometimes crowded over the stems. The fruit includes a dry utricle and a horizontal seed. The plant occurs in saline sandy soil and is used as fodder. It flowers from October to November.

Schismus barbatus (L.) Thell.
GRAMINEAE
Khafor
This very common annual desert grass (above) has erect or prostrate, very numerous, smooth culms about 7-15 cm tall with very narrow involute leaf blades that are green or purplish, erect, and are panicled inflorescence up to 3 cm long. The spikelets are 4-7 mm long, each with 5-10 fertile florets and a rudimentary upper one. The almost equal glumes are acute, glabrous, and persistent. The lemma is bilobed and hairy on the margins. This grass grows in various habitats and is grazed by animals. It flowers from February to March.

Scrophularia deserti Delile
SCROPHULARIACEAE
Zaitah
This perennial (above) usually grows on hard rocky ground such as that found behind the chalets at Ad-Dhubaiyah. It is an erect-standing plant that has a leafy base and small, dark red flowers with conspicuous yellow stamens. The leaves on the stem are opposite, oval-shaped and deeply lobed. New growth arises from the previous year's woody base. This plant has medicinal value.

Seidlitzia rosmarinus Ehrenb ex Bunge
CHENOPODIACEAE
Shinan
This perennial, rounded, glabrous shrub (above) is up to 60 cm high and greatly branched from the base. The branches are opposite, whitish, glossy, and glabrous, except at the nodes. The leaves are opposite, decussate, sessile, fleshy silver-green, cylindrical, linear, semi-terete, and become thicker towards the apex. The flowers are axillary, solitary, and congested with two fleshy bracts. The fruiting perianth is about 10 mm in diameter and the wings are unequal. The fruit is a membranous utricle that is depressed; the seeds are horizontal, black, compressed, and coin-shaped. The plant is found in saline soil at low elevations and rarely on elevated rocky ground. It flowers from September to October. It is a medicinal plant; the bound dried leaves are used by the bedouin as soap.

Senecio glaucus L.
COMPOSITAE
Zamluq
This annual herb (above) is widespread in Kuwait, providing patches of yellow color alongside roads after rainfall. It is a leafy herb with leaves divided into a few well-spaced, linear lobes with a toothed margin. Masses of yellow flowers cover the plant and are followed by seeds on parachutes. It flowers between March and April. This annual plant is used as fodder.

Spergularia diandra (Guss.) Heldr. & Sart.
CARYOPHYLLACEAE
Um Thraib
A very delicate branching annual (above), this plant has slender, thread-like leaves about 20 mm long and 0.5 mm wide. It has a mauve flower comprising five petals. It is found on sandy soil, such as coastal areas, and is used as fodder. It flowers between February and April.

Sphenopus divaricatus (Gouan) Reichb.
GRAMINEAE
This purplish annual grass (above) is found in sabkha areas. Culms are ascending, often kneed near the base, and 30 cm high. The panicle terminal is ovate-oblong in outline. Spikelets are pedicelled on the final branches and laterally compressed. It is usually associated with *Frankenia pulverulenta* and flowers in April. This grass is used as fodder.

Stipa capensis Thunb.
GRAMINEAE
Samaa
This annual grass (above) is profusely branched at the base with very densely tufted, erect or short decumbent culms reaching a height of 40 cm. The leaf blades are erect, narrow, and convolute, and the sheaths are lax, with the uppermost often being inflated and including the base of the inflorescence. It has an erect panicle of very densely crowded silvery spikelets with long awns, 5-10 cm long. This plant is palatable when young, but injurious to animals when fruiting. It flowers from March to April.

Stipagrostis plumosa (L.) Munro ex T. Anders.
GRAMINEAE
Nussi
This densely tufted perennial grass has erect or short, geniculate culms up to 40 cm tall. The nodes and internodes are covered with wool. The inflorescence is a panicle about 15 cm long. The central awns are long, up to 3-5 cm, and plumose except at the base; lateral awns are glabrous. It is a multiform species and is considered to be good fodder. It grows on gravelly and stony ground where the plant accumulates a small heap of sand around its body. Flowering is mainly from March to May.

Suaeda vermiculata Forssk. ex J.F. Gmel. syn. *Suaeda fruticosa* Forssk. ex J.F. Gmel.
CHENOPODIACEAE
Suaida, Sawad
These are low, silvery-green, erect perennial shrubs (above) that turn black when dried. They are divaricately branched with glaucous stems. The leaves are blue-green, short-petioled, glaucous, oblong to obvate, flattened above, 4-15 mm long and 2-6 mm wide. The flowers are perfect, solitary and axillary with two to three bracteoles arranged in a short, loose, leafy, spike-like inflorescence. The perianth is parted into five equal green sepals united at the base, with three yellow stigmas. The seeds are vertical and shiny. The plant grows in salty areas near the coast and is used as fodder. It flowers in October.

Tamarix aucheriana (Decne.) B.R. Baum
TAMARICACEAE
Athal, Tarfa
This plant (above) favors saline areas such as those found on the coast in Sulaibikhat. It is a large shrub, about 1.2-1.5 m high, with scale-like leaves. The flowers are deep rosy pink and appear on a terminal spike. Cone-shaped seedpods can be seen from February to April and again from October to November. This perennial shrub gives shade and is used as fodder. The plants are propagated by cuttings.

Trachynia distachya syn. *Brachypodium distachyon*
GRAMINEAE
Denban
An annual, this plant (above) has glaucous, stiff, clustered culms and grows up to 30 cm tall, with flat broad leaf blades and short pedicelled, crowded spikelets in solitary inflorescence. The glumes and lemma are strongly nerved, and the lemma is awned. It grows in sandy gravel and gypsum plains and flowers from March to April. It is a useful forage grass.

Trigonella stellata Forssk.
LEGUMINOSAE
Nifl. Nafal.
This is a bright green annual mat-forming herb (above), which spreads quickly, especially where there is abundant water. The leaves are trifoliate and dentate. It has yellow flowers and a clover-like scent. The pods are 4-7 mm long and straight, with 6-12 clustered and stellately spreading. It is common in the sandy desert, at roadsides and on pavement. The plant is used as fodder.

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Zygophyllum qatarense Hadidi
ZYGOPHYLLACEAE
Harm
This is a medium-sized perennial shrub (above) commonly found in coastal areas and depressions. It has succulent, almost spherical leaves and tiny yellow flowers on short pedicles. Its fruits are erect, smooth and oblong and appear in mid-summer. It is a medicinal plant and grazed by camels.

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Chapter 9: Wildlife

Abstract

A comprehensive wildlife survey and assessment of Boubyan and Warbah Islands was undertaken by field assessment and data collection from October 2003 to February 2005. The main scope was to determine the populations of wildlife species and their diversity, density and distribution. This involved sampling and making observations to document the islands' fauna and to identify key wildlife habitats, i.e., foraging, nesting, breeding and roosting sites.

Four standard survey and monitoring methodologies were used: (1) invertebrate and reptile pitfall trapping, (2) baited (small and large) mammal trapping, (3) terrestrial- and marine (bird)-based wildlife transect surveys, and (4) fixed point bird transect surveys (bird hides).

The data collected over a period of 17 months indicated that the wildlife present in Boubyan and Warbah Islands are not only important for Kuwait, but of regional and international importance due to their provision of intertidal wetland foraging and nesting habitats for a large number of threatened migratory waterfowl species. The data also indicated that there were three major areas of ecological importance in the project study area. The area with the highest priority is the northern breeding and foraging grounds of Boubyan and Warbah Islands, while the other two nominated areas are sites of importance for foraging habitats for resident and migratory waterfowl and other terrestrial wildlife fauna. It should be emphasized that the entire coastal area of southern Boubyan Island is actually of foraging habitat value; however, the two nominated sites, Ras Al Qayd and Ras Al Barshah, were selected on the basis of high densities of birds feeding in those areas.

It is, therefore, concluded that Boubyan and Warbah Islands are of national, regional and international significance as wildfowl sites and constitute an important international wetland ecosystem with high wildlife conservation value. Both resident and migratory bird species used the area as their wintering habitats.

Both islands appear to meet the criteria to be included in the Important Bird Area (IBA), Conservation of Migratory Wildlife Species (CMS) and Convention on Wetlands (Ramsar) lists, although they are not included on these lists at present.

Survey and Assessment

The State of Kuwait possesses rich and diverse populations of terrestrial and marine wildlife, including rare migratory species of birds. The international, non-government organizations, Birdlife International and the Bird Monitoring and Protection Team (BMPT) of Kuwait have recorded 355 species of birds in Kuwait. Many of these species are coastal and marine migratory birds that arrive each year to forage and nest within the rich coastal and marine areas on the offshore islands. Boubyan and Warbah Islands provide regionally valuable foraging and breeding habitats for these internationally important migratory species.

A detailed survey was carried out, from October 2003 to February 2005, to record species diversity and density of the wildlife fauna of the islands. The survey also identified important wildlife habitats (breeding and foraging sites) on and around the islands. The purposes were to provide information on types of wildlife species that reside on and visit the islands and to identify important habitats for conservation purposes.

The work plan involved four phases: preliminary environment baseline study (field reconnaissance activities) and literature review, environmental field survey and assessment, preliminary land use design and environmental assessment, and draft a final Master Plan and Environmental Assessment.

Table 4. Trips Made by KISR Wildlife Survey Team to Boubyan and Warbah Islands from October 2003 to February 2005

No. of Field Trips	Types of Trips	Purpose of Trips
69	Terrestrial	Reconnaissance, study site locations, field data collections
25	Marine or boat	Reconnaissance, study site locations, field data collections
1	Aerial	Overhead survey of Boubyan and Warbah Islands (helicopter trip)

Preliminary Environment Baseline Study and Literature Review

In October 2003, several field trips were undertaken by the wildlife survey team to both Boubyan and Warbah Islands (**Plate 9**). Three types of surveys (terrestrial, marine, and aerial) were carried out with 95 total field trips taken (**Table 4**). Both diurnal (day) and nocturnal (night) surveys on Boubyan and Warbah Islands were conducted to collect data on birds, insects, reptiles, and mammals (**Table 5**).

Initial visits to the islands resulted in the observation of several bird species, terrestrial reptiles (such as gecko, agama, dried carcass of spiny-tailed lizard [*dhub*], desert monitor), marine reptiles (sea snakes), marine fishes, and marine mammals (**Plates 10 and 11**). During this preliminary field reconnaissance survey to Boubyan Island, terrestrial invertebrates and mammals were also recorded. The wildlife team further coordinated with KISR remote sensing specialists to analyze a map of all vegetation on the islands. The selected vegetated areas (productive areas) were incorporated into the wildlife field survey map to be explored for their potential as wildlife habitat.

To facilitate field data collections, Boubyan and Warbah Islands were divided into seven different field data collecting zones, namely (**Fig. 7**):

1. *Zone A*: The coastal area extending from Ras Al Barshah, the southwestern tip of Boubyan Island, to the edge of the northern intertidal mudflat across Maghasil from the mainland;
2. *Zone B*: The vegetated coastal area of eastern Boubyan Island extending from Ras Al Barshah on the southwest to Ras Al Qayd on the southeast;
3. *Zone C*: The central sabkha area of Boubyan Island;
4. *Zone D*: The eastern coastal area of Boubyan Island from Ras Al Qayd to the eastern edge of the northern intertidal areas (Khor Abdallah);
5. *Zone E*: The intertidal mudflats and oyster reefs of northern Boubyan Island;
6. *Zone F*: The whole of Warbah Island; and
7. *Zone G*: The marine zone surrounding the islands.

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Table 5. Data Collected during Diurnal and Nocturnal Surveys

Diurnal Survey	Nocturnal Survey
1. Data for line transects (BT and T)	1. Data for mammal trappings (large and small)
2. Data for pitfall trappings Diurnal species example: (1) lizards, (2) diurnal spiders (i.e., orb weaver, jumping spiders) and (3) other invertebrates (i.e., butterfly, dragonfly)	2. Data for pitfall trappings Nocturnal species example: (1) beetles, (2) nocturnal spiders (i.e., wolf spiders, camel spiders) and (3) scorpions (i.e., black scorpion, yellow scorpion)
3. Data for bird hide observations	

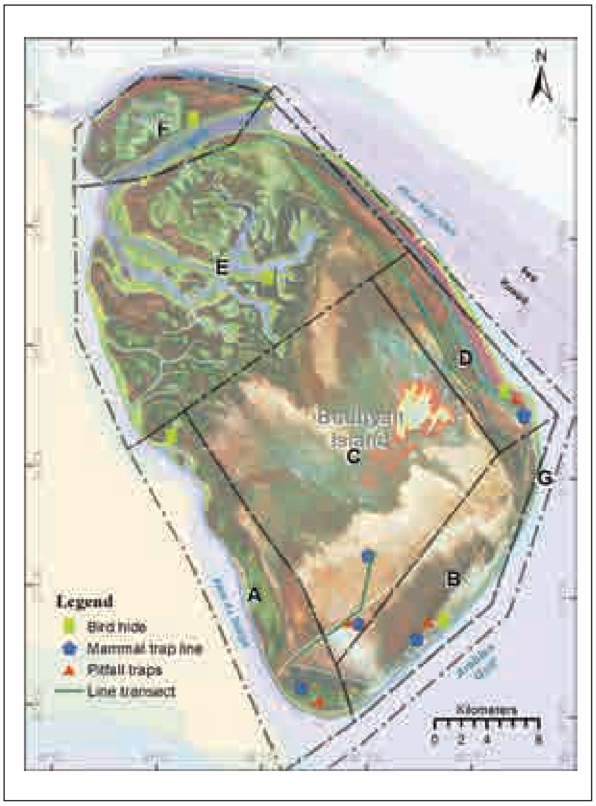

Fig. 7. Working map of Boubyan and Warbah Islands

Plate 9. The initial trip in October 2003 to Boubyan Island

Plate 10. A dead dolphin found by the AAD wildlife team at Ras Al Qayd

Plate 11. A dried guitarfish found by the AAD wildlife team at Ras Al Barshah

Historical Bird Data

The oldest wildlife records from Boubyan Island are concerned with marine birds and date back to 1878, 1879 and 1884. Warbah Island records, also concerning marine birds, are from 1878 (British Museum, 1901–1902). The ornithologists P.Z. Cox and R.E. Cheeseman collected relatively more recent bird records in 1921, 1922 and 1923 for Boubyan Island and in 1903, 1906, 1907, 1921 and 1922 for Warbah Island (Ticehurst et. al., 1925, 1926).

White pelican (*Pelecanus onocrotalus*): C.B. Ticehurst, P.Z. Cox and R.E. Cheeseman (1926) reported that in 1903 "…*according to Arab testimony Pelicans used to breed on Warbah Island*." They also stated that on April 18, 1922, a visit to Boubyan Island, by V.S. Personne, recorded adult white pelicans and a few down young. On April 1, 1923, pelicans were again recorded nesting. Since these times, there have been no further records of white pelicans breeding in Kuwait. In more recent times this species has been observed occasionally, though not annually, and some birds have been present around the islands in the breeding season (Al Nasrallah et al., 2001).

Western reef egret (*Egretta gularis*): Was first recorded breeding in Kuwait on May 3, 1878, when five eggs were collected on Warbah Island and were donated to the British Museum. The museum also has eggs collected in April 1879, April 1884, May 1884 and April 1899, all probably from Warbah Island. On May 30,1906, P. Cox observed breeding colonies of this species on Warbah Island (Ticehurst et al., 1926). Visits to Boubyan Island on April 25 and June 28, 1922 also recorded this species nesting. All eggs and specimens of adults collected at the time are now in the British Museum. Al Nasrallah et al. (2001) reported four pairs of the species nesting on a wrecked ship in Khor Subbiyah. In 2002, members of the BMPT found about 300 pairs of western reef egret on Boubyan Island, including 10 pairs on a wrecked ship in Khor Subbiyah. Eggs were recorded from March 4 and chicks from April 4 (Al Nasrallah and Gregory, 2003).

Grey heron (*Ardea cinerea*): Is observed in Kuwait from March to July, and most birds in Kuwait are concentrated around Boubyan and Warbah Islands. The first known breeding evidence for Kuwait involved an egg collected from Abdallah bank (Warbah/Boubyan Islands) on April 24, 1884, received by W.D. Cumming and donated to the British Museum (British Museum, 1902). P. Cox visited Warbah Island in May 1906 and found grey herons breeding there. On May 19, 1921, V.S. La Personne observed several nests with three or four eggs on Warbah Island. He also visited Boubyan Island on May 21, 1921, May 30, 1922 and April 1, 1923 and found nesting birds (Ticehurst et al., 1926). In March 2001, nine pairs were found nesting on a wrecked ship in Khor Subbiyah (Al Nasrallah et al., 2001). In 2002, the BMPT team found about 100 breeding pairs of grey herons on Boubyan Island, including 5 pairs on a wrecked ship in Khor Subbiyah. Eggs were recorded from March 4 and chicks from April 4 (Al Nasrallah and Gregory, 2003).

Eurasian spoonbill (*Platalea leucorodia*): Occurs in Kuwait from March to July, with most birds concentrated around Boubyan and Warbah Islands. The first known breeding evidence for Kuwait involved four eggs collected on Boubyan Island on May 25, 1878. These were received by W.D. Cumming and donated to the British Museum. Spoonbills were observed by P. Cox to be breeding on Warbah Island on May 19, 1907 (Ticehurst et al., 1926). V.S. La Personne collected an unknown number of eggs on May 20, 1922 and three eggs on June 1, 1922 on Boubyan Island (Ticehurst et al., 1925, 1926). In 2002, members of the BMPT found about 50 breeding pairs of spoonbills on Boubyan Island. Eggs were recorded from March 4 and chicks from April 4 (Al Nasrallah and Gregory, 2003).

Greater flamingo (*Phoenicopterus roseus ruber*): Is easily seen at Ras Al Subbiyah and sometimes on Boubyan Island. The species was first recorded as breeding in Kuwait on May 25, 1878, when 71 eggs were collected on Boubyan Island and were later donated to the British Museum. This institution also has eggs collected on Abdallah bank (Warbah/Boubyan Islands) on April 24, 1884. The names of the actual collectors of the eggs are unknown, but E.A. Butler, D. Hume, W.D. Cumming and S. Baker were involved in receiving them and in donating them as part of various collections to the British Museum. Ticehurst et al. (1925, 1926) wrote that "… *according to Cumming it breeds on the Kuwait side of the head of the Gulf, whence I believe he obtained from the Arabs many eggs which are now in the Karachi Museum*." Ticehurst et al. (1926) wrote about the visit of V.S. La Personne to Boubyan Island in 1921, 1922 and 1923 and his observations: "… *on May 21, 1921 Flamingoes were breeding on Boubyan Island and a rotten egg was picked up. On April 17, 1922, a colony of about 500 pairs was located on Boubyan… nesting on a slightly raised stretch of sand covered with low scrub.*" Two eggs and an adult specimen collected on April 15, 1922 are now in the British Museum. Captain Salem Al-Mulla of the Kuwait Coast Guard, in personal communication to the KISR wildlife survey team, related that on several occasions between 1994-2003, he and his team had observed small colonies of greater flamingoes breeding on Boubyan Island. A maximum of 65 nests were built in one year, and some had eggs and young. On other occasions, the birds built nests but then abandoned them.

Crab plover (*Dromas ardeola*): The two eggs received by W.D. Cumming on May 20, 1900 were the first evidence of the breeding of crab plovers in Kuwait. These two eggs were later donated to the British Museum. V.S. La Personne visited Boubyan Island on April 15, 1922 and collected three specimens of adult crab plovers, which are now in the British Museum. Ticehurst et al. (1926) said of this species: "*It also nests freely on Warba Island.*" In 2002, members of the BMPT found crab plovers breeding on Boubyan Island. About 1,000 adults with two food-begging juveniles were observed on April 4. About 100 active burrows were discovered on May 17, 2002, with many adults and two second-year birds emerging from the burrows. Some eggs were found outside the burrows, including one on an islet with no nest burrow. It was also recorded that the air temperature inside the burrows was lower by 10°C than the outside environmental temperature (Al Nasrallah et al., 2001).

Slender-billed gull (*Larus genei*): The species was first recorded as breeding in Kuwait in 1884, when five eggs were collected on April 24 and one on an unstated date in May on Abdallah bank (Warbah/Boubyan Islands). These eggs were received by W.D. Cumming and were later donated to the British Museum. On May 30, 1906, P. Cox visited Warbah Island and recorded that "*this gull was found breeding with Caspian terns*" (Ticehurst et al., 1926). In 1921, V.S. La Personne collected an adult specimen and two eggs from Warbah Island on May 19. The next day he collected an adult specimen from Warbah Island and another adult specimen and one egg from Boubyan Island. On the Warbah Island visit, he also recorded that slender-billed gulls were "*breeding freely there with Gull-billed terns on the N.E. side … laying had just begun and 31 nests of the two species were counted in an area of 5 yards square. On April 15, 1921, the birds had just arrived for breeding purposes*" (Ticehurst et al., 1926). On May 26, 1922, V.S. La Personne collected two eggs and an adult specimen from Warbah Island and a chick from Boubyan Island. The next day, he collected three chick specimens from Boubyan Island. These specimens are now with the British Museum. This species was not discovered breeding again until 2002, when members of the

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BMPT found it breeding on Boubyan Island, with about 200 agitated and vocal adults flying slowly overhead at one site on April 4; about 50 agitated adults and 4 well-feathered chicks were found at another site on May 17 (Al Nasrallah and Gregory, 2003).

Gull-billed tern (*Gelochelidon nilotica*): Was first recorded breeding in Kuwait on April 3, 1878 by a Mr. Huskisson. The eggs and adult specimen were received by Colonel E. A. Butler at Basrah. The eggs were donated to the British Museum. On May 18, 1921, V.S. La Personne collected an adult specimen from Warbah Island. The next day, he collected two eggs and two adult specimens from Warbah Island. From Boubyan Island, he collected an egg specimen on May 20, 1921. On April 7, 1922, V.S. La Personne collected three eggs and an adult specimen, and again on April 25, he collected adult and immature specimens from Boubyan Island. All of these eggs and specimens were donated to the British Museum. Of V.S. La Personne's observations, C.B. Ticehurst et al. (1926) wrote: "*On 21 May, 1921, the Gull-billed Tern was found nesting on open flat ground or slightly raised ridges along the border of a creek [on Boubyan Island]. Another colony was nesting amongst the Pelican skeletons and on April 18, 1922, some had already hatched. On Warbah Island it was breeding with Slender-billed Gulls on the edge of shingle and scrub, and on May 19, 1921 the nests held 2 to 3, mostly 2, fresh eggs; a slight nest of twigs is made.*" These species were not discovered breeding again until 2002, when members of the BMPT found 69 nests with eggs at a few sites on Boubyan Island on April 4. Many other nests and chicks were found later that year at other sites. One nest contained two eggs of gull-billed tern and one of western reef heron (*Egretta gularis*); possibly egg retrieval was involved (Al Nasrallah and Gregory, 2003).

Caspian tern (*Sterna caspia*): Was first recorded breeding in Kuwait on April 3, 1878, when a Mr. Huskisson collected 97 eggs and an adult specimen from Warbah Island. These were received by Colonel E.A. Butler at Basrah, and the eggs were later donated to the British Museum. This institution also holds 14 eggs collected from Warbah Island on April 6, 1879 and one collected on Abdallah bank (Warbah/Boubyan Islands) on April 24, 1884. Ticehurst et al. (1926) wrote: "*A few pairs bred on Warbah Island in 1906, where on May 30, most had hatched. None there in 1907, 1921 or 1922.*" On April 4, 2002, members of the BMPT observed 30 agitated and vocal adults flying slowly overhead at one site. At another site, they found about 25 adults and 7 nests with apparently predated eggs (Al Nasrallah and Gregory, 2003).

Greater crested tern (*Sterna bergii*): On March 2, 2002, members of the BMPT found seven eggs and many agitated adults at one site on Boubyan Island. On April 4, 2002, the team observed about 300 agitated adults and 100 eggs and four downy chicks on Boubyan Island (Al Nasrallah and Gregory, 2003).

These are the most recent documented bird reports for these two islands. Earlier casual observations by Dickson (1942) confirmed the abundance of birds on the islands. In the 1970s field observations by members of the Ahmadi Natural History Museum (1934-1975) provided additional bird records from the south of Boubyan Island and the nearby Subbiyah area. The observations in 1983 of small terrestrial lizards and sea snakes by the Ministry of Planning are the only existing records for other species on Boubyan Island.

Field Investigations, Sampling and Assessment

The main scope of work involved in this environmental investigation and assessment related to wildlife diversity, density and distribution on the islands. This involved sampling and observations to document the islands' fauna and to identify key wildlife habitats.

The methods of wildlife survey implemented on Boubyan and Warbah Islands are comprised of two components: (1) terrestrial and (2) marine/coastal surveys. Four established wildlife survey and assessment methodologies were implemented for the terrestrial component, namely: (1) pitfall traps (PFT) in association with drift fences for invertebrates and reptiles; (2) baited mammal traps (MT), for small and medium-sized mammals; (3) transect lines (TL), for terrestrial and marine based wildlife; and (4) bird hides (BH), for terrestrial and coastal wildlife observations on a fixed location.

Pitfall trapping: PFTs catch ground-crawling animals, such as reptiles and invertebrates. Each study site (Zones A, B, C and D) had five pitfall traps in association with drift fences. The drift fences were 18 m long by 40 cm high, constructed from shade netting supported by 80 cm bamboo pegs at a distance of about 1.5 m from each other or as required. The direction of the drift fence depends on the wind direction and the presence of vegetation at the site. The pitfall traps consisted of plastic buckets with lids and a mouth diameter of +30 cm. The five pitfall traps were placed 3 m away from each other, i.e., 3, 6, 9, 12 and 15 m from each end of the fence (**Fig. 8**). The pitfall traps were opened on the first day of the visit and closed on the second day or last day of data collections.

Arthropods and other ground-crawling animals (**Plate 12**) trapped in the pitfall traps were identified and counted and then released back to their habitat, at least 10 m away from the drift fence. Unidentified specimens were collected, placed in specimen collection containers and

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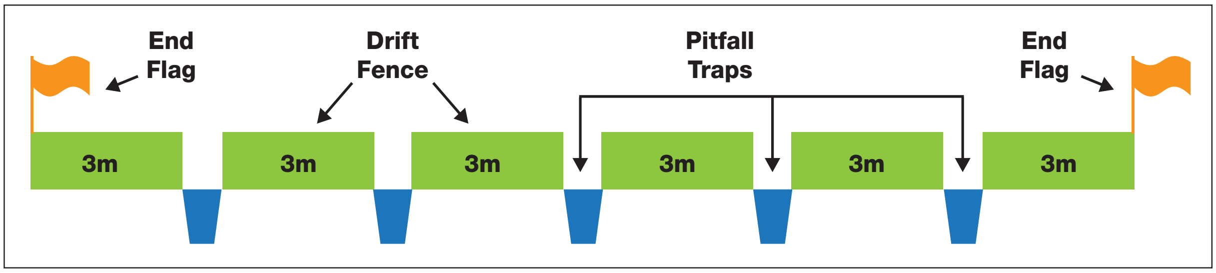

Fig. 8. Schematic diagram of a drift fence with pitfall traps

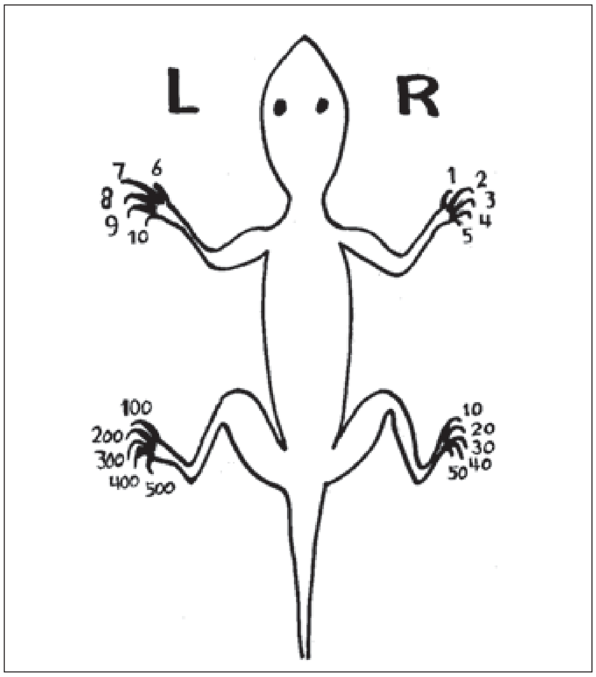

Fig. 9. The numbering code system for small reptiles

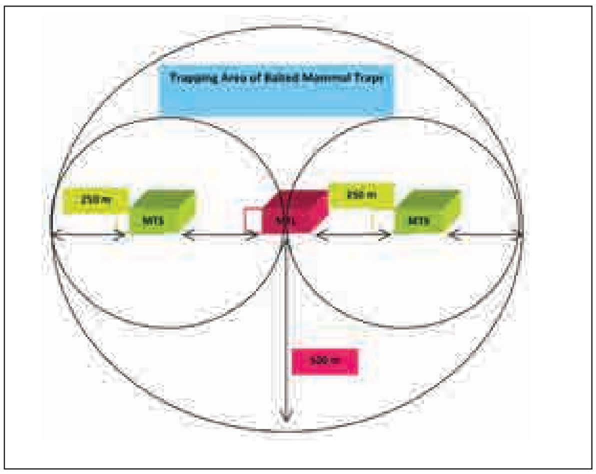

Fig. 10. The schematic diagram of the baited mammal trap line (MTL and MTS)

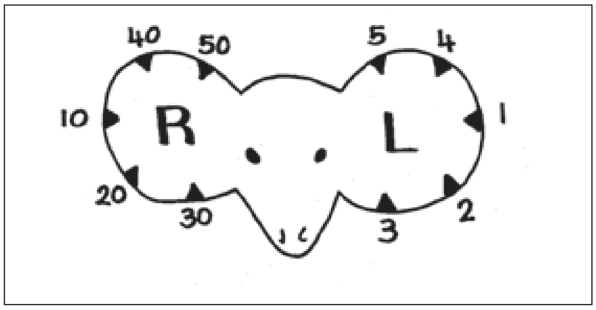

Fig. 11. The numbering code system for rodents

Plate 12. A banded stone gecko (*Bunopus tuberculatus*) handled for marking

Plate 13. A Sundevall's jird (*Meriones crassus sundevalli*) inside the MTS

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brought to KISR for final identification. Dead specimens were identified, counted and either collected for specimen sampling or discarded.

Reptiles (small lizards and geckos) caught in the traps were identified and counted. These were also numbered by cutting the last digit from their feet, which was in accordance to a predetermined numbering system (**Fig. 9**). If all 20 digits on the lizards were utilized, a total of 1,705 numbered animals were recorded.

Baited mammal trap lines: A mammal trap (MT) is one of the methods used to survey and monitor small and medium-sized mammals using baited (small and large) traps. The MT is usually a 1 km long trap line. The large mammal trap (MTL) is placed between two small mammal traps (MTS) at a distance of 250 m (**Fig. 10**).

The MTL has an animal catching radius of 500 m while the MTS has an animal catching radius of 250 m. The traps are set or opened and baited in late afternoon and checked the following early morning for catch. Rodents caught in the traps **(Plate 13**) were released back into their habitats after receiving an identification marking, i.e., ear clipping according to a preset number coding system (**Fig. 11**). The mammal trapping exercises on Boubyan Island captured four species: Sundevall's jird (*Meriones crassus sundevalli*), long-eared hedgehog (*Hemiechinus auritus*), desert monitor (*Varanus griseus*) and a house sparrow (*Passer domesticus*).

Transect lines (TL): A transect line was undertaken to record animals within a specific habitat type or area. Two types of line transects were implemented during the wildlife survey and monitoring on Boubyan and Warbah Islands:

Boat transects: A total of 25 boat transects were performed to survey the coastal wildlife and habitats of Boubyan and Warbah Islands, in conjunction with the Marine/Fisheries project team and with assistance from the Kuwait Coast Guard. The latter, facilitated by Captain Salem Al-Mulla and his staff, was invaluable to successful research because their smaller boats could traverse and penetrate the shallow channels and khors of northern Boubyan Island (**Plate 14**). As a result, surveys located and documented different nesting, breeding and foraging sites of coastal birds of national, regional and international importance on northern Boubyan Island and on Warbah Island (**Figs. 12 and 13**). Mr. George Gregory, the consultant ornithologist for KISR, was always with the AAD wildlife team during boat surveys, to assist in the proper and systematic identification of the different coastal birds (migratory and resident) that utilize Boubyan and Warbah Islands as their foraging, roosting, nesting and/or breeding habitats.

Terrestrial line transects: Two 10 km terrestrial line transects (LT1 and LT2) were selected and established on Boubyan Island. LT1 was located at Zone C and LT2 at Zone D (Fig. 7). A four-wheel-drive vehicle with a mounted Global Positioning System (GPS) was driven at low speed (<20 kph), with a driver and at least one other person recording the data; other observers were sometimes present but were kept to a minimum. A thermometer with relative humidity (RH) (%) was installed in the vehicle. At the start of the transect, the driver set the vehicle odometer to zero and recorded the GPS coordinates, temperature, RH (%) and time. All wildlife fauna observed within a 100 m radius of the vehicle were identified, counted and recorded on field data sheets. High-resolution binoculars/scopes were used to identify different animal species in conjunction with selected field guides. If a species could not be identified, it was described and noted for later reference. A total of 69 terrestrial line transects were performed on Boubyan and Warbah Islands.

Bird hides: Three bird hides were constructed at Zones A, D and E. They differ from line transects in that they are stationary. Regular visits (two to three times per week) to the island were undertaken to document bird presence and activities. Species diversity, density, dates of arrival, dates of departure, feeding and roosting habits and distribution across the islands were recorded. The hide observer had a fixed time of one or two hours for each data collection. Also included on the data sheets were the GPS readings, date and time of observation, temperature, RH (%) and name(s) of observer(s).

Results and Discussion

Some 95 sampling trips were made to the islands from October 2003 to February 2005 (Table 4). These included weekly mammal and pitfall trappings (conducted over at least two consecutive days), line transects, bird observations and at least one boat trip per week to north Boubyan and/or Warbah Island. Additional trips were made by the wildlife team to take part in general field visits by the project coordinators and to discuss ways of coordinating data collection, including an aerial trip by helicopter over Boubyan and Warbah Islands on September 29, 2004. Table 5 lists the data collected during diurnal (day) and nocturnal (night) surveys on Boubyan and Warbah Islands.

Field data collected for phase two indicates that the fauna of the islands consisted mostly of bird species and specifically of coastal birds (**Table 6** and **Fig. 14**). Other wildlife species observed and recorded on Boubyan included desert monitor (*Varanus griseus)*, short-nosed lizard (*Mesalina brevirostris)*, banded stone gecko (*Bunopus tuberculatus)*, toad-headed agama (*Phyrnocephalus maculatus)*, long-eared hedgehog (*Hemiechinus auritus)*, Sundevall's

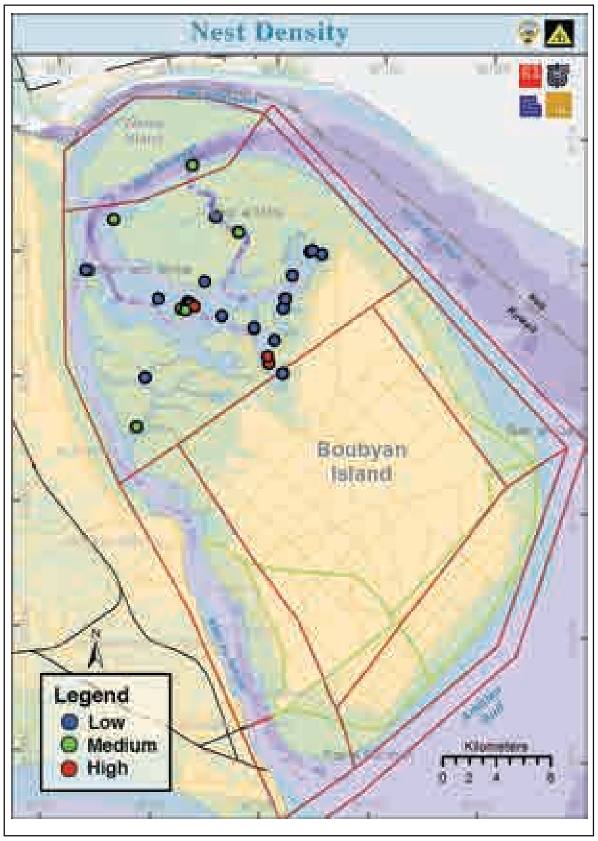

Fig. 12. The Wildlife Constraint Map (No. P2BM-01) showing the recorded nesting areas in northern Boubyan Island

Plate 14. The Kuwait Coast Guard on one of their small boats assisting the AAD wildlife team

Table 6. List of Wildlife Fauna Recorded on Boubyan and Warbah Islands (2003-2005)

Serial No.	Class	No. of Species
1	Mammal	4
2	Bird	143
3	Reptile	4
4	Invertebrates	30

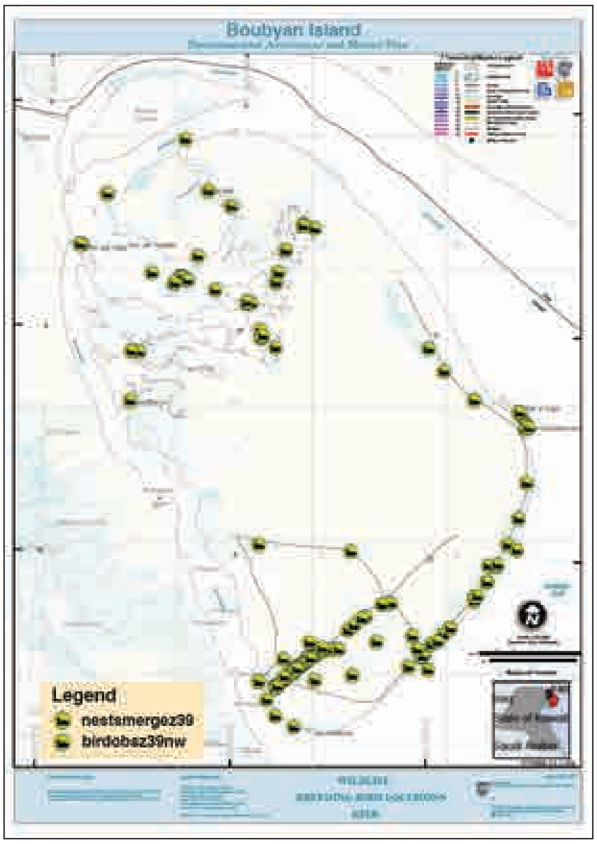

Fig. 13. The Wildlife Constraint Map (No. P2BM-01-L09) showing the bird breeding locations within Boubyan and Warbah Islands

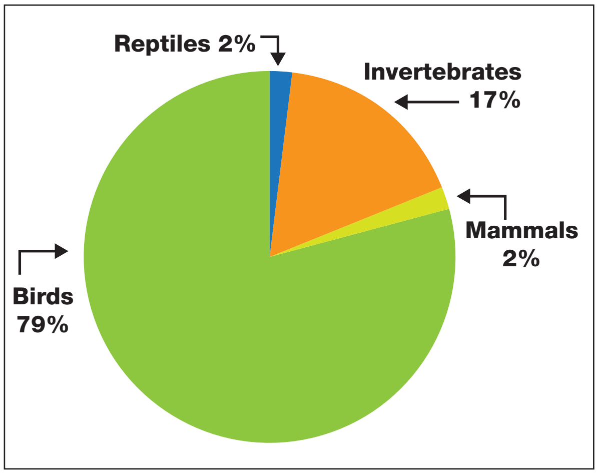

Fig. 14. The wildlife categories recorded on Boubyan and Warbah Islands during diurnal and nocturnal data collections

jird (*Meriones crassus sundevalli*) and hump-backed dolphin (*Souza* sp.).

Figure 14 also shows that the wildlife categories recorded on Boubyan and Warbah Islands during diurnal and nocturnal surveys indicate a healthy ecosystem. The niches of the food chain are balanced from top predator downward, with birds making up the majority (79%). Reptiles and mammals (predators) were relatively low (3 and 2%, respectively), which is the reason why birds dominated the islands' wildlife population. The significant spider species and other invertebrates recorded during pitfall trappings also indicate the richness of the study area. Some other insects (i.e., dragonflies, butterflies, grasshoppers, ground hoppers, gnats, midges, etc.) were not recorded in the database but were observed in swarms (sometimes of millions). These insects and arachnids are prey to lizards and migrating birds.

Significance

During late March and early April 2004, bird nesting commenced mostly on the sabkha areas of southern Boubyan Island and within the intertidal areas of north Boubyan Island. There were no other species recorded nesting on southern Boubyan until mid-April 2004. On the sabkha habitats (Ras Al Barshah and Ras Al Qayd), the Kentish plover (*Charadrius alexandrinus*) nested in many locations and one record of a redshank (*Tringa totanus*) and chick was also recorded. In the northern areas of Boubyan Island (intertidal areas), nests of grey heron (*Ardea cinerea*), western reef egret (*Egretta gularis*), gull-billed tern (*Gelochelidon nilotica*), Caspian tern (Sterna caspia), swift tern (*Sterna bergii*) and spoonbill (*Platalea leucorodia*) were recorded in significantly high densities. During the breeding season of 2004, there was a regionally and internationally important record of crab plover (*Dromas ardeola*) nesting in significantly large numbers in the area. In 2005, the birds were observed to nest earlier (February).

Important foraging areas for numerous species of waterfowl were recorded at Ras Al Qayd, including a new record for Kuwait of the great knot (*Calidris tenuirostris*). Ras Al Barshah on the southwest of Boubyan Island was also significant as foraging habitat for species of waterfowl including the squacco heron (*Ardeola ralloides*) and little egret (*Egretta garzetta*). The vegetated habitats of the southern coast of Boubyan also provide significant foraging and roosting habitat for migratory species including the greater flamingo (*Phoenicopterus ruber*) and a rare large flock of purple heron (*Ardea purpurea*).

Internationally Significant Breeding Birds of the Islands

Crab plover (*Dromas ardeola*): The biggest breeding colony in the world. More than 1,500 breeding pairs (about 5% of the world's population) were observed and recorded on the islands during the breeding season of 2004. This is regionally and internationally significant because the area is the only site within the Western Palearctic where this species breed and nest in such numbers. The nests are in a single colony or groups of colonies interspersed with grey heron (*Ardea cinerea*) nests and western reef egret (*Egretta gularis*) nests. Crab plovers were observed to nest in a chamber at the end of a tunnel, excavated in compacted sand about 1 to 1.5 m long. Two tunnels sharing one entrance is common (**Plate 15**). Each nest contains only one unmarked white egg. About 100 old unused nests on Warbah Island were also observed and recorded but it is unfortunate that these nests had been abandoned due to military disturbances in the area.

Slender-billed gull (*Larus genei*): More that 1% of the breeding population in the Western Palearctic. About 1,600 breeding pairs were observed and recorded on Boubyan Island. This is a major discovery of regional and international importance. Boubyan and Warbah Islands are the only sites in the Arabian Peninsula where this species breeds (**Plate 16**). The nests are in colonies of about 10 to 250 pairs, usually apart from other species. The eggs in a nest usually number two to four and are speckled off-white or pale in color.

Caspian tern (*Sterna caspia*): The largest breeding colony in the Western Palearctic and the biggest breeding population in Arabia. This species nests in large numbers (6 to 250 pairs) on an elevated area, on an interchannel island interspersed with numerous swift tern (*Sterna bergii*) nests. Gull-billed tern (*Gelochelidon nilotica*) nests were also nearby, but distinctly separated (**Plate17**). Two heavily speckled off-white or pale colored eggs are usually in a Caspian tern's nest.

Swift tern (*Sterna bergii*): The only breeding site in the Western Palearctic. Nesting is only at one location in large numbers (up to 600 pairs) on an elevated area on an interchannel island interspersed with numerous Caspian tern nests. The nest is a flat substratum or a shallow depression with one speckled or scrawled off-white or pale colored egg (**Plate 18**).

Gull-billed tern (*Gelochelidon nilotica*): Breeding in regionally significant numbers. Nesting is in large colonies (10 to 500 breeding pairs), often near to nests of western reef egret (*Egretta gularis*), grey heron (*Ardea cinerea*) and spoonbill (*Platalea leucorodia*). The nests are usually in lines, but sometimes are in small two-dimensional clusters

Plate 15. Two nests of crab plovers (*Dromas ardeola*) sharing a single entrance

Plate 18. An egg of a swift tern (*Sterna bergii*)

Plate 16. Slender-billed gulls (*Larus genei*) in their breeding plumage

Plate 19. A grey heron (*Ardea cinerea*) nest with three eggs in it

Plate 17. A colony of Caspian terns (*Sterna caspia*)

up to 10 m apart. The nest is a shallow depression, lined with twigs, reed stems or small pieces of driftwood. The egg clutch consists of two to four speckled off-white or pale in color eggs and is almost always clean and free of droppings.

Western reef egret (*Egretta gularis*): Breeding in nationally important numbers. Nesting is in large colonies (up to 450 pairs), on elevated coastal areas such as low sandy ridges near channels with vegetation. Nests can also be found on wrecked ships along Khor Subbiyah. Nests are usually 0.5 to 1 m tall, made mostly of sticks, on top of low bushes and often fouled with droppings. The nest is interspersed with grey heron (*Ardea cinerea*) nests and spoonbill (*Platalea leucorodia*) nests.

Grey heron (*Ardea cinerea*): Breeding in regionally significant numbers. Nesting is in small colonies (about 150 pairs), on elevated coastal areas (sand spits with vegetation) interspersed with western reef egret nests and spoonbill nests. The egg clutch consists of two to four unmarked pale to medium blue eggs and is often encrusted with muddy deposits (**Plate 19**).

Spoonbill (*Platalea leucorodia*): Breeding in regionally significant numbers. Nesting (up to 150 pairs) is on inter-tidal islands and elevated coastal areas interspersed with grey heron nests, western reef egret nests and gull-billed tern nests. Nests are usually 0.5 to 1 m tall, made mostly of sticks, often on low bushes. Often, the nests are fouled with droppings and contain two to four unmarked pale to medium blue in color eggs.

International Significance of the Islands as Bird Foraging Habitats

Terek sandpiper (*Xenus cinereus*): Only place in the Western Palearctic where this bird overwinters.

Great knot (*Calidris tenuirostris*): Only place in the Western Palearctic where this species overwinters. The first described record of this species in Kuwait was a group of 11 birds seen and photographed (**Plate 20**) on March 11, 2004 by the AAD wildlife team on the eastern side (Ras Al Qayd) of Boubyan Island. On March 25, 2004, the same observers saw 19 great knots on the western side (Ras Al Barshah) of the island. Seven birds were also observed on October 18, 2004 at Ras Al Grab. On February 10, 2005, the AAD wildlife team recorded eight on the western side, along Khor Subbiyah, of Boubyan Island.

Squacco heron (*Ardeola ralloides*): Utilizes Boubyan and Warbah Islands as its winter foraging habitat (**Plate 21**).

Lesser kestrel (*Falco naumanni*): Listed as Endangered on the Bonn Convention List (Conservation of Migratory Wildlife Species). This species was observed and re-corded foraging on the islands during the spring migration of 2004.

Raptors (birds of prey): The following migratory birds of prey were recorded foraging on the islands:

1. Steppe eagle (*Aquila nipalensis*) (**Plate 22**)
2. Marsh harrier (*Circus aeruginosus*) (**Plate 23**)
3. Osprey (*Pandion haliaetus*)
4. Scops owl (*Otus scops*) (**Plate 24**)
5. Booted eagle (*Hieraaetus pennatus*)
6. Common buzzard (*Buteo buteo*)
7. Long-legged buzzard (*Buteo rufinus*)
8. Black kite (*Milvus migrans*)
9. Hen harrier (*Circus cyaneus*)
10. Pallid arrier (*Circus macrourus*)
11. Sparrowhawk (*Accipiter nisus*)
12. Levant sparrowhawk (*Accipiter brevipes*)
13. Hobby (*Falco subbuteo*)

Plate 20. Three great knots (*Calidris tenuirostris*) at Ras Al Qayd

Plate 21. A flock of squacco heron (*Ardeola ralloides*) foraging at Ras Al Qayd

Plate 22. A steppe eagle (*Aquila nepalensis*) roosting at Zone D

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Plate 23. A marsh harrier (*Circus aeruginosus*) foraging at Ras Al Barshah

Plate 24. A scops owl (*Otus scops*) discovered roosting inside one of the abandoned buildings at the military camp at Ras Al Qayd.

14. Sooty falcon (*Falco concolor*)
15. Egyptian vulture (*Neophron percnoterus*)
16. Black vulture (*Aegypius monachus*)

Regional Significance of the Islands for Breeding

Gull-billed tern (*Gelochelidon nilotica*): Only breeding site in Arabia, with colonies of 10 to 500 breeding pairs.

Caspian tern (*Sterna caspia*): The largest breeding site in Arabia, with colonies of 6 to 250 breeding pairs.

Grey heron (*Ardea cinerea*): Only breeding site in Arabia, with colonies of up to 150 breeding pairs.

Spoonbill (*Platalea leucorodia*): Only regular and largest breeding site in the Gulf, with up to 150 breeding pairs.

Slender-billed gull (*Larus genei*): Only breeding site in Arabia, with about 1,600 breeding pairs or more than 1% of the breeding population in the Western Palearctic.

Crab plover (*Dromas ardeola*): Biggest breeding colony in the world, with more than 1,500 breeding pairs or about 5% of the world's population.

Swift tern (*Sterna bergii*): The only place in the Western Palearctic where this species breeds, with more than 600 breeding pairs.

National Significance of the Islands for Birds

Out of a national total of 355 bird species, 143 (40%) have been observed, and this does not include many small passerine species that migrate through the islands each year.

Main Areas of Boubyan and Warbah Islands of Ecological Importance

There are three main areas of ecological importance within the project study area. These areas are used by birds for nesting, roosting and foraging. In order of importance, these areas are:

1. **The northern intertidal areas of Boubyan and Warbah Islands:** Based on existing field data, the most important area for biodiversity conservation within the project study area is the northern intertidal areas of Boubyan and Warbah Islands. These areas are mostly undisturbed and provide extremely important breeding and foraging habitats for migratory waterfowl. They are internationally significant areas and provide both nesting and foraging habitats for over 30 species of waterfowl, including high densities of birds of national, regional and international importance.

   Boubyan and Warbah Islands also provide stopover foraging habitats for migratory passerine birds, and some of them, like the linnet (*Carduelis cannabina*) observed in December 2003, are rare visitors. The 19 great knots (*Calidris tenuirostris*) observed in 2004 were the first record of this species. It is possible that Boubyan Island is the only site in the Western Palearctic region where this species regularly winters.

   During Phase Two field observations, at least eight bird species were observed breeding in this area: (1) grey heron (*Ardea cinerea*), (2) western reef egret (*Egretta gularis*), (3) gull-billed tern (*Gelochelidon nilotica*), (4) Caspian tern (*Sterna caspia*), (5) swift tern (*Sterna bergii*), (6) spoonbill (*Platalea leucorodia*), (7) slender-billed gull (*Larus genei*) and (8) crab plover (*Dromas ardeola*).

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2. **Ras Al Qayd on the eastern coast of Boubyan Island and the vegetated coastal habitat extending south to the most easterly extremity of Boubyan Island:** Based on existing field data, the second most important area for biodiversity conservation within the project study site is Ras Al Qayd. On the eastern coast and including the vegetated coastal habitat extending south to the most easterly extremity of Boubyan Island, the site provides abundant foraging resources for raptors and roosting habitat for migratory bird species. This area provides significant intertidal foraging habitat for up to 39 species of waterfowl including birds of national, regional and international importance.

   Significant bird species that were recorded at Ras Al Qayd during Phase Two field observations include great knot (*Calidris tenuirostris*), purple heron (*Ardea purpurea*), greater flamingo (*Phoenicopterus ruber*), scops owl (*Otus scops*), Kentish plover (*Charadrius alexandrinus*), and sooty falcon (*Falco concolor*).

3. **The southwest coast of Boubyan Island (Ras Al Barshah) including Khor Subbayahh:** Based on existing field data, the third most important area of biodiversity conservation within the project study area is the southwest coast (Ras Al Barshah) including the Khor Subbiyah area adjacent to the coast of Boubyan Island. This area alone recorded the highest number of bird species (terrestrial and coastal). This area provides significant foraging habitats for over 40 species of waterfowl including birds of national and regional importance. During Phase Two field observations, significant wildlife species were observed in this area. Some of these species are squacco heron (*Ardeola ralloides*), little egret (*Egretta garzetta*), lesser kestrel (*Falco naumanni*) and (Indo-Pacific) hump-backed dolphin (*Souza chinensis*).

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Conclusion

Boubyan and Warbah Islands are of critical importance for international, regional and national bird populations. Disturbance to these important breeding areas from either direct or indirect impacts will result in the loss of a significant global bird habitat and possibly even the extirpation of species such as the crab plover (*Dromas ardeola*). Boubyan Island is the only place within the Western Palearctic region where this species breeds in such large numbers.

Historical information presented as background to this document confirms that disturbance on the islands has already resulted in the cessation of breeding of some species, such as the white pelican (*Pelecanus onocrotalus*) and the greater flamingo (*Phoenicopterus ruber*). Recent disturbance by Coast Guard personnel stationed on Warbah Island has also resulted in the cessation of breeding of most species on that island, and the background historical data confirms that Warbah Island was until recently an important breeding area for these species.

It is therefore imperative that disturbance to the remaining breeding areas on Boubyan Island does not occur. The development of residential areas and labor camps on the island will result in numerous disturbances to the breeding birds, despite the provision of protected areas for habitat conservation on the island.

The main threats to ground nesting birds on Boubyan Island are from physical human disturbance and from introduced predators, such as cats, foxes, rats, mongooses and crows, that are commensal with human habitation, and which can easily invade the island via bridges and ports and utilize developed roadways and planted vegetations corridors (i.e., fresh water and shelter) to invade what are presently remote and sensitive bird breeding areas. These predators would destroy eggs, chicks and even nesting populations of adult birds and in a short time would cause the island to be abandoned by most nesting species.

Residential areas on the island will be a constant source of feral cats and rats. Cats and rats have been documented to be responsible for the decline and extinction of ground nesting birds on many other islands throughout the world, and Boubyan will be no exception.

What is also clear from KISR's research findings is that suitable nesting habitats are abundant in the southern areas of Boubyan Island (Ras Al Barshah); however, due to human disturbance including feral cats, most species now nest only in the north, on a few suitable areas of habitat. This data clearly demonstrates that any disturbance to the northern nesting sites would be disastrous for the remaining breeding populations, some of which are of international significance. Since the security restrictions on the area have been eased (post Iraqi war of 2003), KISR has aleady recorded new human disturbance (fishermen) to nesting sites, and this resulted in some nesting areas in the north being abandoned by the birds.

Necessary management steps need to be taken to ensure the conservation of the island and protection of its proposed protected habitats from disturbance and impacts resulting directly or indirectly from development. Conservation of the island's bird life is a priority, and efforts to minimize human disturbance should be the major goal of the Kuwait government's policy for Boubyan Island. Long-term security on the islands can only be achieved through international recognition as an important conservation area. In this, Kuwait would gain important environmental recognition in the international community. International recognition for the islands as either a Ramsar Site, an Important Bird Area or a World Heritage Site would confirm Kuwait's legitimate claim to these islands and ensure strong international criticism of any neighboring country or countries that should seek to disturb the environmental or territorial integrity of the islands.

Recommendations

- Gain international recognition and status for Boubyan and Warbah Islands as internationally important bird breeding and foraging areas.
- Prevent disturbance to the islands and restrict residential development.
- Develop a management plan for each of the three proposed protected habitats on the islands.
- Appoint a new Boubyan Conservation Unit (Boubyan Environmental Rangers) to develop management plans, undertake monitoring and implement the necessary actions to protect the proposed protected habitats. This new unit should have a dual enforcement and public education awareness role. The new unit should be funded and equipped from the profits of any island development and have a board of directors that represents the various stakeholders on the island, for example the Environment Protection Authority (EPA), Ports Authority (PA), Ministry of Defense (MOD), and Ministry of Interior (MOI).
- Restrict development of and access to the mainland shoreline north of Subbiyah using legislation, zoning, fencing, monitoring and enforcement.

Chapter 10: Microflora

Abstract

Investigation and assessment of microbial activity in Boubyan Island are key baseline research needs. The main objective of this project was to conduct an assessment of microbial activity of rhizosphere soil in Boubyan and to develop a comprehensive up-to-date database for rhizosphere microflora. Conventional techniques were used for isolation and identification of the microorganisms from different sites of rhizosphere soil. All isolates were further characterized using the biochemical API test, which uses microbial fermentation schemes. The microbial activity and the type of microbes identified from rhizospheric soil varied with number and type of vegetation in different habitats. Consequently, the microbial counts were exceeded in high vegetation habitats, such as tidal channel habitat and aeolian drift habitat, compared with low vegetation habitat, such as in inland sabkha habitat and muddy soil tidal flat habitat. In contrast, no microbial counts were recorded in inland sabkha with bare vegetation. In general, due to the hyperosmotic environment in the island, halophatic microbes were found to be dominant. Additionally, some of the industrially important strains, such as *Staphylococcus, Bacillus, Actinomycetes* and *Penicillium*, were also identified.

Introduction

Soil is a medium for plant growth and a habitat for myriad microorganisms. Although the microbial biomass constitutes only a very small proportion (3%) of the total organic carbon in the soil (Marten and Harider, 1986), it is the most active and dynamic fraction of the living organic pool. The soil microbiota is important for the degradation and synthesis of organic compounds. It is also involved in the cycling of plant nutrients and in the weathering of primary minerals (Parkinson and Coleman, 1991). As for fungi, the mycelia networks of soil are extensive, several hundred meters per gram of soil (Elmholt and Kjoller, 1987). The mycelia networks of soil have an important function in binding soil particles together, helping to maintain a good soil structure for plant growth (Lunch and Bargg, 1985). The micropopulation of a soil of a definite type has a characteristic composition, consisting of organisms that have become adapted to the particular environment (Razak et al., 1999).

The rhizosphere is not static but rather temporally and spatially dynamic and varies with time and space. For microbiological studies, it must be recognized that the rhizosphere does not represent a fixed distance from the root, but is thought to be constituted by a continuum of activity, from a maximum at the root surface and decreasing gradually to a point of no influence in the soil matrix (Bowen and Rovira, 1991). The plant-microbial interaction increases with proximity to the plant root surface and extends even into the root epidermis and the cortical cell of the plant (Show and Burns, 2003).

In this project various types of soil microflora were isolated, identified, characterized and evaluated from the rhizosphere of selected sites on Boubyan Island. In addition, the efficiency of halophytic bacterial growth was assessed against different salt concentration (halotolerance). This project is a vital source for information which is necessary for understanding the development of the island's vegetation and is a direct implementation of the national strategy for conservation of Kuwait's biodiversity.

Methodology

A quantitative and qualitative investigation of the microbial activity of the coastal salt marshes of the island was conducted. The major halophytic microorganism communities were assessed in relation to soil salinity and plant types for each selected study site and habitat.

The general approach of this study involved collecting representative rhizosphere soil samples from selected sites in Boubyan Island. These samples were used to isolate, characterize and identify all the types of microorganisms (bacteria, fungi, yeast, and actinomyctes) in rhizosphere soil. In addition, investigation of the salt tolerance of the bacterial isolates was also studied in microcosm experiments using different concentrations of salinity.

Selection of the Locations for Soil Sampling

The locations selected for this study were dependent on vegetation distribution in Boubyan Island. The samples were collected from 45 selected locations on the island during the summer, spring and winter seasons, and the sites that were visited during the field trips and their global positioning points were summarized in Table 1 and Fig. 1.

Media for Microbial Growth

Tryptone glucose yeast agar (plate count agar medium [PCA]) was used for the isolation of bacteria. The medium consists of (g/l): tryptone, 5 g; yeast extract, 2.5 g; glucose, 1 g; and agar, 9 g (pH 7).

Sabouraud dextrose agar (SDA) was used for isolation of rihzosphere yeast; the medium composition is (g/l): mycological peptone, 10 g; glucose, 40 g; and agar, 15 g (pH 5.6).

Potato dextrose agar (PDA) was used for the isolation of fungi; the medium consists of potato extract, 4 g; glucose, 20 g; and agar, 15 g (pH 5.6). The entire medium was supplied from Oxoid.

Soil Sampling

Rhizosphere soil samples (20-30 cm deep) were collected from the above-mentioned 45 selected sites from the root zone and uprooted grasses. The root specimens were carefully excavated using a small trowel and ice pick to remove the root with the adhering soil matrix. Then the root from the largest connecting root was cut using a sterile knife. The roots with adhering soil were placed in sealed and labeled plastic bags. In the laboratory, the roots were gently shaken to remove loose soil and subjected to further analysis. To reduce variability within each sampling location, composite samples were prepared from numerous sub-samples taken from different locations of the same plant. In order to provide statistically representative rhizospheric soil samples, a composite sample was prepared from three to six plants of each selected species.

Enumeration of Soil Microflora

Total microbe counts (bacterial, fungal and actinomycetes) were determined using the direct plating method and dilution plate count technique standard.

A 10 g rhizospheric (root and soil) sample was placed into a 250 ml flask containing 90 ml of sterile water and shaken for 5-10 minutes. The sample was serially diluted up to 10-fold in sterile water. Ten milliliters of a selected sterile medium was poured over an aliquot of 0.1 ml of the diluted sample in a Petri dish. The medium was carefully mixed with the sample by gentle hand-rotating on the table surface. The cooled plates (room temperature) were stacked upside down in piles and incubated at 37°C overnight (for bacteria) and at 27ºC for 7 days (for fungi and yeast). For anaerobic bacterial growth, plates were incubated in anaerobic jars with a gas generating kit (Oxoid) at 37°C for 72 hours. The diluted extracted rhizosphere samples were also plated in triplicate on a medium containing 3% NaCl.

Colonies were counted using a hand counter and a magnifying lens in an illuminated counting chamber at those dilutions that developed 30-300 colonies. Bacterial numbers were determined using aerobic and anaerobic plate counts with PCA. Fungal counts were obtained with PDA and yeast counts with SDA. Data from triplicate readings were expressed as colony forming units (CFU) per gram dry soil.

Isolation of Pure Culture

The preparation of a pure culture involves the isolation of a given microorganism from a mixed natural microbial population and the maintenance of the isolated microorganism in an artificial environment. Pure cultures are simply obtained by the streak plating method, which involves the separation and immobilization of individual organisms on or in a nutrient medium solidified with agar. The inoculum is progressively diluted with each successive streak and well-isolated colonies develop along the lines of later streaks. Using a sterilized bent wire, a visible colony is then removed and suspended in a physiological solution (e.g., 0.9% NaCl). An inoculum from the resulting suspension is used to make a series of streaks on the surface of a new agar plate. This procedure should be repeated several times. A colony from the last plate should then be removed and used to inoculate a sterilized agar or liquid medium. The pure culture grown must contain only one type of identical cells exhibiting the same morphology.

Characterization of Soil Microflora Isolated from Soil Samples

Identification of microflora was conducted based on classical taxonomy, morphology and biochemical tests (MacFadin, 1980). Morphological identification of the microflora was achieved by standard methods of Gram staining and motility of the microorganism was observed in wet mounts, as a preliminary way to differentiate bacterial types. Fungal identification was determined by microscopic examination and lactophenol blue dye.

Preliminary physical characterization and grouping of strains were based on API 20E, API 50CH and API Staph systems for biochemical identification of the pure isolate of soil microflora. The API test kit for the identification of bacteria provides an easy way to inoculate and read tests relevant to members of bacteria and associated organisms. A plastic strip holding 20 mini test tubes is inoculated with a saline suspension of a pure culture (as per the manufacturer's directions). This process rehydrates the desiccated medium as well. A few tubes were completely filled and some tubes were overlaid with mineral oil so that anaerobic reactions can be carried out for ADH (arginine dihydrolase), LDC (lysine decarboxylase), ODC (ornithine decarboxylase), H_2S (sulfide production), and URE (urease). After incubation in a humidity chamber for 18-24 hours at 37°C, the color reactions were read (some with the aid of added reagents), and the reactions (plus the oxidize reaction done separately) were converted to a seven-digit code. The codes were analyzed using a profile index. The API 20E identification system mostly identifies the Gram-negative microorganisms whereas the API 50CH system identifies Gram-positive microorganism at the species level.

Results

Study of the Site Trips

Field trips were conducted on Boubyan Island during the 2003 to 2004 seasons. The selected sites for the microbial assessment during the field trips and their locations in Boubyan Island are shown in Table 1 and Fig. 1. The soil samples were collected from different habitats and different host plants, namely *Zygophyllum qatarense, Salicornia europaea, Seidlitzia rosmarnus, Halocnemum strobilaceum* and *Bienertia cycloptera.*

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The assessment of microbial activity conducted classified the microorganisms of Boubyan as moderate halophytic microorganisms. Subsequently, the diverse types and number of microbes in the different habitats in the island were reported as follows:

Tidal channel habitat: This habitat is represented by sites E3, W1, N1, N3 and N4 (Table 1), and characterized as saline habitant, with salt measuring about 52.7 dS/m (soil survey). The vegetation growth and coverage vary from 19-57% (vegetation survey) in the winter up to 100% in the summer with *Halocnemum strobilaceum* in addition to *Salicornia europaea* and *Bienertia cycloptera*, which are classified as halophytes. The samples of rhizosphere soil were collected during the summer season, when the vegetation coverage is 100%.

The total bacterial population measured by colony forming units per gram soil (CFU/g) ranged from 13.5 x 10^3 to 28.5 x 10^3 CFU/g soil (**Table 8**). The results also illustrate that most of these bacteria are salt tolerant when grown on medium containing 3% NaCl, their count ranging from 13 x 10^3 to 2.8 x 10^3 CFU/g soil (**Table 7**).

The dominant types of bacterial population identified in this habitat belong to Gram-positive cocci, which are assigned to *Staphylococcus lugdunensis, Staphylococcus warneri, and Staphylococcus sciuri*; Gram-positive rods, which are assigned to *Bacillus licheniformis;* and Gram-negative rods that belong to the genus *Chryseomonas* (**Tables 8 and 9**). These bacteria are characterized as halophilic bacteria. Moreover, fungal growth was observed in rhizospheric soil of this habitat with a count of 35-50 CFU/g soil (Table 7). The types of fungi observed in these sites were identified by microscopic observation as *Penicillium*, *Rhizopus* and *Aspergillus*. Growing isolated fungi on media containing NaCl determined that these fungi are salt-tolerant fungi (halophytes).

Aeolian drift habitat: This habitat is characterized by high vegetation coverage that varies between 11-46% (vegetation survey). It is covered with *Seidlitzia rosmarinus, Frankenia pulverulenta, Halocnemum strobilaceum, Zygophyllum, Scrophularia, Atriplex, Erodium* and *Aeluropus* (all halophytes). The habitat represents saline soil with salt content ECe ranging from 21 dS/m in sites C3 and F09 to 57 dS/m in sites E2 and F07 (soil survey).

Samples from sites of this habitat were collected during the spring. The bacterial numbers isolated from the rhizosphere of sites C3 and F09 range from 25.5 x 10^3 to 27.5 x 10^3 CFU/g soil (Table 7). In sites E2 and F07 the number of bacteria exceeds 29.4 x 10^3 CFU/g soil (Table 7). In contrast, site W1C contains a low number of bacterial counts ranging from 17 x 10^3 to 12.2 x 10^3 CFU/g soil (Table 7). This diversity of microbial count is due to the type and nature of plants in these habitats, which vary between halophytic plants and non-halophytic plants (perennial and annual species). In addition, the high number of counts noticed in the habitat is due to the low range of soil salinity.

Table 7. Microbial Counts for Different Selected Sites at Boubyan Island

Site*	Bacterial Counts CFU/g Soil		Fungal Counts CFU/g Soil		Plant	Habitat
	- NaCl	+ NaCl	- NaCl	+ NaCl		
E3	13.5 x 10^3	13.22 x 10^3	45	44	*Halocnemum*	Tidal channel habitat
W1	23.1 x 10^3	22.0 x 10^3	35	32	*Salicornia*	Tidal channel habitat
N1	25 x 10^3	21 x 10^3	38	38	*Salicornia*	Tidal channel habitat
N3	28.5 x 10^3	28 x 10^3	45	30	*Halocnemum*	Tidal channel habitat
N4	19.95 x 10^3	19.93 x 10^3	50	23	*Bienertia*	Tidal channel habitat
C3	27.5 x 10^3	25 x 10^3	50	40	*Seidlitzia*	Aeolian drift habitat, high vegetation area
C3	25.05 x 10^3	20.55 x 10^3	40	20	*Frankenia*	Aeolian drift habitat, high vegetation area
F09	25 x 10^3	23.55 x 10^3	50	40	*Halocnemum*	Aeolian drift habitat, high vegetation area
E2	29.4 x 10^3	13.5 x 10^3	65	45	*Zygophyllum*	Aeolian drift habitat, high vegetation area
E2	25 x 10^3	19.15 x 10^3	90	70	*Scrophularia*	Aeolian drift habitat, high vegetation area
F07	20.51 x 10^3	15.85 x 10^3	60	50	*Seidlitzia*	Aeolian drift habitat, high vegetation area
W1C	12.2 x 10^3	12.1 x 10^3	20	17	*Atriplex*	Aeolian drift habitat, high vegetation area
W1C	15.323 x 10^3	15.173 x 10^3	15	12	*Erodium*	Aeolian drift habitat, high vegetation area
W1C	17.04 x 10^3	17.02 x 10^3	21	19	*Aeluropus*	Aeolian drift habitat, high vegetation area
E8	0.08 x 10^2	0.05 x 10^2	2	1	-	Bare vegetation sabkha
C11	1.55 x 10^3	1.075 x 10^3	10	4	*Frankenia*	Low vegetation sabkha
C12	5	0	0	0	-	Low vegetation sabkha
C13	1.6 x 10^3	1.4 x 10^3	12	5	*Halocnemum*	Low vegetation sabkha
C5	1.4 x 10^3	1.36 x 10^3	11	7	*Frankenia*	Low vegetation sabkha
C6	1.7 x 10^3	1.67 x 10^3	10	4	*Halocnemum*	Low vegetation sabkha
E12	2.2 x 10^3	2.19 x 10^3	5	3	*Frankenia*	Low vegetation sabkha
E13	1.41 x 10^3	1.389 x 10^3	2	1	*Halocnemum*	Low vegetation sabkha
E15	1.7 x 10^3	1.69 x 10^3	0	0	*Sphenopus*	Low vegetation sabkha
W2a	1.35 x 10^3	1.125 x 10^3	6	3	*Halocnemum*	Low vegetation sabkha
W2c	2.85 x 10^3	2.755 x 10^3	5	4	*Halocnemum*	Low vegetation sabkha
W1D	2.006 x 10^3	2 x 10^3	9	5	*Sphenopus*	Low vegetation sabkha
W3	1.95 x 10^3	1.923 x 10^3	5	4	*Halocnemum*	Low vegetation sabkha
W2	0.515 x 10^3	0.5 x 10^3	3	1	*Salicornia*	Muddy soil along tidal flat habitat
W7	0.643 x 10^3	0.635 x 10^3	5	2	*Salicornia*	Muddy soil along tidal flat habitat

*Sites and locations are presented in Table 1 and Fig. 1.

Table 8. Representative Types of Microbes Isolated from Rhizospheric Area from Selected Sites at Boubyan Island

Zones	Sites*	Plants	Bacteria	Other Microbes
Tidal channel habitat	E3, W1, N1, N3, N4	*Halocnemum* *Salicornia* *Bienertia*	*Staphylococcus lugdunensis* *Bacillus licheniformis* *Staphylococcus warneri* *Staphylococcus sciuri* *Chryseomonas luteola* *Bacillus subtilis*	*Penicillium* (fungi) *Rhizopus* (fungi) *Aspergillus* (fungi)
Aeolian drift habitat	C3, E2, W1C	*Seidlitzia* *Frankenia* *Halocnemum* *Zygophyllum* *Scrophularia* *Atriplex* *Erodium* *Aeluropus*	*Sphingo multivorum* *Serratia plymuthica* *Brevundimonas vesicularis* *Shewanella putrefaciens* *Aeromonas hydrophila gr.* *Bacillus licheniformis* *Chryseomona luteola* *Bacillus megaterium* *Staphylococcus aureus*	*Mucor* (fungi) *Fusarium* (fungi) *Rhizopus* (fungi) *Penicillium* (fungi) *Rhodo. mucilaginosa* (yeast in C3 and E2) Actinomycetes
Inland sabkha 1: bare vegetation sabkha	E5, E6, E7, E8, E14, E16, C4, C7, C8, C9, C10, C14, C15, C16, W1a, W1b, W2b, W4, W5, W5a, F10	No vegetation cover	No microbial activity	
Inland sabkha 2: low vegetation sabkha	E12, E13, E15	*Salicornia* *Strobilaceum* *Halocnemum* *Sphenopus* *Frankenia*	*Serratia plymuthica* *Pseudomonas aeruginosa*	*Fusarium* (fungi) *Rhizopus* (fungi) *Aspergillus* (fungi)
Inland sabkha 2: low vegetation sabkha	C5, C6, C11, C12, C13	*Salicornia* *Strobilaceum* *Halocnemum* *Sphenopus* *Frankenia*	*Serratia plymuthica* *Kocuria varians/rosea*	*Penicillium* (fungi)
Inland sabkha 2: low vegetation sabkha	W2a, W1d, W3	*Salicornia* *Strobilaceum* *Halocnemum* *Sphenopus* *Frankenia*	*Staphylococcus lugdunensis* *Brevundimonas vesicularis*	*Fusarium* (fungi) *Rhizopus* (fungi) *Aspergillus* (fungi)
Muddy soil flat	W2	*Halocnemum* *Salicornia*	*Staphylococcus* *Bacillus licheniformis*	*Penicillium* (fungi) *Mucor* (fungi) Actinomycetes
Muddy soil flat	W7	*Halocnemum* *Salicornia*	*Bacillus licheniformis* *Pseudomonas aeruginosa*	

*Sites and locations are presented in Table 1 and Fig. 1.

All the bacteria identified in this habitat were found to be salt tolerant. The dominant types encountered belong to *Sphingo multivorum, Serratia plymuthica*, *Brevundimonas vesicularis* (Table 8) and *Shewanella putrefaciens, Aeromonas hydrophila gr., Bacillus licheniformis* (Tables 8 and 9) and *Chryseomonas luteola* (Tables 8 and 9). In addition, one type of yeast was observed in sites C3 and E2 and assigned to *Rhodo*. *mucilaginosa* (Tables 8 and 9). Salt-tolerant fungi were also observed in this habitat; the number of fungi in sites C3 and E2 ranged from 50-90 CFU/g soil (Table 7). Conversely, the number of fungi obtained from site W1C was 20 CFU/g soil, which was smaller than found in sites C3 and E2 (Table 7). The dominant types of fungi encountered in this habitat belong to the genera *Mucor* (Table 8), *Fusarium*, *Rhizopus* and *Penicillium* (Table 8). Finally, some moderate halophytic actinomycetes were isolated from this habitat (Table 8).

Table 9. Representative Characterization of Microorganisms Isolated from Boubyan Rhizosphere Soil

Pigment Formation	Shape	Motility	Gram Stain	Bacteria
Light yellow	Grape-like cluster cocci	Non-motile	Gram positive	*Staphylococcus lugdunensis*
Pale white	Grape-like cluster cocci	Non-motile	Gram positive	*Staphylococcus warneri*
Yellow	Grape-like cluster cocci	Non-motile	Gram positive	*Staphylococcus sciuri*
Creamy	Rod	Non-motile	Gram positive	*Bacillus licheniformis*
	Rod	Non-motile	Gram negative	*Chryseomonas luteola*
Red	Rod	Motile	Gram negative	*Serratia plymuthica*
Bluish-green	Rod	Motile	Gram negative	*Pseudomonas aeruginosa*
Yellow	Grape-like cluster cocci	Non-motile	Gram positive	*Staphylococcus aureus*
Creamy	Rod	Non-motile	Gram positive	*Bacillus subtilis*
Creamy to light brown	Large rod	Non-motile	Gram positive	*Bacillus megaterium*

Table 10. Halotolerance Assessment of Three Bacterial Isolates from Boubyan Island Soil

NaCl Concentration (w/v) Bacterial Isolates	Control	5%	8%	10%	13%	15%
Staphylococcus lugdunensis	4+	4+	3+	4+	3+	1+
Staphylococcus warneri	4+	4+	4+	4+	4+	0
Staphylococcus aureus	4+	4+	3+	3+	3+	0
Bacillus licheniformis	4+	4+	4+	4+	4+	1+
Bacillus subtilis	4+	4+	4+	3+	3+	1+
Bacillus megaterium	4+	4+	2+	0	0	0
Sphingo multivorum	3+	3+	3+	4+	4+	1+
Brevundimonas vesicularis	4+	4+	4+	4+	3+	1+
Kocuria varians/rosea	4+	3+	4+	4+	4+	0
Rhodo mucilaginosa	4+	4+	4+	4+	4+	1+

Key: Growth is judged by the naked eye where 4+ = best growth, 3+ = moderate growth, 2+ = weak growth, 1+ = least growth, 0 = no growth.

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Inland sabkha habitat: This is characterized by its high saline soil. A large part of the area is bare vegetation and covered with crystals of salts. The soil salinity content ranges from 105.79-175.33 dS/m (soil survey). Sites E5, E6, E7, E8, E14, E16, C4, C7, C8, C9, C10, C14, C15, C16, W1a, W1b, W2b, W4, W5, W5a, F00, F03 and F10 represent the sites in this part of the habitat. There is no microbial activity in the soil samples that were collected from these sites, except site E8, wherein the number of bacteria was very low, about 0.08 x 10^2 CFU/g soil, and the number of fungi was 1-2 CFU/g soil (**Table 10**). Low microbial activity is due to the absence of vegetation and high salinity to the level that no microbes can survive.

Low vegetation sabkha is characterized by low vegetation cover ranging from 0.5-9% (vegetation survey). The soil is characterized as high saline soil, where the salinity ranges from 106.44-172 dS/m (soil survey). *Salicornia, Strobilaceum, Halocnemum, Sphenopus*, and *Frankenia* are the dominant vegetation in this habitat.

Assessment of microbial activity for the samples collected from the rhizosphere soil of sites E12, E13, E1, C5, C6, C11, C12, C13, W1D, W2a, W2C, W3, F00, F01, F02, F03, F04, F05 and F06 in low vegetation sabkha showed that the microbial count in this habitat is less than other habitats (e.g., tidal channel and aeolian drift habitat). The bacterial counts in sites C11, C12, and C13 were 1.6 x 10^3 CFU/g soil (Table 7) and 1.7 x 10^3 CFU/g soil in sites C5 and C6 (Table 7). Two species of Gram-negative rods, *Serratia plymuthica* and *Kocuria varians/rosea*, dominated these sites (Table 8). The bacteria count in sites E12, E13 and E15 was 2.2 x 10^3 CFU/g soil (Table 7), and species of bacteria identified were Gram-negative rods of *Serratia plymuthia* in addition to Gram-negative rods of *Pseudomonas aeruginosa* (Table 8). On the other hand, the bacterial count in sites W2c, W2a, W1d, and W3 ranged from 1.35 x 10^3 to 2.85 x 10^3 CFU/g soil (Table 7). The dominant types of bacteria encountered belong to Gram-positive cocci *Staphylococcus lugdunensis* and *Brevundimonas vesicularis* (Table 8). Fungal count obtained in sites C11, C12, and C13 (Table 7) was 12 CFU/g soil and one species of *Penicillium* fungi was identified. In sites E12, E13, and E15, the fungal count was 5 CFU/g soil (Table 7) and 5-6 CFU/g soil in sites W2a, W2c, W1d, and W3 (Table 7). *Fusarium, Aspergillus* and *Rhizopus* were the fungi that dominated in these sites.

The microbial count in bare vegetation sabkha was very low, 0.08 x 10^2 CFU/g soil (Table 7). In contrast, the microbial activity in the low vegetation sabkha ranged from 1.3 x 10^3 to 2.8 x 10^3 CFU/g soil for bacteria (Table 7) and 2-12 CFU/g soil for fungi (Table 7).

These results reveal that the microbial number for inland bare vegetation sabkha habitat is very low compared to inland low vegetation sabkha habitat. The disappearance of microorganisms in bare vegetation sabkha habitat was due to the high salinity (175.33 dS/m) of this area and lack of vegetation coverage.

Muddy soil tidal flat habitat: This habitat is represented by sites W2 and W7 (Table 1) and characterized by low vegetation coverage ranging from 10-20% (vegetation survey). Soil salinity was measured at 51.14-57.08 dS/m (soil survey). Most of the vegetation was perennial species such as *Halocnemum strobilaceum*, in addition to the annual halophytes such as *Salicornia europaea*.

This habitat was characterized generally by a low microbial count. The total count of bacteria obtained from the rhizospheric soil samples collected from sites W2 and W7 was 0.5 x 10^3 to 0.643 x 10^3 CFU/g soil, and the number of fungi was 3-5 CFU/g soil (Table 7).

The most abundant bacteria in site W2 were Gram-positive cocci, which were assigned to the genus *Staphylococcus* (Table 9), and Gram-positive rods, which were assigned to the genus *Bacillus licheniformis* (Tables 8 and 9); on the other hand, site W7 is dominated by Gram-negative rods such as *Pseudomonas aeruginosa* and Gram-positive rods belonging to *Bacillus licheniformis* (Tables 8 and 9). Two types of fungi identified in site W2 were *Penicillium* and *Mucor*. In addition, *Actinomycetes* were also found in this habitat.

Halotolerance of Representative Bacterial Isolates

Ten bacterial species (*Sphingo multivorum, Bacillus licheniformis, Brevundimonas vesicularis, Rhodo mucilaginosa, Staphylococcus lugdunensis, Staphylococcus warneri, Staphylococcus aureus, Kocuria varians/rosea, Bacillus subtilis*, and *Bacillus megaterium*) were selected for testing their ability to survive under different NaCl concentrations (from 5% up to 15% [w/v]) (Table 10). Most of the bacteria tested were able to grow at a concentration of up to 13% NaCl and just about cope with a saline concentration up to 15% NaCl. In contrast, *Bacillus megaterium* growth was completely inhibited at 10% (w/v) (Table 10).

Finding salt-tolerant microbes in Boubyan's soil is an expected result because Boubyan Island is badly affected by salinity. In some sites, salinity reaches as high as 175.33 dS/m during high water-table levels.

Discussion

The shift of Boubyan Island towards saline lands due to frequent seawater intrusion has affected the environment and has already depleted natural resources. Salinity and the high water table have influenced the type and distribution of plants and microorganisms. Kernick (1966) and Halwagy and Halwagy (1974) described the vegetation in Boubyan Island as coastal saltbush associated with other halophytes. The types of microorganisms in the soil vary according to the type and the amount of vegetation cover. In this project, the microorganisms from the rhizosphere soil of the island were successfully isolated and identified from different habitats.

The results demonstrate that the island is mainly dominated by halophytic microorganisms that can grow in NaCl solution from 3-13% (w/v). The microbial counts varied according to the type and percentage of vegetation cover and the prevailing soil salinity. Plant root exudates provide the surrounding microorganisms with enhancers or inhibitors that affect their growth (Walton et al., 1994). Subsequently, microbial counts recorded in tidal channel habitat and in aeolian drift habitat (both characterized by high vegetation coverage and soil salinity of 52.7 dS/m) exceeded those isolated from muddy soil tidal flat habitat (characterized by low vegetation coverage and soil salinity of 51.14-57.08 dS/m) and inland sabhka of low vegetation (characterized by low vegetation and soil salinity of 106.44-172 dS/m). In contrast, no microbial counts were recorded in inland sabhka with bare vegetation (which is characterized by high soil salinity and no vegetation coverage). This showed the correlation between distribution and percent of plant cover and microbial growth. It also suggested that vegetation can have a profound influence on the diversity and growth of the soil microbial population.

The growth of microorganisms in Boubyan rhizosphere soil is very limited, as in other saline environments, varying from 0.5 x 10^3 to 28.5 x 10^3 CFU/g soil. These results agreed with the finding of Findrich (1988) for bacterial counts isolated from Lake Assal in Djibouti containing 27.7% salts, which range from 1.5 x 10^3 to 7.5 x 10^5 cells/ml, and with Vreeland et al. (1998), who reported that the bacterial count was up to 10 CFU/g in soil isolated from rock salt from the Salado Formation in New Mexico, USA. Henis and Eren (1963) suggested a reason for this limited growth in saline environments: microorganisms may be unable to multiply easily in saline soil. Moreover, the low counts of microorganisms in Boubyan soil are also due to the lack of variety in plant life and harsh climatic conditions combined with very high saline soil.

Boubyan Island is mainly dominated by halophytic microorganisms. Fifteen bacterial species and five fungi were successfully isolated, identified and characterized. In addition, actinomycetes and yeast were isolated from different sites in the island (Table 8). One particular characteristic of the isolates is that they could grow on a medium containing 3% (w/v) salinity. The halotolerant properties were estimated by growing nine of the bacterial isolates and one yeast (*Rhodo mucilaginosa*) on a solid medium containing different concentrations of NaCl (5% up to 15% [w/v], Table 10). All the tested microorganisms grow optimally at high salt concentrations ranging from 5-13% (w/v) NaCl and a few still grow at salt concentrations up to 15% (w/v) NaCl, such as *Staphylococcus lugdunensis, Bacillus licheniformis, Sphingo multivorum, Brevundimonas vesicularis* and *Rhodo mucilaginosa* (Table 10). This may be because the microorganisms isolated from Boubyan Island have developed different basic mechanisms of osmoregulatory solute accumulation, such as organic solutes (polyols), glycine, bentine and ectoinin, to cope with ionic strength (salt stress). These mechanisms allow halophytes to proliferate and survive in hypersaline soil like Boubyan soil (Ventosa et al., 1998).

Moderate halophilic bacteria have the potential to be of considerable industrial interest (for enzymes, polymers and osmoprotectants) and they possess useful physiological properties, which can facilitate their exploitation for commercial purposes. Consequently, this suggests potential economic and commercial value of the moderate halophilic bacteria isolated form Boubyan Island. Moreover, the ability of halophytic *Actinomycetes* to synthesize and accumulate high concentrations of compatible solutes such as glycine, bentine and ectoinin, which are used in industrial enzyme technology (biosensor technology, PCR) and in pharmaceuticals and cosmetics, makes *Actinomycetes* of economic importance (Galinski and Tindall, 1992). Moderate halophytes such as *Bacillus* spp. and *Pseudomonas* spp. are used as starter for fermentation in soy sauce manufacture, such as Thai fish sauce preparation (Thongthai and Suntinanalert, 1991). This suggested that economically important halophytic microorganisms may be present in Boubyan Island. Hence it can be explored for the isolation of a number of novel and potentially unique organisms.

Therefore, advanced study is recommended into the biological activity of the microorganisms isolated from Boubyan Island. This will provide rich and important information about their potential for industrial application.

Chapter 11: Marine Life

Abstract

Trawls, gill nets, plankton nets, Niskin bottles, and salinity-temperature-depth meters were used to sample 7 to 12 stations circling Boubyan Island each month, except November, from February 2004 through February 2005. During all activities, quantitative observations of sea snakes and marine mammals were recorded. All trawl and gill net catches, with the exception of large skates and rays, were returned to the laboratory for identification and processing. A total of 431 five-minute trawl tows captured 80,905 individuals weighing a total of 310.5 kg. Species caught included 31 crustaceans, 7 mollusks, 4 echinoderms, 1 tunicate, 89 fishes, and 1 sea snake. From June through October, numerical and biomass catches per 100 m^2 ranged from 30 to 50 individuals (125 to 160 g, respectively). Most of the crustaceans and fishes were juveniles, showing the region to be a major nursery area, particularly for the shrimps *Metapenaeus affinis* and, to a lesser degree, *Parapenaeopsis stylifera*. The biomass of juvenile and subadult *M. affinis* reached overall densities in excess of 60 g/100 m^2 in September and October. Fish families well represented in the catches included the clupeids (shads and sardines), pristigasterids (ilishas), engraulids (anchovies), ariids (catfishes), and sciaenids (croakers). The clupeids, pristigasterids, and engraulids are secondary consumers that serve as a major link between lower and higher trophic levels. Catfish and croakers are both bottom feeders and play an important role in energy transfer from inshore to offshore waters. Gillnetting activities captured 1,475 individuals weighing 551 kg. The 60 species captured by gill net included 10 crustaceans, 1 squid, and 49 fishes. Among the fishes were 8 species of sharks and 10 species of rays. Most of the 77 saboor (*Tenualosa ilisha*) captured by gill net exceeded 35 cm in total length and were captured during the spring months. The majority of females were gravid. Fifty-one gill-netted zobaidy (*Pampus argenteus*) averaged only 100 g in weight, showing that Boubyan is also a nursery ground for this important species. Zobaidy captures ranged from March through October. Dolphins (*Sousa* sp.) were observed throughout the year in the waters around Boubyan, with the highest rate of 524 observations occurring during the spring in Khor Abdullah. The most dolphins observed in a single day was 66 on April 28, 2004. Only 38 *Hydrophis* sea snakes were observed during the study period, but this low number was attributed to the difficulties of observing the snakes rather than their scarcity. Rates of 0.2 per observation hour occurred from May through August when water temperatures exceeded 25°C. After August, water temperatures remained above 25°C, but sea snake sightings dropped off considerably.

Introduction

Boubyan Island is located in the Arabian Gulf's extreme northwest corner. It is essentially undeveloped, and as the Gulf's second largest island after Qesham, Boubyan offers significant potential for development. From a fisheries perspective, Boubyan's waters occupy a transition zone between the Gulf's hypersalinities and the fresh waters of the Tigris and Euphrates river system. Most commercial shrimp species exhibit a life cycle that involves an estuarine phase; Al-Attar (1984) implied that the shrimp *Metapenaeus affinis*, Kuwait's second most important species, may utilize the low-salinity waters of the Tigris and Euphrates marshes as nursery habitat.

Since the latter part of 2003, access to Boubyan Island has been possible on a restricted basis, and the Kuwait government funded a project to produce a master plan for the island's development. The Kuwait Institute for Scientific Research (KISR) was a principal member of the environmental survey team, and the Mariculture and Fisheries Department (MFD) was responsible for a substantial part of the marine-related work. The scope and responsibilities of the MFD's participation are outlined below. This chapter presents the results covered in the five progress reports as well as those from all data collected since their production (Bishop, 2005; Bishop and Al-Yamani, 2005; Bishop et al., 2005a, b, c).

Methodology

The objective of this investigation was to provide the necessary spatial and temporal information on renewable marine resources for the development of a comprehensive master plan for Boubyan Island.

From February 2004 through February 2005, nekton, plankton, and physicochemical parameters were sampled monthly at established stations encircling Boubyan. Additionally, during routine monthly investigations, incidental observations were made on air-breathing marine vertebrates (dolphins and sea snakes). The work involved two activities: literature review and fieldwork preparation, and actual data collection and analysis.

Literature Review and Preparation for Fieldwork

Boubyan and Warbah Islands are located at the extreme northwestern corner of the Arabian Gulf and are the furthest from the Gulf's connection with the Sea of Oman via the Strait of Hormuz. Boubyan Island and its surrounding waters rank as one of the most important areas for marine-related research in Kuwait for a number of reasons. Firstly, Boubyan is a coastal island of significant size. Secondly, discharge from the Shatt Al-Arab and Shatt Al-Basrah (i.e., the Third River) results in a transition zone where reduced salinities increase to near oceanic conditions over a relatively short distance. With evaporation greatly exceeding freshwater input, the Gulf as a whole is hyperhaline (Reynolds, 1993), so reduced salinities are an unusual feature, particularly for the western Gulf.

The Shatt Al-Arab is the Gulf's major source of freshwater, and Boubyan is considered a deltaic depositional island (Abou-Seida et al., 1989). Thus, the Shatt Al-Arab and Boubyan are geological components of a single system. In addition to being a buffer zone, Boubyan Island represents a unique transition zone within the Gulf. Due to its location at the upper end of the Gulf, Boubyan Island experiences the Gulf's highest tides. Salinities around Boubyan Island are often 35% (lower during the spring flooding of the Shatt Al-Arab), whereas salinities in Kuwait's offshore waters range from 38 to 42 psu or more.

Boubyan Island has tidal creeks, marshes, extensive mudflats and oyster reefs. The tidal creeks are deep, often exceeding 25 m in depth, and reach a maximum of 33 m deep at low tide. These conditions easily qualify Boubyan Island as an area of special scientific interest. Published information on Boubyan Island and studies of intertidal mudflats in Kuwait Bay indicate that the shallow waters surrounding Boubyan Island are likely to be some of the most biologically productive in the Gulf.

Although there had been no comprehensive studies of Boubyan Island and its surrounding waters prior to the present project, a considerable body of literature exists. This literature review covers all available published reports and some unpublished information. Source materials consist of ministry reports, including those from KISR, articles published in refereed journals, and some unpublished data.

Table 11. Characteristics of Water Bodies Associated with Boubyan Island

Water Body	Length (km)	Maximum Width Low Tide (km)	Maximum Width High Tide (km)	Maximum Depth Low Tide (m)	Common Features
Khor Abdullah	42	15	20	11	Extensive mudflats
Khor Boubyan	14	1.3	3	20	Oyster reefs (few)
Khor Al-Milh	17.5	0.5	3	33	Oyster reefs & intertidal mudflats
Khor Al-Mughwi	17	0.5	>5	20	Oyster reefs & intertidal mudflats
Khor Al-Subbiyah	49	1.5	3	23	Oyster reefs & intertidal mudflats
Khor Ath-Thala'ab	11	0.5	>5	4	Oyster reefs & intertidal mudflats

Hydrodynamics, Bathymetry and Flood Patterns

Bathymetry charts of the Boubyan area were obtained from Kuwait's Ministry of Communication. Charts KU2 (MOC, 1999a) and KU10 (MOC, 1999b) cover the Boubyan area and Khor Al-Subbiyah, respectively (**Fig. 15**). The waters surrounding Boubyan Island are referred to as *khors*, which translates to tidal creeks or inlets. Starting at Boubyan Island's southwest corner, Ras Al-Barshah (Fig. 15), and continuing in a clockwise fashion, the island is separated from the Kuwait mainland by Khor Al-Subbiyah, which continues north for about 49 km (**Table 11**) and joins Khor Boubyan. Khor Boubyan flows east-west, separating Boubyan Island from Warbah Island, Kuwait's northernmost island. As Khor Boubyan makes its way eastward, it joins Khor Abdullah, an internationally important water body that forms the boundary between Kuwait and Iraq's Fao Peninsula. South Boubyan is bathed by open Gulf waters north of Failaka Island.

Khor Al-Subbiyah's southern end terminates between Ras Al-Barshah on the east and Ras Al-Subbiyah on the west (Fig. 15). Waters in Khor Al-Subbiyah range in depth to 23 m, but most areas are less than 6 m deep. Khor Al-Subbiyah is characterized by extensive intertidal mudflats and shallow areas that may consist of mud, sand, shell, or some combination. At low tide, Khor Al-Subbiyah's maximum width is about 1.5 km, but this dimension easily doubles during high tides. Depending on location, intertidal oyster reefs (tentatively identified as *Saccostrea cucullata*) are a prominent feature. The locations of these reefs appear to be in areas sheltered from heavy wave action.

Khor Boubyan ranges in width from 1.33 to 3 km depending on the tidal state. This 14-km water body reaches a maximum depth of 20 m and is subject to strong tidal currents.

Fig. 15. Boubyan Island with the locations of Dames and Moore stations (D&M 405 and 406), KISR's Station A, and sea snake (*Hydrophis*) capture

Along Boubyan Island's eastern edge, intertidal mudflats may extend for 3 km into Khor Abdullah during low tide. The depth of subtidal waters in Khor Abdullah increases quickly to about 10 m, with maximum depths of 12 m. The most prominent feature along the eastern coast of Boubyan Island is Ras Al-Gayde, a peninsula that probably results from the regular conflict of southeasterly winds and the net flow south of Khor Abdullah's waters. The Ras Al-Gayde peninsula projects north about 1.5 km and has a base width of 1 km (MOC, 1999a). Some 3.5 km east of Ras

Al-Gayde, but within Khor Abdullah, is Khor Al-Gayde, a subtidal channel. This channel, which is 1 km in width and exceeds 5 m in depth at low tide, is defined by very shallow waters (<1 m) along its western and eastern boundaries. Eastward of Khor Al-Gayde, the waters of Khor Abdullah deepen to 6 to 9 m. The water bottom along the southeastern and southern coasts of Boubyan Island exhibits a low gradient with extensive areas, 4 to 10 km from the coast, less than 2 to 3 m deep at low tide.

Three major khors penetrate the northwestern quadrant of Boubyan Island. In a clockwise direction facing north, these are Khor Al-Mughwi, Khor Ath-Thala'ab, and Khor Al-Milh. The first two khors run roughly northwest-southeast and share a common mouth where they join Khor Al-Subbiyah, which has a depth that exceeds 23 m at this point. Boubyan Island's northern coast is bisected by Khor Al-Milh, which progresses south for about 10 km before turning sharply east. At low tide, these khors are about 0.5 km in width at their widest and vary in length from 11 to 17.5 km (Table 11). At high tide, all of the khors lose their distinctive boundaries and form a large body of water exceeding 5 km in width. Khor Al-Milh and Khor Al-Mughwi end in cul-de-sacs. These khors are uncharacteristically deep, a reflection of the amount of water flushing in and out due to extensive intertidal areas and the exaggerated tidal heights at the Gulf's northern extreme. In Khor Al-Milh, depths reach 33 m and are often in excess of 20 m. Depths greater than 10 m are common in Khor Al-Mughwi. Khor Ath-Thala'ab and Khor Al-Milh are connected throughout all but the very lowest tides.

Located immediately north of Boubyan Island is Warbah Island. This 3,624-ha island is the northernmost in the Gulf and is separated from Iraq by Khor Shituyanah, another international boundary shared with Iraq. Overall, Warbah Island is somewhat crescent-shaped, with a maximum north-south distance of 4 km and an east-west length of 14 to 15 km depending on tidal state. With its very low relief, inundation of almost the entire island is likely during extreme high tides. At least one small tidal creek penetrates the southern coast of Warbah Island, but this khor is too small to be featured on the Khor Al-Subbiyah hydrographic chart (MOC, 1999b).

Several studies have addressed the hydrodynamics of waters south of Boubyan Island (Abou-Seida and Gopalakrishnan, 1980; Abou-Seida et al., 1989; Samhan et al., 1989), but only one appears to have measured the currents in Khor Al-Subbiyah (Dames and Moore, 1983a). Dames and Moore (1983a) placed current meters at two locations in the southern portion of Khor Al-Subbiyah and recorded the speed and direction of surface and bottom currents. One Dames and Moore station (D&M 405) recorded data from September 13, 1981 through April 4, 1982, and the other (D&M 406) recorded data from September 13 through October 22, 1981 (Fig. 15). Mean maximum surface and bottom current speeds during flood tides (55 and 59 cm/s) exceeded those during ebb tides (51 cm/s for both surface and bottom) during the six-month study. Maximum surface current speeds averaged from 41 to 69 cm/s, whereas maximum bottom current speeds averaged from 44 to 70 cm/s. Maximum current speeds generally ranged between 80 and 100 cm/s, with the greatest speeds exceeding 100 cm/s. Another study reported maximum current velocities at the mouth of Khor Al-Subbiyah to be only 0.5 m/s (Abou-Seida and Gopalakrishnan, 1980). Maximum wave height along Boubyan Island's southwestern coast ranged from 2.4 to 3.5 m (Abou-Seida and Gopalakrishnan, 1980).

No information on flood patterns was found in the literature review. Abou-Seida and Gopalakrishnan (1980) provided a general circulation pattern of waters south of Boubyan Island.

Marine Water and Sediment Quality

The chemical characteristics of Boubyan's Island's marine waters were first analyzed by Jacob et al. (1981). Their 40 stations, sampled in December 1979 and January 1980, encircled the island, and the water analysis included electrical conductivity, salinity, temperature, dissolved oxygen, pH, turbidity, ammonia, nitrite, nitrate, phosphate, silicate and sulfate (**Table 12**).

December 1979 temperatures around the Boubyan area averaged two degrees cooler than those in Kuwait Bay (15 vs. 17ºC), but in January 1980, Kuwait Bay's temperatures averaged about one degree colder (Table 12). Salinities between the two areas differed by 4 to 5 ppt each month (37 vs. 42 psu), and salinities in January 1989 were about 3 ppt lower than those in December 1979, reflecting the freshwater discharge of the Shatt Al-Arab (Table 12). pH values ranged from 8.1 to 8.3, and oxygen values were close to saturation (Table 12).

Nutrient values in both water bodies were generally low with concentrations around Boubyan exceeding those in Kuwait Bay in December 1979 and, to a lesser extent, in January 1980 (Table 12). Sulfate was an exception, with values in Kuwait Bay exceeding those in the Boubyan area in both months. Boubyan's waters were also more turbid than those in Kuwait Bay (Table 12).

Following the pioneering work of Jacob et al. (1981), Dames and Moore (1983a) established a hydrological station in Khor Al-Subbiyah, where they collected samples monthly from September 1981 through August 1982. Analysis of the water samples involved 26 variables: salinity; tem-

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Table 12. Mean Values of Selected Parameters in Kuwait's Waters in December 1979 and January 1980 (after Jacob et al., 1981)

Period	Region	Temperature (ºC)	Salinity (psu)	pH	Oxygen (mg/l)	Turbidity (ppm)	Ammonia (ppm)	Nitrite (ppm)	Nitrate (ppm)	Phosphate (ppm)	Silicate (ppm)	Sulfate (ppm)
Dec 1979	Kuwait Bay	17.2	41.8	8.3	8.1	8.4	0.7	0.007	0.02	0.06	1.2	3,000
	Boubyan area	15.1	37.1	8.1	7.3	160.0	2.0	0.02	0.8	0.17	1.4	2,720
Jan 1980	Kuwait Bay	14.7	39.5	8.3	8.1	4.8	1.4	0.008	0.02	0.03	0.6	2,900
	Boubyan area	15.7	34.6	8.3	7.9	11.0	0.4	0.009	0.2	0.04	1.0	2,600

Table 13. Mean, Maximum, and Minimum Values of Selected Parameters in Khor Al-Subbiyah Just South of Boubyan Bridge from October 1995 to July 1996 (Source: Al-Yamani et al., 1997, pp. 55-58)

Overall	Temperature (0ᶜ)	Salinity (psu)	pH	DO (mg/l)	NH_3-N (µg/l)	NO_2-N (µg/l)	NO_3-N (µg/l)	PO_4-P (µg/l)	SiO_3-Si (µg/l)	Chlorophyll a (µg/l)
Minimum	13.8	19.1	7.7	2.6	0.0	1.4	68.6	3.0	244	0.35
Maximum	30.1	29.0	8.8	9.1	96.6	25.2	29.4	80.5	2561	15.71
Mean	22.6	23.8	8.4	5.5	18.2	9.8	336.0	18.6	1293	3.63

Key: DO = Dissolved oxygen

perature; dissolved oxygen (DO); biochemical oxygen demand (BOD); oil and grease; pH; alkalinity; turbidity; chlorophyll a, b, and c; total suspended solids (TSS); total dissolved solids (TDS); total phosphorus; total nitrogen, ammonia, nitrite and nitrate; total dissolved cadmium, lead, mercury, zinc, calcium and magnesium; and hardness due to calcium and magnesium. Salinities ranged from 33.7% in April to 39.9 psu in September (**Fig. 16**), and TSS ranged from a low of 87 ppm in March to nearly 921 ppm in August (**Fig. 17**). Nitrate concentrations ranged as high as 150 ppb, whereas ammonia and nitrite concentrations rarely exceeded 20 ppb (**Fig. 18**).

These historical data are particularly important because of subsequent major changes in the Tigris-Euphrates watersheds. In December 1992, Iraq completed the Third River, a man-made canal connecting the Euphrates River with Khor Al-Zubair, an inlet immediately north of Warbah Island (Al-Yamani and Khan, 2002). This resulted in an influx of freshwater directly into Khor Al-Subbiyah, Khor Boubyan and Khor Abdullah, which changed the chemical and physical characteristics of the waters. In southeastern Anatolia, Turkey is currently involved in a massive scheme to impound the waters of the Tigris and Euphrates Rivers behind 22 dams, 19 of which are, or will be, capable of generating electricity. Following the Gulf War of 1990-91, Iraq began draining the marshlands near the confluence of the Tigris-Euphrates Rivers. These changes have undoubtedly affected the waters around Boubyan Island, but documentation of these changes has been either indirect or relatively short term. Hussain (1997) reported a major increase in catches of the anadromous hilsa shad (*Tenualosa ilisha*) in Khor Al-Zubair following the connection of the Euphrates and Tigris Rivers to Khor Al-Zubair by a channel. This channel changed the salinity of Khor Al-Zubair from that of a hyperhaline lagoon (>40 psu) to that of an oligohaline estuary where salinities dropped to <10 psu. The lower salinities allowed the growth of reeds (presumably *Phragmites australis*).

Al-Yamani et al. (1997) established six stations in Kuwait's waters, including Station A immediately south of the Boubyan Bridge across Khor Al-Subbiyah (Fig. 15), and measured selected water parameters monthly from October 1995 through July 1996. Published data were averaged for all stations by month and for each station over time (**Table 13**). Included in the tables published by Al-Yamani et al. (1997) are monthly maxima and minima, and for salinity, it is assumed that the minimum monthly value is representative of the Khor Al-Subbiyah station (**Fig. 19**). Salinities remained around 26 psu in the fall and winter, and dropped to 17 psu in April 1996 (Fig. 19), well below

Table 14. Physiochemical Variables at Station A in Khor Al-Subbiyah Measured on a Monthly Basis from 2001 to 2003 (Source: F. Al-Yamani)

Variable	Range
Temperature (ºC)	14.6-31.9
Salinity (psu)	36-42
DO (mg/l)	4.9-8.0
Secchi depth (m)	0.1-0.4
TSS (mg/l)	70->200
Turbidity (NTU)	10->100
Chlorophyll a (µg/l)	0.4-3
Key: DO = dissolved oxygen, TSS = total suspended solids	

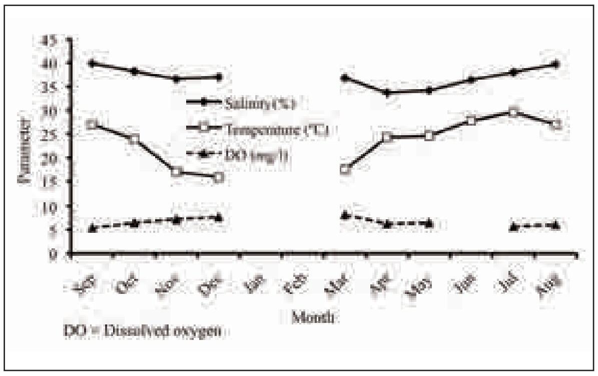

Fig. 16. Salinity, temperature, and DO at a 4-m depth in Khor Al-Subbiyah from September 1981 to August 1982 (Source: Dames and Moore, 1983a)

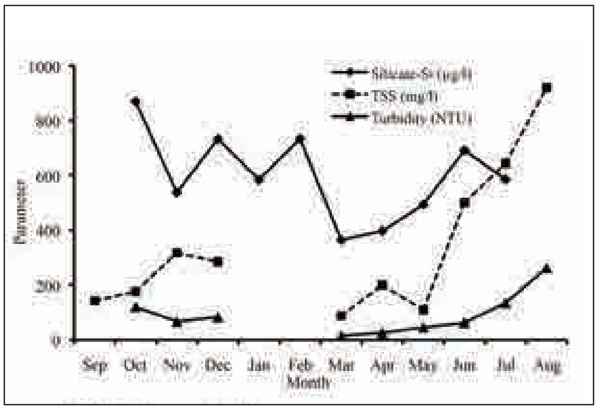

Fig. 17. TSS and turbidity from September and October 1981, respectively, through August 1982 and silicates from October 1995 to July 1996 in Khor Al-Subbiyah (Source: Dames and Moore, 1983a; Al-Yamani et al., 1997, pp. 55-58)

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the 35 to 40% reported by Dames and Moore (1983a). Obviously, the low salinities reflected the completion of the Third River in 1992 (Al-Yamani and Khan, 2002). DO values were similar between the two studies, as were temperatures (Figs. 16 and 19). Concentrations of other nutrients (i.e., NH_3-N, NO_2-N, NO_3-N, and PO_4-P) were roughly similar between the studies of Dames and Moore (1983a) and Al-Yamani et al. (1997), even though about 15 years separated the sampling periods (Fig. 18 and **Fig. 20**).

The key hydrochemical features of Khor Al-Subbiyah noted in the study of Al-Yamani et al. (1997) were lower salinities and high concentrations of nitrate and silicate, with varying concentrations of phosphate and ammonia. Concentrations of nitrates and phosphates were never found to be zero during the study period, showing that these nutrients were not limiting factors (Fig. 20). During periods of high phytoplankton growth, however, phosphate concentrations were nearly depleted, which was interpreted as being indicative of optimal utilization of phosphorus by the phytoplankton community. Sampling at Station A has continued, as often as possible on a monthly basis, and **Table 14** presents a summary of the concentration ranges of the variables measured.

A biotope mapping project recorded selected physiochemical data in July 2002 (Bishop et al., 2002) and found depth-averaged salinities ranging from 36.8 to 38.0 psu and temperatures varying from 30.9 to 32.1ºC. Turbidity values were as low as 27.7 NTU, but usually ranged well above 133 NTU. Percent DO was at least 73 and ranged up to 86 during the study. pH values showed little variation between 8.1 and 8.2, and chlorophyll concentrations varied from 2.0 to 5.5 µg/l.

A shortcoming of studies of only one-year's length is that they provide a biased or partial view of any long-term trends. This is particularly true when considering all of the modifying factors occurring in the Tigris-Euphrates watershed.

Silt and clay dominate the subtidal sediment around Boubyan Island (Khalaf et al., 1984). In Khor Al-Subbiyah, the sand component is high enough to classify the sediment as sandy mud. North and south of the Boubyan Bridge, bottom grabs have revealed considerable areas of gravelly sand and shell hash, with little living material (Bishop et al., 2002). Both living and dead oyster reefs are conspicuous components of the intertidal area of Khor Al-Subbiyah and are prominent enough to be depicted on the hydrographic charts published by the Ministry of Communication. Course sand, mud, and combinations were all present in the intertidal areas depending on tidal height (Bishop et al., 2002). Shoreline types around Boubyan

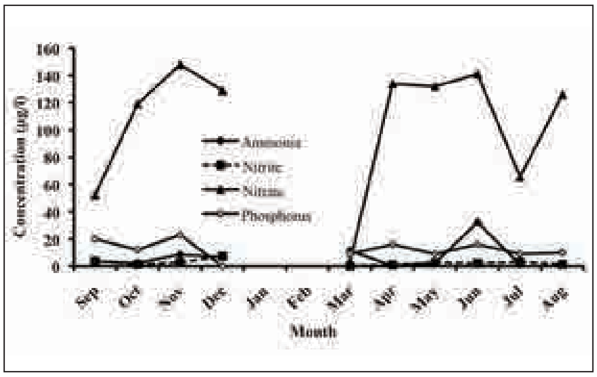

Fig. 18. Concentrations of selected nutrients in Khor Al-Subbiyah at a 4-m depth from September 1981 to August 1982 (Source: Dames and Moore, 1983a)

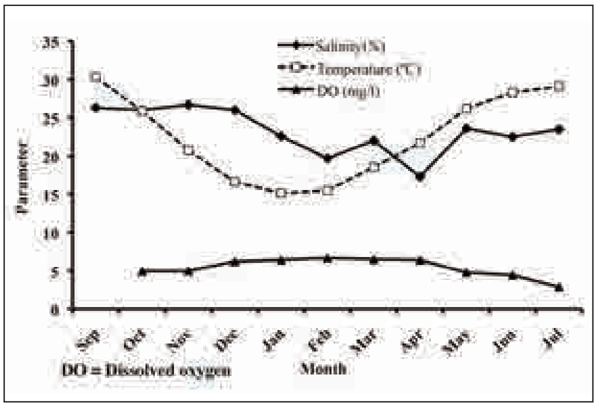

Fig. 19. Salinity from Khor Al-Subbiyah south of the Boubyan Bridge; temperature and DO averaged over depth from six stations in Kuwait's waters from September 1995 to July 1996 (Source: Al-Yamani et al., 1997, pp. 55-58)

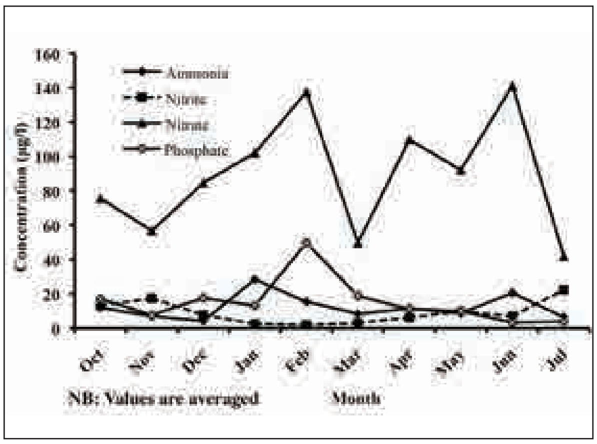

Fig. 20. Average nutrient concentrations at six stations in Kuwait's waters from October 1995 to July 1996 (Source: Al-Yamani et al., 1997, pp. 55-58)

Island identified by Al-Sarawi et al. (1985) consist mostly of soft mud in the lower intertidal zone and medium to coarse sand beaches or tidal mudflats in the upper intertidal areas. Most of the intertidal area of the island's interior khors is soft mud (Al-Sarawi et al., 1985).

In spite of being associated with the Shatt Al-Arab Delta, most of the recent sediment in Kuwait's northern waters, both intertidal and subtidal, is of aeolian origin (Khalaf and Ala, 1980; Al-Bakri et al., 1984). Wilson (1925) estimated that the northern Gulf received only about 10% of the suspended load of the Tigris and Euphrates Rivers.

Marine Biological Resources

Initial reports on the fauna of Boubyan Island concerned birds (Ticehurst et al., 1925, 1926). Prior to these early investigations, Calman (1920) described the burrowing crab *Chiromantes boulengeri* along the banks of the Euphrates; this species has since been documented at the mouth of the Shatt Al-Arab (Apel and Türkey, 1999).

Since the pioneering work on Boubyan's avifauna, over 50 years elapsed before Boubyan's marine fauna received attention from scientists. Dames and Moore (1983b) sampled one or two stations in Khor Al-Subbiyah for 12 months from September 1981 through August 1982, with plankton nets, seines, and trawls. Initially, they employed a 0.5-m-diameter plankton net of 0.202-mm mesh in September and October, but clogging by phytoplankton posed a problem. This problem was solved in subsequent sampling by employing a 0.505-mm mesh net. Their monthly invertebrate zooplankton data ranged from a low of 471 individuals/100 m^3 in February to a high of 881,366 individuals/100 m^3 in September (Dames and Moore, 1983b). Identification of the zooplankton to the lowest possible taxon provides information on abundance and timing of holozooplankton and larval phases of commercial and noncommercial species. Often, what is not caught is just as informative as what is caught. Copepods, considered to be one of the most important primary consumers (or secondary producers), were most abundant in September and October, when numbers per 100 m^3 ranged from 4,000 to 53,000. Densities at other times of the year did not exceed 900/100 m^3 (Dames and Moore, 1983b).

The only study which has included phytoplankton is that of Al-Yamani et al. (1997). In Khor Al-Subbiyah, they found a mean phytoplankton density of 64,351 individuals/l (ranging from 0 to 565,305 individuals/l), with the genus *Nitzschia* dominating. The phytoplankton community consisted of no fewer than 23 species with concentrations greater than 100 individuals/m^3. Mean zooplankton density was 62,594 individuals/m^3 (ranging from 9,530 to 330,469), with abundances of 15 groups greater than 100 individuals/m^3. Some of these groups, however, covered entire classes of animals, so the number of species could be huge. The most important genera numerically were the copepods *Parvocalanus* and *Acartia*, and Al-Yamani et al. (1997) stated that the Khor Al-Subbiyah area was a rich feeding ground for larval fish and shrimp.

Kuwait's shrimp landings depend on three species; in descending order of importance, they are *Penaeus semisulcatus*, *Metapenaeus affinis*, and *Parapenaeopsis stylifera*. Zooplankton samples from Khor Al-Subbiyah did not contain any penaeid eggs or penaeid nauplii, and only a few larval *P. stylifera* (Dames and Moore, 1983b). Both protozoa and mysis stages of P. *stylifera* were captured in June. Postlarval *Metapenaeus* and *P. stylifera* were found in June, July, and/or August samples. Larval *P. semisulcatus* were also absent from the zooplankton samples, but postlarvae were captured almost throughout the year, with the highest numbers captured in April and June (18 to 50 individuals/100 m^3). One plankton tow (at Station 615) in April failed to capture any postlarvae, while a tow at a companion station (Station 614) captured 50, showing the patchy distribution characteristic of plankton (Dames and Moore, 1983b).

Another shrimp of importance is *Acetes* sp. With a total length of only 6 mm, this species is of no direct commercial use in Kuwait, but it provides forage for higher trophic levels and represents an important component of energy transfer. Numbers of adult *Acetes* were highest in the summer and fall, with an average monthly density of 163 individuals/100 m^3 at Station 614 and 62 individuals/100 m^3 at Station 615 (Dames and Moore, 1983b).

Brachyuran larvae were also a significant component of the zooplankton captures. Monthly abundances ranged from 2,000 to 7,000 depending on the station, with monthly maxima of up to 35,000 individuals/100 m^3 occurring in the spring and summer. Ghost and fiddler crab (Ocypodidae) larvae averaged about 2,800 and 142 individuals/100 m^3 at Stations 614 and 615, respectively. Numbers were highest (>32,000) in June (Dames and Moore, 1983b).

Spring and summer sampling produced the most fish eggs and fish larvae. A maximum of 1,154 eggs/100 m^3 was obtained from Station 614 in June. Overall, Station 614 had about three times more fish eggs than Station 615 on average (108 vs. 35). Three fish families contributed the most fish larvae, with 70 and 222 clupeid, 6 and 276 sciaenid, and 148 and 165 gobiid larvae/100 m^3 on average at Stations 614 and 615, respectively. Sciaenids were particularly abundant in May. Zobaidy (*Pampus argenteus*) ranked as the main species of commercial interest. Sampling in May captured 362 *P. argenteus* larvae/100 m^3, strong evidence that the waters around Boubyan serve as a primary nursery ground for this species (Dames and Moore, 1983b).

Al-Yamani et al. (1997) reported the waters of Khor Al-Subbiyah to be very rich in phytoplankton. Using a 110-µm mesh net, they obtained mean phytoplankton concentrations of 5.57 x 10^6 individuals/m^3, with the fewest in April 1996 (11,086 individuals/m^3) and the most the following June (66.89 x 10^6 individuals/m^3). These concentrations in Khor Al-Subbiyah are more than 20 times the mean of 0.2 x 10^6 individuals/m^3 reported by Lee et al. (1990) for all of Kuwait's waters south of Failaka. These results indicate that the waters around Boubyan are some of Kuwait's most productive. Al-Yamani (personal communication) identified 38 diatom and 5 dinoflagellate taxa from Khor Al-Subbiyah.

Using a combination of characteristic flora or fauna and substratum type, Bishop et al. (2002) identified 12 intertidal biotopes in Khor Al-Subbiyah within 5 km north and south of the Boubyan Bridge. Most obvious of these biotopes were oyster reefs (*Saccostrea cucullata*), muddy sands with the mud snail *Cerithidea cingulata*, muddy sand with hermit crabs (*Diogenes* sp.), mud with the crab *Macrophthalmus* and mudskippers (*Boleophthalmus dussumieri*), and muddy sand with fiddler crabs (*Uca lactea*). The halophytes *Salicornia* and *Halocnemon* dominated two intertidal biotopes. The intertidal salt marshes on Boubyan and the west side of Khor Al-Subbiyah are the largest and most important in Kuwait.

During the October 2003 field trip around Boubyan Island, many of the biotopes identified by Bishop et al. (2002) appeared to be characteristic of Khor Al-Subbiyah north of the Coast Guard Station and in the creeks, including Khor Al-Milh. In particular, oyster reefs (*Saccostrea cucullata*), mudskippers (*Boleophthalmus*), crabs (*Macrophthalmus*), and fiddler crabs (*Uca* sp.) were common components of the intertidal areas. Findings by Dames and Moore (1983b) and Al-Yamani et al. (1997) show that larvae of these species often dominate the zooplankton.

Coad and Papahn (1988) and Coad and Al-Hassan (1989) documented shark attacks on humans over a number of years in the Karun and Shatt Al-Arab Rivers, respectively. They identified the offending species as probably the bull shark (*Carcharhinus leucas*), and it is likely that this shark is relatively common in waters around Boubyan Island.

Fisheries

Largely as a result of regional instabilities, information on the fisheries around Boubyan Island is mostly anecdotal. It is believed, however, that Boubyan serves as a major nursery area for many commercial species, particularly shrimps of the genera *Penaeus*, *Metapenaeus*, and *Par-*

apenaeopsis; zobaidy (*Pampus argenteus*); nagroor (*Pomadasys kaakan*) and croakers. Supporting data are provided by zooplankton studies, mostly those of Dames and Moore (1983b), which reported postlarvae of all shrimp species, good numbers of zobaidy larvae, as well as croaker larvae (Sciaenidae). Al-Hussaini et al. (2001) found juvenile nagroor (with total lengths of 70 to 120 mm) to be common in the intertidal stake nets on Mischan Island, a small island immediately south of the mouth of Khor Al-Subbiyah. Bishop et al. (2002) captured small nagroor and the tiger-tooth croaker (*Otolithes ruber*) in July 2002 trawl samples in Khor Al-Subbiyah's shallow waters. During the biotope mapping study, subtidal fish traps (gargoor) and gill nets were noted south of the Boubyan Bridge, and intertidal fish traps (hadrah) were common along the western shore of Khor Al-Subbiyah (Bishop et al., 2002). Commercial fishermen target zobaidy, saboor (*Tenualosa ilisha*) and mullet using gill nets up to 4 km in length north of Failaka Island (M. Al-Husaini, personal communication).

Marine Reptiles and Mammals

There are few published records of marine reptiles and mammals in the Boubyan area. Dar Al-Handasah Consultants (1983) and Al-Zamel et al. (1985) reported the occurrence of sea snakes to be common on mudflats and at inlets where they fed on mudskippers, but provided no documentation. An annulated sea snake, *Hydrophis cyanocinctus*, was captured in July 1982, in Khor Al-Subbiyah (Fig. 11) by seine, and its photograph was published (Leviton et al., 1992). Capture data, such as water temperature and salinity, were not provided, however.

Sea snakes are common in Kuwait's waters during the summer months, and as many as five species may occur (J. Bishop, personal observation). During the shrimping season in September and October, sea snakes are commonly captured by trawls as by-catch (J. Bishop, personal observation). No records of turtles are reported from the Boubyan area, but the southern coast of Boubyan Island could provide nesting habitat for them.

The Indo-Pacific humpback dolphin (*Sousa chinensis)* is known to frequent the lower reaches of Khor Al-Subbiyah. A pod of about 22 individuals was observed and reported during the July biotope mapping project (Bishop et al., 2002). This species is regularly observed during monthly sampling of the hydrological station just below the Boubyan Bridge (A. Lennox, personal communication). The Indo-Pacific humpback dolphin in the Arabian Gulf and western Indian Ocean exhibits a more pronounced hump and darker coloration than do specimens from Hong Kong and Australia (Jefferson and Karczmarski, 2001).

Three other cetaceans might be expected to occur in the waters around Boubyan Island: the bottlenose dolphin (*Tursiops truncates*), the common dolphin (*Delphinus delphis*), and the finless porpoise (*Neophocaena phocaenoides*) (Al-Robaae, 1975; Carpenter et al., 1997). The common dolphin is usually found in offshore waters, so it is less likely than the other two species to be observed near Boubyan Island. Al-Robaae (1974) summarizes reports of cetaceans in the region, but most of the records refer to strandings only.

Trawling

Materials and Methods

Trawling activities were conducted at 12 stations (**Fig. 21**) positioned to study Khor Al-Subbiyah (Stations BUB-01, 02, 03), Khor Boubyan at the extreme western end of Warbah Island (Station BUB-05), Khor Al-Mughwi (Station BUB-04) and Khor Al-Milh (Stations BUB-06, 07, and 08), Khor Abdullah (Stations BUB-09 and 10) and South Boubyan (Stations BUB-11 and 12). Sampling at each station consisted of three separate trawl tows at depths of 1 and 2 m and a companion trawl tow in deeper waters. Due to the steep bottom gradients at some stations, however, the desired depth throughout the trawl tow was not maintained as consistently as desired. Stations BUB-07 and 08, both in Khor Al-Milh, were particularly difficult because of the steep bottom gradients. Also, tidal states were not always ideal for selective trawling. During the 12 months of sampling, only one tow was not completed, i.e., the 2-m-depth trawl tow at Station BUB-05 in May 2004. Otherwise, all trawl tows were completed as scheduled for a total of 431 tows (12 months x 36 stations/month - 1 tow). Trawling activities were conducted from February 2004 through February 2005; no sampling took place during the month of November 2004 due to persistent high winds.

Two different vessels, depending on availability and convenience, served the project. The smaller of the two vessels, Abhath 4, was a 4.3-m Boston Whaler powered by a 63.4-kW (85-hp) engine. The larger vessel, Sea Lab 4, was an 11-m Magellan 36, powered by two 186.5-kW (250-hp) engines. Most of the sampling activities, including trawling, were conducted with Sea Lab 4. Engine speeds of Abhath 4 and Sea Lab 4 during trawling operations varied from 1,000 to 1,450 rpm and from 600 to 1,200 rpm, respectively, depending on wind and currents. Boat speed varied from 2.1 to 6.1 km/h, but generally averaged 4.1 km/h. Swept width was estimated by observing the distance between the otter doors while trawling in shallow water.

A 5-m chain-line length otter trawl of 34-mm stretch mesh with a 10-mm cod end of stretch mesh swept a width of 3 m and covered from 1,012 ± 230 m^2 (ranging from 225 to 1,675 m^2) during a timed five-minute tow. The entire catch, except jellyfish, was saved and returned to the laboratory for processing. Ancillary data collected with

Fig. 21. Station locations of the Boubyan Island study from February 2004 to February 2005 (BUB-01 to BUB-12)

each tow included the following: tow start time, Global Positioning System (GPS) location to the nearest 0.1" at the start and finish, depth range, engine speed, and tow speed to the nearest 0.1 km as provided by the GPS. At each station, surface water salinity and temperature were measured and recorded to the nearest 0.1 unit.

Sample processing included separating each catch by species and measuring each individual to the nearest millimeter. Measurements included total weight of each species and individual total lengths of all bony fishes, carapace lengths for shrimps and hermit crabs, carapace widths for other crabs, and mantle lengths for cephalopods and nudibranchs. Penaeid shrimp and most crabs were separated by sex, and ovarian development was noted. For caridean shrimps, gravid females were recorded; otherwise the sex was listed as unknown. In situations where larger numbers of a single species were captured, a subsample of a minimum of 50 individuals was measured after weighing and counting the total.

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All samples from February 2004 through February 2005 were processed, and the results are expressed on a swept-area basis, i.e., numerical density as number per 100 m^2 and as biomass density in grams per 100 m^2, with respect to depth, water body, station, month, season and selected combinations.

Results

A total of 431 five-minute trawl tows swept 436,236 m^2 of bottom habitat and captured 80,903 individuals with a total mass of 309.5 kg (**Table 15** on page 187). Monthly, trawl tows swept an area ranging from 32,125 m^2 in December to 39,850 m^2 in March. Tidal currents and tow direction accounted for the monthly differences. Monthly catches ranged from a low of 570 individuals in February 2004 to a high of 16,537 individuals in June 2004, and monthly biomass ranged from 1.7 kg in January 2005 to a high of 62.5 kg in October 2004 (Table 15 and Appendix 1).

Catches were variable, with adjacent tows often yielding quite different results in species composition as well as volume. Seasonally, numerical and biomass catch rates in summer and fall greatly exceeded those in spring and winter (**Fig. 22**). Catches during these two seasons averaged 31 to 38 individuals/100 m^2 weighing 136 to 142 g (Fig. 22). This represents an average biomass well in excess of 1 g/m^2 throughout all of Boubyan's waters over a five-month period from June through October. The month of June 2004 witnessed an initial influx in numbers with a jump from 12 individuals/100 m^2 weighing 56 g in May 2004 to 47 individuals/100 m^2 weighing 170 g (**Fig. 23**). Numerical density decreased in August 2004, but exhibited a secondary peak in October 2004 at 36 individuals/100 m^2. Biomass decreased from the June 2004 high, but remained above 1 g/m^2 from July through September 2004, reaching a secondary peak in October 2004 of 154 g/100 m^2. Dramatic drops in numbers and biomass followed in December 2004 and January and February 2005 (Fig. 23).

Overall, numbers and biomass tended to increase with depth (**Fig. 24**). Trawl tows at 1-m depths produced, on average, 17 individuals/100 m^2 weighing 58 g. At depths of 3 m or greater, trawl tows produced an average of 21 individuals/100 m^2 weighing 90 g (Fig. 24). Overall, catches at depths of 1, 2, and >3 m averaged about 20 individuals/100 m^2 (Fig. 24). Seasonal distributions with depth were particularly well stratified in the fall and to a lesser degree in the spring (**Fig. 25**). In the fall, catch rates increased with depth. Trawl tows at 1-m depths captured 21 individuals/100 m^2 weighing 73 g, whereas tows at depths ≥3 m captured an average of 41 individuals/100 m^2 weighing 215 g (Fig. 25).

Numerical catch rates with respect to different water bodies ranged from 12.8 to 25.5 indiviudals/100 m^2 in Khor Al-Subbiyah and Khor Abdullah, respectively. Biomass catch rates varied from a low of 46.7 g/100 m^2 in Khor Boubyan to nearly twice as much (87.3 g/100 m^2) in South Boubyan (**Fig. 26**). Station BUB-03 in Khor Al-Subbiyah averaged the fewest individuals (8/100 m^2), and Station BUB-09 in Khor Abdullah averaged the most (32/100 m^2) (**Fig. 27**). Biomass catch rates by station did not follow the same trend as numerical catch rates. Stations BUB-01 and 02 averaged the highest and lowest biomass catch rates, i.e., 107 and 29 g/100 m^2, respectively (Fig. 27). Seasonal catch rates in separate khors were more consistent numerically than biomass catch rates, which tended to be somewhat irregular (**Fig. 28**). This irregularity is due to variations in the catches of larger individual specimens such as rays or small sharks.

Three groups dominated trawl catches numerically. Of the 80,229 specimens captured during the study, commercial crustaceans accounted for 45%, noncommercial crustaceans accounted for 16%, and noncommercial bony fishes accounted for 36% (**Fig. 29**). When expressed on a seasonal basis, commercial crustaceans contributed from a low of 24% in the winter to a high of 78% in the fall. The percent seasonal contribution of noncommercial bony fishes ranged from a low of 11% in the winter to a high of 56% in the summer. Noncommercial crustaceans easily dominated the winter numerical catches (Fig. 29). The trawl catches totaled 310 kg, and biomass composition data show some differences from the numerical data. The most obvious difference was the contribution of sharks and rays, which barely showed numerically in the composition data. Overall sharks and rays contributed 24% of the total, with seasonal values of 15, 30 and 24% in the spring, summer, and fall, respectively (**Fig. 30**). Sharks and rays were essentially absent in the winter months (Fig. 30).

The shrimp *Metapenaeus affinis* was the most important of the commercial crustaceans in the catches. This species was by far most abundant in the fall when catches per 100 m^2 swept area yielded an average of 22 individuals weighing 60 g (**Fig. 31**). On a monthly basis, numerical catch rates increased gradually from 0.2 individuals/100 m^2 in February 2004 to 26 individuals/100 m^2 in October 2004 (**Fig. 32**). In December 2004, catch rates dropped back to 1/100 m^2. Monthly biomass catch rates remained below 20 g/100 m^2 from February 2004 through August 2004, before jumping to 55 to 65 g/100 m^2 in September and October 2004 (Fig. 32). Overall, the most *M. affinis* were captured in Khor Al-Mughwi and Khor Al-Milh (**Fig. 33**). *M. affinis* showed preferences for selected stations, with BUB-01 in Khor Al-Subbiyah, BUB-04 in Khor Al-Mughwi, and BUB-06 and 07 in Khor Al-Milh exhibiting the highest overall catch rates (**Fig. 34**).

Catch rates of *M. affinis* also varied with depth, showing a positive relationship with increasing depth. Catch rates at 1-m depths averaged about 5 individuals/100 m^2 weighing 10 g, whereas at depths greater than 3 m, catches averaged nearly 9 individuals/100 m^2 weighing 25 g (**Fig. 35**). This relationship with depth was consistent for Khor Al-Subbiyah, Khor Boubyan, Khor Al-Mughwi, and Khor Al-Milh, but not for Khor Abdullah and South Boubyan (**Fig. 36**). The relationship with depth failed to hold when expressed on a monthly basis, except for August and September 2004 (**Fig. 37**). In these two months, numerical and biomass catch rates increased with depth, and in October 2004, the deepest stations also had the highest catch rates (Fig. 37).

Kuwait's third most important shrimp species, *Parapenaeopsis stylifera*, was also a common component of trawl catches. This species was most abundant in the summer, averaging 4 individuals/100 m^2 weighing 5.5 g (**Fig. 38**). Catch rates dropped during the fall months and were less than 1 individual/100 m^2 in the coldest months. Low catch rates were consistent during all of the spring and winter months except May 2004, when catches suddenly increased. Even at their highest in June, catches barely averaged 6 individuals/100 m^2 weighing 8.6 g (**Fig. 39**). A second peak occurred in October 2004, coinciding with the highest catch rates of *M. affinis* (Fig. 32). *P. stylifera* were most abundant in Khor Abdullah and South Boubyan (**Fig. 40**), but Station BUB-01 in Khor Al-Subbiyah had the highest catch rates (**Fig. 41**). Trawl tows in waters deeper than 3 m captured two to three times the number of *P. stylifera* captured in shallower waters (**Fig. 42**). The deepest stations were particularly productive in Khor Al-Subbiyah and Khor Al-Milh, but not necessarily in Khor Abdullah and South Boubyan (**Fig. 43**). Catch rates consistently increased with depth from May through October 2004 (**Fig. 44**).

Fish considered as a link between primary and secondary producers, i.e., phytoplankton and zooplankton, and higher trophic levels made up a large portion of the catch. Forage species include members of the sardine and shad family (Clupeidae), the ilisha family (Pristigasteridae), and the anchovy family (Engraulidae). These species were most abundant in the summer when an average of 4 individuals weighing about 10 g/100 m^2 were captured (**Fig. 45**). From summer highs, abundance decreased to a winter low of less than 1 individual/100 m^2. Catch rates increased with warming water temperatures in spring (Fig. 45). There was a gradual monthly increase in number and biomass from February 2004 through July 2004, followed by gradual decrease (**Fig. 46**). Numerical and biomass catch rates were highest in Khor Al-Mughwi, South Boubyan, and Khor Boubyan (**Fig. 47**); this trend in the data was reinforced by data for individual stations (**Fig. 48**). Catch rates at the different depths varied relatively little, ranging from 1 to 2 individuals/100 m^2 weighing from 5 to 6 g (**Fig. 49**).

The croaker family (Sciaenidae) was one of the most consistent and prominent fish groups in the trawl catches. The highest catch rates occurred in the summer (**Fig. 50**) with a notable increase in June 2004 (**Fig. 51**). Numbers and biomass decreased after the June and July 2004 maxima, respectively, and by December 2004 catches were insig-

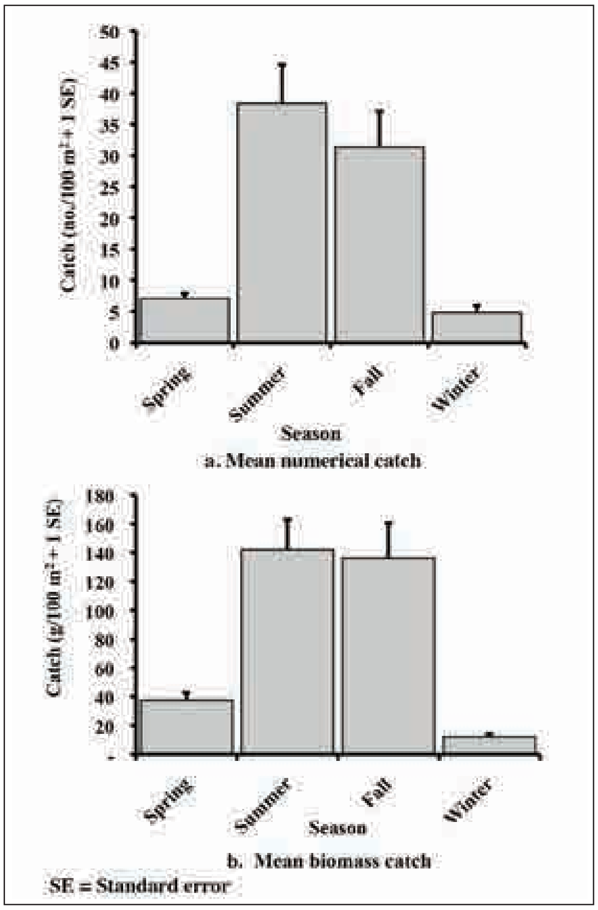

Fig. 22. Mean numerical and biomass catch by season from 12 trawl stations in waters around Boubyan Island from February 2004 to February 2005

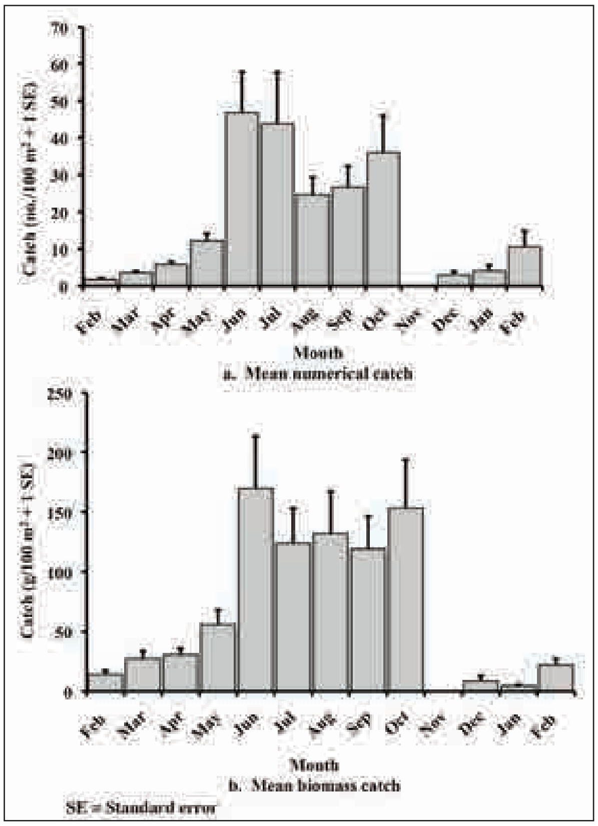

Fig. 23. Mean numerical and biomass catch by month from 12 trawl stations in waters around Boubyan Island from January 2004 through February 2005

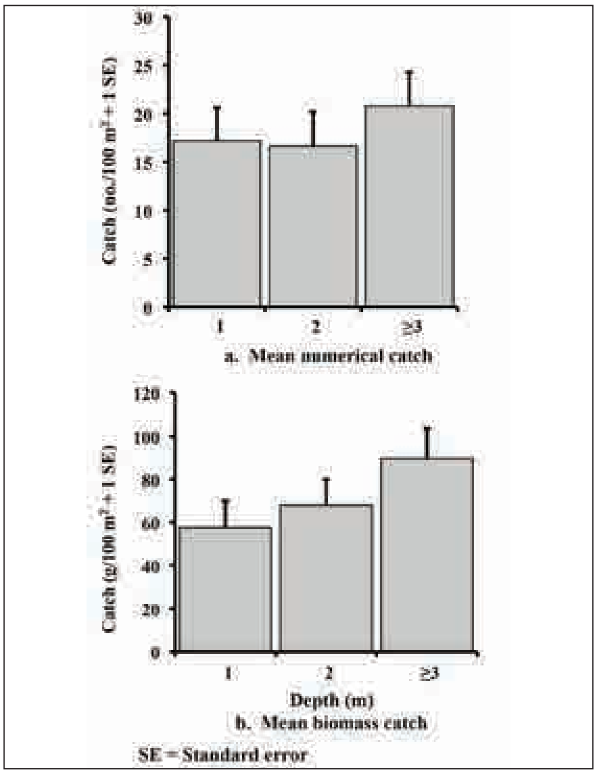

Fig. 24. Mean numerical and biomass catch by depth from 12 trawl stations in waters around Boubyan Island from February 2004 to February 2005

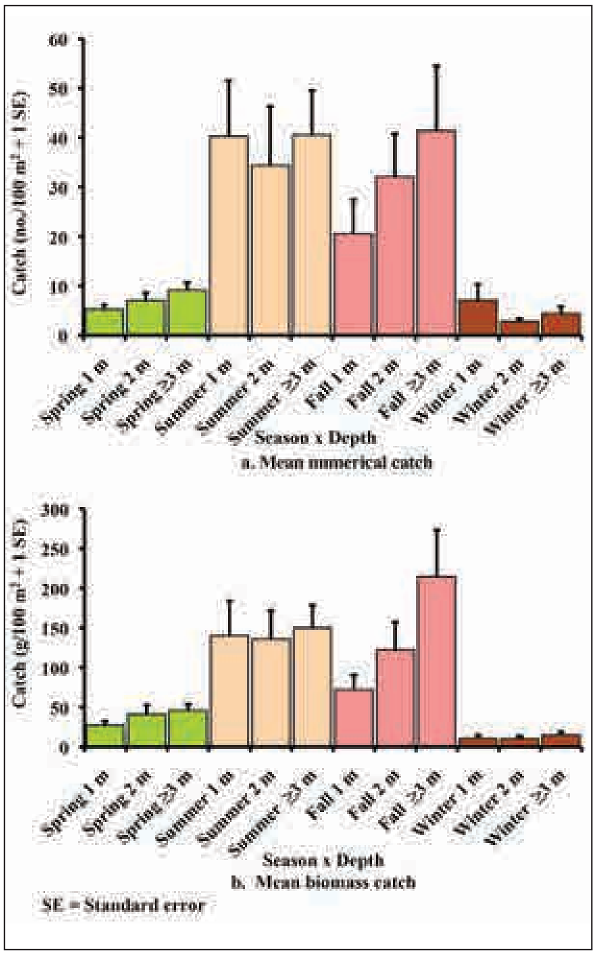

Fig. 25. Mean numerical and biomass catch by season and depth from 12 trawl stations in waters around Boubyan Island from January 2004 to February 2005

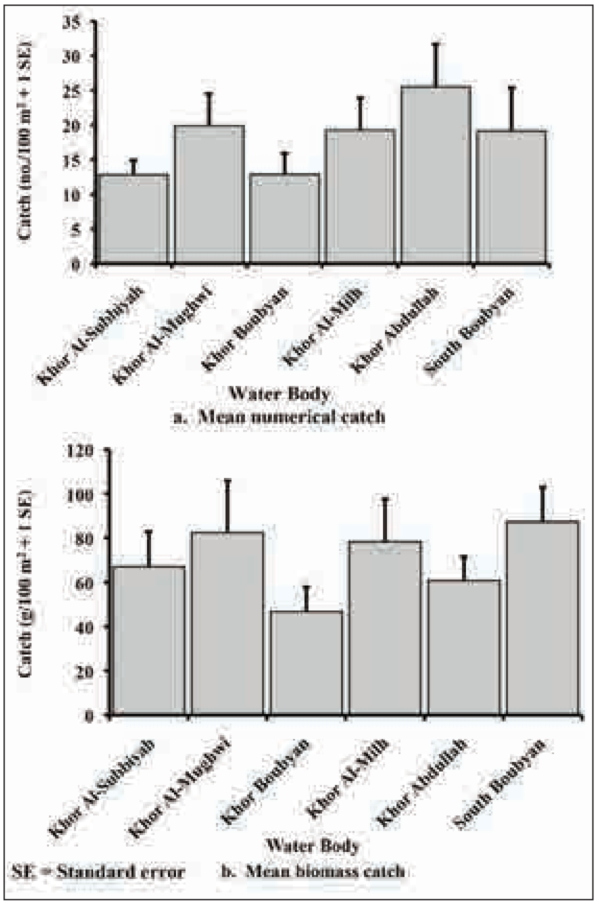

Fig. 26. Mean numerical and biomass catch by water body from 12 trawl stations in waters around Boubyan Island from January 2004 to February 2005

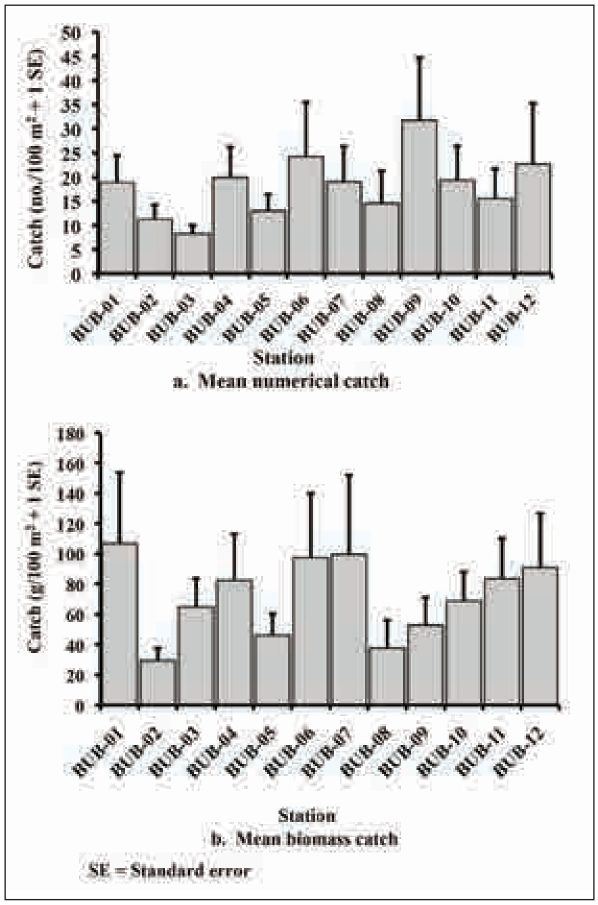

Fig. 27. Mean numerical and biomass catch from 12 trawl stations in waters around Boubyan Island from January 2004 to February 2005

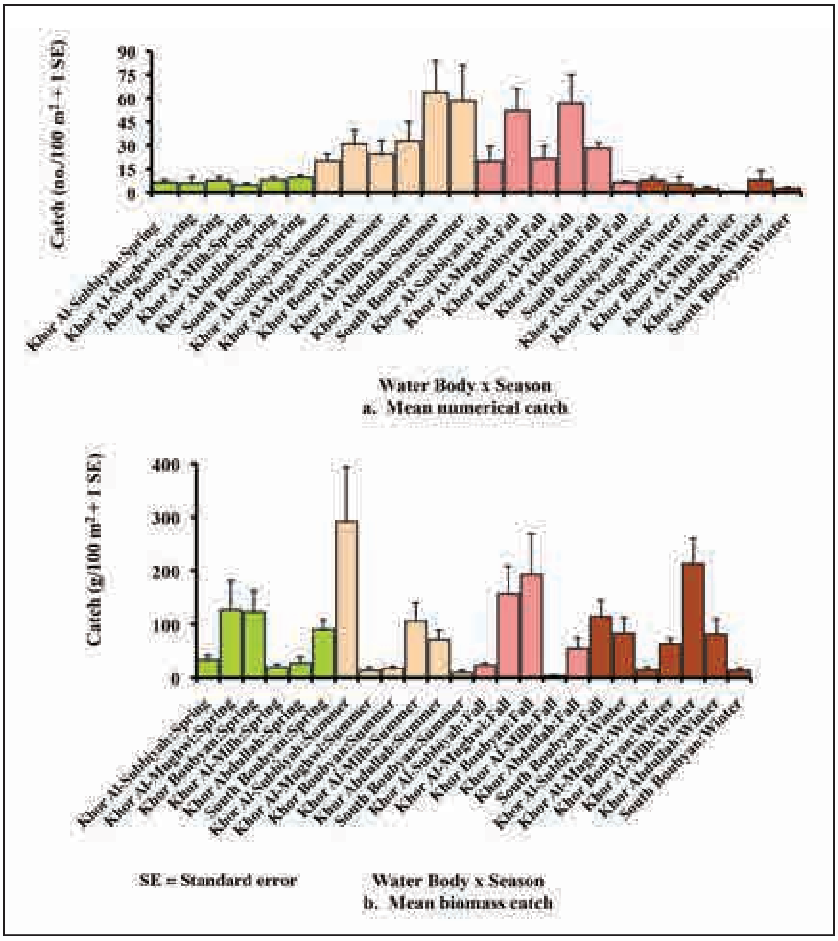

Fig. 28. Mean numerical and biomass catch by water body and season from 12 trawl stations in waters around Boubyan Island from February 2004 to February 2005

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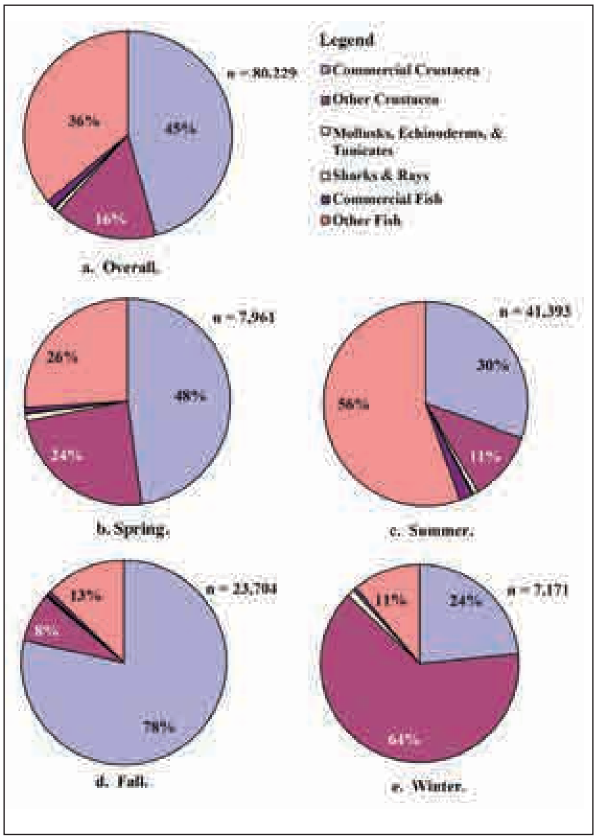

Fig. 29. Numerical catch composition by season from trawl tows in waters around Boubyan Island from February 2004 to February 2005

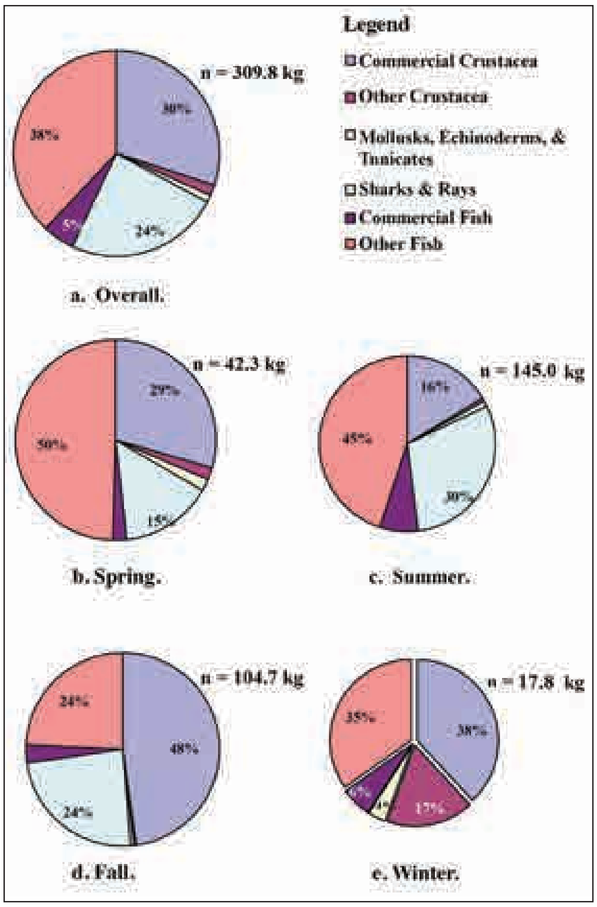

Fig. 30. Biomass catch composition by season from trawl tows in waters around Boubyan Island from February 2004 to February 2005

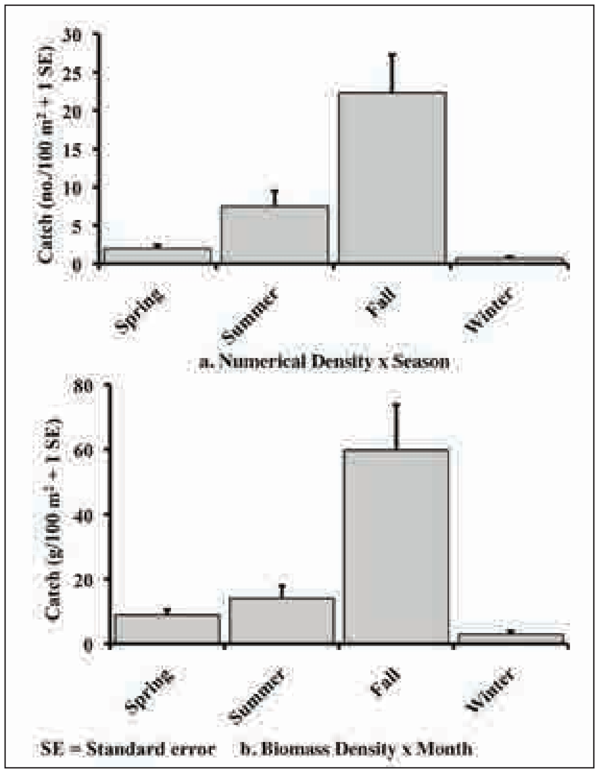

Fig. 31. Numerical and biomass catch of *Metapenaeus affinis* by season from waters around Boubyan Island from February 2004 to February 2005

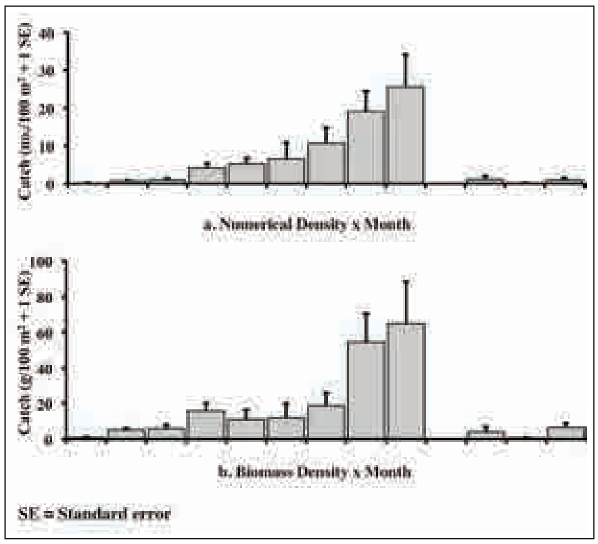

Fig. 32. Numerical and biomass catch of forage species by month from waters around Boubyan Island from February 2004 to February 2005

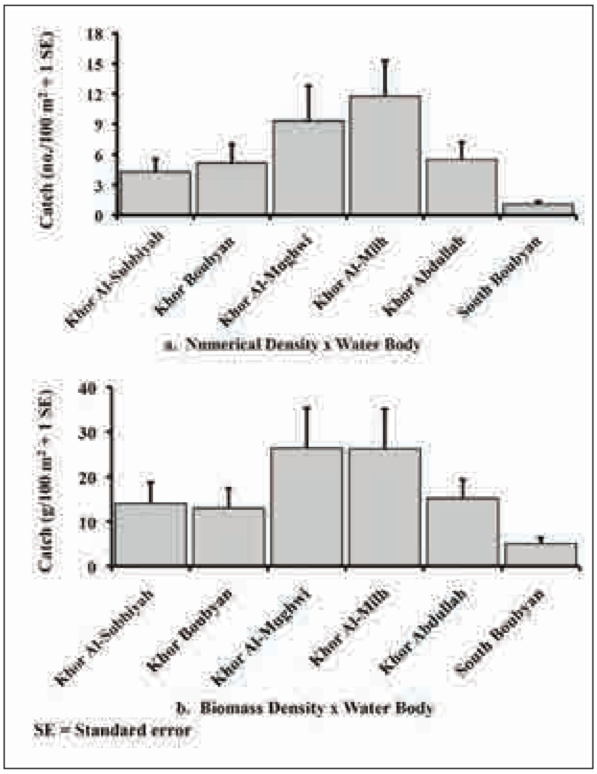

Fig. 33. Numerical and biomass catch of *Metapenaeus affinis* from waters around Boubyan Island from February 2004 to February 2005

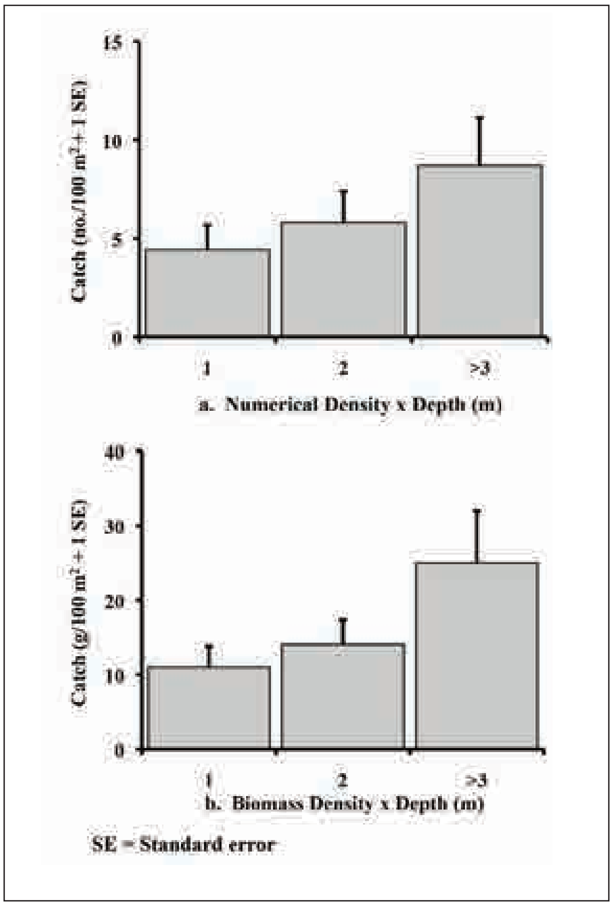

Fig. 35. Numerical and biomass catch of *Metapenaeus affinis* by depth from waters around Boubyan Island from February 2004 to February 2005

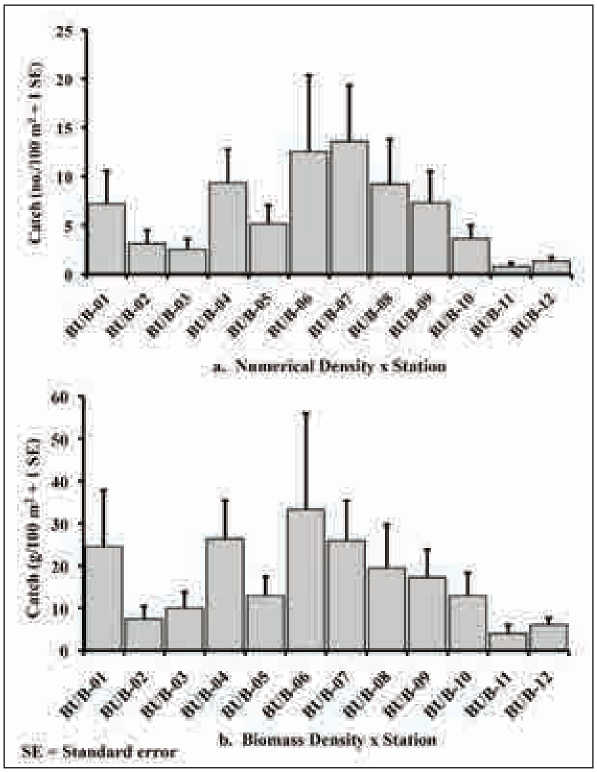

Fig. 34. Numerical and biomass catch of *Metapenaeus affinis* by station from waters around Boubyan Island from February 2004 to February 2005

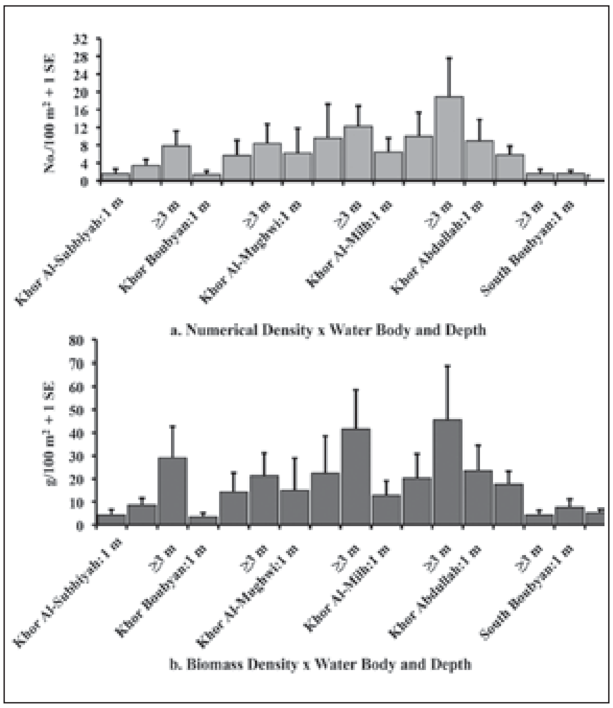

Fig. 36. Numerical and biomass catch of *Metapenaeus affinis* by depth and water body from waters around Boubyan Island from February 2004 to February 2005

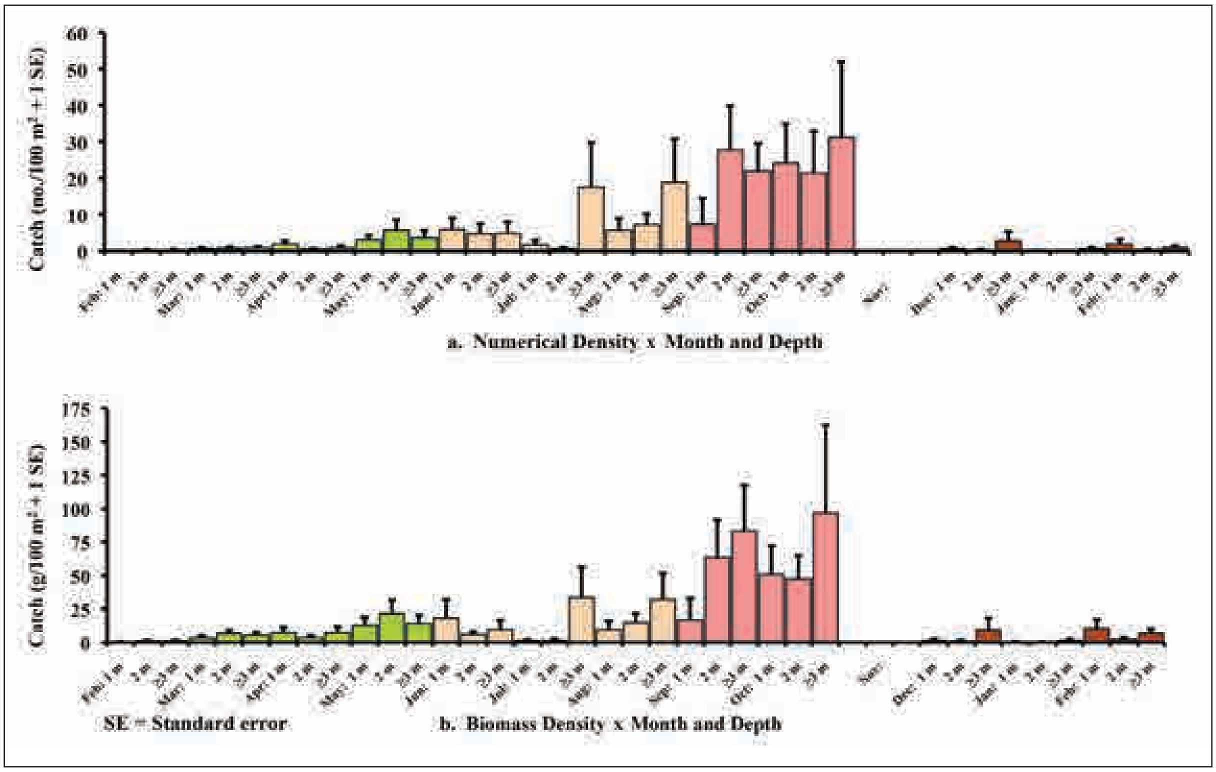

Fig. 37. Numerical and biomass catch of *Metapenaeus affinis* by depth and month from waters around Boubyan Island from February 2004 to February 2005

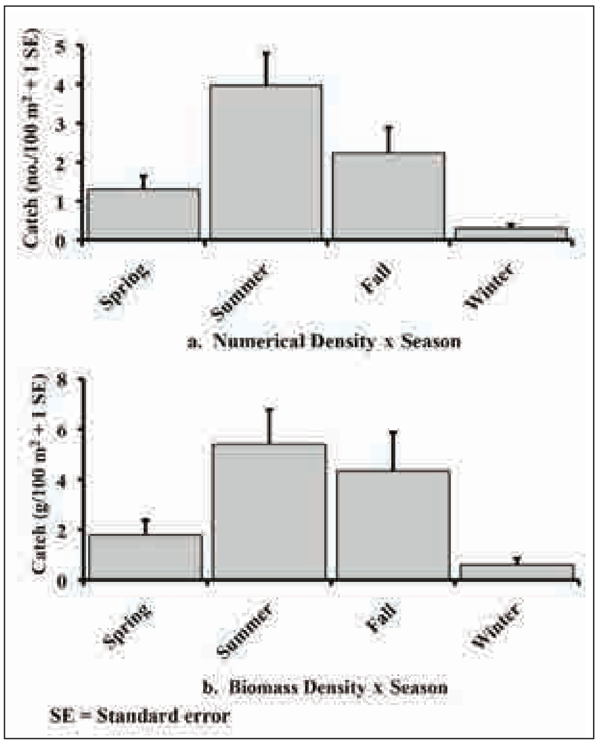

Fig. 38. Numerical and biomass catch of *Parapenaeopsis stylifera* by season from waters around Boubyan Island from February 2004 to February 2005

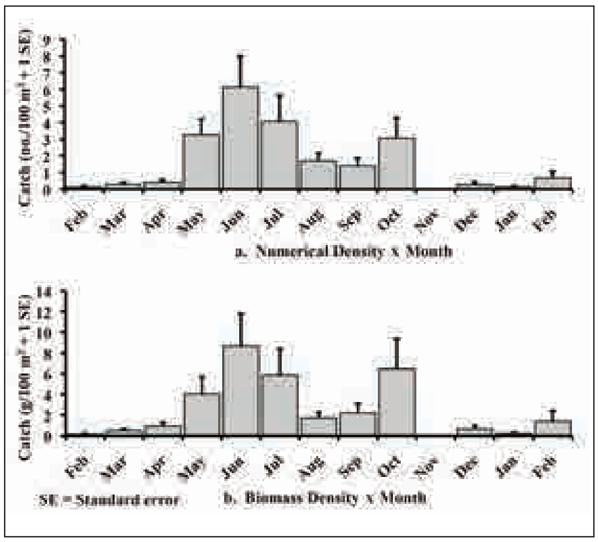

Fig. 39. Numerical and biomass catch of *Parapenaeopsis stylifera* by month from waters around Boubyan Island from February 2004 to February 2005

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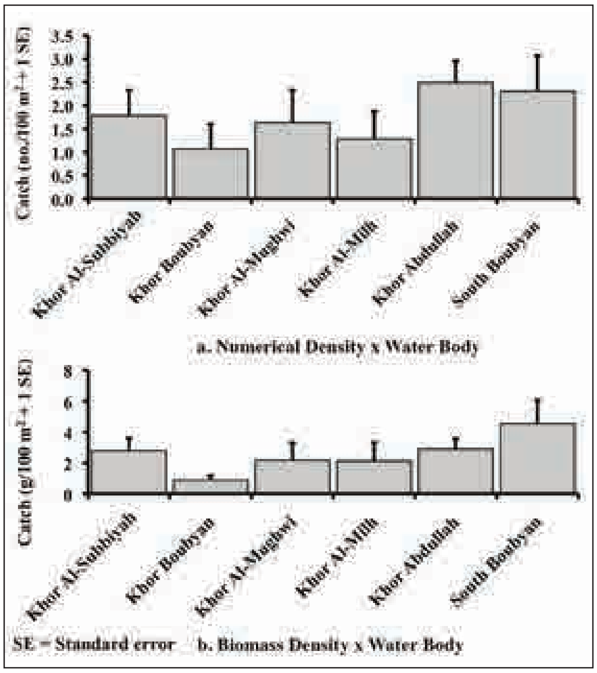

Fig. 40. Numerical and biomass catch of *Parapenaeopsis stylifera* from different water bodies around Boubyan Island from February 2004 to February 2005

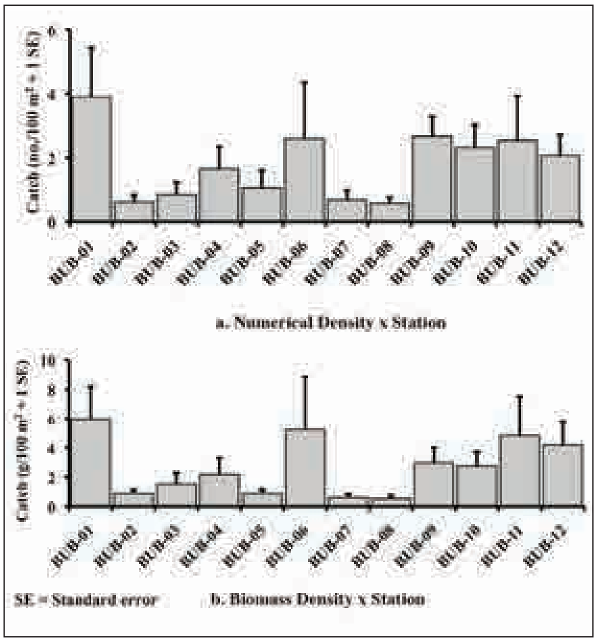

Fig. 41. Numerical and biomass catch of *Parapenaeopsis stylifera* by station from waters around Boubyan Island from February 2004 to February 2005

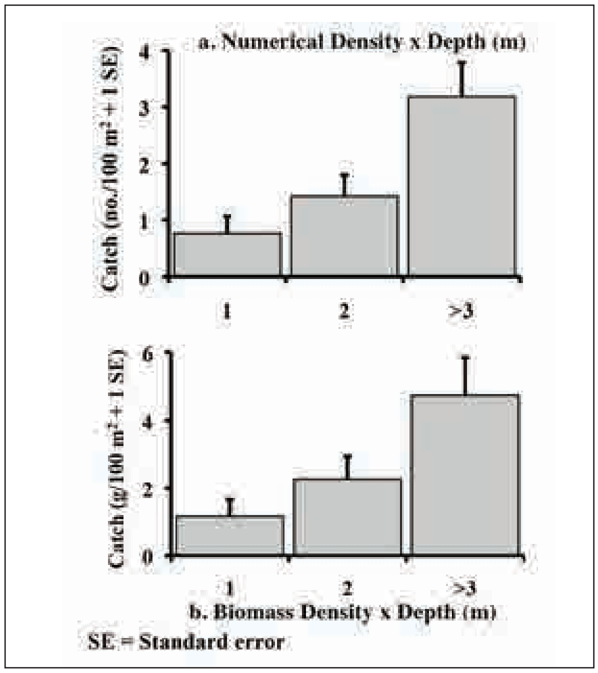

Fig. 42. Numerical and biomass catch of *Parapenaeopsis stylifera* by depth from waters around Boubyan Island from February 2004 to February 2005

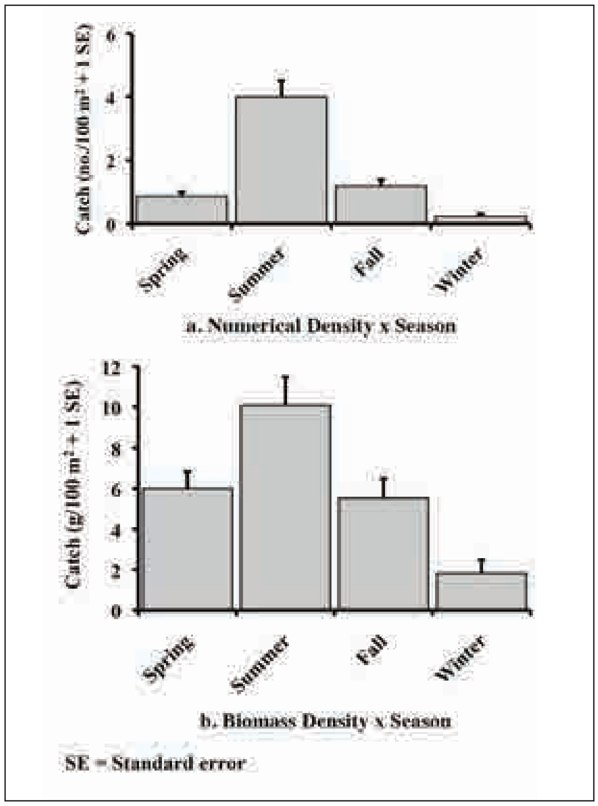

Fig. 45. Numerical and biomass catch of forage species by season from waters around Boubyan Island from February 2004 to February 2005

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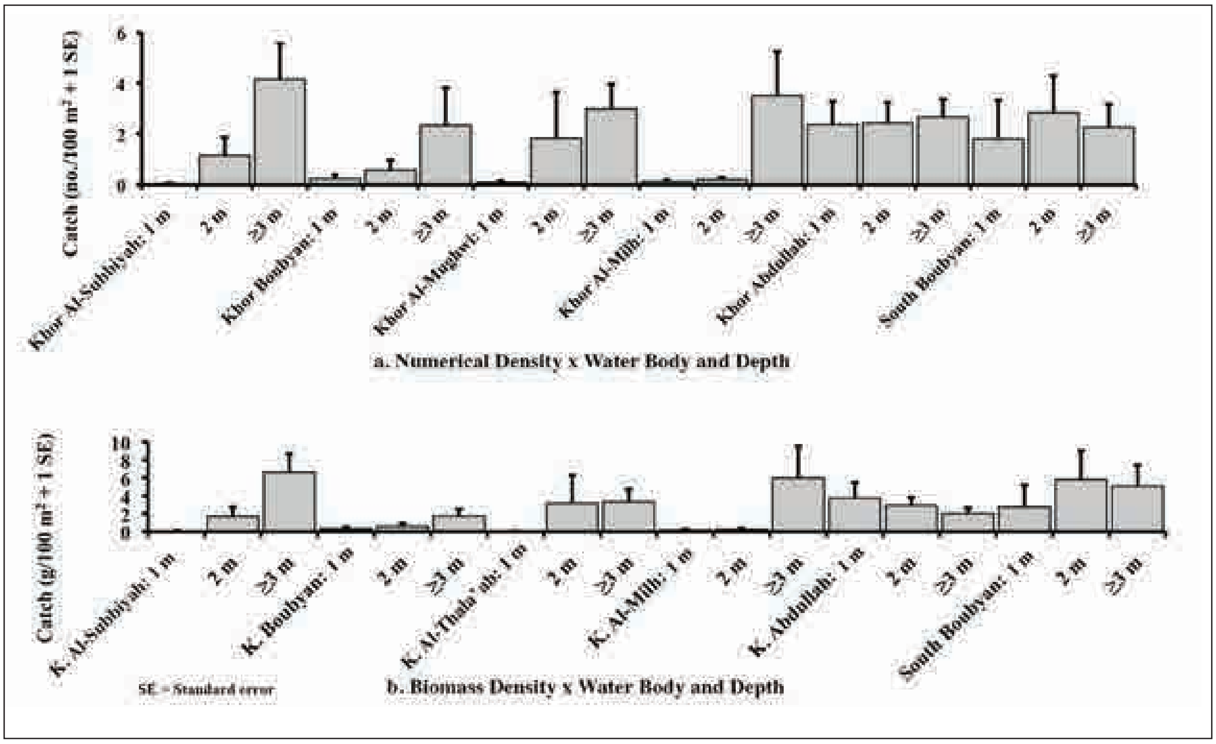

Fig. 43. Numerical and biomass catch of *Parapenaeopsis stylifera* by water body and depth in waters around Boubyan Island from February 2004 to February 2005

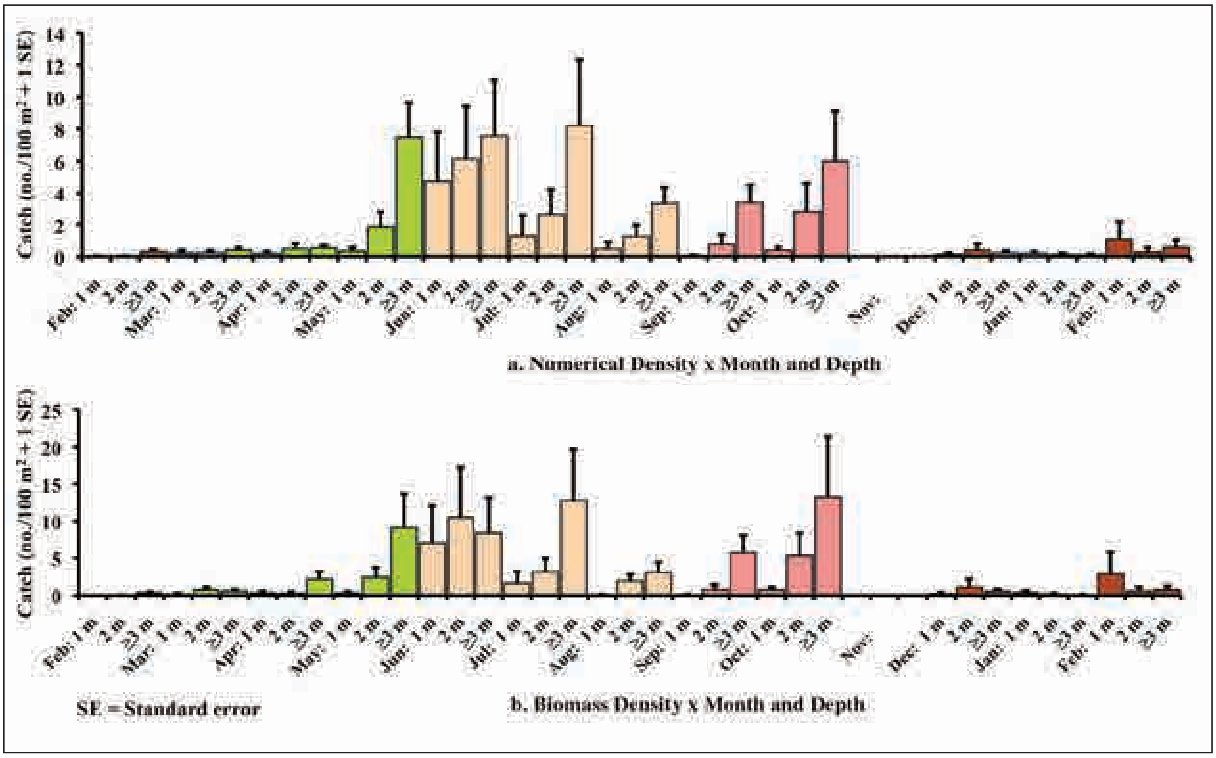

Fig. 44. Numerical and biomass catch of *Parapenaeopsis stylifera* by month and depth from waters around Boubyan Island from February 2004 to February 2005

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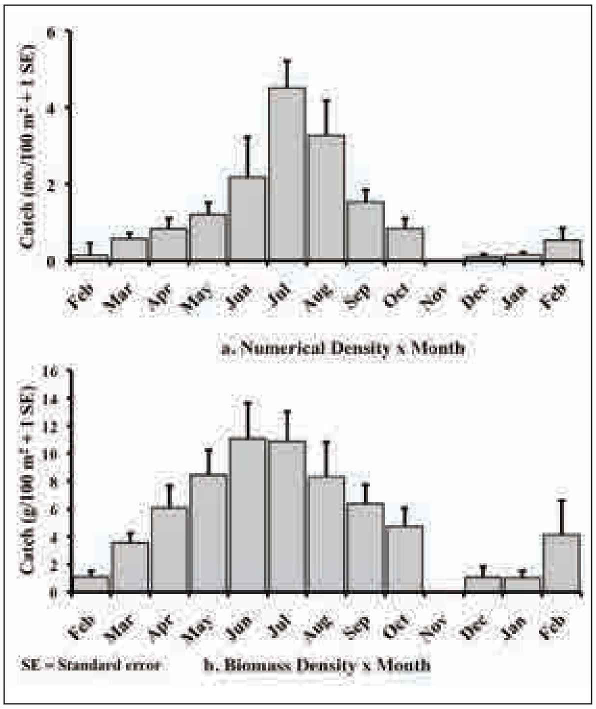

Fig. 46. Numerical and biomass catch of forage species by month from waters around Boubyan Island from February 2004 to February 2005

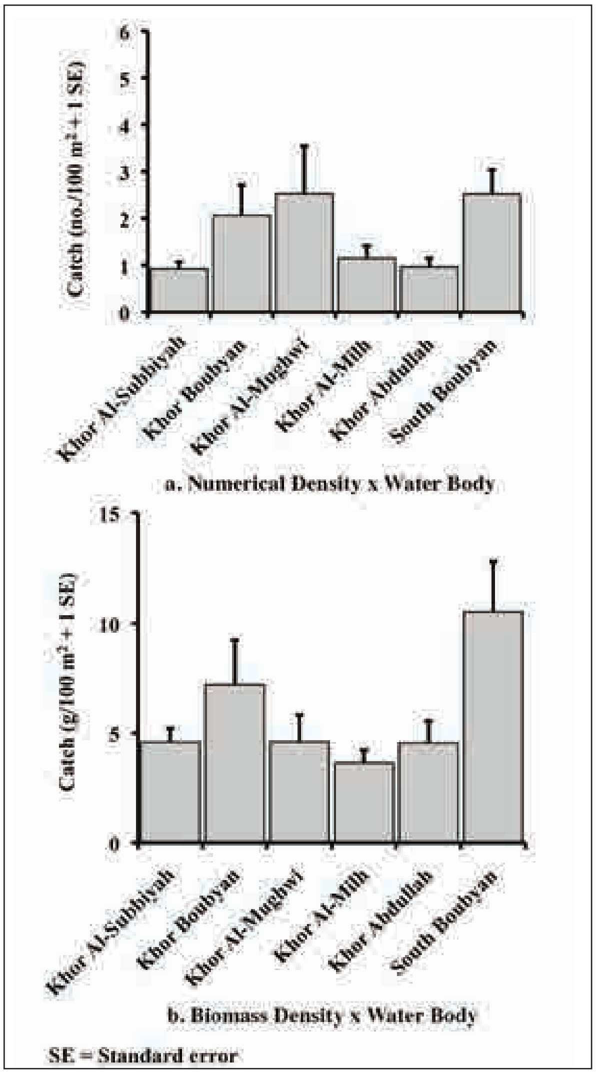

Fig. 47. Numerical and biomass catch of forage species from waters around Boubyan Island from February 2004 to February 2005

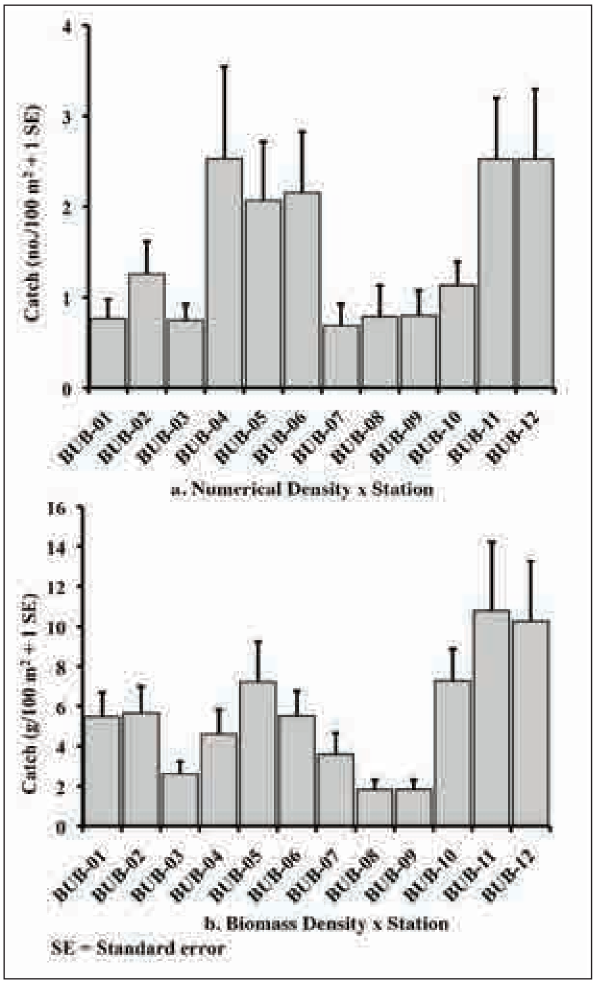

Fig. 48. Numerical and biomass catch of forage species in waters around Boubyan Island from Feb 2004 to Feb 2005

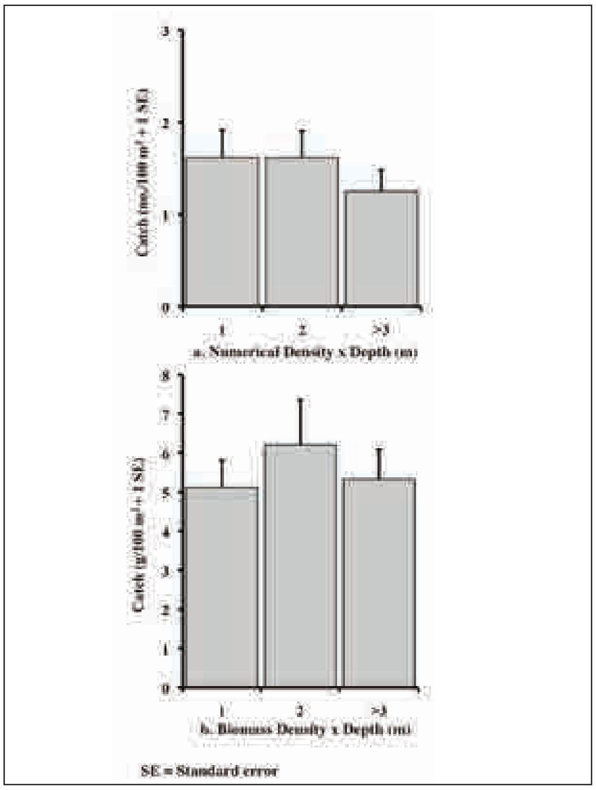

Fig. 49. Numerical and biomass catch of forage species by depth from waters around Boubyan Island from February 2004 to February 2005

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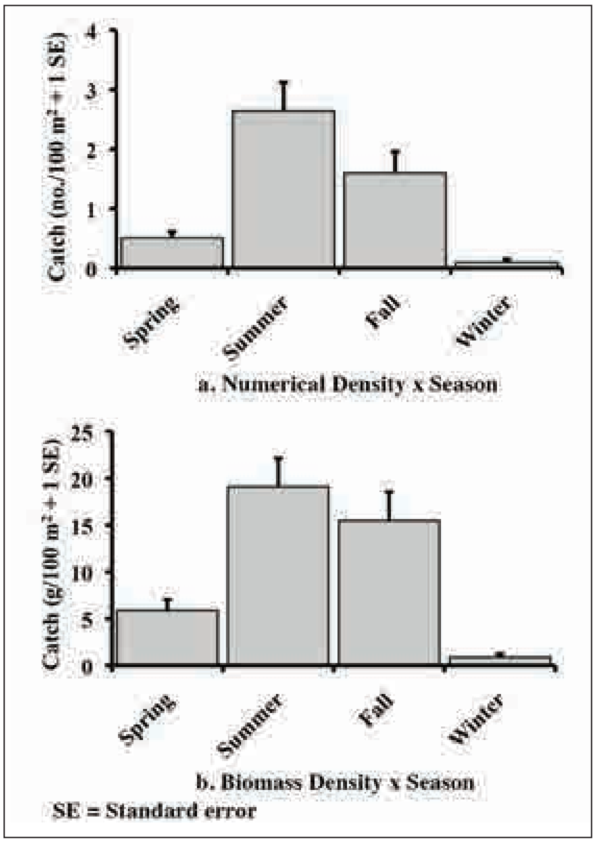

Fig. 50. Numerical and biomass catch of sciaenids (croakers) by season from waters around Boubyan Island from February 2004 to February 2005

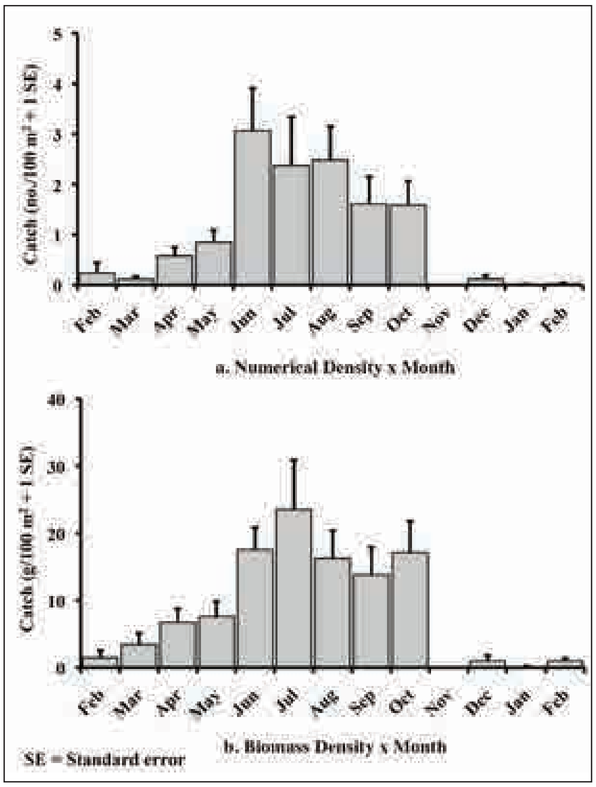

Fig. 51. Numerical and biomass catch of sciaenids (croakers) by month from waters around Boubyan Island from February 2004 to February 2005

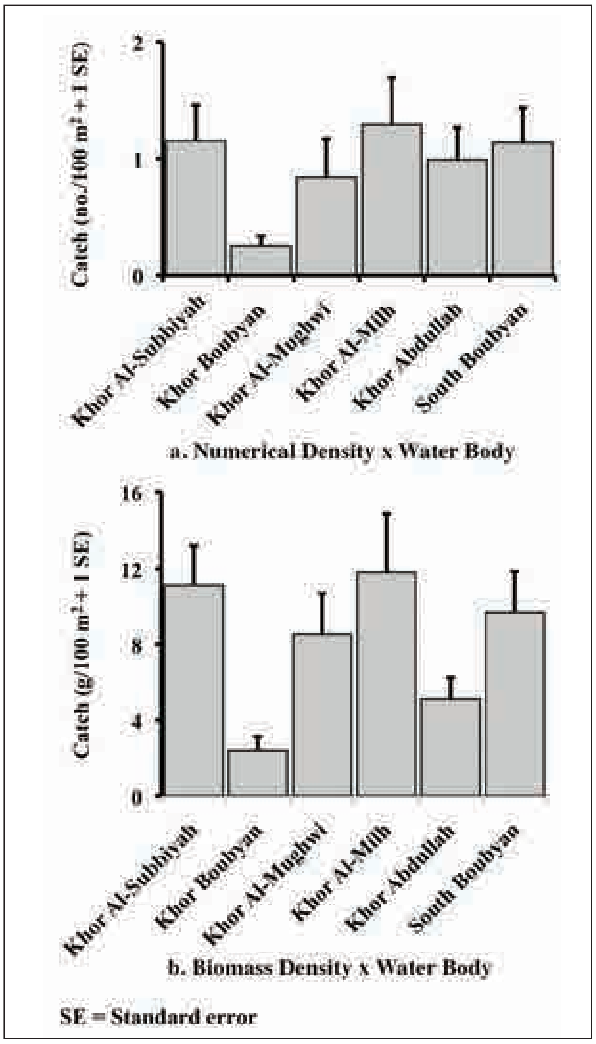

Fig. 52. Numerical and biomass catches of sciaenids (croakers) from waters around Boubyan Island from February 2004 to February 2005

nificant. Croaker catches were relatively consistent throughout Boubyan's waters, except in Khor Boubyan (**Fig. 52**). In Khor Abdullah, numbers were about the same as in adjacent water bodies, but biomass was about one-half (Fig. 52). The numerical catch rates stood out for Stations BUB-01 and 06, and Stations BUB-01, 03, and 06 produced the highest biomass catch rates (**Fig. 53**). When expressed by depth, overall catch rates were considerably greater in the deepest depths, with an average of 2 fish weighing 15 grams captured for each 100 m² of area swept (**Fig. 54**).

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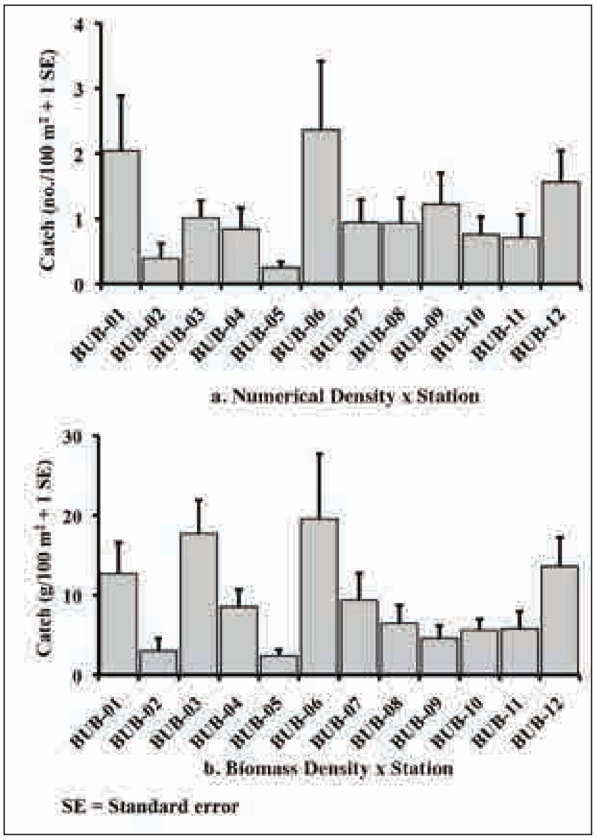

Fig. 53. Numerical and biomass catch of sciaenids (croakers) by station in waters around Boubyan Island from February 2004 to February 2005

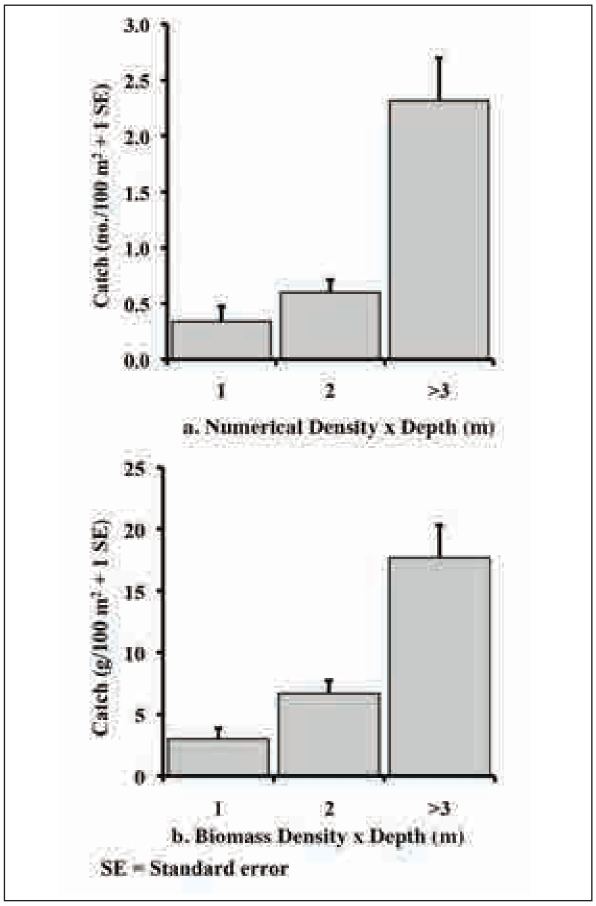

Fig. 54. Numerical and biomass catch of sciaenids (croakers) by depth from waters around Boubyan Island from February 2004 to February 2005

Table 15. Monthly Summary of Trawl Results for the Waters around Boubyan Island from February 2004 through February 2005

Month-Year	Salinity (psu)	Temp (°C)	GPS speed (km/h)	No. of tows	Tow time (min)	Tow distance (m)	Net width (m)	Swept area (m²)	Trawl catch (no.)	Trawl catch (g)
Feb 2004	30.4	16.6	3.9	36	180.0	328	3	35,375	570	4,364
Mar 2004	33.2	20.4	4.4	36	180.0	365	3	39,850	1,491	10,445
Apr 2004	32.3	23.4	4.0	36	180.0	330	3	36,055	2,085	11,168
May 2004	29.4	24.1	3.8	35	175.0	313	3	34,375	4,383	19,711
Jun 2004	33.6	27.6	3.8	36	179.7	314	3	33,856	16,537	49,063
Jul 2004	34.5	31.8	4.1	36	180.0	344	3	36,875	15,530	44,338
Aug 2004	37.0	27.6	4.3	36	180.0	353	3	38,300	9,326	51,569
Sep 2004	37.9	28.2	4.1	36	180.0	330	3	36,500	9,410	42,881
Oct 2004	37.6	28.0	4.4	36	180.0	365	3	39,375	14,295	62,475
Nov 2004	No sampling due to inclement weather									
Dec 2004	35.9	13.9	3.6	36	180.0	291	3	32,125	935	2,559
Jan 2005	34.8	12.9	3.8	36	180.0	319	3	34,425	2,032	1,665
Feb 2005	32.7	14.1	4.3	36	180.0	362	3	39,125	4,309	9,227
Total	NA	NA	NA	431	2,155	4,014	NA	436,236	80,903	309,467
Average	34.1	22.4	4.0	NA	NA	NA	3	NA	NA	NA

GPS = Global Positioning System, NA = not applicable

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Gillnetting

Of the 12 established stations, gillnetting activities were conducted at 7: 2 in Khor Al-Subbiyah (BUB-01 and 03), 1 in Khor Al-Mughwi (BUB-04), 1 in Khor Boubyan near the mouth of Khor Al-Milh (BUB-08), 2 in Khor Abdullah (BUB-09 and 10), and 1 in south Boubyan (BUB-12). A 300-m gill net constructed of four different mesh sizes was deployed at 6 or 7 stations every month. Net panels consisted of 4-, 4.5-, 5.5-, and 5.75-inch mesh. Depending on weather conditions and tides, net deployment required 3 to 5 minutes, and net retrieval took about 10 minutes, assuming that catches were not large. Soak time, defined as the difference between the midpoint of net deployment and the midpoint of net retrieval, varied depending on current and location, but the target was a soak time of 20 to 30 minutes at each station. Nuisance catches included jellyfish, a variety of rays, the intertidal crab *Macrophthalmus pectinipes*, and in December 2004 a heavy bloom of the colonial phytoplankton *Phaeocystis* sp. On average, soak time for the 79 gill net sets was 24.1 minutes for a total of 31 hours and 51 minutes. Catches were sorted by species and weighed, and the total lengths of individuals were measured to the nearest centimeter (or millimeter depending on the species). Three commercial fishermen hired on a daily basis each month assisted in deploying and retrieving the nets, making it possible to complete this monthly task in a single day.

Results

Over the 12-month period from early March 2004 through March 1, 2005, the 79 gill net sets captured 1,476 individuals with a combined mass of 550.737 kg (**Fig. 55**). This amounts to an hourly catch rate of 46 individuals weighing 17.3 kg/300 m of net. From spring through fall, numerical catch rates decreased with season. One hour of gillnetting in the spring resulted in an average of 69 individuals, whereas in the fall, this amount of effort produced only 35 individuals (Fig. 55). Much of the high spring catch rate, however, was due to a single incident in March 2004 in which 332 individuals of the intertidal crab *Macrophthalmus pectinipes* were captured at Station BUB-03 when currents carried the net into shallow waters (**Figs. 56 to 58**).

In contrast to numerical catches, biomass catch rates increased with season from spring through fall (Fig. 55). Catch rates increased from 11 kg/h in the spring to 27 kg/h in the fall. The longheaded eagle ray (*Aetobatus flagellum*) accounted for 172 specimens, or nearly 12% of the numerical total. Most of the eagle rays were captured in July 2004 at Station BUB-03 (**Fig. 59**) and in October 2004 at Station BUB-12, with 85 and 18 individuals, respectively (Figs. 58 and 59).

Two important commercial species contributed to the gill net catches: the saboor *Tenualosa ilisha* and the silver pomfret *Pampus argenteus*. Gillnetting activities captured a total of 77 saboor weighing 46.463 kg, for an average of 2.4 saboor weighing 1.46 kg/h for 300 m of net. Saboor were captured throughout Boubyan's waters (**Fig. 60**) and in every season except winter (**Fig. 61**). Nearly 25% of the total saboor catch occurred in the month of April 2004 (**Fig. 62**). Stations in Khor Al-Subbiyah (BUB-01) and Khor Al-Mughwi (BUB-04) produced the most saboor (Fig. 60). Saboor ranged in size from 18 to 50 cm in total length, with the majority falling in the 33- to 44-cm range (**Fig. 63**). About 30% of the captured saboor measured 36 or 37 cm in total length, a spread of just 2 cm. Spring catch rates were best in Khor Boubyan (Station BUB-08), Khor Abdullah (Station BUB-10), and South Boubyan (Station BUB-12), whereas fall catch rates were best in Khor Al-Subbiyah (Stations BUB-02 and 03) (**Figs. 64 and 65**). Ovaries of many of the saboor captured in the spring and early summer were gravid. This condition is unusual in Kuwait's waters as saboor are anadromous and spawn in freshwater rivers, i.e., the Tigris and Euphrates. This is direct evidence that the waters around Boubyan Island serve as a staging area for gravid females before their spawning migration.

Fifty-one zobaidy weighing a total of 5.985 kg were captured by gillnet activities. This translates into an average catch rate of 1.6 individuals/h of soak time. Zobaidy were captured throughout Boubyan's waters (**Fig. 66**) in all seasons except winter (**Fig. 67**). Stations BUB-03 in Khor Al-Subbiyah and BUB-10 in Khor Abdullah accounted for 66% of the 51 zobaidy captured during the 12 months of sampling (**Figs. 68 and 69**). The highest catches (by percentage) occurred in May (25%) and October 2004 (22%) (**Fig. 70**). The fork lengths of the zobaidy captured ranged from 8 to 21 cm (**Fig. 71**) and 62% fell within the 10- to 15-cm range. These sizes are substantially below the usual commercial size of 20 to 30 cm. Zobaidy averaged 117 g each, clearly showing that the waters around Boubyan Island serve as a nursery habitat for this important species. Catch rates of zobaidy in the spring were fairly consistent throughout Boubyan's waters, but fall catches were restricted to Khor Al-Subbiyah (BUB-01 and 03) (Figs. 68 and 69).

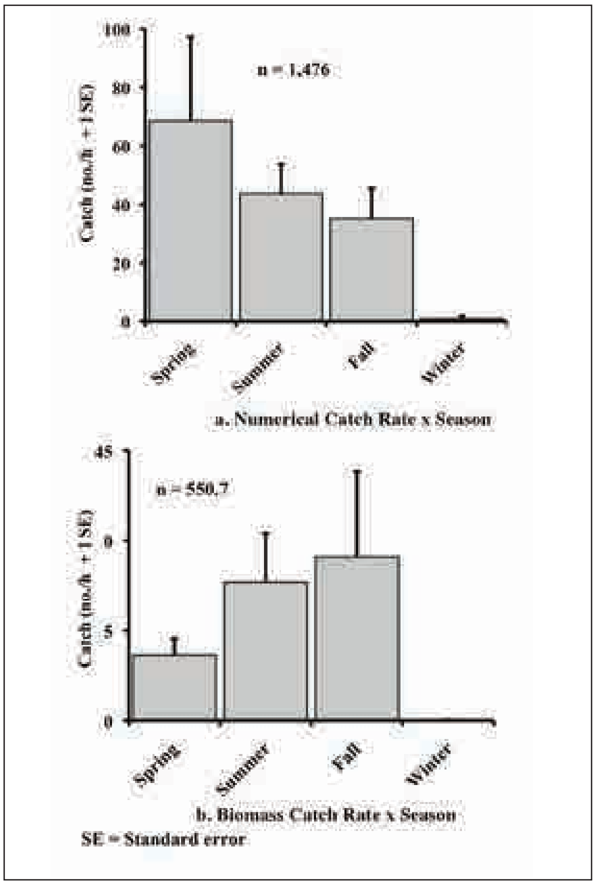

Fig. 55. Numerical and biomass catch per hour soak time from seven stations in waters around Boubyan Island from March 2004 to March 2005

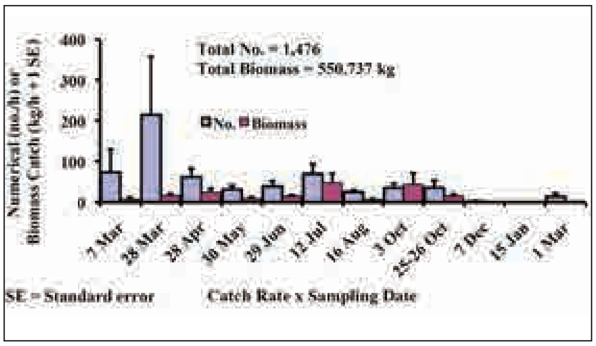

Fig. 56. Gill net catch by sampling period per hour soak time per 300 m of gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

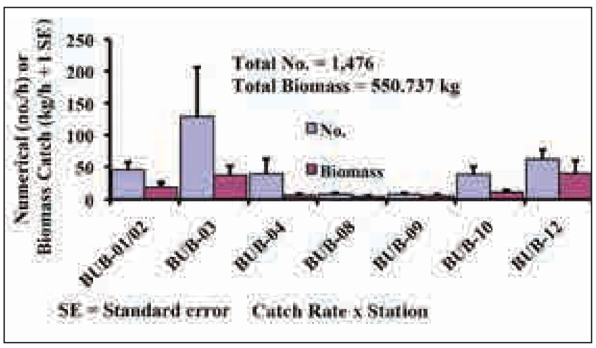

Fig. 57. Gill net catch by station per hour soak time per 300 m of gill net from seven stations around Boubyan Island from March 2004 to March 2005

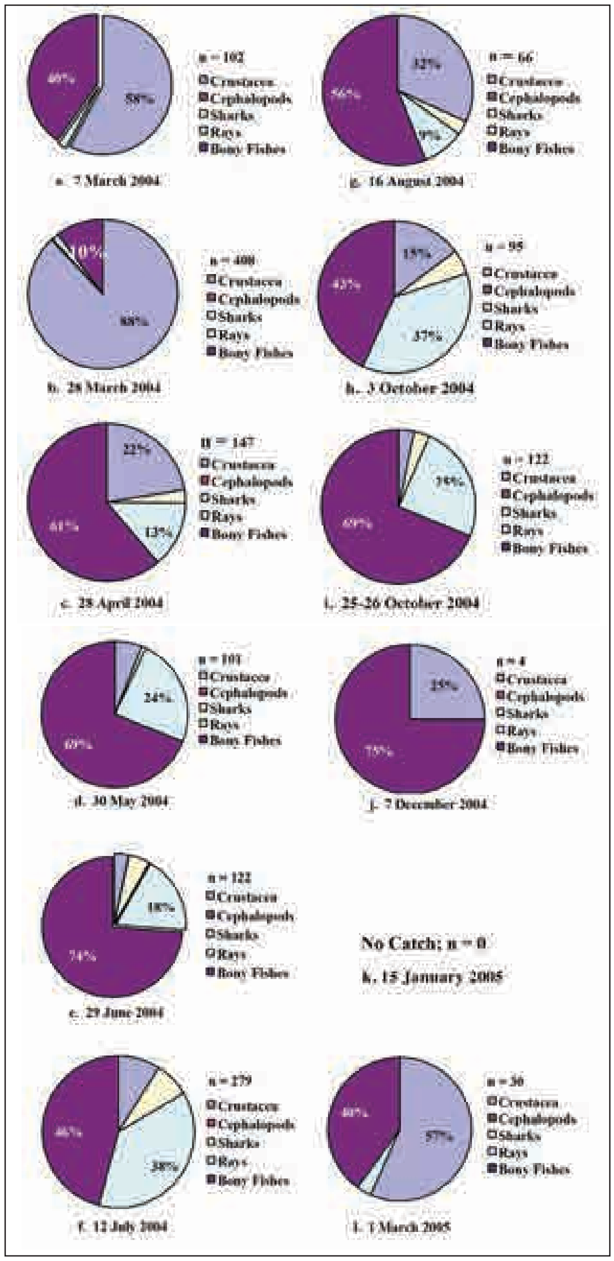

Fig. 58. Gill net catch composition by month from seven stations in waters around Boubyan Island from March 2004 to March 2005

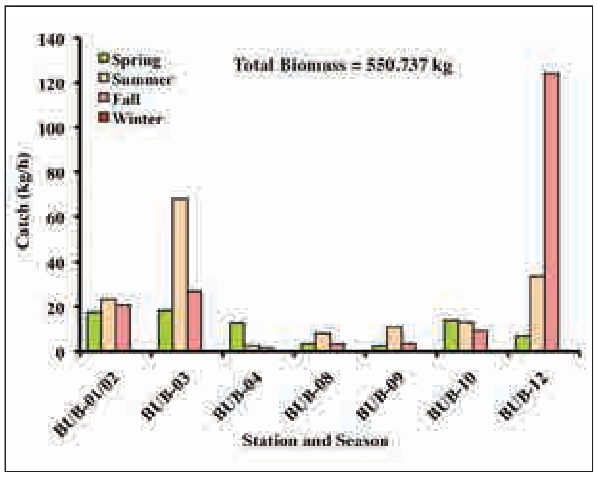

Fig. 59. Biomass catch by gill net per hour soak time by season and station in waters around Boubyan Island from March 2004 to March 2005

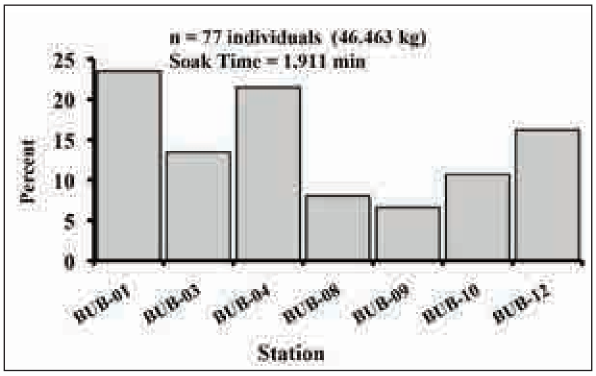

Fig. 60. Percent catch rate of saboor (*Tenualosa ilisha*) by station captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

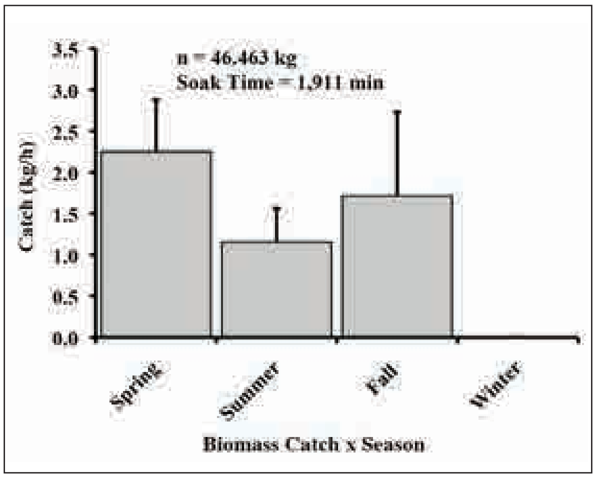

Fig. 61. Catch rate of saboor (*Tenualosa ilisha*) by season captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

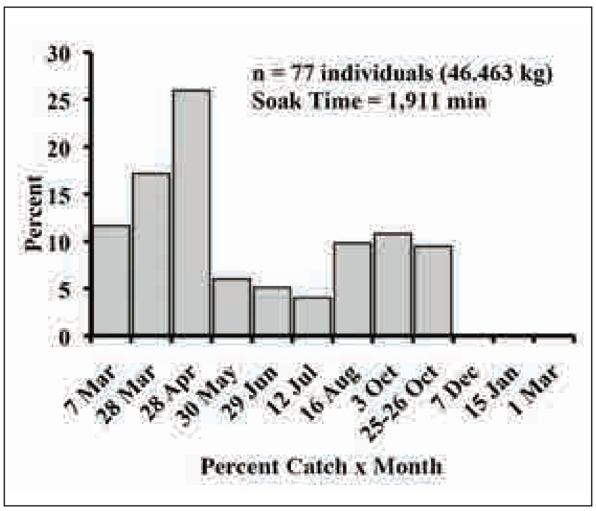

Fig. 62. Percent catch rate of saboor (*Tenualosa ilisha*) by month captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

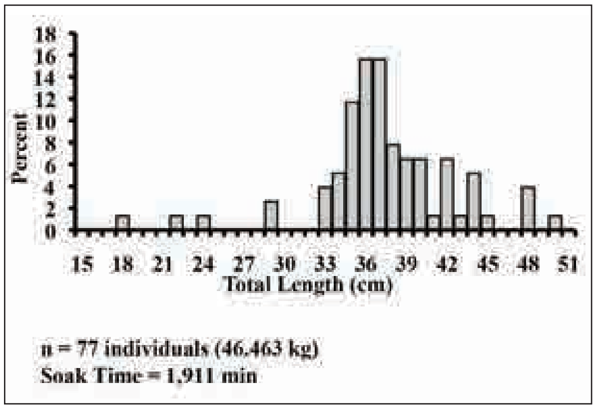

Fig. 63. Length frequency of saboor (*Tenualosa ilisha*) captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

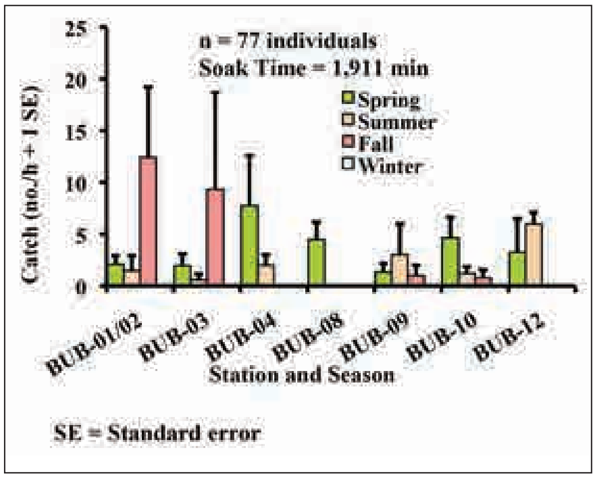

Fig. 64. Numerical catch rate of saboor (*Tenualosa ilisha*) captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

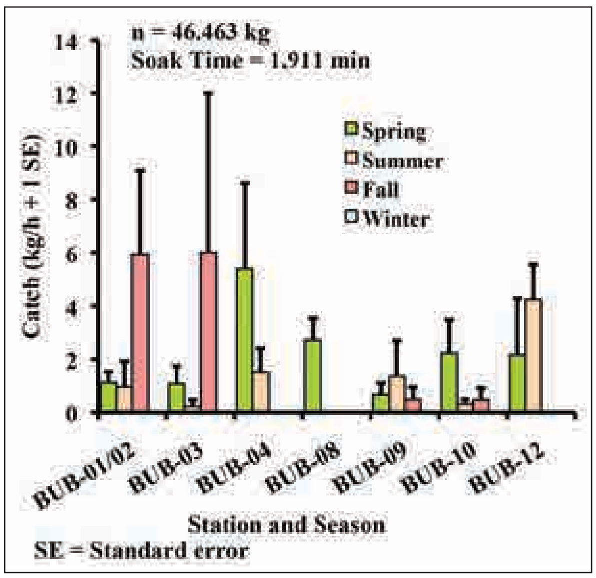

Fig. 65. Biomass catch rate of saboor (*Tenualosa ilisha*) by station and season captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

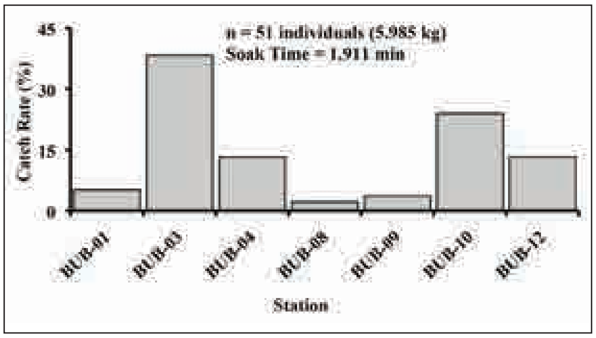

Fig. 66. Catch rate by station of zobaidy (*Pampus argenteus*) captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

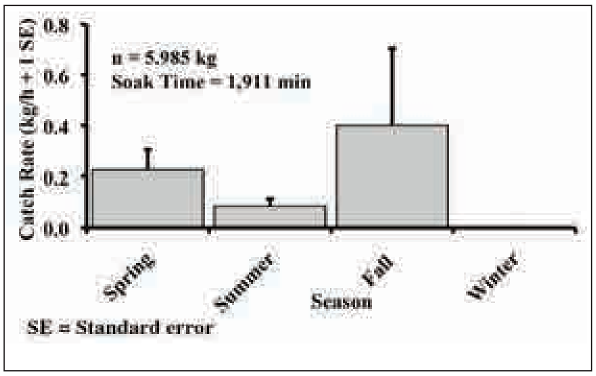

Fig. 67. Biomass catch of zobaidy (*Pampus argenteus*) by season captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

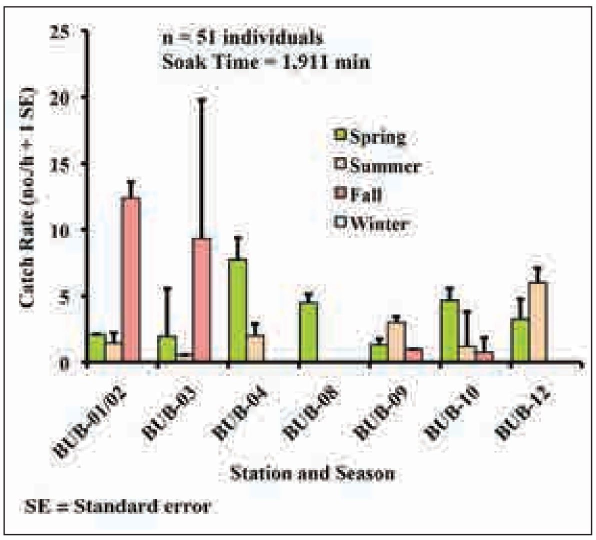

Fig. 68. Numerical catch rate of zobaidy (*Pampus argenteus*) by station and season captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

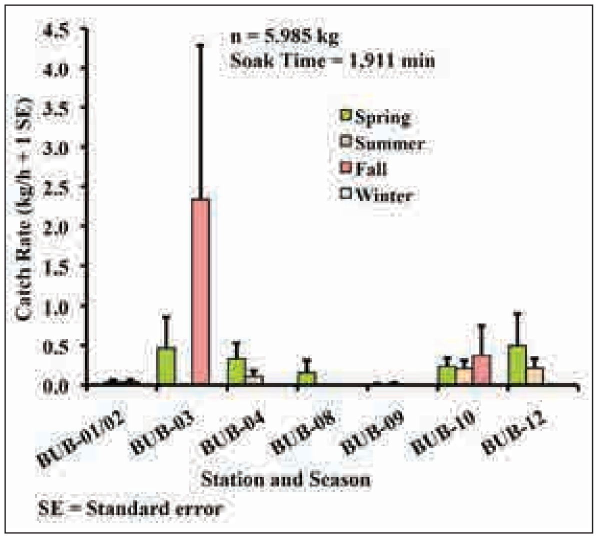

Fig. 69. Biomass catch rate of zobaidy (*Pampus argenteus*) by station and season captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

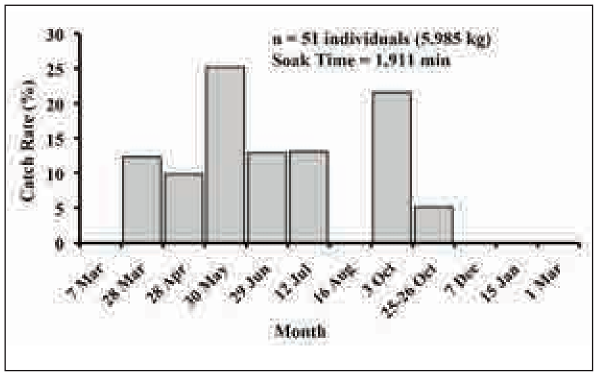

Fig. 70. Catch rate by month of zobaidy (*Pampus argenteus*) captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

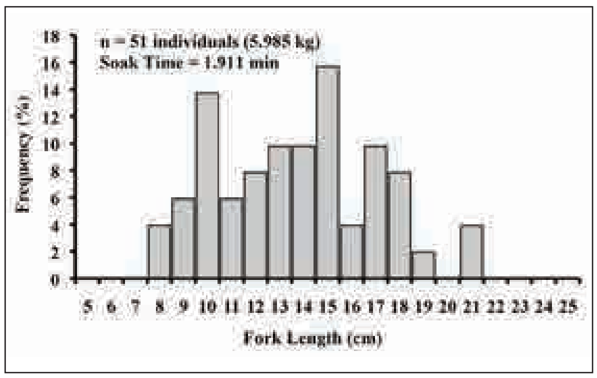

Fig. 71. Length frequency of zobaidy (*Pampus argenteus*) captured by gill net from seven stations in waters around Boubyan Island from March 2004 to March 2005

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Plankton

Materials and Methods

Selected physical and chemical variables were measured at the sea surface and bottom at seven stations including two in Khor Al-Subbiyah (BUB-01 and BUB-03), one in Khor Al-Mughwi (BUB-04), two in Khor Al-Milh (BUB-06 and BUB-08), and one each in Khor Abdullah (BUB-10) and South Boubyan (BUB-12). At each of these stations, a salinity-temperature-depth (STD) meter (Model AAQ1183, Alec Electronics Co., Japan) measured depth, salinity, temperature, dissolved oxygen (and saturation percentage), pH, chlorophyll, and turbidity. Salinity is reported in practical salinity units, a reflection that this variable is not measured directly in parts per thousand, but as electrical conductivity.

A 5-l Niskin bottle collected water samples from 1 m below the surface and 1 m above the bottom for nutrient and quantitative phytoplankton analyses. From the Niskin 5-l bottle, four 1-l bottles were each filled with one the following: phytoplankton to which formalin was added as a preservative, phytoplankton to which Lugol's solution was added as a preservative, nutrients, and the last for settleable solids. A 250-ml dark glass bottle was filled for phosphate determination. Upon returning to the laboratory, the samples to be analyzed for nutrients and phosphate were filtered immediately using an appropriate 0.54-µm filter. Aliquots of the filtrate were frozen until analysis with a Skalar San Plus segmented flow analyzer. The results are expressed in molar concentrations.

Three different nets were employed for the collection of plankton samples. Oblique tows were made using a 20-µm net with a 20.5-cm inside ring diameter for phytoplankton, a 110-µm net with a 48-cm inside ring diameter for zooplankton, and 300-µm nets with a 57.5-cm inside ring diameter for ichthyoplankton. Readings from calibrated flowmeters were recorded before and after each tow. Plankton samples were carefully transferred to 1-l bottles to which formalin preservative was added.

After full sedimentation over at least two months, the phytoplankton samples collected in Niskin bottles were concentrated by careful reduction of superfluous water (using a rubber hose curved at one end) from 1,000 ml down to between 160 and 180 ml. For quantitative analysis, all of the groups of phytoplankton were counted in a 1 ml counting chamber under an inverted microscope with a magnification of 200; the contents of the entire chamber were counted.

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The number of cells per cubic meter was calculated according to:

$$N = n \cdot K_1 \cdot K_2 \cdot 10^3; \quad K_1 = \frac{V'sample}{Vchamber}; \quad K_2 = \frac{1}{Vchamber}$$

where n = number of cells in the counting chamber, $V'sample$ = volume of the concentrated sample, $Vchamber$ = volume counted, and $Vsample$ = volume of the sample.

Samples from the 20-µm-mesh plankton nets were shaken, and 1 ml was taken for counting without any sample concentration. The number of cells per liter was calculated according to:

$$N = \frac{n \bullet \frac{Vsample}{Vchamber}}{\frac{\Pi d^2}{4}\,[(FMend - FMstart)\,R]} \text{ X } 1000$$

where n = number of cells in the counting chamber, $Vsample$ = volume of the sample, $Vchamber$ = volume counted, d = diameter of the plankton net, FM = flowmeter, and R = rotor constant (R = 26,873/106). Materials from samples collected by both Niskin bottle and plankton net were used for comparative qualitative and quantitative analysis of phytoplankton.

The counting error ($r \pm \%$) was estimated according to:

$$r = \frac{2}{\sqrt{n}}\ 100$$

where n = number of cells counted.

To estimate biomass, the volume of cells (V) of each species was calculated according to approximated geometrical figures (Hillebrand et al., 1999). The individual weights (W) of cells were calculated using:

$$W = \rho \cdot V$$

where $\rho = 1$ and V = cell volume.

Some taxa, in particular the diatoms and some dinoflagellates, could not be identified to the genus or species level at the magnification used for counting. For taxonomic analysis of Dinophyta, temporary microscope slides were prepared. Diatom algae were analyzed using permanent slides. A mixture of sulfuric acid with potassium dichromate was used to clean the diatoms. Then the material was washed with distilled water, dried on a cover glass and mounted using Pleurax resin. Microalgae were photographed with a Nikon Coolpix 4500 digital camera and drawn and identified using guides by Schiller (1937), Sournia (1967), Steidinger and Williams (1970), Dowidar (1983), Husted (1985), Balech (1988), and Thomas (1997).

Twenty-four Niskin bottle samples, 84 plankton net samples and 84 permanent slides were counted and analyzed in all. All of the data were transferred to an agreed-upon format (i.e., Microsoft Excel spreadsheets). For statistical analysis, MS Excel 2000, SigmaPlot 2001 and Systat v. 7.0 software were used. For analysis of the similarity between species compositions, Jaccard (I_J) and Czekanowski-Sørenesen (I_{CS}) indexes of association were employed:

$$I_J = \frac{a}{a+b+c}$$

$$I_{CS} = \frac{2a}{(a+b)+(a+c)}$$

where a = number of species occurring in both the i^{th} and the j^{th} lists, b = number of species in i^{th} list, and c = number of species in the j^{th} list.

These indexes were chosen as the most adequate in the field of maximal values of absolute similarity, because the high sensitivity of tests is necessary where insignificant changes of absolute similarity occur among very similar species compositions for more exact estimation of their interrelations (Pesenko, 1982).

To estimate species richness, the Margalef index (I_{Mg}) was used:

$$I_{Mg} = \frac{S-1}{\text{In}(n)}$$

where S = number of species and n = number of individuals in the sample.

To calculate species diversity, the Shannon index (I_{Sh}) was used:

$$I_{Sh} = \sum p_i \cdot \log(p_i)$$

where p_i = proportion of i^{th} species in the sample.

For calculation of similarity between local structures of the community, the Czekanowski similarity index (I_{Cz}) was used:

$$I_{Cz} = \frac{2\sum \min(n_{ij}, n_{ik})}{\sum_i n_{ij} + \sum_i n_{ik}}$$

where n = proportion of i^{th} species in the j^{th} or k^{th} sample.

For mesozooplankton, the collected material was analyzed using the method of portions (Yashnov, 1939). Samples were reduced to volumes of 150, 200 or 250 ml, depending upon the zooplankton density, and mixed intensively until all organisms were distributed randomly in the sample volume. Then, 1 ml of sample was taken using a calibrated Stempel pipette. This operation was repeated twice, and the subsample was considered representative if the number of individuals of each species was not less than 25. If divergence between two examined subsamples was more than 30%, an additional subsample was examined.

Large (>1 mm in body length) and not abundant species were calculated in 1/2, 1/4, 1/8, 1/16 or 1/32 parts of the sample. The Motoda plankton splitter (Motoda, 1959) was used to split the samples.

Counting and measuring of organisms were achieved in a Bogorov chamber under a Leica microscope to the lowest taxon possible. A minimum of at least 1,000 individuals was counted in each sample.

The number of organisms per sample was calculated as a simple average of the mean of two subsamples multiplied by the subsamples' volume. For recalculation of the number of species per cubic meter, the following equations were used:

Volume filtered (V) = 3.14 x (Net diameter) x Distance
Distance = Difference in counts x Rotor constant/999,999

where the rotor constant = 26,873, and the difference in counts was calculated as follows:
Difference in counts = Flowmeter end – Flowmeter start

Density = Number of individuals in subsample x Fraction sampled/Filtered volume

Phytoplankton Results

Phytoplankton abundance in the coastal waters of Boubyan Island varied over a wide range during the year and was on average 8.21 ± 28.58 x 10^5 cells/l and 16.79 ± 53.4 mg/l. The lowest number of cells per liter, 3.25 x 10^2, occurred at Station BUB-03 in April 2004, while the highest number of cells per liter, 1.66 x 10^7, occurred at Station BUB-01 in January 2005. Biomass ranged from a minimum of 0.01 mg/l at Station BUB-03 in August 2004 to a maximum of 378.09 mg/l at Station BUB-12 in February 2005.

Space-Time Variability of the Total Phytoplankton Abundance: The highest total annual phytoplankton was observed at Stations BUB-01, 03, 06, and 08, while the lowest values occurred at Stations BUB-10 and 12 (**Fig. 72**). The highest total biomass values occurred in Khor

Table 16. Numerical Totals for Different Phytoplankton Taxa Found in the Waters around Boubyan Island from February 2004 through February 2005

Cell Type	Division/Phylum	Class	Number of Taxa
Prokaryota	Cyanophyta	Cyanophyceae	3
Eukaryota	Chromophyta	Bacillariophyceae	150
Eukaryota	Chromophyta	Dinophyceae	41
Eukaryota	Chromophyta	Prymnesiophyceae	1
Eukaryota	Chromophyta	Dictyochophyceae	2
Eukaryota	Chlorophyta	Chlorophyceae	3
Eukaryota	Chlorophyta	Euglenophyceae	1
Eukaryota	Chlorophyta	Prasinophyceae	4
Eukaryota	Zoomastigophora	Ebriideae	1

Al-Milh (Station BUB-08), Khor Abdullah (BUB-10), and South Boubyan (BUB-12). These seemingly contradictory results reflect species differences.

High numbers of phytoplankton at Stations BUB-01, 03, 04, 06 and 08 were the result of blooms of *Chaetoceros socialis* during the winter months. Numbers of *C. socialis* were insignificant at Stations BUB-10 and 12 in January 2005. Although *C. socialis* ranked high in total number, this species contributed little to total biomass. The prevalence of large-sized species of phytoplankton at Stations BUB-10 and BUB-12 and their mass development there in comparison with the other stations resulted in high total biomass and significant differences between these stations and the others.

The greatest phytoplankton development was observed during the winter period from December 2004 through February 2005 (**Fig. 73**). Phytoplankton abundance was significantly lower in all other seasons. Obvious density differences occurred between February 2004 and February 2005, which could reflect temperature differences. In February 2004, surface water temperatures averaged 16.2°C, whereas in February 2005, water temperatures averaged 12.8°C.

Taxonomic Structure: A total of 206 taxa of phytoplankton algae representing nine classes of marine microalgae were identified (**Table 16**) using the classification of Thomas (1997). Quantitative analysis of samples fixed on permanent slides revealed 191 taxa and 16 species.

Diatoms (Bacillariophyta) dominated the phytoplankton species, accounting for 73% of the diversity (**Fig. 74**). Dinoflagellates (Dinophyta) ranked second in importance with 20%. Members of all other groups contributed a combined total of 7% to the taxonomical structure of the phytoplankton community (Fig. 74).

The phytoplankton community in the waters around Boubyan Island differs from that of the usual open sea in that diatoms dominate as a result of the reduced diversity of Dinophyta. Additionally, the abundance of typically benthic large and small diatom algae from periphytone, epipelon and epipsammon associations (genus *Pleurosigma, Diploneis, Surirella, Trachyneis,* and *Nitzschia*) makes the Boubyan community different. Some species (i.e., *Pleurosigma* sp. 1 [cf. *diverse-striatum*], *Surirella fastuosa* and *Trachyneis antillarum*) were notably abundant in some locations. These findings, along with high concentrations of detritus and silt particles, are indicative of strong mixing within the water column due to strong tidal currents.

There was both spatial and temporal stability at higher taxonomic levels. As a whole, phytoplankton species composition was fairly consistent at most stations, particularly Stations BUB-01, 03, 04, and 06. Station BUB-08, at the mouth of Khor Al-Milh, showed higher species richness for diatoms, while Stations BUB-10 and 12 had higher representations of Dinophyta. At the other stations, Dinophyta contributed 8 to 11% to the species richness, whereas at Stations BUB-10 and 12, Dinophyta accounted for 19 to 24% of the species richness. These two stations are located at the southern and southeastern corners of Boubyan Island and are less influenced by discharges of the Shatt Al-Basrah, i.e., the Third River, than other stations sampled.

Temporal variability in phytoplankton species composition was fairly consistent over the 12-month sampling period (Fig. 74). The percentage of diatoms during the year varied from 70.5 to 98%. The contribution of Dinophyta was not as consistent, however; from February through June 2004, Dinophyta composition did not exceed 10%. After June 2004, Dinophyta species increased and contributed from 11 to 19% of the diversity through February 2005 (Fig. 74).

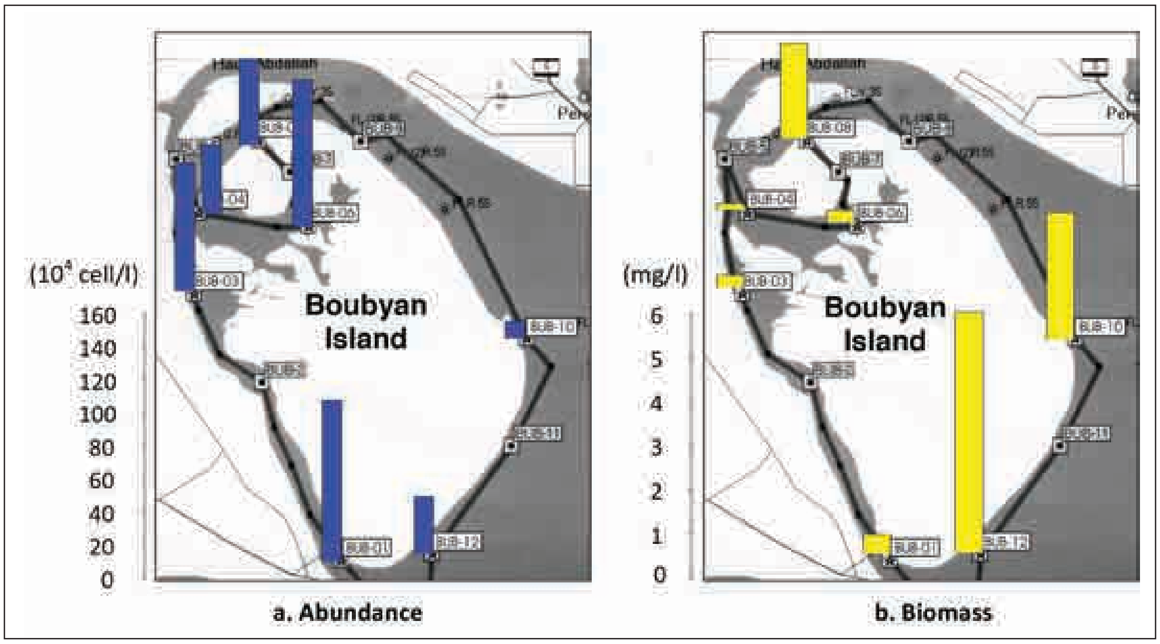

Fig. 72. Spatial distribution of total annual abundance and biomass of phytoplankton from seven stations around Boubyan Island from February 2004 to February 2005

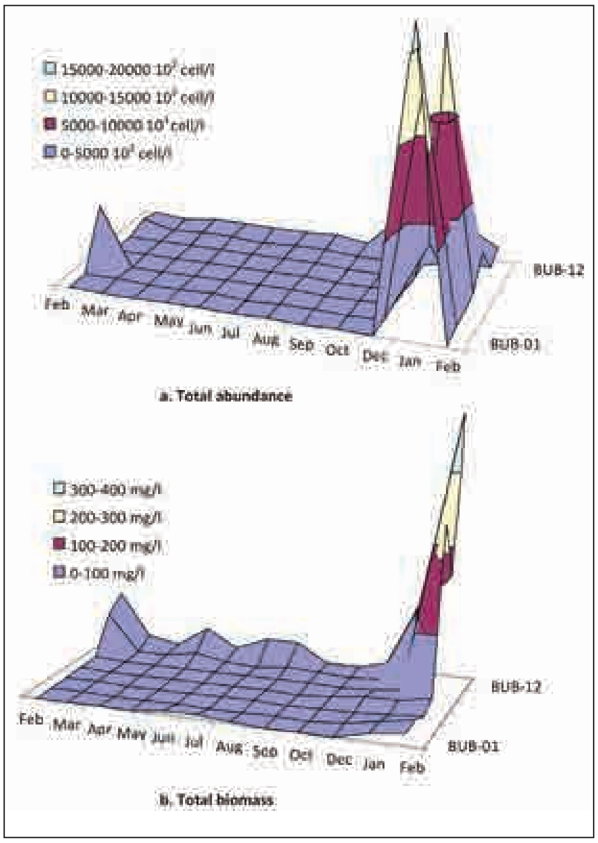

Fig. 73. Annual dynamics of phytoplankton total abundance and biomass in coastal waters around Boubyan Island from February 2004 to February 2005

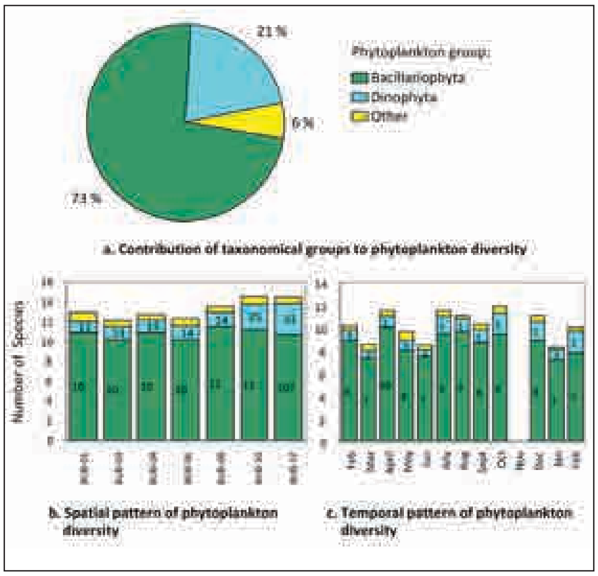

Fig. 74. Taxonomic structure of phytoplankton species diversity in the waters around Boubyan Island from February 2004 to February 2005

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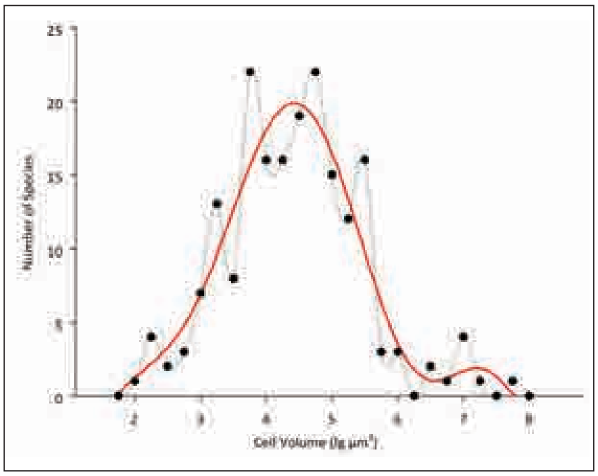

Fig. 75. Size structure of phytoplankton species from waters around Boubyan Island from February 2004 to February 2005

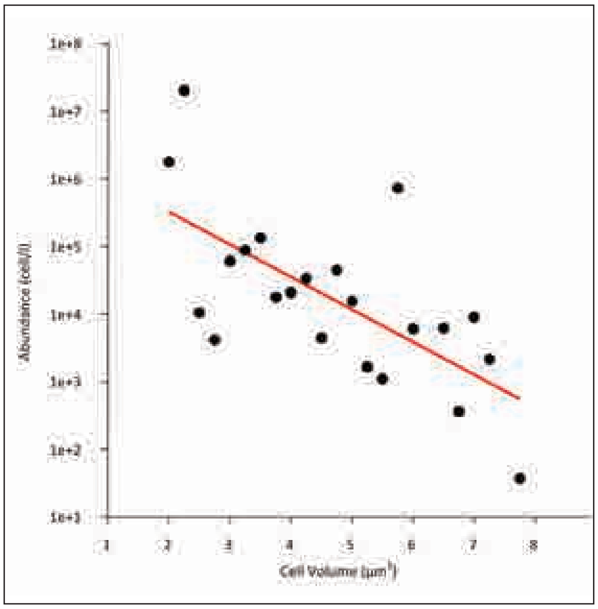

Fig. 76. Log-log relationship between abundance and cell volume for phytoplankton community in the waters around Boubyan Island from February 2004 to February 2005

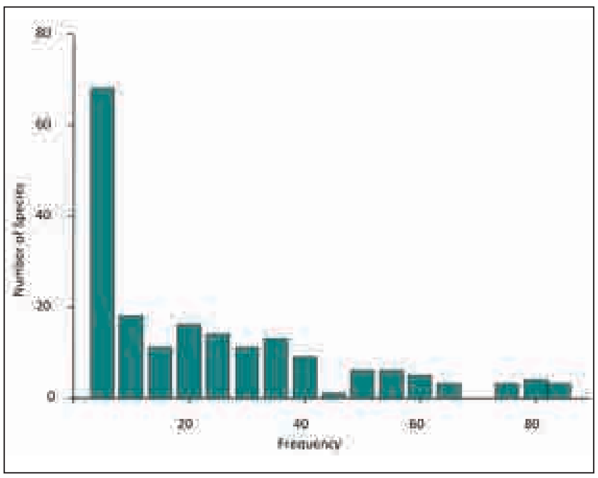

Fig. 77. Frequency of occurrence of phytoplankton species in Boubyan's waters from February 2004 to February 2005

Size Structure: The microalgae forming Boubyan's phytoplankton community differ considerably in size. Size and phytoplankton abundance determine the differences in the functional roles of specific species and their contribution to the total biomass of the community. The size spectrum of phytoplankton ranged over six orders of magnitude, from 10^2 to 10^8 µm^3 (**Fig. 75**). *Phaeocystis* sp. (83.0 µm^3), *Nitzschia* sp. (100.4 µm^3), *Cylindrotheca closterium* (107.5 µm^3) and *Chaetoceros socialis* (164.8 µm^3) had the smallest cell volumes, while *Coscinodiscus wailesii* (44.4 x 10^6 µm^3), *Rhizosolenia robusta* (14.9 x 10^6 µm^3), *R. cochlea* (9.4 x 10^6 µm^3) and *Palmeria hardmanniana* (8.9 x 10^6 µm^3) had the largest. The size structure of the community is close to normal with a slight skewing towards larger species (10^7 to 10^8 µm^3) (Fig. 75).

The total abundance of species of different sizes was unequal. The relationship between abundance and cell volume appears as a negative linear regression (**Fig. 76**). The smallest species are the most abundant, and numbers decrease as size increases (Fig. 76).

Frequency of Occurrence: Species occurrence can be categorized as rare, common, and frequent. Species identified in five or fewer samples were considered rare; of the 68 taxa represented, 22 were found in only one of the 84 samples (**Fig. 77**). Ninety-two species were considered to be common because they were found in 50% of the samples. Most of the common species were associated either with a particular station or with specific months of the year. Thirty-one species were classified as frequent as they occurred in more than 50% of the samples. The three most frequently observed species were *Thalassira excentrica* (in all 84 samples), *Thalassionema nitzschioides* (in all but one sample), and *Nitzschia lorenziana* (in all but two samples).

Species Diversity: The simplest measure of diversity is the number of species in a sample. At some stations, this parameter differed by a factor of four over the sampling period (**Table 17**). The lowest number of species observed, 20, was in April at Station BUB-03, and the highest number, 80, was in September at Station BUB-12. Overall, species richness was the lowest in the spring (March to April) and highest in December.

The number of species per sample averaged 48. For the community as a whole, species occurrence (β-diversity of 25) and similarity of species structure (an average paired samples' similarity according to the Sørensen index of 0.50 ± 0.1) were both high.

Monthly sampling at several stations allowed estimation of spatial as well as temporal variability for many parameters of abundance and structure for Boubyan's phyto-

Table 17. Extreme Values of Species Richness (Lowest and Highest Numbers of Species in Samples) for Different Stations

Station	Date (d.mo.y)	Low No. of species	Date (d.mo.y)	High No. of species
BUB-01	17.03.04	37	08.12.04	65
BUB-03	19.04.04	20	12.12.04	56
BUB-04	20.06.04	26	12.12.04	62
BUB-06	20.03.04	21	12.12.04	62
BUB-08	20.03.04	24	12.12.04	62
BUB-10	23.06.04	44	18.04.04	73
BUB-12	20.03.04	47	01.09.04	80

Table 18. Space-Time Variability of Boubyan's Phytoplankton Species Diversity from Seven Stations from February 2004 through February 2005

Attribute	Spatial Variability	Temporal Variability
Mean number of species in sample	116.7	89.5
Number of species with absolute occurrence	76	27
Number of samples containing all species	0	0
Occurrence index (β-diversity)	67.08	52.03
Sørensen index	0.83 ± 0.04	0.73 ± 0.05

plankton community. The results of the analysis of spatial and temporal selections from the general data array calculated on matrixes of the qualitative data (presence or absence of species) are presented in **Table 18**.

The high levels of average paired similarity among the species compositions at the different stations (0.831) and during the year (0.726) and small dispersion of the parameters show the phytoplankton community in the waters around Boubyan Island to be rather homogeneous. The similarity of the species compositions in different habitats in the waters around Boubyan Island was high, but the local phytoplankton communities were not identical. Cluster analyses were computed using the index of association (Jaccard index, I_J) as a degree of overlap for species among all stations (**Fig. 78**). The results showed that the stations were about 70% alike, falling into two broad categories near 75% similarity. That is, stations to the west and north of Boubyan Island (i.e., Stations BUB-01, 03, 04, 06, and 08) differed from those to the east and south of Boubyan Island (i.e., Stations BUB-10 and 12). Stations BUB-03 and 04 were the most similar with a similarity value of 84.3%. Identified phytoplankton species from Stations BUB-03 and 04 numbered 121 and 127, respectively, with 113 species in common.

This result is a reflection of the greater influence being exerted on the western side of Boubyan Island, i.e., in Khor Al-Subbiyah, by the discharge from Iraq's Third River than on the eastern side, which is more heavily influenced by

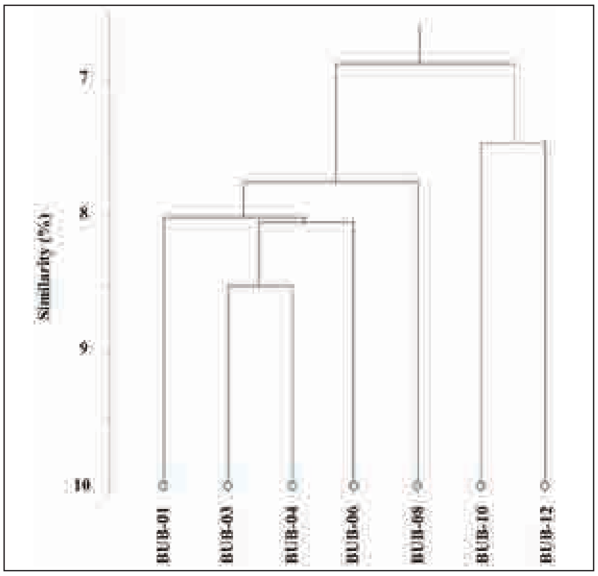

Fig. 78. Cluster analysis of similarity indices for phytoplankton species among seven stations in Boubyan's waters from February 2004 to February 2005

the Gulf's waters. Boubyan's phytoplankton communities were more uniform during summer and December 2004 than during the spring and fall (**Fig. 79**).

To examine phytoplankton species structure, the Margalef index of species richness (I_{Mg}) and the Shannon index of species diversity (I_{Sh}) were calculated using phytoplankton species biomass rather than numerical abundance. Species biomass is believed to be a better indicator of functional

Table 19. Space-Time Variability of Extreme Values of Species Richness and Diversity for Phytoplankton from the Waters around Boubyan Island from February 2004 to February 2005

Species Richness (I_{Mg})					Species Diversity (I_{Sh})			
Station	Low	Date	High	Date	Low	Date	High	Date
BUB-01	4.39	Jan 2004	12.57	Oct 2004	1.27	Jul 2004	3.91	Oct 2004
BUB-03	3.00	Feb 2004	17.45	Oct 2004	1.27	Dec 2004	3.89	Oct 2004
BUB-04	4.35	Feb 2004	14.24	Oct 2004	1.58	Jun 2004	3.92	Oct 2004
BUB-06	3.66	Feb 2004	16.39	Aug 2004	1.53	Jun 2004	3.39	Aug 2004
BUB-08	3.22	Feb 2004	11.75	Oct 2004	0.76	Feb 2004	3.50	Sep 2004
BUB-10	4.29	Feb 2004	09.65	Oct 2004	0.82	Feb 2004	3.41	Jul 2004
BUB-12	3.72	Feb 2004	09.76	Oct 2004	0.38	Feb 2004	3.46	Sep 2004

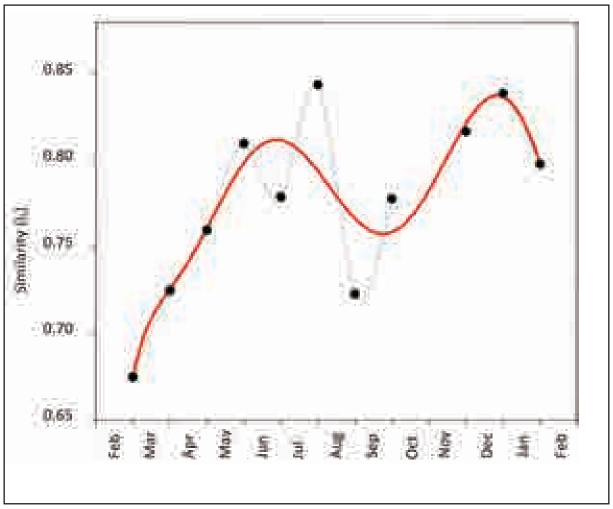

Fig. 79. Sørensen index of similarity by month for Boubyan's phytoplankton community from February 2004 to February 2005

contributions by species to the ecosystem. The results show that both the species richness and the species diversity of the phytoplankton community varied, by factors of 6 for I_{Mg} and 10 for I_{Sh} (**Table 19**).

Species richness (I_{Mg}) was minimal in January and February 2004 and highest in August (one station) and October 2004 (Table 19). Species diversity was not as consistent, with low values in February, June, July and December 2004 and the highest values in July, August, September and October 2004 at some stations (Table 19). Averaged over all stations and months, species richness was 7.3 ± 3.6 (I_{Mg}) and species diversity was 2.4 ± 0.8 (I_{Sh}). These results show that Boubyan's phytoplankton community as a whole exhibited high species diversity.

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Zooplankton Results

Seventy zooplankton taxa were identified from the 84 plankton samples. Taxa included representatives from 14 phyla (**Table 20**) and 40 copepod species (**Table 21**), the dominant zooplankton group. Common to all 84 samples were five taxa, which included three copepods (i.e., *Acartia pacifica*, *Bestiolina* sp., and *Subeucalanus flemingeri*), Sagittidae chaetognaths, and larval stages of Polychaeta. Taxa found throughout the year, but not in all samples, included the copepods *Corycaeus andrewsi*, *Euterpina acutifrons*, *Microsetella* sp. (*rosea*?), and indeterminate Harpacticoida; indeterminate Anthomedusae and Leptomedusae; larval stages of Lamellibranchiata; Gastropoda and Echinodermata; and Oikopleuridae larvacea. Six taxa contributed more than 50% to the total numerical zooplankton in a sample at least once: the dinoflagellate *Noctiluca scintillans*, the tintinnid *Tintinnopsis* sp. (*ampla*?), a rotifera, and the copepods *Acartia pacifica*, *Bestiolina* sp, and *Oithona* sp. (*simplex*?).

Numbers of zooplankton varied over three orders of magnitude. The lowest and highest densities were recorded at the mouth of Khor Al-Subbiyah (Station BUB-01) within the space of a month, 4.6 x 10^3 individuals/m^3 in December 2004 to 5.3 x 10^6 individuals/m^3 in January 2005 (**Fig. 80**). This maximum value is suspect, however, because the flowmeter recorded only eight revolutions, possibly a result of a clogged net, and only 0.0388 m^3 of water was sampled. The second-highest density of zooplankton recorded was 1.9 x 10^6 individuals/m^3 at Station BUB-06 in February 2005. Overall, the total zooplankton abundance was highest in January and February 2005 (**Fig. 81**).

The structure of the zooplankton community changed considerably during the year. In 8 of the 12 months, April through December 2004, copepods dominated the zooplankton community (**Fig. 82**). Only in the colder months of January 2005, February 2004 and 2005, and March 2004 did other zooplankton groups make significant contributions. In February 2004, copepods, the dinoflagellate *Noctiluca scintillans,* and tintinnids accounted for most of the zooplankton. The following month, the importance of tintinnids decreased, leaving dominance to copepods and *N. scintillans.* When water temperatures dropped below 15ºC (Fig. 81) in January and February 2005, the dominance of copepods was replaced by tintinnids*, N. scintillans*, and

Table 20. List of Zooplankton Taxa Identified from 84 Samples Collected in the Waters around Boubyan Island from February 2004 to February 2005

Phylum	Taxon	Occurrence	% Min	% Max
Annelida	**Polychaeta**	**84**	**0.01**	**16.52**
Arthropoda	Cirripedia	60	<0.01	3.82
Arthropoda	Cladocera	1	<0.01	<0.01
Arthropoda	Cumacea	4	<0.01	0.01
Arthropoda	**Gammaridae**	**17**	**<0.01**	**0.06**
Arthropoda	**Isopoda**	**50**	**<0.01**	**4.04**
Arthropoda	Ostracoda	15	<0.01	0.56
Chaetognatha	**Sagittidae**	**84**	**<0.01**	**3.27**
Chordata	**Ascidia**	**1**	**<<0.01**	**<0.01**
Chordata	**Cephalochordata**	**2**	**<0.01**	**0.01**
Chordata	Doliolida	3	<0.01	1.63
Chordata	Oikopleuridae	60	<0.01	12.14
Ciliophora	*Favella* sp.	22	0.01	39.86
Ciliophora	*Leprotintinnus boubyanicus*	46	<0.01	5.86
Ciliophora	*Tintinnopsis* sp. *(ampla)*	56	0.02	62.57
Ciliophora	*Tintinnopsis radix*	4	<0.01	19.41
Cnidaria	**Anthomedusae**	**40**	**<0.01**	**0.23**
Cnidaria	Diphyidae	1	<0.01	<0.01
Cnidaria	**Leptomedusae**	**38**	**<0.01**	**0.23**
Cnidaria	**Rhizostomeae**	**2**	**<0.01**	**<0.01**
Cnidaria	**Scyphomedusae**	**3**	**<0.01**	**0.02**
Ctenophora	*Pleurobrachia pileus*	53	<0.01	2.30
Dinoflagellata	*Noctiluca scintillans*	55	0.02	97.63
Echinodermata	**Echinodermata**	**42**	**<0.01**	**3.29**
Mollusca	**Bivalvia**	**76**	**<0.01**	**22.89**
Mollusca	Gastropoda	79	<0.01	2.98
Nemathelminthes	Nematoda	2	0.04	0.06
Phoronida	Phoronida	28	<0.01	0.88
Platyhelminthes	Turbellaria	14	<0.01	0.01
Rotifera		**26**	**0.02**	**55.24**

rotifers. In February 2005, zooplankton consisted mosty of *N. scintillans* (Fig. 82).

Similarities in the zooplankton communities among stations fell into two major groups: group 1 = Stations BUB-10 and 12 and Group 2 = Stations BUB-01, 03, 04, 06, and 08 (**Fig. 83**). The analysis showed that these two groups share similarities at a level of 65%. Station BUB-10 in Khor Abdullah and Station BUB-12 in South Boubyan are much more strongly influenced by the waters of the open Gulf than are the other stations, including Station BUB-01, which is relatively close to Station BUB-12. Group 2 was further divided into two major groupings with shared similarities of 80% (Fig. 83). Stations BUB-01 and 03 are

Table 21. Copepod Species from 84 Plankton Samples Collected in the Waters around Boubyan Island from February 2004 to February 2005

Taxon (Genus and Species)	Occurrence	Min (%)	Max (%)
Acartia pacifica	84	0.01	64.49
Acartiella sp.	32	<0.01	5.03
Acrocalanus gibber	32	<0.01	1.43
Bestiolina sp.	84	<0.01	62.29
Calanopia elliptica	1	0.01	0.01
Canthocalanus pauper	13	<0.01	0.17
Centropages furcatus	1	0.01	0.01
Centropages sp.	6	<0.01	0.16
Centropages tenuiremis	7	<0.01	0.04
Clytemnestra scutellata	9	<0.01	0.08
Corycaeus andrewsi	31	<0.01	3.41
Corycaeus dahli	26	<0.01	0.99
Corycaeus lubbocki	5	<0.01	0.70
Cyclopoida	41	<0.01	3.10
Euterpina acutifrons	79	<0.01	27.72
Harpacticoida	56	<0.01	2.69
Labidocera bengalensis	3	<0.01	0.01
Labidocera sp.	34	<0.01	0.16
Macrosetella gracilis	1	0.03	0.03
Microsetella sp. "*rosea*"	52	<0.01	3.10
Oithona attenuata	51	<0.01	32.49
Oithona brevicornis	13	0.01	2.70
Oithona nana	4	<0.01	0.29
Oithona plumifera	1	<0.01	<0.01
Oithona sp. "*simplex*"	73	0.01	66.44
Oncaea clevei	13	<0.01	1.40
Oncaea sp.	1	0.05	0.05
Paracalanus sp.	31	<0.01	0.87
Parvocalanus crassirostris	47	<0.01	4.17
Parvocalanus elegans	14	0.02	5.75
Parvocalanus sp.	36	<0.01	19.07
Poecilostomatoida	55	<0.01	1.72
Pontella danae	2	<0.01	<0.01
Pseudodiaptomus arabicus	30	<0.01	0.60
Pseudodiaptomus sp.	29	<0.01	0.17
Sapphirina sp.	2	0.01	0.02
Subeucalanus flemingeri	84	0.01	10.48
Temora discaudata	1	<0.01	<0.01
Temora turbinata	30	<0.01	19.54
Tortanus forcipatus	15	<0.01	0.12

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Table 22. Spatial Composition of the Larvae of Different Decapod Groups from Seven Stations in the Waters around Boubyan Island from February to August 2004

Composition (%)							
Station	BUB-01	BUB-03	BUB-04	BUB-06	BUB-08	BUB-10	BUB-12
Brachyura	95	94	98	85	98	71	58
Caridea	1	5	1	12	1	4	3
Peneidae	1	0	0	0	0	13	26
Sergestidae	2	1	1	1	0	8	8
Palinura	0	0	0	0	0	0	0
Thalassinidae	0	0	0	1	0	0	0
Anomura	1	0	0	1	0	4	5

both in Khor Al-Subbiyah, while the remaining stations are all in the tidal creeks Khor Al-Mughwi and Khor Al-Milh.

Copepods overwhelmingly dominated Boubyan's zooplankton community in most months (**Figs. 84 and 85**), with densities often exceeding 50,000/m^3 and even approaching 250,000/m^3 at Station BUB-10 in July 2004 (Fig. 85). A total of 47 copepod species representing 17 families and 22 genera were identified from the 84 samples. The majority of these species are common in the Arabian Gulf. A few species — *Acartiella* sp., *Pseudodiaptomus* sp. and an indeterminate Cyclopoida — were recorded most often from stations in or near Khor Al-Subbiyah (Stations BUB-01, 03, 04, 06, and BUB-08), but seldom from stations closer to Khor Abdullah (Stations BUB-10 and 12). Copepods dominated the zooplankton community from April through December 2004 at all stations with rare exceptions (Fig. 84).

Two families dominated the copepod community. Family level was chosen because it is often impossible to identify copepodit (immature) stages of copepods at the lower taxonomic level, and the number of immature copepods was often high. Overall, the Paracalanidae ranked first among copepod families. This family showed a decreasing trend throughout the sampling period, but accounted for over 90% of the 46,000 copepods/m^3 captured in February 2004 (**Fig. 86**). Bimodal peaks in population abundance were noted in May and September 2004, followed by a regular attenuation to very low densities by February 2005 (Fig. 86). Oithonidae exhibited a much more seasonal occurrence that was positively related to temperature. The highest abundance of Oithonidae in July 2004, nearly 60% of 70,000 copepods/m^3, coincided with the highest temperature of 31.5ºC (Fig. 86).

Decapod Larvae: Larval decapods were dominated by brachyurans, particularly at Stations BUB-04 and 08 (**Table 22** and **Fig. 87**). Larval *Parapenaeopsis stylifera*, Kuwait's third most important commercial shrimp, dominated the penaeid zooplankton and were more abundant at Khor Abdullah and South Boubyan (Stations BUB-10 and 12) and during May and July 2004 (**Fig. 88**). Larvae of Kuwait's second most abundant shrimp species, *Metapenaeus affinis*, were most abundant at the mouths of Khor Al-Subbiyah (Station BUB-01) and Khor Abdullah (Station BUB-10) (**Fig. 89**), an indication that this species probably spawns in deeper waters and the larvae immigrate to Boubyan's estuarine waters for their juvenile life phase.

Ichthyoplankton: Larvae of 8 to 17 different families of fishes were identified from each station. Two groups dominated almost every month: Gobiidae and Clupeiformes accounted for nearly 100% of the ichthyoplankton at most stations (**Fig. 90**). Clupeiformes larvae included representatives of Clupeidae (herrings and sardines), Chirocentridae (wolf herrings), and Engraulidae (anchovies). Gobiidae ichthyoplankton are probably the larvae of *Boleophthalmus dussumieri* and other species that as amphibious adults are a dominant component of the intertidal mudflats, particularly along the Khor Al-Subbiyah (Stations BUB-01 and 03), Khor Al-Milh (Stations BUB-06 and 08), and Khor Al-Mughwi (Station BUB-04).

Water Chemistry

Fourteen physical parameters, including depth, were recorded for surface and bottom water samples (**Table 23**). Except for turbidity, and to a lesser extent chlorophyll and phosphates, differences between surface and bottom samples were slight. This is attributed to turbulent mixing from strong tidal currents as suggested for the phytoplankton. Differences were apparent between stations in Boubyan's northern waters (Stations BUB-03, 04, 06, and 08) and those in Boubyan's southern waters (Stations BUB-01, 10 and 12) (**Figs. 91 to 110**).

Overall salinity ranged from a low of 28% to a high of 40% depending on month and location, while temperatures varied from a low of 11.6ºC to a high of 32.4ºC (Table 23).

Table 23. Overall Mean, Maxima, Minima, Range Difference, and SE of the Mean of Measured Variables from Seven Stations in Boubyan's Waters from February 2004 through February 2005

Station	Measure	Conduct (mS/cm)	Salinity (psu)	Temp. (°C)	Dissolved O_2 (% Saturation)	Dissolved O_2 (mg/l)
BUB-01	Mean	49.7	33.5	21.1	97.2	7.3
	Minimum	38.1	30.6	11.8	88.8	6.1
	Maximum	59.8	37.6	31.3	104.3	10.0
	Range Difference	21.6	7.0	19.5	15.5	3.9
	Std. Error of Mean	1.8	0.6	1.4	0.9	0.2
	N	20	24	24	20	24
BUB-03	Mean	49.5	32.7	21.6	99.0	7.5
	Minimum	37.6	30.0	12.1	94.9	6.2
	Maximum	60.0	37.2	31.6	105.8	9.6
	Range Difference	22.5	7.2	19.5	10.9	3.4
	Std. Error of Mean	2.0	0.5	1.4	0.8	0.2
	N	16	22	24	16	22
BUB-04	Mean	51.3	32.8	21.9	99.7	7.5
	Minimum	40.2	28.4	11.9	94.1	6.2
	Maximum	60.8	37.3	31.4	105.4	9.8
	Range Difference	20.6	8.9	19.4	11.2	3.6
	Std. Error of Mean	1.9	0.6	1.4	0.8	0.3
	N	15	22	23	14	20
BUB-06	Mean	52.5	33.6	21.6	97.8	7.6
	Minimum	41.3	30.5	11.6	94.3	5.9
	Maximum	60.6	38.5	31.2	103.9	10.5
	Range Difference	19.3	8.0	19.5	9.6	4.5
	Std. Error of Mean	1.9	0.6	1.4	0.8	0.4
	N	14	22	24	14	20
BUB-08	Mean	52.2	33.3	21.7	96.6	7.2
	Minimum	41.6	29.4	12.0	88.4	5.3
	Maximum	61.8	37.6	31.3	102.1	11.2
	Range Difference	20.1	8.2	19.3	13.7	5.8
	Std. Error of Mean	1.9	0.6	1.4	1.1	0.3
	N	14	22	24	14	20
BUB-10	Mean	56.2	36.9	22.1	100.7	7.1
	Minimum	45.6	33.0	13.2	82.4	4.9
	Maximum	65.8	39.7	32.4	120.0	9.7
	Range Difference	20.2	6.7	19.2	37.6	4.8
	Std. Error of Mean	1.8	0.4	1.4	2.2	0.3
	N	18	24	24	18	22
BUB-12	Mean	54.7	36.3	21.5	107.1	7.6
	Minimum	42.6	32.9	12.1	94.6	6.1
	Maximum	65.3	39.9	31.3	119.8	9.6
	Range Difference	22.7	7.0	19.2	25.3	3.5
	Std. Error of Mean	1.7	0.4	1.4	2.1	0.2
	N	18	24	24	18	22
OVERALL	Mean	52.3	34.1	21.6	99.7	7.4
	Minimum	37.6	28.4	11.6	82.4	4.9
	Maximum	65.8	39.9	32.4	120.0	11.2
	Range Difference	28.3	11.5	20.7	37.6	6.3
	Std. Error of Mean	1.9	0.5	1.4	1.2	0.3
	N	16	23	24	16	21

pH	NH_3 (µg-at/l)	NO_2 (µg-at/l)	NO_3 (µg-at/l)	PO_4 (µg-at/l)	SiO_3 (µg-at/l)	Turbidity (NTU)	Chloro. (µg/l)
8.1	9.1	0.5	17.7	0.8	29.8	150.9	5.9
7.6	1.0	0.1	2.3	0.0	8.9	13.0	0.0
8.2	16.3	1.1	52.9	4.5	43.0	390.5	26.8
0.6	15.4	1.0	50.6	4.5	34.1	377.4	26.8
0.0	1.0	0.1	3.6	0.2	1.9	23.9	1.5
24	19	23	23	23	23	24	23
8.0	9.6	0.7	17.3	0.3	31.3	42.4	3.6
7.4	0.8	0.1	0.0	0.0	15.6	1.2	0.8
8.2	31.6	2.0	73.4	1.4	63.5	180.0	15.7
0.8	30.8	2.0	73.4	1.4	47.9	178.7	15.0
0.1	1.7	0.1	4.3	0.1	2.2	8.5	0.8
22	20	24	24	24	24	22	24
8.0	13.0	0.5	16.3	0.4	29.8	95.9	6.2
7.4	3.1	0.1	1.9	0.0	15.9	3.6	0.9
8.2	54.7	1.4	56.4	1.0	51.9	315.4	32.8
0.9	51.6	1.3	54.5	1.0	36.0	311.9	32.0
0.1	2.9	0.1	3.5	0.0	1.8	21.1	1.7
18	20	24	24	23	23	20	24
8.1	9.8	0.8	16.3	0.2	27.9	134.1	5.0
7.3	4.6	0.0	1.2	0.0	11.0	3.0	0.7
8.3	18.8	2.8	97.6	0.5	44.7	1,796.0	16.9
1.0	14.2	2.8	96.4	0.5	33.7	1,793.0	16.2
0.1	1.0	0.2	5.3	0.0	2.1	87.9	1.0
18	20	24	24	24	24	20	22
8.0	10.0	0.4	15.2	0.4	30.2	199.8	4.3
6.8	2.3	0.1	2.8	0.0	17.3	5.1	0.8
8.2	31.9	1.0	48.9	0.9	48.1	567.0	17.7
1.5	29.5	1.0	46.1	0.9	30.8	561.9	16.9
0.1	1.6	0.0	2.9	0.0	1.7	37.3	1.1
18	20	24	24	24	24	20	22
8.2	11.9	0.2	6.2	0.4	12.6	77.1	9.0
8.0	2.0	0.0	1.4	0.1	0.7	8.6	3.3
8.3	44.2	1.3	19.0	1.3	26.9	203.5	27.2
0.3	42.3	1.3	17.6	1.2	26.2	194.9	23.9
0.0	2.2	0.1	1.2	0.1	1.6	13.6	1.4
20	20	24	24	24	24	22	22
8.2	10.9	0.1	6.2	0.3	18.7	54.6	8.2
8.0	3.7	0.0	0.0	0.0	0.7	2.1	3.3
8.6	20.4	1.1	29.9	0.5	40.9	190.6	19.9
0.6	16.8	1.1	29.9	0.5	40.2	188.5	16.6
0.0	1.2	0.0	1.9	0.0	2.2	12.2	1.0
20	20	24	24	24	24	22	22
8.1	10.6	0.5	13.6	0.4	25.7	107.8	6.0
6.8	0.8	0.0	0.0	0.0	0.7	1.2	0.0
8.6	54.7	2.8	97.6	4.5	63.5	1,796.0	32.8
1.8	53.9	2.8	97.6	4.5	62.8	1,794.8	32.8
0.1	1.7	0.1	3.2	0.1	1.9	29.2	1.2
20	20	24	24	24	24	21	23

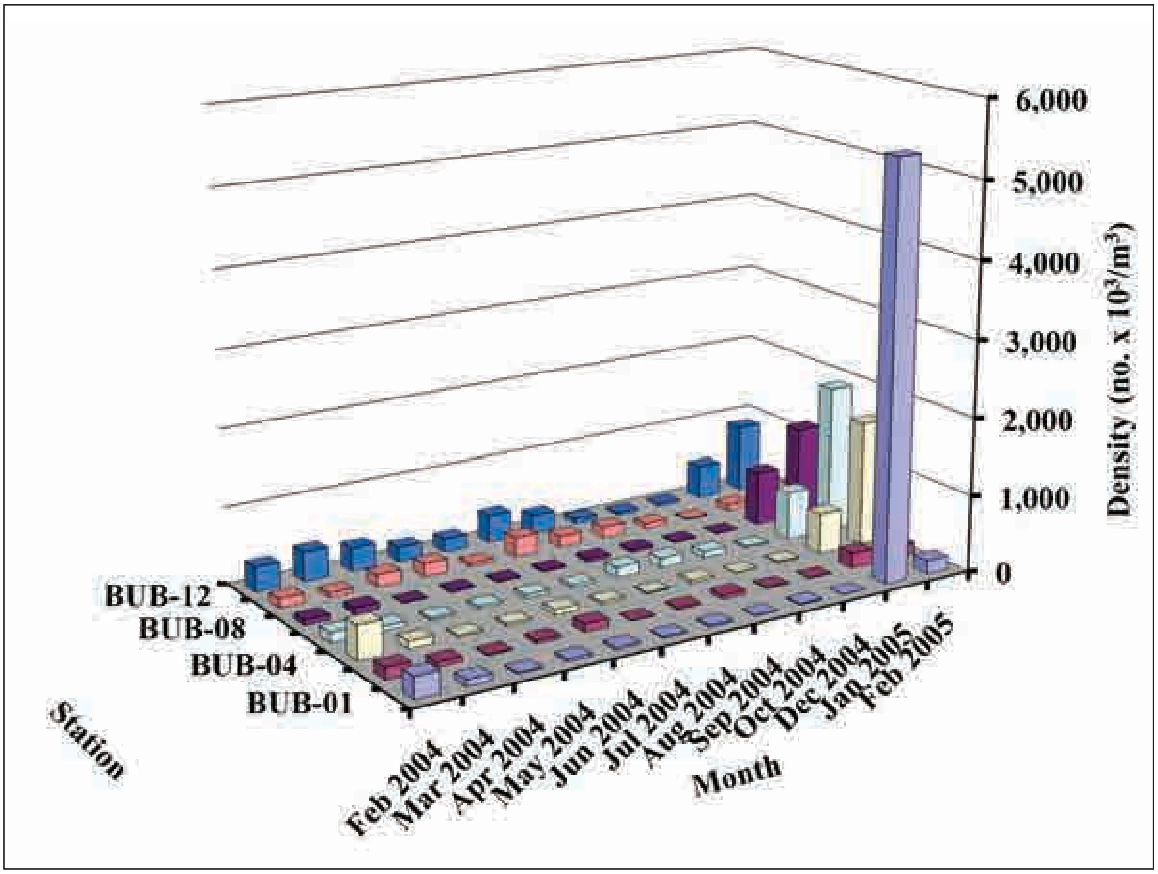

Fig. 80. Monthly density of zooplankton from seven stations in the waters around Boubyan Island from February 2004 to February 2005

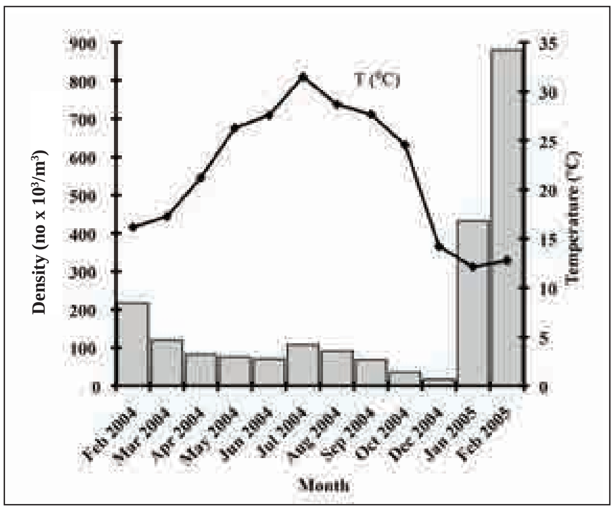

Fig. 81. Monthly density of zooplankton averaged over seven stations in the waters around Boubyan Island from February 2004 to February 2005

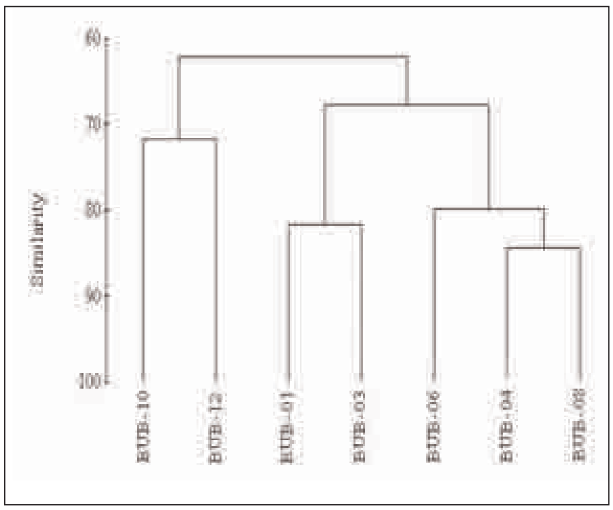

Fig. 83. Dendogram of hierarchical clustering based on the Bray-Curtis similarity matrix for the zooplankton communities from seven stations in the waters around Boubyan Island from February 2004 to February 2005

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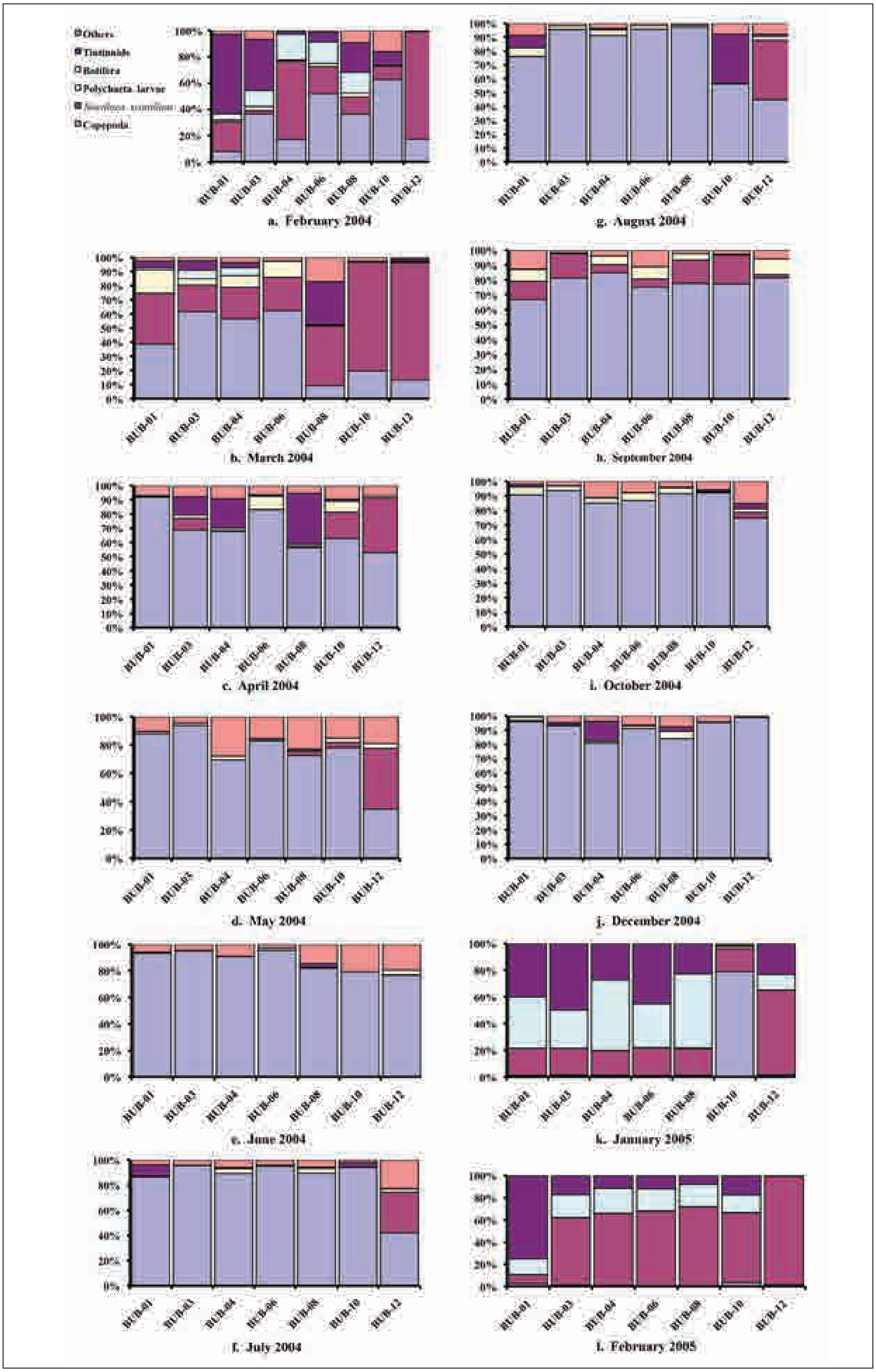

Fig. 82. Monthly percent distribution of zooplankton groups from seven stations in waters around Boubyan Island from February 2004 to February 2005

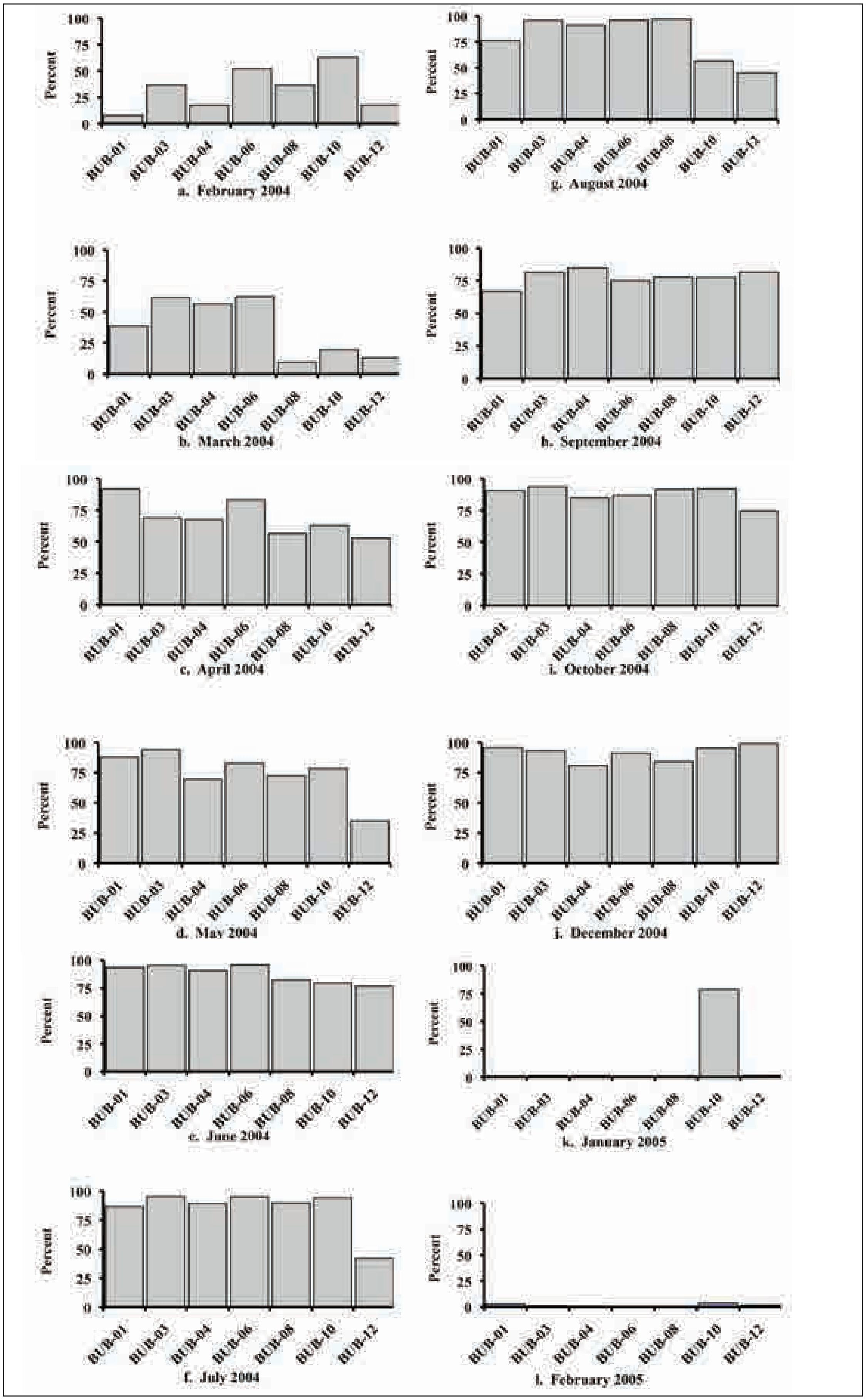

Fig. 84. Monthly distribution of copepods by station in the waters around Boubyan Island from February 2004 to February 2005

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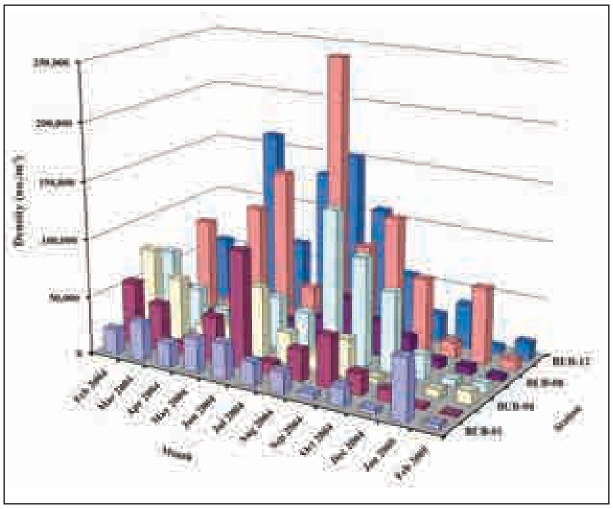

Fig. 85. Density of copepods from seven stations in the waters around Boubyan Island from February 2004 to February 2005

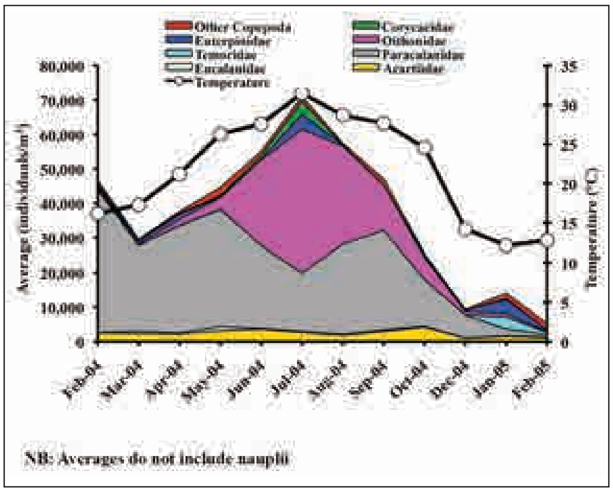

Fig. 86. Monthly mean total Copepoda by temperature from seven stations in the waters around Boubyan Island from February 2004 to February 2005

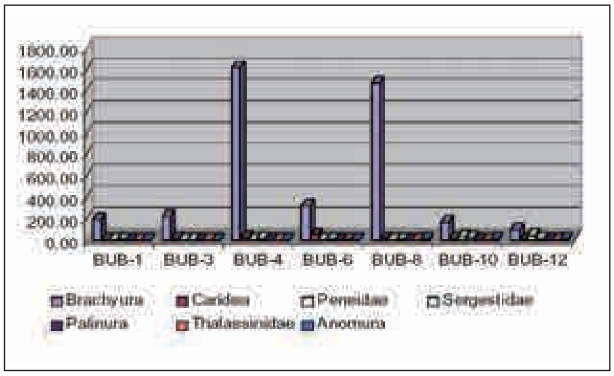

Fig. 87. Spatial patterns of the mean abundance of Decapoda larvae by taxa from seven stations in the waters around Boubyan Island from February to July 2004

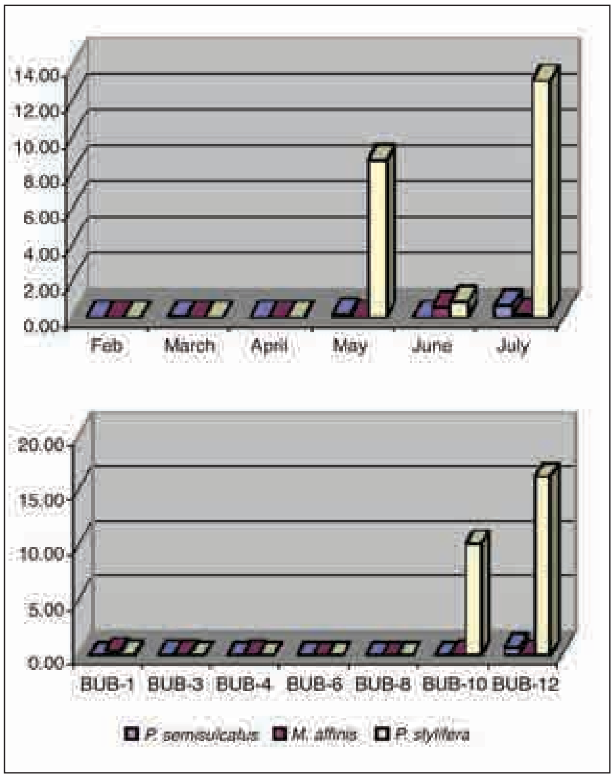

Fig. 88. Mean abundance of penaeid shrimp larvae from seven stations in the waters around Boubyan Island from February to July 2004

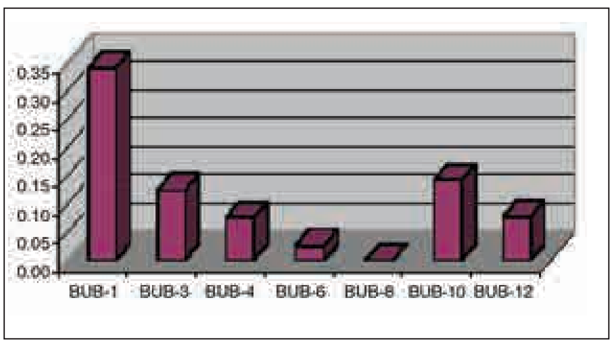

Fig. 89. Mean abundance of *Metapenaeus affinis* larvae by station in the waters around Boubyan Island from February to July 2004

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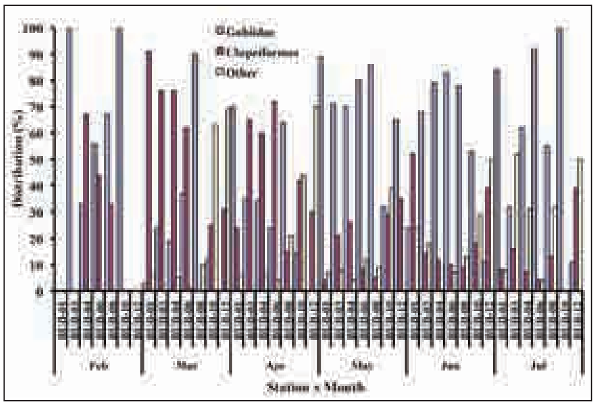

Fig. 90. Monthly distribution of ichthyoplankton from seven stations in the waters around Boubyan Island from February to July 2004

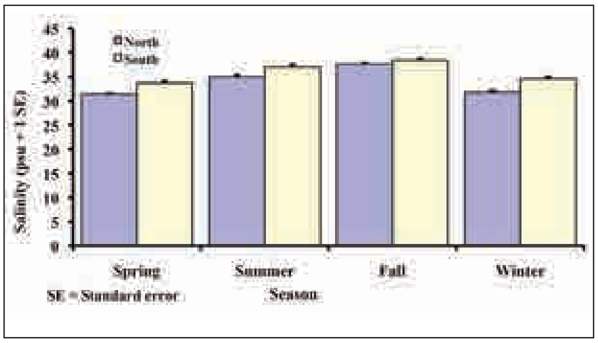

Fig. 91. Seasonal salinities for Boubyan Island's northern and southern waters from February 2004 to February 2005

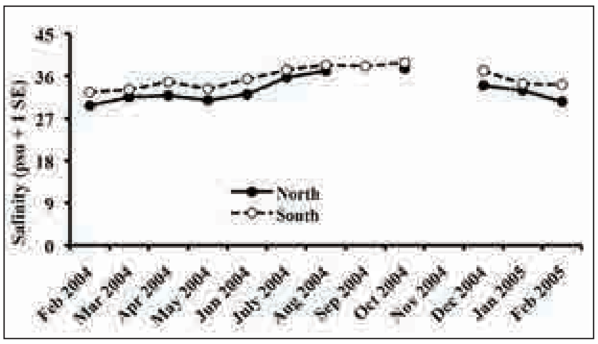

Fig. 92. Monthly salinities for Boubyan Island's northern and southern waters from February 2004 to February 2005

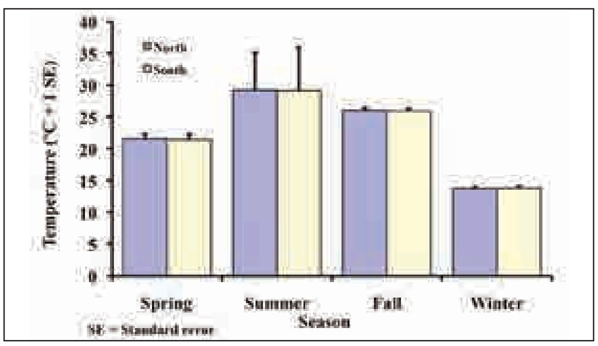

Fig. 93. Seasonal temperature for Boubyan Island's northern and southern waters from February 2004 to February 2005

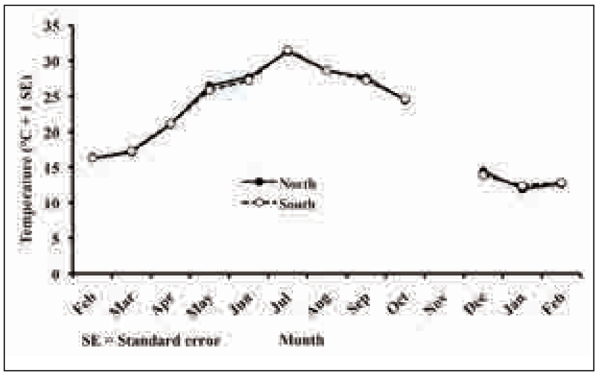

Fig. 94. Monthly temperatures for Boubyan Island's northern and southern waters from February 2004 to February 2005

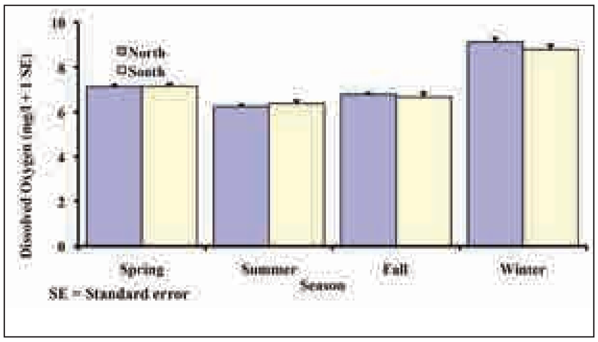

Fig. 95. Seasonal dissolved oxygen values for Boubyan Island's northern and southern waters from February 2004 to February 2005

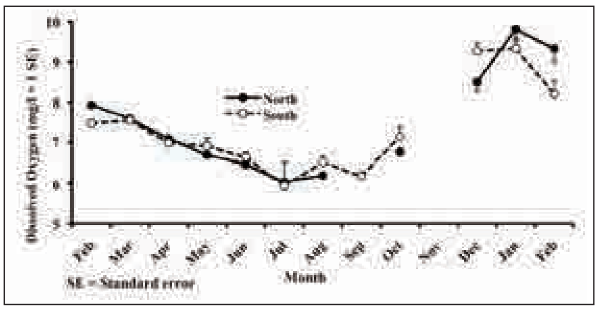

Fig. 96. Monthly dissolved oxygen values for Boubyan Island's northern and southern waters from February 2004 to February 2005

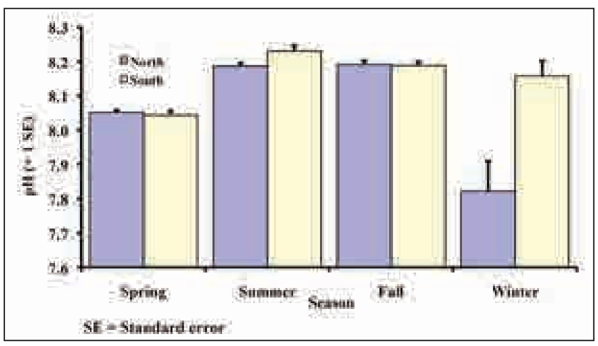

Fig. 97. Seasonal pH values for the northern and southern waters around Boubyan Island from February 2004 to February 2005

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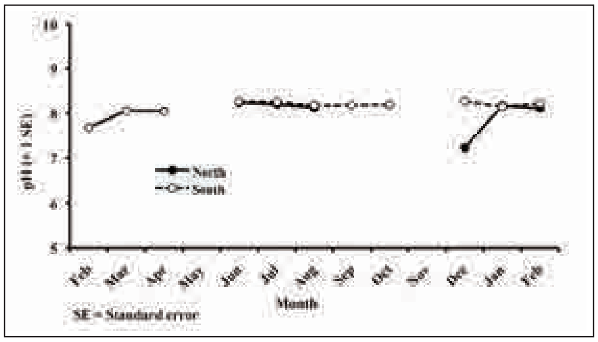

Fig. 98. Monthly pH values for the northern and southern waters around Boubyan Island from February 2004 to February 2005

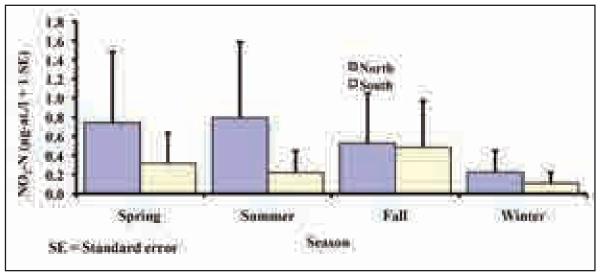

Fig. 102. Seasonal dissolved nitrite-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

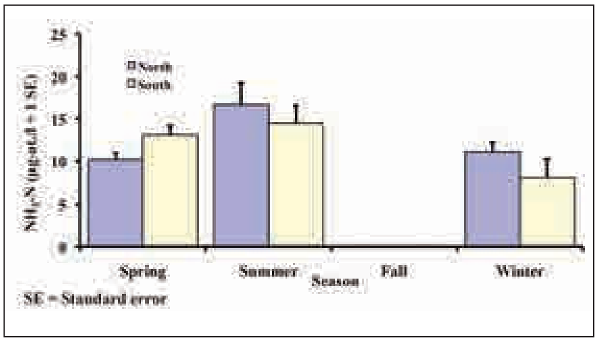

Fig. 99. Seasonal dissolved ammonia-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

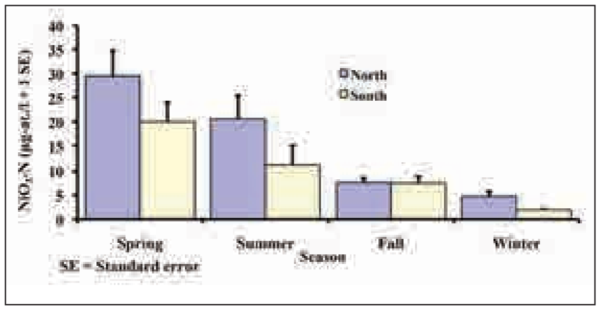

Fig. 103. Seasonal dissolved nitrate-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

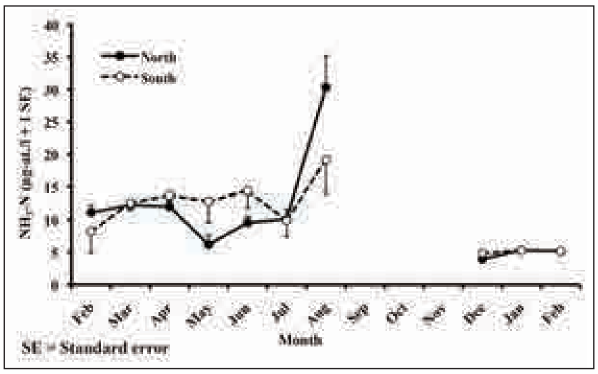

Fig. 100. Monthly dissolved ammonia-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

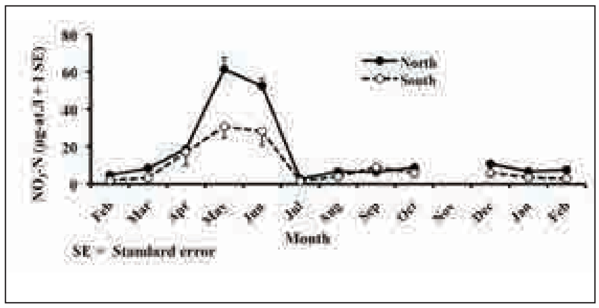

Fig. 104. Monthly dissolved nitrate-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

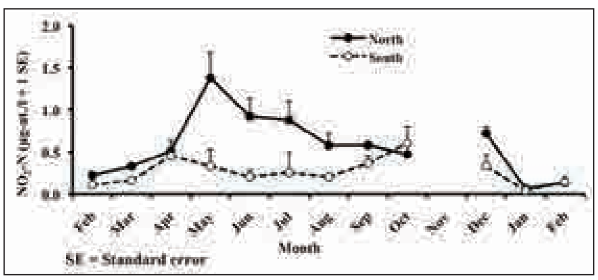

Fig. 101. Monthly dissolved nitrite-nitrogen values for northern and southern waters around Boubyan Island from February 2004 to February 2005

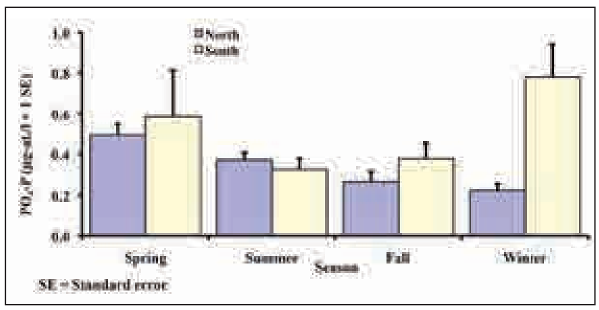

Fig. 105. Seasonal dissolved phosphate-phosphorus values for northern and southern waters around Boubyan Island from February 2004 to February 2005

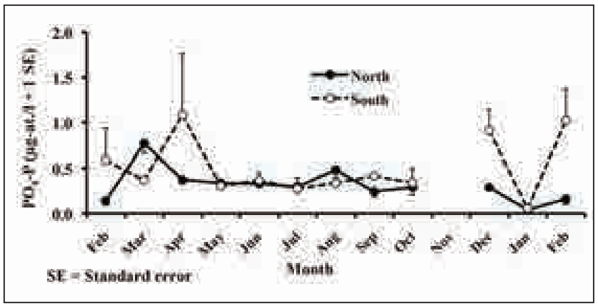

Fig. 106. Monthly dissolved phosphate-phosphorus values for northern and southern waters around Boubyan Island from February 2004 to February 2005

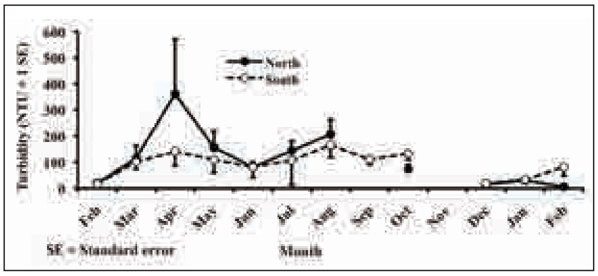

Fig. 110. Monthly turbidity values for northern and southern waters around Boubyan Island from February 2004 to February 2005

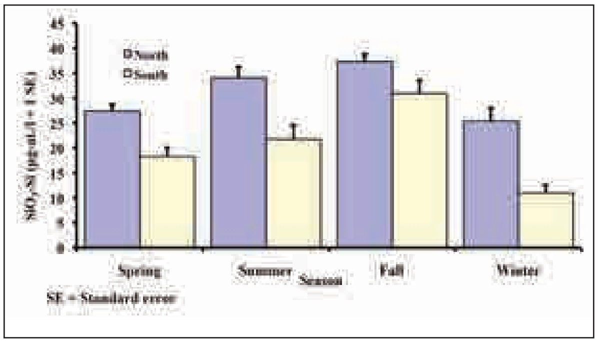

Fig. 107. Seasonal dissolved silicate-silicon values for northern and southern waters around Boubyan Island from February 2004 to February 2005

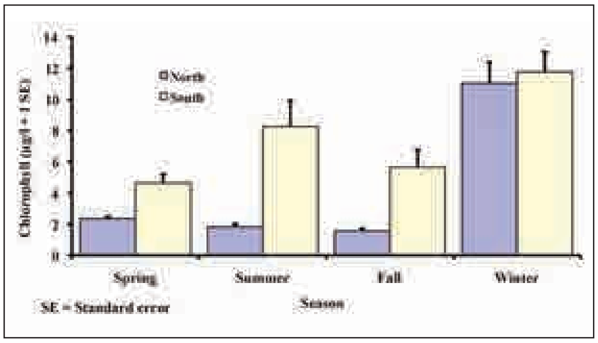

Fig. 111. Seasonal chlorophyll concentrations for northern and southern waters around Boubyan Island from February 2004 to February 2005

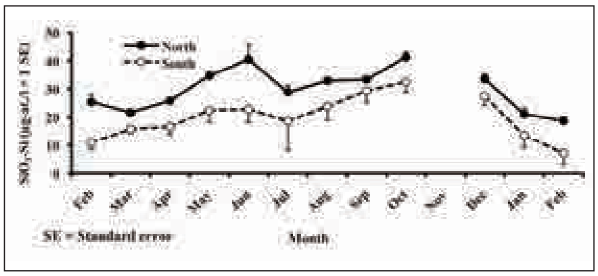

Fig. 108. Monthly dissolved silicate-silicon values for northern and southern waters around Boubyan Island from February 2004 to February 2005

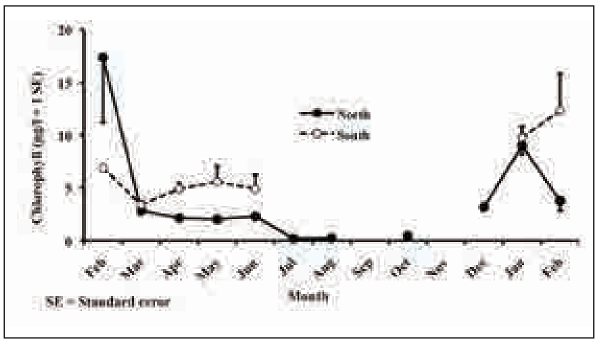

Fig. 112. Monthly chlorophyll concentrations for northern and southern waters around Boubyan Island from February 2004 to February 2005

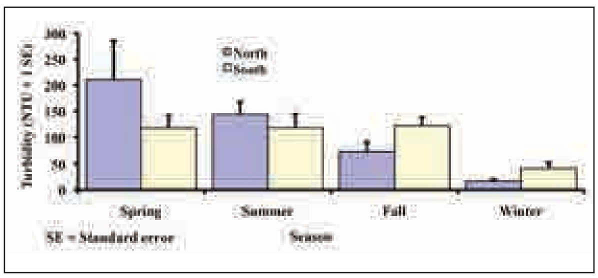

Fig. 109. Seasonal turbidity values for northern and southern waters around Boubyan Island from February 2004 to February 2005

Salinities in the northern waters around Boubyan Island averaged about 2.6% less than those in the southern waters (**Figs. 91 and 92**) and tended to increase from spring to fall, before dropping in winter (Figs. 91 and 92). The winter drop was obviously a result in increased discharge from Iraq's Third River. Temperatures in the northern waters essentially mirrored those of the southern stations, and differences between Boubyan Island's northern and southern waters were essentially nonexistent (**Figs. 93 and 94**), with little or no standard deviation except in the summer (Fig. 93). Temperatures averaged about 16ºC in February and increased to 31ºC by July, before decreas-

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ing to 24°C in September. From mid-March to May 23, temperatures increased by 9.35°C (Fig. 94). Temperatures in February 2005 averaged about 3.5°C lower than those the previous February (Fig. 94).

Dissolved oxygen remained near saturation throughout the study period with concentrations varying from 4.9 to 10.0 mg/l (Table 23). Seasonally, concentrations were lowest in summer and highest in winter (**Fig. 95**). Concentrations decreased from just under 8 mg/l in February to 6 mg/l in July (**Fig. 96**), a reflection of increasing temperatures (Fig. 94). Throughout the study, oxygen saturation never dipped below 82% (Table 23). From February 2004 through February 2005, pH varied from 6.8 to 8.1 (Table 23). Most values, however, varied above 8 (**Figs. 97 and 98**). The slightly acidic pH of 6.8 in December 2004 at Station BUB-08 (Table 23, Fig. 98) could have been either an anomaly or the erroneous results of a malfunction of the pH probe.

Ammonia concentrations varied from 0.8 to 54.7 µg-at/l with an annual mean of 10.6 µg-at/l (Table 23). Seasonal concentrations increased between spring and summer, with winter showing the lowest concentration (**Fig. 99**). Equipment malfunction prevented analysis of ammonia during the fall. In August, ammonia concentrations in Boubyan's northern waters averaged 28 µg-at/l, 12 µg-at/l greater than in Boubyan's southern waters (**Fig. 100**). Nitrite concentrations in Boubyan's waters averaged 0.5 µg-at/l and ranged from less than 1.01 to 2.8 µg-at/l (Table 23). Generally, nitrites were less than 1.0 µg-at/l, especially at the southern stations (**Fig. 101**). Seasonal concentrations consistently averaged higher in northern waters, particularly in the spring and summer (**Figs. 101 and 102**). Differences during the fall and winter were much less pronounced. Nitrate values ranged from less than 0.1 to 97.6 µg-at/l, but averaged 13.6 µg-at/l. A very obvious seasonal decline in concentrations occurred from spring to winter (**Fig. 103**), with peak concentrations in May and June (**Fig. 104**). Like nitrites, concentrations of nitrates were higher (or at least equal) in Boubyan's northern waters compared to concentrations in southern waters (Figs. 103 and 104).

Phosphate concentrations were low throughout the study period and averaged only 0.4 µg-at/l (Table 23). The highest recorded value was 4.5 µg-at/l, but concentrations exceed 1 µg-at/l infrequently. Phosphate concentrations in Boubyan Island's southern waters averaged higher than those in the northern waters in the spring, summer and winter (**Fig. 105**), but differences were usually minor (**Fig. 106**). Concentrations of silicates were consistently higher in Boubyan's northern waters (**Figs. 107 and 108**). Overall, silicates averaged 25.7 µg-at/l and ranged from 0.7 to 63.5 µg-at/l (Table 23). Silicates tended to increase from 11 to 25 µg-at/l in February to 23 to 40 µg-at/l in June, before decreasing in July (Fig. 108). From August through October, silicates again increased, with concentrations in Boubyan Island's northern and southern waters approaching 31 µg-at/l (Fig. 108). In February 2005, silicate concentrations reached their lowest values for the study period (Fig. 108).

Turbidity in Boubyan's waters varied greatly during the study period. Overall, turbidity averaged 107.8 NTU, but values varied greatly, from 1.2 to 1,796 NTU (Table 23), depending on month and station. Boubyan's northern waters were more turbid than its southern waters during the spring and summer (**Fig. 109**), but this situation was reversed in the fall and winter. Turbidity tended to decrease from spring to winter (Fig. 109), but caution must be exercised with regard to this finding because sampling was not consistent with a particular tide phase. Additionally, there was a substantial difference in turbidity between surface and bottom samples. In April, the turbidity difference between Boubyan's northern and southern stations was 221 NTU (361 vs. 140 NTU, **Fig. 110**).

Chlorophyll averaged 6 µg/l and ranged from less than 0.01 to 32.8 µg/l (Table 23). The highest chlorophyll value was recorded in the surface waters of Khor Al-Mughwi (Station BUB-04) in April. Chlorophyll concentrations in Boubyan's southern waters exceeded those in the northern waters in each season (**Figs. 111 and 112**). The highest values were recorded in the winter, which coincided with the lowest turbidity values (Figs. 109 and 110).

Marine Mammal and Reptile Surveys

Materials and Methods

The waters around Boubyan Island were divided into five subareas according to named khors or region: Khor Al-Subbiyah, Khors Al-Mughwi and Ath-Thala'ab; Khor Boubyan; Khor Al-Milh; Khor Abdullah; and South Boubyan. Exact demarcation between different water bodies was subjective, but this is not considered to be a serious drawback to observations time recorded for each area. Khor Al-Mughwi and Khor Ath-Thala'ab were treated as a single body of water because at high tide visible separation between them was not possible. Time spent in each area was recorded to the nearest minute. Recorded sightings of a marine mammal or reptile also included water body, nearest station, GPS location, water depth, time, cloud cover, wind direction and speed. All observations were recorded coincidental to fieldwork, including gill netting, trawling, and plankton and water chemistry tasks. Additionally, whenever project personnel were involved in other activities around Boubyan Island, observations on marine mammals and reptiles were recorded. Data were compiled on the number of observations per hour of observation time for each water body.

Results

From February 2004 through March 1, 2005, a total of 23,352 min (389 h) of observation time was spent in the Boubyan area. Total time per month ranged from a low in February 2004 of 1,390 min to a high in April 2004 of 3,186 min. The high value was due to a 24-h station in Khor Al-Subbiyah. Observation time in most months ranged between 1,662 min (27.7 h) and 1,932 min (32.2 h). Among the various water bodies, Khor Al-Subbiyah ranked first with 8,633 min (37%). This ranking was due to the fact that Khor Abudllah was avoided when possible due to occasional security problems.

During the 12 months of fieldwork from February 2004 to March 1, 2005 (no fieldwork was conducted in November 2004 due to high winds), we observed 524 humpback dolphins (*Sousa* sp.), at an overall rate of 1.3 individuals/h. Dolphins were present throughout every season of the year, but spring and fall had the highest observation rates (**Fig. 113**). In the spring, numbers were highest in April (**Fig. 114**). Dolphin observations showed a bimodal distribution, with an initial maximum in March (2.2 individuals/h) and April (3.3 individuals/h) and a second in September (1.8 individuals/h) (Fig. 114). Dolphins were observed in every water body, but most regularly in Khor Abdullah (2.4 individuals/h) and Khors Al-Mughwi and Ath-Thala'ab (1.6 individuals/h; **Fig. 115**). Dolphins were most regularly observed in the waters of Khor Boubyan, Khor Al-Mughwi, and Khor Abdullah in the spring and in Khor Abdullah in the summer and fall (**Fig. 116**).

These observations support the assumption that humpback dolphins are resident in Kuwait's waters. Dolphins are always on the move, however, and their home range certainly includes a much larger area than the waters around Boubyan Island. Dolphins frequently use the east side of Khor Abdullah and likely include Khor Zubair as part of their territory. Additionally, there is no reason that they would not frequent the northern Gulf waters east of the mouth of the Shatt Al-Arab, i.e., Iranian waters. With so much habitat available, the fact that dolphins are regularly observed in the waters around Boubyan Island is an indication of the area's richness. On April 28, 2004, a total of 66 dolphins were counted around Boubyan Island, leading to a rough population estimate approaching 100 individuals.

In general, most dolphins were observed surfacing, presumably during routine feeding activities. At times, dolphins surfaced at regular short intervals, which probably indicates either a traveling mode or, when in shallow water, feeding. At other times, they surface infrequently, which was assumed to be an indication of feeding in deeper waters.

Relying on surface counts to estimate population size usually results in an underestimation of the numbers actually present. Dolphins appear in loosely associated groups of one to three or more individuals. Often dolphins travel in pairs and, when doing so, surface almost simultaneously. Depending on the distance, viewing angle, wave height, sun's reflection on the water, boat speed, etc., it is easy to underestimate the actual number present.

On occasion, dolphins exhibited unexpected behavior. In Khors Al-Mughwi and Al-Subbiyah, we observed individuals floating on their sides, with their head and a pectoral fin above the water, jaws agape (**Fig. 117**). Although such observations were never made at close distances, the position assumed may have been to accommodate birth or some aspect of reproduction. On another occasion in Khor Boubyan, similar behavior was observed and other dolphins were seen swimming with their head and their entire dorsal fin exposed well above the water (**Fig. 118**). The significance of this behavior is at present unknown, but obviously the waters around Boubyan Island serve as more than just a feeding ground (Bishop and Alsaffar, 2008).

The 389 hours of observation conducted during the 12-month sampling period around Boubyan Island resulted in the sighting of only 38 sea snakes. This low number is probably not due to the rarity of sea snakes, but to their less conspicuous nature and their seasonal movements. Being cold blooded, sea snakes are migratory and are present in Kuwait's waters only during the warmer months (**Fig. 119**). Initial sightings occurred in April, when water temperatures were just above 21ºC. Sea snakes were most commonly observed from May through August, when water temperatures ranged from 26 to 31ºC (Fig. 81 and **Fig. 120**). Water temperatures alone do not completely explain their presence, however. In September and October 2004, water temperatures were above 24ºC, but sea snake observations were substantially reduced. This may be due to migratory movement to deeper offshore waters or the initiation of their migration south. The highest rate of sea snake observations occurred in Khor Al-Milh (**Fig. 121**), particularly in the summer (**Fig. 122**). This is likely due to the fact that sea snakes were more easily observed in the narrower khor than in the other water bodies, and with three stations in Khor Al-Milh, a high percentage of time spent there was either anchored or trawling at slow speeds. The most sea snakes observed in a single body of water was 13 (34% of the total) in Khor Al-Subbiyah, but the rate of observation was low because most of our time in Khor Al-Subbiyah was moving at speed between stations. Sea snakes were commonly observed either feeding along the

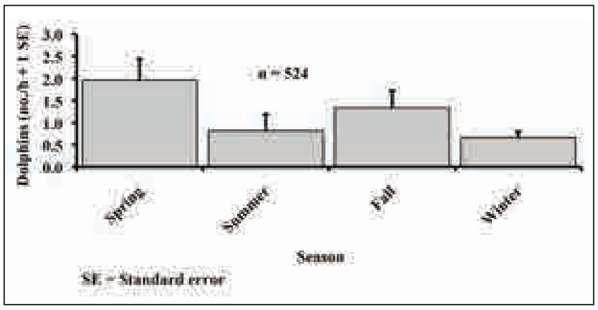

Fig. 113. Mean number of *Sousa* dolphins observed per hour by season in waters around Boubyan Island from February 2004 to March 2005

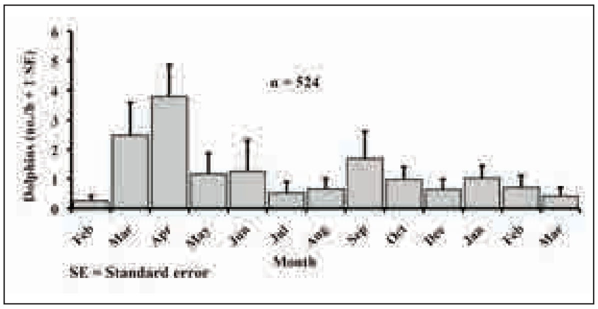

Fig. 114. Mean number of *Sousa* dolphins observed per hour by month in waters around Boubyan Island from February 2004 to March 2005

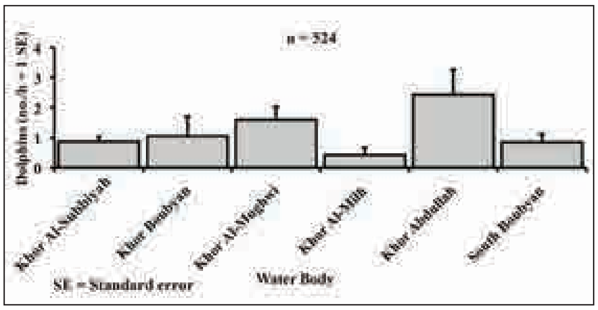

Fig. 115. Mean number of *Sousa* dolphins observed per hour by water body around Boubyan Island from February 2004 to March 2005

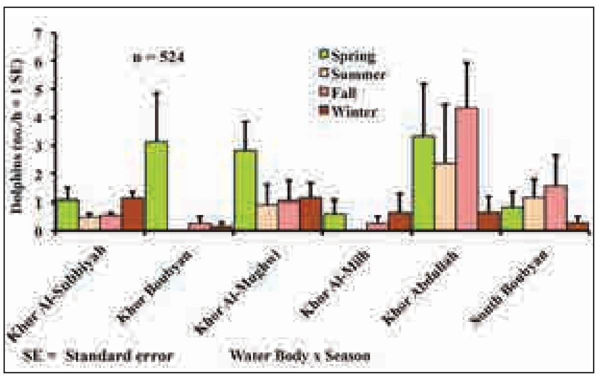

Fig. 116. Mean number of *Sousa* dolphins observed per hour by season in different water bodies around Boubyan Island from February 2004 to March 2005

Fig. 117. *Sousa* on its side with jaws agape and left pectoral fin out of the water at mouth of Khor Al-Mughwi (Photo by Alan Lennox, March 29, 2004)

Fig. 118. *Sousa* with rostrum and head pointing up and with dorsal fin exposed at mouth of Khor Al-Mughwi (Photo by Alan Lennox, March 29, 2004)

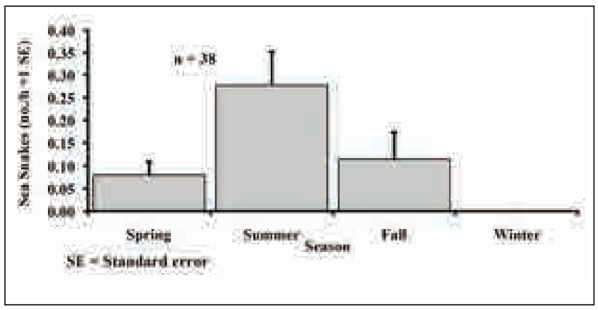

Fig. 119. Mean number of *Hydrophis* sea snakes observed per hour by season in waters around Boubyan Island from February 2004 to March 2005

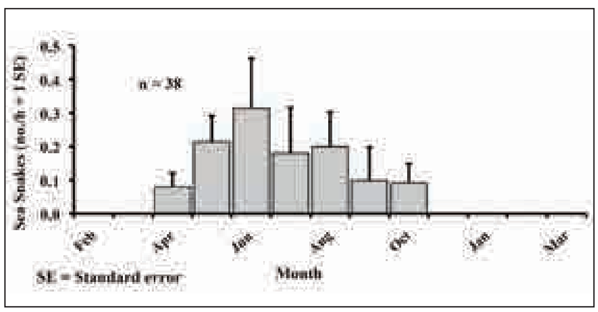

Fig. 120. Mean number of *Hydrophis* sea snakes observed per hour by month in waters around Boubyan Island from February 2004 to March 2005

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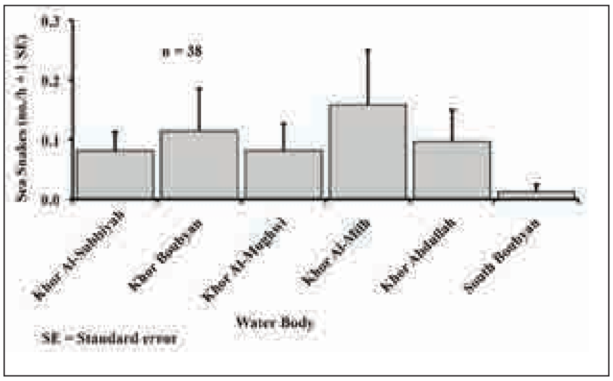

Fig. 121. Mean number of *Hydrophis* sea snakes observed per hour by water body around Boubyan Island from February 2004 to March 2005

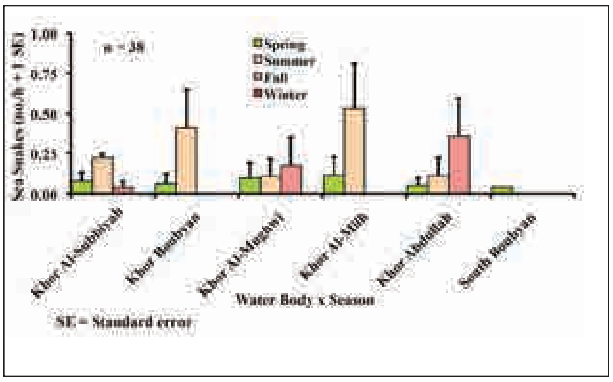

Fig. 122. Mean number of *Hydrophis* sea snakes observed per hour by season and water body in the waters around Boubyan Island from February 2004 to March 2005

tidal edge of mudflats, presumably in search of mudskippers, their primary dietary item, or near the water's surface during maximum tidal current speed. Sampling by trawl captured only one sea snake, *Hydrophis cyanocinctus*, commonly known as the annulated sea snake, on September 26, 2004 at Station BUB-02 in Khor Al-Subbiyah.

Sea snakes have no commercial value in the Gulf region, but they are an obvious component of the ecosystem and are excellent environmental indicators. Besides being top carnivores and thus accumulators of various pollutants passed up the food web, sea snakes are extremely vulnerable to oil spills because they must surface to breathe. Dead sea snakes were the most common beached air-breathing vertebrate found during a survey of the impact of the Nawroz oil spill (Burchard and McCain, 1984). The oil spill during the Iraq War of 1991 had relatively little impact on sea snakes because it occurred in February, when sea snakes were not present in any numbers in the northern Gulf.

Summary

Results of trawling activities in 2004-05 have shown the waters around Boubyan Island to be among the most, if not the most, productive in Kuwait and possibly the entire Gulf region. The area provides rich nursery habitat for a number of commercial and noncommercial species, the latter also of indirect commercial importance. Boubyan's standing stock should be viewed from a dynamic perspective with prolonged recruitment, rapid growth, and continuous emigration of many forage and commercial species.

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Boubyan's role as a nursery habitat cannot be overemphasized. Populations of Kuwait's second most important shrimp species, *Metapenaeus affinis,* were high, averaging from 10 to nearly 30 g/100 m^2 throughout the year depending on depth. These numbers may appear relatively insignificant, but it must be remembered that these densities refer to juveniles and that turnover is rapid, i.e., every three to four weeks brings new recruits, with the older individuals immigrating to offshore waters). This pattern of juveniles replacing subadults holds for many other species including another commercial shrimp, *Parapenaeopsis stylifera*, and commercial fishes such as hamoor, sheim, nagroor, sobaity, newaiby, and zobaidy, to name some of the more important. The 294 nagroor captured during the study weighed an average of 7 g each, and newaiby weighed an average of 12 g each. Zobaidy captured by gill net averaged only 100 g in size, showing the importance of this area to the juvenile and subadult phases of their life cycle. On the other hand, saboor captured by gill net were adults, and almost all females were gravid. The waters around Boubyan Island are obviously staging areas for saboor prior to their anadromous run up the Shatt Al-Arab to spawn in freshwater. Boubyan waters also serve as a staging area for juveniles and subadults emigrating from more northern marine waters to the Gulf to complete their adult life cycle and subsequent spawning. This was especially noticeable for the shrimp *M. affinis* as water temperatures dropped in the fall. The average biomass in June, July and August was 14 g/100 m^2, whereas in September and October 2004, this value jumped by a factor of four to 55 and 65 g, respectively.

The presence of many apex species, i.e., those at the top of the food chain, in substantial numbers throughout the year is direct evidence of the productivity of Boubyan's waters. These apex species included the Chinese humpback dolphin (*Sousa* sp.) with day counts as high as 66 (April 28 2004), sea snakes (*Hydrophis* sp.), at least 7 species of sharks, 11 species of rays, and abundant birdlife. In winter, Boubyan's intertidal mudflats serve as prime feeding grounds for migratory shorebirds which pass through or overwinter in Kuwait. During the summer, thousands of pairs of herons, egrets, spoonbills, several species of terns and gulls, and crab plovers nest on the very isolated patches of higher ground along the khors of northern Boubyan Island. Boubyan's highly productive waters provide these top-level carnivores with the excess energy necessary for breeding and rearing their young.

Most obvious of the resident species dominating Boubyan's mudflats are mudskippers and ocypodid crabs. These two groups of animals account for significant standing biomass, but no figures are available. In Sulaibikhat Bay, a subsystem of Kuwait Bay, mudskippers exhibit unusual behavior by constructing mud walls in polygon-shaped territories. Until recently, it was believed that this behavior was unique to Sulaibikhat Bay, but similar behavior has been reported from Iran's Khor-e Mussa (Höpner and Maraschi, 1999). More recently, mud-walled territories were observed in an intertidal creek off Khor Al-Mughwi. All things considered, Boubyan Island and its surrounding waters can be summed up as a nursery area of major importance for renewable resources of commercial importance and an area of special scientific interest.

Although the master plan calls for protection of the intertidal area, experience has shown that once development starts, it is virtually impossible to avoid piecemeal encroachment, pier by pier, jetty by jetty, boat slip by boat slip. One has to look no further than the report by Al-Sarawi et al. (1995) to realize that preventing the erection of illegal structures is nearly impossible.

Conclusions and Recommendations

Any development on Boubyan and Khor Al-Subbiyah, irrespective of its sensitivity to environmental considerations, will particularly exert negative impacts on the marine ecosystem. Since the 1990 Gulf War, the northern Gulf's marine environment has experienced significant setbacks from the destruction of the marshes in Iraq and the drastic reduction in freshwater discharge by the Shatt Al-Arab due to the massive dam construction scheme in southeastern Turkey. Of all Kuwait's coastal environments, only north Kuwait Bay and Boubyan Island remain relatively pristine, and every effort should be made to maintain both these environments in as natural a state as possible. This is because of the dual role of nursery habitat and ecological services that the intertidal areas provide. Eutrophication of Kuwait Bay has resulted in far more frequent outbreaks of red tides, and since the Iraqi invasion, the biomass of the alga *Enteromorpha* has increased exponentially during colder months along Salam Beach near Shuwaikh Port and Kuwait City. The increase of *Enteromorpha* is a direct ramification of excessive nutrients

Metaphorically, the intertidal zone is the "kidneys and lungs" of coastal waters. Twice daily, tides sweep over the intertidal zone, covering and exposing tidal mudflats. When the area is inundated, bacteria, algae, and other micro-meioflora and fauna absorb nutrients, and macrofauna consume these primary and secondary producers. During low tide, these services continue: algae photosynthesize during daylight, and many compounds absorbed by the sediments are oxidized upon exposure to air. The destruction of most of Kuwait's intertidal habitat along Kuwait Bay's southern shoreline has critically reduced the Bay's ability to process the huge load of nutrients from urban and industrial runoff (Bishop, 1999). Consequently, the importance of the relatively pristine waters of Boubyan and the ecological services provided by the extensive intertidal mudflats is enhanced.

Trawling is not allowed within three nautical miles of Kuwait's coast, and because of Boubyan's status as a nursery habitat, waters around Boubyan should be protected from all trawling and gillnetting activities. The recommendation to establish a hatchery on Khor Al-Subbiyah cannot be supported given the fact that Boubyan's waters are already teaming with juvenile stages of crustaceans and fishes. The most important "enhancement" policy that could be followed is to prevent any man-made degradation of the environment, particularly the intertidal zone. All recreational development along Boubyan's coast should be approached with extreme caution and a realistic perspective, as Boubyan's waters do not qualify as a tourist attraction. In addition to a high silt content, there are frequent blooms of red tide algae, jelly fish numbers are often in plague proportions, and sharks, rays, and sea snakes are common, particularly during the warmer months when recreation is popular. Most activity on Boubyan should be focused on research as this is one of the Gulf's greatest living laboratories.

Destruction of the intertidal habitat results in a permanent loss of shrimp. For each square kilometer of intertidal mudflat destroyed, there was a permanent loss of six tonnes of a single species of shrimp in Japan (Doi, 1981). This figure did not include other commercial shrimp or fish species and no species of indirect importance, such as food for commercial species. Costanza et al. (1997) assigned dollar values to different ecological habitats based on the "ecological" services they provided. The tidal marsh/mangrove biome is probably the closest to intertidal mudflats and was valued at US$10,000/hectare/year in ecological services alone. The fact that intertidal mudflats were not specifically identified in the paper by Costanza et al. (1997) shows just how little this environment is appreciated. But as elegantly and cogently stated by Peterson and Peterson (1979): "intertidal flats are most important for what consistently happens on them rather than what is permanently found on them." In short, mudflats are not visually beautiful, but they are vital to the functioning of the ecosystem. Therefore, to summarize:

- It is recommended that because of the ecological services they provide and their role in nursery habitat, all intertidal and immediate subtidal areas be given the highest priority for protection from any modifications
- It is recommended that because of the nursery role of the waters around Boubyan Island, fishing with gill nets and shrimp trawls should be forbidden.

Appendix 1:

Associated Trawl Data from Five-Minute Tows at 12 Stations around Boubyan Island in February 2004

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
17	Feb	BUB-01	1	30.6	15.1	29.60111	48.17806
			2-4			29.59944	48.17889
			6-10			29.60167	48.17694
29	Feb	BUB-02	1	30.2	15.3	29.75078	48.10272
			2			29.75589	48.09900
			6			29.75186	48.10017
17	Feb	BUB-03	1-2	30.0	15.2	29.82500	48.03222
			2-3			29.82472	48.03194
			7			29.82417	48.03111
29	Feb	BUB-04	1	30.7	15.5	29.89864	48.04097
			2			29.90325	48.04408
			5-7			29.90297	48.04278
20	Feb	BUB-05	1-2	NR	18.0	29.94981	48.02311
			2-3			29.94947	48.02425
			11-12			29.94831	48.03181
20	Feb	BUB-06	1	NR	16.9	29.88975	48.16781
			1.8-2.1			29.89003	48.16750
			6-8			29.89058	48.16117
20	Feb	BUB-07	1	NR	NR	29.92669	48.14483
			4-13			29.93153	48.14442
			10-15			29.93436	48.14036
20	Feb	BUB-08	0.5-1.4	NR	17.0	29.96333	48.10503
			2			29.96333	48.10472
			3-5			29.96058	48.10614
20	Feb	BUB-09	0.8-1.5	NR	16.5	29.96403	48.21697
			1.5-2.2			29.96653	48.21328
			4.8-5.1			29.96361	48.21922
19	Feb	BUB-10	1-1.5	NR	17.0	29.77936	48.38294
			2-2.4			29.78164	48.38739
			3.2			29.78678	48.38919
19	Feb	BUB-11	1	NR	19.0	29.68972	48.35336
			2			29.68592	48.35828
			2.9			29.68739	48.37247
19	Feb	BUB-12	1-1.5	NR	16.8	29.60264	48.26253
			2			29.60331	48.26469
			3.5			29.59083	48.26944
Total				NA	NA		
Average				30.4	16.6		

NR = not recorded; NA = not applicable

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m^2)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.59917	48.17917	3.0	5.0	250	3	750	4	45.7
29.59750	48.18028	3.3	5.0	275	3	825	66	351.9
29.59972	48.17667	2.8	5.0	233	3	700	0	0.0
29.75369	48.10167	4.3	5.0	358	3	1,075	2	4.3
29.75306	48.09903	4.0	5.0	333	3	1,000	6	119.7
29.74878	48.10017	4.1	5.0	342	3	1,025	15	145.0
29.82306	48.03306	2.5	5.0	208	3	625	18	474.1
29.82278	48.03278	2.7	5.0	225	3	675	27	554.7
29.82194	48.03250	3.9	5.0	325	3	975	41	332.2
29.90031	48.04586	2.7	5.0	225	3	675	16	349.4
29.89947	48.04592	5.4	5.0	450	3	1,350	0	0.0
29.90528	48.04214	3.3	5.0	275	3	825	7	15.6
29.95064	48.02136	4.4	5.0	367	3	1,100	3	17.2
29.94933	48.02789	4.4	5.0	367	3	1,100	14	31.7
29.95122	48.01889	6.6	5.0	550	3	1,650	0	0.0
29.88719	48.16861	3.8	5.0	317	3	950	7	311.2
29.88761	48.16894	4.0	5.0	333	3	1,000	6	20.8
29.89114	48.16528	5.5	5.0	458	3	1,375	5	0.3
29.92369	48.14269	4.4	5.0	367	3	1,100	1	0.1
29.92822	48.14575	3.9	5.0	325	3	975	5	29.0
29.93406	48.14003	0.9	5.0	75	3	225	0	0.0
29.96078	48.09019	4.7	5.0	392	3	1,175	9	82.6
29.96417	48.1????	3.0	5.0	250	3	750	0	0.0
29.96206	48.10519	2.5	5.0	208	3	625	14	25.4
29.96567	48.23097	4.3	5.0	358	3	1,075	6	35.5
29.96847	48.20972	5.3	5.0	442	3	1,325	39	251.1
29.96325	48.22094	2.7	5.0	225	3	675	33	113.7
29.77686	48.38303	4.8	5.0	400	3	1,200	0	0.0
29.77847	48.38797	4.7	5.0	392	3	1,175	71	469.3
29.78292	48.39044	5.7	5.0	475	3	1,425	5	0.3
29.68756	48.35181	4.2	5.0	350	3	1,050	86	111.9
29.68831	48.35900	3.7	5.0	308	3	925	4	9.7
29.68381	48.37136	4.6	5.0	383	3	1,150	34	360.6
29.60461	48.26472	4.1	5.0	342	3	1,025	9	0.4
29.60117	48.26311	3.6	5.0	300	3	900	5	0.1
29.59242	48.26681	3.7	5.0	308	3	925	12	100.5
		NA	180.0	NA	NA	35,375	570	4,364
		3.9	NA	328	3	NA	NA	NA

Appendix 1 (continued). Associated Trawl Data from 5-min Tows at 12 Stations Around Boubyan Island in March 2004

Date		Station	Depth Range (m)	Salinity (psu)	T (°C)	Tow Start	
Day	Month					Latitude	Longitude
17	Mar	BUB-01	1	32.1	21.6	29.59469	48.18344
			2			29.59328	48.18481
			4-5			29.59522	48.18222
29	Mar	BUB-02	1	32.2	21.1	29.75089	48.09881
			2			29.75486	48.09897
			4			29.75217	48.09947
17	Mar	BUB-03	1	31.4	16.8	29.82461	48.03319
			1.5-2			29.82458	48.03267
			5-7			29.82322	48.03233
29	Mar	BUB-04	1-2	31.3	16.7	29.89100	48.05111
			3-4			29.88903	48.05203
			5-6			29.89003	48.05050
20	Mar	BUB-05	0.5-1	NR	19.5	29.95089	48.02111
			2-3			29.94956	48.02392
			3-5			29.94994	48.02931
20	Mar	BUB-06	0.7-1	NR	21.0	29.88775	48.15914
			2-2.5			29.88975	48.16139
			8-9			29.89203	48.16528
20	Mar	BUB-07	0.5-1.5	NR	20.0	29.93363	48.13497
			1.7-2.4			29.93644	48.13664
			4-8			29.93606	48.14189
20	Mar	BUB-08	0.5-1.2	NR	21.0	29.96936	48.10456
			2-2.5			29.97186	48.10511
			10-24			29.96781	48.10308
20	Mar	BUB-09	0.6-1.1	NR	22.0	29.96561	48.21369
			1.5-2.5			29.96578	48.21406
			5			29.96900	48.21003
19	Mar	BUB-10	1	36.7	21.8	29.78497	48.37636
			2			29.78372	48.37825
			4			29.78792	48.37250
19	Mar	BUB-11	1	35.3	21.7	29.69386	48.35364
			2			29.68969	48.35611
			4			29.67947	48.37433
19	Mar	BUB-12	1	33.2	21.4	29.60092	48.26069
			2			29.59753	48.25719
			4			29.58869	48.25756
Total				NR	NR		
Average				33.2	20.4		

NR = not recorded

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.59219	48.18575	5.0	5.0	417	3	1,250	13	114.7
29.59603	48.19869	5.5	5.0	458	3	1,375	23	316.0
29.59314	48.16814	5.0	5.0	417	3	1,250	57	359.3
29.75489	48.09872	6.0	5.0	500	3	1,500	4	37.0
29.75158	48.09900	5.0	5.0	417	3	1,250	18	41.4
29.75622	48.09950	6.0	5.0	500	3	1,500	66	106.4
29.82164	48.03425	3.9	5.0	325	3	975	20	168.2
29.82189	48.03369	4.3	5.0	358	3	1,075	71	1,269.5
29.82072	48.03344	4.1	5.0	342	3	1,025	0	0.0
29.89267	48.05114	2.2	5.0	183	3	550	7	169.8
29.89033	48.05100	2.4	5.0	200	3	600	0	0.0
29.89064	48.05075	2.2	5.0	183	3	550	20	182.3
29.94956	48.02478	4.2	5.0	350	3	1,050	26	32.0
29.94950	48.02725	4.1	5.0	342	3	1,025	15	98.0
29.95183	48.03192	4.5	5.0	375	3	1,125	74	329.1
29.88914	48.16211	4.2	5.0	350	3	1,050	1	5.0
29.89075	48.16519	4.9	5.0	408	3	1,225	6	43.0
29.89086	48.16294	3.5	5.0	292	3	875	20	204.0
29.93681	48.13792	3.5	5.0	292	3	875	1	3.0
29.93667	48.13989	4.0	5.0	333	3	1,000	0	0.0
29.93642	48.13878	4.0	5.0	333	3	1,000	24	232.0
29.97183	48.10539	3.5	5.0	292	3	875	38	70.0
29.96781	48.10125	4.6	5.0	383	3	1,150	22	56.0
29.96319	48.10325	4.0	5.0	333	3	1,000	47	6.0
29.96472	48.21511	2.7	5.0	225	3	675	25	413.0
29.96747	48.21100	4.7	5.0	392	3	1,175	48	247.0
29.97108	48.20669	5.1	5.0	425	3	1,275	104	179.0
29.79883	48.37583	4.3	5.0	358	3	1,075	41	123.0
29.78686	48.37906	5.8	5.0	483	3	1,450	98	675.0
29.78531	48.37383	5.4	5.0	450	3	1,350	29	209.0
29.69103	48.35186	4.2	5.0	350	3	1,050	46	214.0
29.68831	48.35381	5.2	5.0	433	3	1,300	82	868.4
29.67642	48.37233	5.6	5.0	467	3	1,400	30	550.1
29.59864	48.25822	5.3	5.0	442	3	1,325	65	146.7
29.59511	48.25400	5.1	5.0	425	3	1,275	181	522.7
29.58706	48.25350	5.4	5.0	450	3	1,350	169	2,454.4
		NR	180.0	NR	NR	39,850	1,491	10,445
		4.4	NR	369	3	NR	NR	NR

11

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
28	Apr	BUB-01	0.5-0.7	31.1	26.9	29.59711	48.18147
			1.5-2			29.59872	48.17981
			4.2-6.5			29.59828	48.17972
24	Apr	BUB-02	1-1.1	31.0	23.0	29.75356	48.09828
			1.9-2.4			29.75739	48.09872
			7-9.2			29.75906	48.09872
24	Apr	BUB-03	1-1.4	30.9	22.7	29.82619	48.03922
			2-2.4			29.82403	48.03942
			5-6			29.82272	48.03325
24	Apr	BUB-04	1	30.7	22.1	29.89578	48.03514
			1.8-2			29.89478	48.03783
			3.1-4			29.89542	48.04169
24	Apr	BUB-05	0.5-1	31.2	22.2	29.95353	48.01733
			2-3.5			29.95514	48.01444
			8-10.6			29.95389	48.01578
21	Apr	BUB-06	0.7-1.4	32.8	23.5	29.88725	48.16108
			1.7-2			29.88778	48.15867
			4-6.4			29.88769	48.15281
21	Apr	BUB-07	1-1.4	31.5	22.0	29.93631	48.13411
			2-2.4			29.93614	48.13436
			4-5.2			29.93619	48.13481
26	Apr	BUB-08	0.9-1	31.9	22.1	29.96514	48.09964
			1.5-2			29.96642	48.09656
			3.9-5			29.96636	48.09958
21	Apr	BUB-09	0.7-1	32.6	23.7	29.96208	48.21181
			1.5-2			29.96692	48.20981
			3.6-4.5			29.97022	48.20556
28	Apr	BUB-10	1-1.1	34.4	24.5	29.78147	48.37897
			2.1-2.3			29.78497	48.38531
			4.1			29.78375	48.39189
28	Apr	BUB-11	1	34.9	24.4	29.69833	48.35700
			2.1			29.68919	48.35981
			3			29.67647	48.36711
28	Apr	BUB-12	1-1.5	34.6	23.9	29.60508	48.26525
			2.1			29.60347	48.26611
			3.2-3.4			29.59378	48.26547
Total				NA	NA		
Average				32.3	23.4		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.59914	48.18000	3.3	5.0	277	3	830	32	212.0
29.60089	48.17828	3.7	5.0	308	3	925	4	56.6
29.59569	48.18181	4.5	5.0	375	3	1,125	178	505.5
29.75611	48.09775	3.3	5.0	275	3	825	4	0.5
29.76011	48.09753	3.9	5.0	325	3	975	11	78.5
29.76058	48.09867	2.4	5.0	200	3	600	11	6.1
29.82842	48.03717	4.2	5.0	350	3	1,050	59	134.0
29.82639	48.03742	3.5	5.0	292	3	875	11	123.7
29.82489	48.03194	3.6	5.0	300	3	900	91	1,113.6
29.89286	48.03650	4.2	5.0	350	3	1,050	1	10.1
29.89719	48.03653	3.9	5.0	325	3	975	12	133.6
29.89250	48.04331	4.9	5.0	408	3	1,225	128	766.9
29.95500	48.01489	3.6	5.0	300	3	900	103	280.3
29.95369	48.01689	3.3	5.0	275	3	825	54	193.3
29.95181	48.01869	4.3	5.0	358	3	1,075	7	39.4
29.88531	48.15811	4.4	5.0	367	3	1,100	17	451.9
29.88644	48.15472	5.0	5.0	417	3	1,250	46	270.8
29.88772	48.14794	6.1	5.0	508	3	1,525	35	838.9
29.93653	48.13636	2.7	5.0	225	3	675	77	356.8
29.93644	48.13617	2.2	5.0	183	3	550	10	2.0
29.93633	48.13636	2.2	5.0	183	3	550	29	234.0
29.96247	48.08386	4.0	5.0	333	3	1,000	62	211.4
29.96378	48.10014	3.6	5.0	300	3	900	29	113.2
29.96378	48.10056	3.8	5.0	317	3	950	28	126.9
29.96386	48.20894	4.6	5.0	383	3	1,150	3	16.5
29.96881	48.20667	4.9	5.0	408	3	1,225	6	1.8
29.97228	48.20147	5.5	5.0	458	3	1,375	96	23.0
29.78481	48.37819	4.5	5.0	375	3	1,125	49	173.5
29.78319	48.38550	3.9	5.0	325	3	975	59	193.8
29.78697	48.39083	4.9	5.0	408	3	1,225	105	163.6
29.69556	48.35550	4.1	5.0	342	3	1,025	213	615.6
29.68650	48.35800	4.0	5.0	333	3	1,000	117	230.7
29.67439	48.36453	4.0	5.0	333	3	1,000	138	1,165.1
29.60686	48.26714	3.5	5.0	292	3	875	50	621.8
29.60117	48.26317	4.8	5.0	400	3	1,200	156	1,234.8
29.59147	49.92872	4.9	5.0	408	3	1,225	54	468.2
		NA	180.0	NA	NA	36,055	2,085	11,168
		4.0	NA	333.8	3	NA	NA	NA

11

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
24	May	BUB-01	1	30.8	26.0	29.59444	48.18417
			2			29.59192	48.18594
			4			29.59469	48.19961
25	May	BUB-02	1	30.7	25.7	29.74992	48.09933
			2			29.73631	48.09908
			4			29.73369	48.09967
25	May	BUB-03	1	30.2	26.0	29.82781	48.03311
			2			29.82731	48.03125
			4			29.82656	48.03147
25	May	BUB-04	1	30.4	26.5	29.89533	48.03925
			2			29.89558	48.04133
			4			29.89669	48.04147
25	May	BUB-05	1	31.4	25.9	29.95097	48.02081
			No Tow	-	-	-	-
			4			29.94936	48.02411
25	May	BUB-06	1	31.3	28.5	29.88553	48.15833
			2			29.88756	48.15567
			7-9			29.88806	48.15064
25	May	BUB-07	1	30.5	27.0	29.93681	48.13803
			2			29.93669	48.13758
			5-8			29.93653	48.13817
25	May	BUB-08	1	30.2	26.8	29.96522	48.09975
			2			29.96533	48.09989
			5			29.96222	48.10133
25	May	BUB-09	0.5-1	31.5	28.0	29.96550	48.21142
			2			29.96772	48.20956
			4			29.97100	48.20469
24	May	BUB-10	1	34.4	25.5	29.77847	48.37736
			2			29.77611	48.37978
			4			29.77364	48.39200
24	May	BUB-11	1	35.0	24.0	29.69600	48.37078
			2			29.69178	48.37081
			4			29.68467	48.36908
24	May	BUB-12	1	35.8	24.0	29.60417	48.26411
			2			29.60083	48.26056
			5			29.58831	48.25167
Total				NA	NA		
Average				29.4	24.1		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m^2)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.59158	48.18633	4.6	5.0	383	3	1,150	71	375
29.59303	48.18511	2.4	5.0	200	3	600	79	115
29.59153	48.18614	6.1	5.0	508	3	1,525	636	2,692
29.75314	48.09897	4.6	5.0	383	3	1,150	22	117
29.73422	48.09919	3.0	5.0	250	3	750	11	30
29.73144	48.09944	3.1	5.0	258	3	775	54	366
29.83014	48.03500	4.0	5.0	333	3	1,000	19	37
29.82542	48.03228	4.5	5.0	375	3	1,125	344	1,133
29.82969	48.02981	5.4	5.0	450	3	1,350	129	880
29.89564	48.03697	3.6	5.0	300	3	900	3	16
29.89719	48.04058	2.8	5.0	233	3	700	9	31
29.89808	48.04078	2.8	5.0	233	3	700	260	686
29.94978	48.02350	4.3	5.0	358	3	1,075	120	289
-	-	-	0.0	-	-	0	0	0
29.94917	48.02775	4.5	5.0	375	3	1,125	261	172
29.88678	48.16078	3.5	5.0	292	3	875	33	764
29.88683	48.15239	4.3	5.0	358	3	1,075	23	23
29.88789	48.14689	4.9	5.0	408	3	1,225	65	59
29.93678	48.14081	3.2	5.0	267	3	800	121	493
29.93661	48.14047	3.5	5.0	292	3	875	270	854
29.93628	48.14067	3.2	5.0	267	3	800	130	108
29.96700	48.09894	2.7	5.0	225	3	675	3	20
29.96253	48.10069	3.7	5.0	308	3	925	24	147
29.96419	48.10061	2.6	5.0	217	3	650	40	77
29.96683	48.20894	3.6	5.0	300	3	900	39	77
29.96928	48.20600	4.7	5.0	392	3	1,175	438	1,254
29.97331	48.20469	5.4	5.0	450	3	1,350	108	99
29.77575	48.37706	3.7	5.0	308	3	925	123	584
29.77408	48.38081	3.3	5.0	275	3	825	59	3,145
29.77217	48.39408	3.4	5.0	283	3	850	194	936
29.69358	48.36922	4.3	5.0	358	3	1,075	241	1,286
29.68919	48.36958	4.3	5.0	358	3	1,075	45	272
29.68197	48.36975	3.9	5.0	325	3	975	69	391
29.60222	48.26203	3.7	5.0	308	3	925	76	528
29.59825	48.25769	5.0	5.0	417	3	1,250	148	688
29.58831	48.24847	4.9	5.0	408	3	1,225	116	966
		NA	175.0	NA	NA	34,375	4,383	19,711
		3.8	NA	318.3	3	NA	NA	NA

11

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
28	Jun	BUB-01	0.7-1	32.1	27.1	29.58892	48.19072
			2			29.58728	48.19247
			3-4			29.58647	48.19325
28	Jun	BUB-02	1	32.3	27.6	29.75339	48.09886
			2			29.75400	48.09908
			4			29.75314	48.09944
28	Jun	BUB-03	1.1	32.3	27.5	29.82900	48.03086
			2			29.82864	48.03086
			4			29.82886	48.02997
28	Jun	BUB-04	1	32.3	28.0	29.89814	48.04039
			2			29.89400	48.04261
			4-5			29.89481	48.04256
28	Jun	BUB-05	1	30.1	27.7	29.94428	48.02539
			2			29.94536	48.02619
			4-6			29.94419	48.02650
29	Jun	BUB-06	0.7-1	33.4	28.9	29.88769	48.15564
			2-3			29.88806	48.15531
			3-4			29.88889	48.15819
29	Jun	BUB-07	1	32.8	28.1	29.93650	48.13700
			2			29.93631	48.13656
			4-6			29.93603	48.13586
29	Jun	BUB-08	1	32.9	28.2	29.96658	48.09958
			2-3			29.96683	48.09961
			4			29.80025	48.10017
27	Jun	BUB-09	1	34.0	27.1	*	*
			2			*	*
			4			*	*
27	Jun	BUB-10	1	37.3	27.2	*	*
			2			*	*
			4			*	*
27	Jun	BUB-11	1	37.9	27.1	29.68772	48.35775
			2			29.67353	48.35794
			4			29.65253	48.38117
27	Jun	BUB-12	1	35.5	27.2	29.60347	48.26539
			2			29.59578	48.26533
			4			29.58136	48.27511
Total				NA	NA		
Average				33.6	27.6		

*Original data sheets lost at sea; NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.58931	48.19022	1.3	4.7	102	3	306	24	4,606.3
29.58789	48.19192	2.1	5.0	175	3	525	395	709.1
29.58686	48.19239	1.8	5.0	150	3	450	420	650.3
29.75042	48.09919	4.2	5.0	350	3	1,050	123	141.8
29.75058	48.09928	4.7	5.0	392	3	1,175	303	361.3
29.74994	45.09978	4.4	5.0	367	3	1,100	342	1,060.5
29.82639	48.03206	3.8	5.0	317	3	950	16	227.7
29.82533	48.03181	4.6	5.0	383	3	1,150	25	625.8
29.82606	48.03111	3.9	5.0	325	3	975	73	1,051.0
29.89536	48.04181	3.9	5.0	325	3	975	786	1,027.4
29.89128	48.04439	4.2	5.0	350	3	1,050	578	1,354.2
29.89597	48.04183	2.3	5.0	192	3	575	226	835.3
29.94197	48.02453	3.3	5.0	275	3	825	159	629.7
29.94303	48.02517	3.5	5.0	292	3	875	135	236.8
29.94186	48.02556	3.4	5.0	283	3	850	500	1,089.5
29.88869	48.15856	3.9	5.0	325	3	975	187	211.8
29.88772	48.15211	3.9	5.0	325	3	975	275	909.6
29.88811	48.15417	4.2	5.0	350	3	1,050	679	1,341.0
29.93653	48.13961	3.0	5.0	250	3	750	245	2,030.1
29.93644	48.13939	3.4	5.0	283	3	850	58	208.0
29.93631	48.13869	3.4	5.0	283	3	850	33	83.0
29.96392	48.10050	3.9	5.0	325	3	975	179	500.5
29.96400	48.10067	4.3	5.0	358	3	1,075	114	407.9
29.96364	48.10142	4.4	5.0	367	3	1,100	72	128.4
*	*	4.8	5.0	400	3	1,200	4,246	6,151.4
*	*	4.8	5.0	400	3	1,200	837	1,302.3
*	*	4.8	5.0	400	3	1,200	626	805.2
*	*	4.0	5.0	333	3	1,000	1,958	3,671.4
*	*	4.5	5.0	375	3	1,125	47	371.6
*	*	4.0	5.0	333	3	1,000	111	1,102.1
29.68486	48.35678	3.9	5.0	325	3	975	1,290	4,578.3
29.67586	48.35833	4.5	5.0	375	3	1,125	563	4,808.8
29.64992	48.38117	3.6	5.0	300	3	900	90	1,022.4
29.60144	48.26347	3.6	5.0	300	3	900	230	956.9
29.59386	48.26300	3.9	5.0	325	3	975	331	2,697.9
29.57928	48.27550	3.3	5.0	275	3	825	261	1,168.0
		NA	179.7	NA	NA	33,856	16,537	49,063
		3.8	NA	313.5	3	NA	NA	NA

Date		Station	Depth Range (m)	Salinity (psu)	T (°C)	Tow Start	
Day	Month					Latitude	Longitude
13	July	BUB-01	1	33.7	31.6	29.59683	48.18153
			2			29.59708	48.18117
			3.7-4.2			29.59792	48.17994
13	July	BUB-02	1	33.9	31.8	29.75086	48.09889
			2			29.75453	48.09897
			4			29.75119	48.09939
13	July	BUB-03	1	34.0	32.0	29.82728	48.03114
			2			29.83031	48.02981
			4			29.82681	48.03039
13	July	BUB-04	1	33.7	34.0	29.89797	48.04053
			2			29.89564	48.04172
			4			29.89706	48.04136
13	July	BUB-05	1	29.6	30.9	29.94625	48.02622
			2			29.94325	48.02547
			4			29.93958	48.02425
14	July	BUB-06	1	34.5	30.8	29.88692	48.15442
			2			29.88764	48.15417
			4			29.88775	48.15208
14	July	BUB-07	1	34.1	30.4	29.93644	48.13608
			2			29.93664	48.13742
			4			29.93614	48.13411
14	July	BUB-08	1	34.2	30.7	29.96494	48.09119
			2			29.96706	48.09397
			4			29.96681	48.09164
12	July	BUB-09	1	34.9	30.7	29.97047	48.20400
			2			29.97219	48.20200
			4			29.97186	48.20469
12	July	BUB-10	1	39.3	34.2	29.78892	48.38283
			2			29.79189	48.38619
			4.2-4.5			29.08231	48.39028
13	July	BUB-11	1	36.4	32.6	29.69561	48.35369
			2			29.69069	48.35353
			4			29.67811	48.37439
13	July	BUB-12	1	35.5	32.0	29.60419	48.26433
			2			29.60233	48.26286
			4			29.58339	48.28106
Total				NA	NA		
Average				34.5	31.8		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.59903	48.17975	3.6	5.0	300	3	900	69	237.0
29.59892	48.17933	3.4	5.0	283	3	850	57	206.2
29.59475	48.18294	6.1	5.0	508	3	1,525	526	2,085.0
29.75439	48.09892	4.8	5.0	400	3	1,200	30	95.0
29.75100	48.09917	4.8	5.0	400	3	1,200	139	196.1
29.75403	48.09953	3.8	5.0	317	3	950	435	2,124.7
29.83033	48.03031	4.7	5.0	392	3	1,175	36	555.8
29.82781	48.03069	3.9	5.0	325	3	975	48	828.1
29.82992	48.02903	5.0	5.0	417	3	1,250	71	1,074.3
29.89544	48.04178	3.6	5.0	300	3	900	175	414.6
29.89792	48.04067	3.3	5.0	275	3	825	52	397.1
29.89464	48.04264	3.6	5.0	300	3	900	104	1,512.6
29.94325	48.02492	4.5	5.0	375	3	1,125	890	1,157.2
29.94008	48.02414	4.8	5.0	400	3	1,200	53	498.0
29.93647	48.02342	4.5	5.0	375	3	1,125	112	635.1
29.88692	48.15781	4.7	5.0	392	3	1,175	68	189.9
29.88703	48.15211	4.7	5.0	392	3	1,175	156	1,901.7
29.88764	48.15500	3.9	5.0	325	3	975	2,892	6,707.6
29.93689	48.13883	3.2	5.0	267	3	800	44	89.5
29.93639	48.13325	4.9	5.0	408	3	1,225	59	193.7
29.93617	48.13583	2.1	5.0	175	3	525	60	428.8
29.96658	48.09411	3.9	5.0	325	3	975	15	23.3
29.96608	48.09225	2.6	5.0	217	3	650	14	24.2
29.96861	48.09556	5.2	5.0	433	3	1,300	207	419.6
29.97167	48.20117	3.6	5.0	300	3	900	639	577.6
29.97106	48.20425	3.1	5.0	258	3	775	171	217.9
29.97344	48.20183	3.9	5.0	325	3	975	357	542.7
29.78786	48.38214	2.7	5.0	225	3	675	633	1,080.9
29.79525	48.38467	4.8	5.0	400	3	1,200	544	1,130.9
29.80594	48.38956	4.8	5.0	400	3	1,200	697	1,769.6
29.69542	48.35194	4.4	5.0	367	3	1,100	298	1,554.4
29.68783	48.35133	4.7	5.0	392	3	1,175	1,074	1,782.5
29.67481	48.37392	4.8	5.0	400	3	1,200	537	1,613.7
29.60208	48.26197	4.1	5.0	342	3	1,025	98	768.4
29.60058	48.26067	3.6	5.0	300	3	900	3,872	6,954.9
29.58192	48.27914	3.4	5.0	283	3	850	298	4,349.6
		NA	180.0	NA	NA	36,875	15,530	44,338
		4.1	NA	341.4	3	NA	NA	NA

Date		Station	Depth Range (m)	Salinity (psu)	T (°C)	Tow Start	
Day	Month					Latitude	Longitude
21	Aug	BUB-01	1	36.2	27.1	29.59731	48.18111
			2			29.60283	48.17700
			4-5			29.60133	48.17758
22	Aug	BUB-02	1	36.1	27.4	29.75111	48.09889
			2			29.75700	48.09886
			4			29.75583	48.09914
22	Aug	BUB-03	1	36.1	27.6	29.83153	48.03017
			2			29.82775	48.03114
			4			29.82944	48.03006
23	Aug	BUB-04	1	36.2	31.2	29.89294	48.04308
			2			29.89289	48.04336
			4			29.88953	48.04586
22	Aug	BUB-05	1	35.4	27.6	29.94594	48.02592
			2			29.94217	48.02478
			4			29.94331	48.02611
23	Aug	BUB-06	1	37.6	28.8	29.88814	48.15547
			2			29.88808	48.15403
			4			29.88950	48.15869
23	Aug	BUB-07	1	37.0	27.6	29.93656	48.13894
			2			29.93533	48.14392
			4-5			29.91678	48.14650
22	Aug	BUB-08	1	36.7	27.5	29.96842	48.09889
			2			29.96439	48.10039
			4-5			29.96153	48.10228
22	Aug	BUB-09	1	36.7	28.3	29.96500	48.21525
			2			29.96647	48.21294
			4			29.96933	48.20933
21	Aug	BUB-10	1	39.5	27.3	29.77775	48.38431
			2			29.77894	48.38906
			4			29.78075	48.39833
21	Aug	BUB-11	1	39.7	25.0	29.69022	48.35717
			2			29.69925	48.35914
			3.2			29.66394	48.37597
21	Aug	BUB-12	1	37.1	26.1	29.60278	48.26286
			2			29.59692	48.25997
			3			29.57867	48.25539
Total				NA	NA		
Average				37.0	27.6		

NA = not applicable

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	**Longitude**							
29.59883	48.17986	2.1	5.0	175	3	525	52	175.1
29.60069	48.17842	3.6	5.0	300	3	900	124	340.6
29.60458	48.17539	5.4	5.0	450	3	1,350	141	1,449.0
29.75500	48.09886	5.3	5.0	442	3	1,325	504	1,133.7
29.75472	48.09897	3.3	5.0	275	3	825	195	598.5
29.75422	48.09906	2.5	5.0	208	3	625	31	412.3
29.83050	48.03381	4.6	5.0	383	3	1,150	32	57.7
29.83058	48.03008	4.8	5.0	400	3	1,200	484	1,719.3
29.82678	48.03078	3.9	5.0	325	3	975	261	1,054.3
29.89497	48.04181	3.1	5.0	258	3	775	52	250.9
29.88944	48.04578	5.6	5.0	467	3	1,400	141	188.3
29.89172	48.04400	4.0	5.0	333	3	1,000	505	1,208.2
29.94250	48.02458	5.2	5.0	433	3	1,300	234	493.2
29.94481	48.02589	3.9	5.0	325	3	975	66	3,425.1
29.93947	48.02408	5.7	5.0	475	3	1,425	149	1,874.9
29.88769	48.15239	3.6	5.0	300	3	900	477	2,690.8
29.88889	48.15806	4.9	5.0	408	3	1,225	214	1,442.7
29.89078	48.16297	5.3	5.0	442	3	1,325	90	519.5
29.93581	48.14267	4.4	5.0	367	3	1,100	109	674.2
29.93311	48.14689	4.7	5.0	392	3	1,175	40	12,285.0
29.93022	48.14800	4.5	5.0	375	3	1,125	1,816	9,263.0
29.96525	48.10008	4.6	5.0	383	3	1,150	114	366.9
29.96114	48.10225	5.0	5.0	417	3	1,250	22	138.2
29.96428	48.10117	4.0	5.0	333	3	1,000	794	1,531.6
29.96650	48.21258	3.8	5.0	317	3	950	76	295.1
29.96831	48.20981	4.6	5.0	383	3	1,150	148	387.9
29.97114	48.20589	4.7	5.0	392	3	1,175	283	413.3
29.77847	48.38636	3.3	5.0	275	3	825	260	629.5
29.77664	48.39000	3.7	5.0	308	3	925	439	729.9
29.77936	48.40069	3.4	5.0	283	3	850	132	474.0
29.68806	48.35536	3.9	5.0	325	3	975	92	404.9
29.67972	48.35908	4.0	5.0	333	3	1,000	239	1,018.3
29.66133	48.37669	3.7	5.0	308	3	925	215	1,198.4
29.60003	48.25967	4.8	5.0	400	3	1,200	322	927.6
29.59403	48.25619	6.0	5.0	500	3	1,500	230	945.7
29.57728	48.25731	3.3	5.0	275	3	825	243	851.8
		NA	180.0	NA	NA	38,300	9,326	51,569
		4.3	NA	354.6	3	NA	NA	NA

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Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
26	Sep	BUB-01	1	37.7	27.7	29.60264	48.17764
			2			29.60492	48.17622
			4-4.5			29.60186	48.17719
26	Sep	BUB-02	1	37.6	27.2	29.75142	48.09828
			1.5-2			29.75367	48.09867
			4-5			29.74981	48.09969
26	Sep	BUB-03	1	37.3	27.7	29.83064	48.03506
			2			29.82808	48.03472
			4-5			29.82714	48.03072
26	Sep	BUB-04	1	37.3	28.0	29.89906	48.03839
			2			29.89822	48.03972
			4-6			29.89731	48.04108
29	Sep	BUB-05	1	37.5	28.2	29.94392	48.02242
			2			29.94750	48.02289
			4			29.94878	48.02031
29	Sep	BUB-06	1	38.1	27.6	29.88681	48.15619
			2			29.88769	48.15439
			4			29.88919	48.15917
29	Sep	BUB-07	1	37.8	27.6	29.93689	48.13881
			2			29.93642	48.14192
			4			29.93503	48.14481
29	Sep	BUB-08	1	37.9	27.8	29.96314	48.10031
			2			29.96339	48.10031
			4			29.96233	48.10131
29	Sep	BUB-09	1	38.6	29.2	29.95778	48.20825
			2			29.95189	48.20728
			4			29.96806	48.21039
28	Sep	BUB-10	1	39.4	29.1	29.77942	48.37408
			2			29.78233	48.37458
			4			29.78075	48.38872
28	Sep	BUB-11	1	NR	29.2	29.69408	48.35253
			2			29.69589	48.35372
			4			29.68806	48.36583
28	Sep	BUB-12	1	37.6	28.6	29.60239	48.26194
			2			29.60300	48.26306
			4			29.59239	48.26500
Total				NA	NA		
Average				37.9	28.2		

NR = not recorded, NA = not applicable

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.60514	48.17606	3.9	5.0	325	3	975	38	79.9
29.60239	48.17767	3.7	5.0	308	3	925	23	97.7
29.60464	48.17547	4.4	5.0	367	3	1,100	1,177	5,766.3
29.75381	48.09825	3.4	5.0	283	3	850	22	850.8
29.75039	48.09892	4.4	5.0	367	3	1,100	31	117.9
29.75194	48.09892	3.2	5.0	267	3	800	50	310.0
29.82811	48.03586	3.6	5.0	300	3	900	0	0.0
29.82819	48.03142	3.9	5.0	325	3	975	3	182.3
29.82453	48.03219	4.2	5.0	350	3	1,050	394	2,376.2
29.89703	48.03819	3.0	5.0	250	3	750	16	93.4
29.89675	48.04094	3.2	5.0	267	3	800	782	6,064.0
29.89606	48.04178	2.5	5.0	208	3	625	355	1,585.3
29.94592	48.01967	4.3	5.0	358	3	1,075	50	159.8
29.94897	48.94897	4.3	5.0	358	3	1,075	387	1,023.9
29.94792	48.02286	3.5	5.0	292	3	875	425	1,024.2
29.88619	48.15350	3.2	5.0	267	3	800	0	0.0
29.88833	48.15822	4.6	5.0	383	3	1,150	18	173.3
29.89044	48.16347	5.7	5.0	475	3	1,425	471	2,871.5
29.93639	48.14169	3.2	5.0	267	3	800	73	280.0
29.93497	48.14528	4.2	5.0	350	3	1,050	580	1,351.4
29.93606	48.14167	4.1	5.0	342	3	1,025	676	1,606.2
29.96603	48.09936	3.9	5.0	325	3	975	890	3,101.6
29.96106	48.10156	3.4	5.0	283	3	850	1,104	2,867.7
29.96469	48.10017	3.5	5.0	292	3	875	134	289.6
29.96681	48.20511	3.9	5.0	325	3	975	52	72.3
29.96683	48.20914	4.1	5.0	342	3	1,025	389	765.0
29.96653	48.21333	4.6	5.0	383	3	1,150	223	654.2
29.78256	48.37375	4.5	5.0	375	3	1,125	24	195.6
29.77875	48.37447	4.8	5.0	400	3	1,200	483	955.5
29.77733	48.39069	5.1	5.0	425	3	1,275	166	650.6
29.69664	48.35425	3.8	5.0	317	3	950	43	155.6
29.69306	48.35194	4.6	5.0	383	3	1,150	16	76.2
29.68600	48.36239	4.9	5.0	408	3	1,225	17	4,553.3
29.60408	48.26400	3.2	5.0	267	3	800	62	291.1
29.60019	48.25981	5.4	5.0	450	3	1,350	90	340.0
29.58986	48.26108	5.8	5.0	483	3	1,450	146	1,898.9
		NA	180.0	NA	NA	36,500	9,410	42,881
		4.1	NA	338.0	3	NA	NA	NA

Appendix 1 (continued). Associated Trawl Data from 5-min Tows at 12 Stations Around Boubyan Island in October 2004

Date		Station	Depth Range (m)	Salinity (psu)	T (°C)	Tow Start	
Day	Month					Latitude	Longitude
19	Oct	BUB-01	1-1.5	36.9	27.8	29.76500	48.77667
			1.7-2			29.73167	48.79167
			3.5-4			29.78667	48.74000
19	Oct	BUB-02	1-1.5	36.8	27.7	29.85500	49.03667
			2-2.5			29.75500	49.05500
			3-4			29.99333	49.06500
19	Oct	BUB-03	0.9-1.2	37.0	27.6	30.37000	48.94333
			1.6-2			30.48167	48.89333
			3.5-4.5			30.35667	48.90500
19	Oct	BUB-04	1-1.5	36.9	27.4	30.65167	48.50167
			2-2.5			30.54833	48.57167
			4-5			30.21167	48.82500
18	Oct	BUB-05	0.8-1	36.8	28.4	30.77333	48.29000
			2			30.70667	48.54500
			2-8			30.15500	48.39833
19	Oct	BUB-06	1-1.1	37.5	27.3	30.12667	48.58167
			1.5-2			30.10667	48.41500
			4			30.15667	48.31833
19	Oct	BUB-07	1-1.2	37.1	27.6	30.12667	48.58500
			1.5-2			30.11833	48.30833
			3-3.5			29.97000	48.90667
18	Oct	BUB-08	1	37.1	28.3	30.76333	48.12000
			1.5-2			30.79833	48.11000
			4			30.69167	48.18167
18	Oct	BUB-09	1	37.5	29.0	30.57167	48.52167
			2			30.75500	48.25000
			3			30.04333	48.83833
18	Oct	BUB-10	1-1.1	39.8	28.4	30.61167	49.27667
			2			30.02167	48.47500
			4			30.74167	48.93667
18	Oct	BUB-11	1	40.3	28.9	30.12000	49.06833
			2			30.02500	48.86000
			3			30.19167	49.12833
19	Oct	BUB-12	0.9-1	37.3	27.8	30.58167	48.59000
			1.7-2			29.70333	48.63667
			2.5-3.9			30.31500	48.88833
Total				NA	NA		
Average				37.6	28.0		

NA = not applicable

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.60833	48.87333	4.2	5.0	350	3	1,050	71	279.5
30.59500	48.87833	3.5	5.0	292	3	875	29	443.9
29.66333	48.81500	3.1	5.0	258	3	775	1,061	2,583.5
30.66833	49.05667	2.4	5.0	200	3	600	62	383.6
29.98333	49.03000	5.4	5.0	450	3	1,350	52	124.2
29.85333	49.07500	3.2	5.0	267	3	800	40	334.5
30.43000	48.92500	3.0	5.0	250	3	750	33	898.8
30.70500	48.99167	5.6	5.0	467	3	1,400	269	1,723.9
30.13333	48.04333	5.6	5.0	467	3	1,400	177	7,160.2
30.46333	48.60167	4.8	5.0	400	3	1,200	925	3,243.0
30.35500	48.68833	4.8	5.0	400	3	1,200	552	3,440.0
30.04500	49.00167	5.0	5.0	417	3	1,250	426	2,123.2
30.66500	48.34667	3.0	5.0	250	3	750	22	238.6
30.51167	48.45833	4.6	5.0	383	3	1,150	375	1,256.4
30.14833	48.40000	4.0	5.0	333	3	1,000	64	607.0
29.96667	48.53667	3.8	5.0	317	3	950	17	425.4
30.09000	48.28000	3.0	5.0	250	3	750	18	81.6
30.19167	48.54333	4.6	5.0	383	3	1,150	3,463	15,996.9
30.04833	48.82000	5.1	5.0	425	3	1,275	471	1,516.4
30.13500	48.50667	3.8	5.0	317	3	950	1,522	3,793.7
30.74000	49.01833	5.3	5.0	442	3	1,325	322	1,070.2
30.90500	49.07167	3.4	5.0	283	3	850	638	1,184.8
30.62667	48.19000	4.2	5.0	350	3	1,050	17	44.7
30.81667	48.13333	3.1	5.0	258	3	775	159	298.9
30.69500	48.30500	5.3	5.0	442	3	1,325	1,603	3,058.8
30.89833	48.99333	5.7	5.0	475	3	1,425	710	1,289.8
30.20667	48.57000	6.7	5.0	558	3	1,675	77	245.2
29.83000	49.25667	4.7	5.0	392	3	1,175	65	445.6
30.28167	48.46833	6.0	5.0	500	3	1,500	365	2,315.1
30.60833	48.89500	3.6	5.0	300	3	900	153	1,604.3
30.33833	49.16667	5.2	5.0	433	3	1,300	106	642.5
30.05333	48.60833	4.9	5.0	408	3	1,225	58	963.4
30.15167	48.40000	3.8	5.0	317	3	950	77	1,063.6
30.44833	48.73167	4.0	5.0	333	3	1,000	94	397.1
30.49667	48.72167	4.6	5.0	383	3	1,150	109	605.3
30.13500	48.96833	4.5	5.0	375	3	1,125	93	591.6
		NA	180.0	NA	3	39,375	14,295	62,475
		4.4	NA	365	NA	NA	NA	NA

11

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
5	Dec	BUB-01	1	35.6	14.2	29.89333	48.71500
			2			29.75167	48.79333
			3.5-4			29.65000	48.80833
5	Dec	BUB-02	1	35.2	14.1	29.76500	49.04333
			2			29.85500	49.04667
			3-4			30.22167	49.06667
5	Dec	BUB-03	1	34.9	14.5	30.45833	48.88333
			2			30.40000	48.91000
			4-5			30.51333	48.81500
5	Dec	BUB-04	1	35.2	14.0	30.42667	48.65000
			2			30.47500	48.62000
			4-5			30.56333	48.59667
5	Dec	BUB-05	1	34.9	14.7	30.60167	48.55333
			2			30.46167	48.50333
			4			30.58667	48.62167
6	Dec	BUB-06	1	36.1	12.1	30.23167	48.71000
			2			30.22500	48.62167
			4			30.32000	48.84000
6	Dec	BUB-07	1	35.7	12.9	30.13000	48.47333
			2			30.09167	48.64833
			4-5			30.02667	48.76833
6	Dec	BUB-08	1	35.2	14.5	30.61333	48.22333
			2			30.71000	48.16333
			4-5			30.72167	48.20667
6	Dec	BUB-09	1	32.6	15.9	30.16667	48.51333
			2			30.27333	48.40500
			4			30.23333	48.55333
7	Dec	BUB-10	1	38.0	13.9	30.04667	49.26167
			2			30.20667	48.53833
			4			30.36833	48.85000
4	Dec	BUB-11	1	40.3	11.8	29.83333	48.79833
			2			29.82500	48.61833
			3-4			30.33500	48.76000
4	Dec	BUB-12	1	36.9	14.2	30.50000	48.66167
			2			29.67167	49.16833
			3-4			29.81667	48.70167
Total				NA	NA		
Average				35.9	13.9		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m^2)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	**Longitude**							
29.76167	48.78833	3.3	5.0	275	3	825	7	76.7
29.62667	48.86000	3.2	5.0	267	3	800	5	7.9
30.55167	48.90333	3.0	5.0	250	3	750	268	1,251.6
29.92167	49.03000	3.6	5.0	300	3	900	47	48.7
30.05833	49.03667	4.6	5.0	383	3	1,150	23	5.4
30.07500	49.07000	3.2	5.0	267	3	800	64	274.7
30.33333	48.93833	3.1	5.0	258	3	775	93	8.1
30.57333	48.83167	4.5	5.0	375	3	1,125	42	5.4
30.40167	48.83000	2.6	5.0	217	3	650	10	10.3
30.53167	48.58500	2.9	5.0	242	3	725	3	4.6
30.58333	48.56667	3.0	5.0	250	3	750	2	2.8
30.68500	48.53167	3.2	5.0	267	3	800	10	65.6
30.43167	48.48833	4.0	5.0	333	3	1,000	12	3.3
30.62000	48.58833	3.9	5.0	325	3	975	1	0.1
30.44667	48.56833	3.5	5.0	292	3	875	2	10.8
30.18833	48.56000	3.1	5.0	258	3	775	6	0.6
30.27167	48.79667	3.7	5.0	308	3	925	3	2.0
30.34500	49.02167	3.5	5.0	292	3	875	0	0.0
30.1Marine life 0500	48.62667	2.7	5.0	225	3	675	1	0.1
30.03333	48.80167	3.5	5.0	292	3	875	3	0.3
30.09833	48.63167	3.3	5.0	275	3	825	1	3.2
30.72167	48.15833	2.9	5.0	242	3	725	1	29.3
30.82167	48.13667	2.7	5.0	225	3	675	0	0.0
30.53667	48.31667	4.6	5.0	383	3	1,150	5	11.4
30.24000	48.35500	3.6	5.0	300	3	900	5	23.4
30.19000	48.52333	3.2	5.0	267	3	800	1	7.6
30.13667	48.67167	3.2	5.0	267	3	800	6	0.6
30.18667	49.28167	3.7	5.0	308	3	925	6	9.8
29.98500	48.52167	3.4	5.0	283	3	850	1	4.5
30.21167	48.82500	3.7	5.0	308	3	925	22	39.0
30.00500	48.90500	4.7	5.0	392	3	1,175	2	33.0
30.65000	48.63667	3.8	5.0	317	3	950	0	0.0
30.19167	48.77500	3.3	5.0	275	3	825	3	10.2
30.38500	48.47667	4.7	5.0	392	3	1,175	99	199.9
30.51667	49.01667	4.7	5.0	392	3	1,175	149	395.9
29.61833	48.56333	4.9	5.0	408	3	1,225	32	12.3
		NA	180.0	NA	NA	32,125	935	2,559
		3.6	NA	297.5	3	NA	NA	NA

Date		Station	Depth Range (m)	Salinity (psu)	T (ºC)	Tow Start	
Day	Month					Latitude	Longitude
5	Jan	BUB-01	1	33.8	13.0	29.88500	48.71833
			2			29.76833	48.78500
			4			29.65500	48.81333
9	Jan	BUB-02	1	33.5	12.9	29.80333	49.00500
			2			29.92500	49.01167
			4-5			29.77167	49.06500
9	Jan	BUB-03	1	33.2	12.6	30.77167	48.13167
			2			30.56000	48.13167
			4			30.43500	48.89333
9	Jan	BUB-04	1	33.3	12.7	30.50000	48.39000
			2			30.62833	48.49500
			4			30.74167	48.47667
9	Jan	BUB-05	1	33.4	12.6	30.38167	48.48500
			2			30.41833	48.44167
			4-6			30.47333	48.52000
11	Jan	BUB-06	1	33.6	12.6	30.18833	48.81000
			2			30.29000	48.89500
			7-8			30.30333	48.76167
11	Jan	BUB-07	1	33.2	12.6	30.14000	48.54500
			2			30.10833	48.64500
			4-10			30.11500	48.53333
9	Jan	BUB-08	1	34.6	12.6	30.65167	48.17167
			2			30.75500	48.13000
			4			30.64500	48.22000
11	Jan	BUB-09	1	34.8	12.6	30.20333	48.37167
			2			30.31667	49.16000
			4-5			30.33667	48.29000
5	Jan	BUB-10	1	40.1	13.5	30.57833	49.33333
			2			30.75000	48.65000
			4.5			30.45500	48.38667
5	Jan	BUB-11	1	39.3	13.5	30.54000	48.61167
			2			30.21500	49.15667
			4			30.20833	48.74833
5	Jan	BUB-12	1	34.5	13.7	29.73333	48.37833
			2			30.40500	48.54500
			4			30.43833	49.28000
Total				NA	NA		
Average				34.8	12.9		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.76667	48.61333	3.0	5.0	250	3	750	4	0.9
29.65833	48.84667	2.9	5.0	242	3	725	4	8.1
30.53833	48.90667	3.2	5.0	267	3	800	5	8.1
29.96167	49.01333	3.6	5.0	300	3	900	480	35.5
30.73667	49.03000	4.6	5.0	383	3	1,150	782	66.2
29.91167	49.04167	3.4	5.0	283	3	850	119	80.4
30.59333	48.18500	4.1	5.0	342	3	1,025	58	30.3
30.69000	48.08167	3.2	5.0	267	3	800	38	6.5
30.20000	48.99833	5.6	5.0	467	3	1,400	47	58.5
30.60667	48.26833	3.3	5.0	275	3	825	8	7.7
30.51333	48.53167	3.3	5.0	275	3	825	7	46.9
30.86000	48.43000	2.9	5.0	242	3	725	6	4.8
30.42500	48.44000	3.3	5.0	275	3	825	8	9.3
30.53000	48.51333	3.4	5.0	283	3	850	118	15.8
30.26833	48.44167	5.1	5.0	425	3	1,275	60	226.8
30.26500	48.94833	3.5	5.0	292	3	875	6	0.4
30.24500	48.78167	2.9	5.0	242	3	725	1	3.4
30.31000	48.63000	2.6	5.0	217	3	650	12	23.5
30.10000	48.68833	3.2	5.0	267	3	800	1	0.2
30.13833	48.47833	3.5	5.0	292	3	875	2	3.1
30.07833	48.70500	3.5	5.0	292	3	875	59	217.2
30.80667	48.10667	3.8	5.0	317	3	950	5	0.6
30.58667	48.22833	4.4	5.0	367	3	1,100	1	0.1
30.77000	48.14167	3.4	5.0	283	3	850	28	205.3
30.29667	49.15667	4.5	5.0	375	3	1,125	55	191.3
30.25500	48.28167	2.6	5.0	217	3	650	16	34.2
30.49500	49.00500	6.2	5.0	517	3	1,550	25	80.8
30.72500	49.35667	3.6	5.0	300	3	900	22	42.4
30.53167	48.75333	5.1	5.0	425	3	1,275	7	29.4
30.23000	48.45333	5.4	5.0	450	3	1,350	19	149.5
30.52833	48.42333	3.8	5.0	383	3	1,150	10	5.9
30.40500	49.18000	4.4	5.0	367	3	1,100	2	0.1
30.02667	48.66167	4.6	5.0	383	3	1,150	2	2.9
29.66000	49.20333	3.5	5.0	292	3	875	7	31.0
30.29833	48.44000	3.2	5.0	267	3	800	8	38.0
30.37333	49.06000	4.3	5.0	358	3	1,075	0	0.0
		NA	180.0	NA	NA	34,425	2,032	1,665
		3.8	NA	318.8	3	NA	NA	NA

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Date		Station	Depth Range (m)	Salinity (psu)	T (°C)	Tow Start	
Day	Month					Latitude	Longitude
7	Feb	BUB-01	1	32.0	14.0	29.82333	48.77000
			2			29.80167	48.77833
			4			30.46333	48.96500
9	Feb	BUB-02	1	31.0	13.6	29.77167	49.03833
			2			30.07167	49.02667
			4			30.00833	49.05667
9	Feb	BUB-03	1	30.8	13.8	30.56500	48.19833
			2			30.45333	48.17833
			4			30.46167	48.87833
9	Feb	BUB-04	1	30.8	13.5	30.53833	48.53000
			2			30.60000	48.53333
			4			30.56500	48.59833
9	Feb	BUB-05	1	30.7	13.8	30.46667	48.48167
			2			30.44667	48.48667
			4			30.34000	48.48000
8	Feb	BUB-06	1	31.7	14.1	30.12833	48.74667
			2			29.99000	48.54167
			4			30.18333	48.57167
8	Feb	BUB-07	1	31.1	13.9	30.14333	48.52333
			2			30.08667	48.71833
			4			29.97000	48.90667
8	Feb	BUB-08	1	31.0	13.7	30.59167	48.21000
			2			30.64000	48.17833
			4			30.65667	48.20167
8	Feb	BUB-09	1	32.0	13.8	30.69333	48.32333
			2			30.82167	49.11000
			4			30.03167	48.86333
7	Feb	BUB-10	1	37.6	15.0	30.44833	49.03000
			2			30.44167	49.20000
			4			30.10000	48.98667
7	Feb	BUB-11	1	38.1	15.1	30.47833	48.73333
			2			30.37333	48.95333
			4			30.58667	49.29333
7	Feb	BUB-12	1	35	14.6	29.88333	49.15833
			2			29.71667	49.10833
			4			29.77167	48.51667
Total				NA	NA		
Average				32.7	14.1		

NA = not applicable

11

Tow End		GPS Speed (km/h)	Tow Time (min)	Tow Distance (m)	Net Width (m)	Swept Area (m²)	Trawl Catch (no.)	Trawl Catch (g)
Latitude	Longitude							
29.63333	48.88833	4.7	5.0	392	3	1,175	65	406.2
29.60500	48.88667	5.0	5.0	417	3	1,250	56	426.1
30.26500	49.13333	5.4	5.0	450	3	1,350	182	1,045.6
29.93500	49.02500	3.9	5.0	325	3	975	507	39.1
29.91333	49.03000	3.7	5.0	308	3	925	126	13.0
29.85333	49.04500	3.7	5.0	308	3	925	13	62.3
30.40000	48.33167	4.7	5.0	392	3	1,175	94	40.1
30.28500	48.30333	4.9	5.0	408	3	1,225	81	9.8
30.22667	48.96500	5.5	5.0	458	3	1,375	54	106.7
30.61500	48.51167	2.2	5.0	183	3	550	2	49.8
30.69167	48.47833	3.2	5.0	267	3	800	32	210.4
30.34500	48.69500	5.6	5.0	467	3	1,400	784	803.8
30.56833	48.48833	3.0	5.0	250	3	750	11	13.5
30.20500	48.42000	5.7	5.0	475	3	1,425	19	431.4
30.08000	48.41833	6.1	5.0	508	3	1,525	126	793.9
29.97333	48.58833	4.9	5.0	408	3	1,225	2	1.0
30.10667	48.59333	3.6	5.0	300	3	900	0	0.0
30.16167	48.35000	4.7	5.0	392	3	1,175	3	11.1
30.10833	48.67667	3.0	5.0	250	3	750	0	0.0
30.00167	48.89500	4.3	5.0	358	3	1,075	0	0.0
30.82500	48.99833	3.6	5.0	300	3	900	8	17.1
30.72333	48.13167	3.6	5.0	300	3	900	24	25.7
30.83833	48.10500	5.0	5.0	417	3	1,250	14	142.1
30.81667	48.11167	4.2	5.0	350	3	1,050	17	47.8
30.81333	49.14333	4.4	5.0	367	3	1,100	1,517	1,503.0
29.97500	48.91333	5.3	5.0	442	3	1,325	160	417.5
29.97500	48.95833	3.3	5.0	275	3	825	92	224.4
30.58000	49.11667	3.2	5.0	267	3	800	5	43.7
30.20333	49.28000	5.7	5.0	475	3	1,425	3	31.6
29.91000	49.08500	5.0	5.0	417	3	1,250	22	155.1
30.56500	48.86833	3.4	5.0	383	3	1,150	8	60.7
30.18333	48.86333	4.7	5.0	392	3	1,175	136	1,063.4
30.38333	48.39167	4.6	5.0	383	3	1,150	12	107.1
29.78500	49.04167	3.3	5.0	275	3	825	104	574.9
29.65167	48.96500	3.9	5.0	325	3	975	5	44.5
29.60833	48.63167	4.3	5.0	358	3	1,075	25	304.8
		NA	180.0	NA	NA	39,125	4,309	9,227
		4.3	NA	362.3	3	NA	NA	NA

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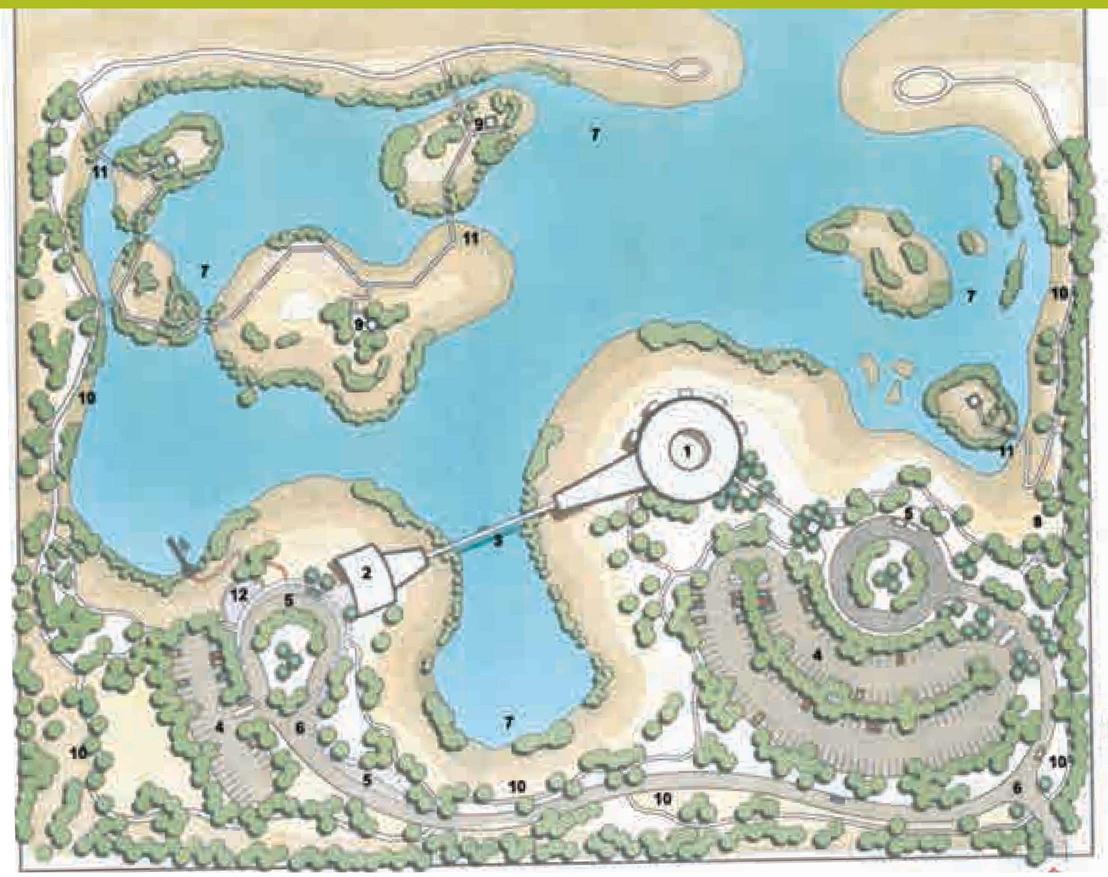
Section 4

Planning for Sustainable Development

Chapter 12: Site Planning Inventory



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Section 4

Chapter 12: Site Planning Inventory

Abstract

The Boubyan Island Environmental Assessment and Master Plan project was successfully executed for the first Kuwaiti island to receive a sustainable development plan driven by a systematic environmental assessment. A number of unique habitats have evolved from the distinct geomorphologic surface features and physiographic settings of Boubyan and Warbah Islands. This study project conducted an assessment of the islands' unique land character with resulting viewsheds identified and key vistas recorded. Due to the island's position, the project conducted an evaluation for potential historic cultural importance. The biological setting of the islands includes a variety of vegetation, wildlife, and marine life and the survey results indicated enormous potential for conservation of Kuwait's natural biodiversity and related ecotourism. The Boubyan Island recreation land use proposal for areas with coastal shorelines was consistent with the recommendations of the National Greenery Plan (NGP) of Kuwait developed by the Kuwait Institute for Scientific Research (KISR) in 1996, while maintaining and supporting conservation in designated protected areas of sensitive or unique habitats. The Third Kuwait Master Plan Review of Kuwait Municipality also indicated a resort and other developments on the island and these were modified after a thorough site planning inventory and ecosystem analysis was executed for this project. The island-wide site analysis coupled with the macro-scale preliminary environmental impact evaluation were prerequisites to compatible land use decisions and a sustainable development master plan for the islands.

The scope of work completed by the Site Planning Inventory project included compilation and reviews of available data, published literature, and maps; procurement coordination for required equipment and facilities to conduct a site inventory field survey; creation and updating of a GIS database; and development, manipulation, and production of over 100 cartographic data theme layer and constraint map images that guided the development of alternative land use plans and the preparation of a master plan by HOK Planning Group, Canada and Gulf Consult (HOK/GC). Additional tasks included in this project were a literature review and assessment of island archaeology potential and concept design plans for an energy-efficient visitor educational nature center. The research role and technical services provided for this project were organized into 12 tasks.

Plate 1. Project official kickoff at KISR, 2003

Plate 2. Design charette for south coast Boubyan resort and campground planning session, KISR and HOK team

Plate 3. Documenting Boubyan projects by interviewing Dr. Samira Omar with CTV producer Laurie Few at KISR GIS Center

Introduction

The Site Planning Inventory project required the supporting environmental studies and planning work, undertaken on behalf of KISR for the Boubyan Island Environmental Assessment and Master Plan consultancy project, documented in this chapter. The project work covered a period from September 2003 to March 2006 (**Plate 1**).

This chapter presents the project contributions in summary for all four master planning activities:

- Compilation of existing data and information
- Data management and GIS mapping
- Preparation of and refinement of alternatives including land use improvement
- Preparation of a master plan

Traditional site planning inventory analysis typically encompasses assessments of existing natural factors and human factors. In this case, the physiologic and biotic disciplines received specific in-depth scientific analysis from individual Boubyan investigative projects carried out by KISR and others under this commission. The Site Planning Inventory project focused on gathering other supplemental planning criteria of interest to the planning process and design decision makers. Island character assessment along with visual quality and analysis aided the planner in making aesthetic judgments about specific areas. Potential noise zones and urban light glare considerations from existing or proposed neighboring development excluded specific uses from identified areas. Development opportunity and constraint maps incorporated these criteria and, when overlaid with the physiological and biota characteristic maps of the islands, provided a tool for rational environmental assessment and master planning process decisions (**Plate 2**). Another function of the Site Planning Inventory project provided a bridge from the valuable raw scientific field data and conclusions to a cartographic and planning summary context for optimum use by the project planners. This involved utilization of planning-oriented GIS overlay maps, graphics interpretation and utilizing design office project management principles to interface scientific findings with planning process needs. The outputs contributed to stewardship for the resources of Kuwait and implementation of sustainable planning principles in the region (**Plate 3**).

The project work included compiling the available existing data and documents, undertaking a detailed inventory and analysis of site planning elements that complement other project biological and physical land assessments (including archaeological potential, access and circulation and viewshed elements) and cartographic input, development, and manipulation. The resulting study information was utilized in the environmental assessment and development of the master plan for the islands.

Background

The physiographic features of Boubyan and Warbah Islands have greatly influenced their current land uses. Boubyan Island's extreme northeast location at the head of the Arabian Gulf has kept it removed from Kuwait's developing population centers. This strategic location has made it vital to Kuwait's security due to its proximity to Iraq's Fao Peninsula and the adjacent Iranian coastline. It has an approximate area of 811 km^2, making it the largest Kuwaiti island and second largest island in all of the Arabian Gulf. Warbah Island, 37 km^2, is much smaller, but is closer to the source of freshwater inflow from the Shatt Al-Arab, which creates unique ecosystems of significant importance to Kuwait. This combination of interesting land formations, flooding characteristics, and restricted access has resulted in relatively low human influence and development on both islands. An unfortunate exception has been the recent military activities from three wars, leaving in its wake unexploded ordnance, bunker construction, and land surface impacts from live-fire exercises and military equipment maneuvers. Significant regional historical and cultural finds have been discovered in southern Iraq, along the Subbiyah coast, and on neighboring Failaka Island. The repaired original bridge connects Boubyan to the mainland but access currently remains under government control. The surface of the island consists of superficial flats with associated drainage channels and intertidal mudflats, creating moist soils for much of the year. While Boubyan is mostly sabkha, the south and southeastern coasts consist of ground high enough for possible commercial ventures. Many interesting and important views are generated, both on the island and in offshore directions.

A biological overview of the islands demonstrates the potential for further unique attributes of the islands. Although some of earlier studies suggested that the islands are a bare land (Ergun, 1969), the recent vegetation map presented by Omar et al. (2000) showed the distribution of *Zygophyllum coccineum* as a dominant species. The surrounding waters provide some of the most interesting and likely productive marine habitats of Kuwait. The birdlife associated with the islands is diverse and well established as a major migration route between Europe and Africa.

Boubyan and Warbah Islands clearly have an enormous potential for conservation of Kuwait's natural biodiversity, public education opportunities, and the promotion of ecotourism. Several proposals and plans in the past have addressed a variety of uses on Boubyan Island including holiday villages, leisure activities, a national nature resource (Municipality of Kuwait, 1997), coastal recreation development (KISR, 1996), an aluminium plant, a fishing port, a national park, aquaculture, and agriculture (Nishikawa, 1969) as well as other commercial uses by government stakeholders. Across Khor Al-Subbiyah from Boubyan, an urban infrastructure was planned for an environmentally responsive new town of 500,000 residents (the Subbiyah New Town Project—Master Plan Update, 2005), increased from the previous studies of 250,000 inhabitants. Both the ecological sensitivity and physical characteristics of the islands offer constraints to many traditional development activities. To integrate the long-term planning of the islands with previous and current influences, the State of Kuwait signed an agreement with an international consulting firm, HOK Planning Group, Canada, and their local Kuwaiti representative Gulf Consult (GC), to conduct an environmental assessment and prepare a master plan for development of the islands.

Documents such as the Third Kuwait Master Plan (Municipality of Kuwait, 1997), the National Greenery Plan (KISR, 1996), the New Town Plan for Subbiyah (Municipality of Kuwait, 1990), and other planning studies were assembled as baseline planning data and reviewed within the context of the proposed land use alternatives process. Concurrent studies on the Boubyan port and Subbiyah New Town were integrated into the project master plan process. Cartographic information related to site inventory, land physiology, and land use planning (such as available reconnaissance scale maps of 1:100,000 or MOD 1:50,000 scale maps) was utilized for baseline mapping activities and manipulated as GIS base maps where applicable, along with appropriate existing or newly purchased remote sensing images. Available aerial mapping, other declassified military maps, and bathymetric maps were also utilized as needed.

The project research elements were undertaken in the context of extracting and identifying the key site analysis elements, such as physical surroundings, land character, man-made activities and influences, viewsheds, and sensitive ecological zones, and relating them to the specific needs of the planning perspective and process. The resulting documents and cartographic tools to accomplish this were developed from the raw scientific database GIS maps into the format of thematic maps and then into constraints and opportunities maps utilized in the environmental assessment and master planning phases of the overall project. The fact that this area of Kuwait has been off-limits for the past 23 years required that extensive environmental field data assessments be carried out and that the information be organized and presented in formats most easily adapted to the project's planning activities and process.

Fig. 1. National Physical Plan for the State of Kuwait (from 3KMPR1, 2003).

Development of Boubyan and Warbah Islands will be of vital importance for Kuwait both from environmental and strategic standpoints. Therefore, this project provided benefits for the people and the State of Kuwait in the following ways:

- The detailed site planning inventory and analysis of the island provided comprehensive information on visual resources of Boubyan Island, which can be used as baseline data for land use planning.
- The outcome of the project can be used by a wide range of organizations to formulate future research needs, to develop a sustainable ecotourism industry, to create ecological resource management plans, and to propose compatible/suitable land uses utilizing the available resources in an efficient and sustainable manner.
- The archaeological and cultural heritage potential of the islands was evaluated.
- The information was compared with earlier data to assess the damage to the island's physical and biological resources so appropriate rehabilitation plans can be developed to conserve natural biodiversity and restore any damaged natural resources of the island.
- The updated information can be used by both the State of Kuwait and investors to support investment and manage risks associated with development projects.
- The project's GIS-based and environmentally responsive planning process can serve as a model for other future projects in Kuwait and the region.

Compilation of Existing Data and Information

Site Planning

A comprehensive investigation was undertaken regarding the existing site planning documents related to Boubyan and Warbah Islands. The following documents were identified, which are pertinent to previously or currently proposed land uses, adjacent mainland developments, land character, accessibility, circulation, archaeology, and historical context. Some of the key master plans of the last 30 years with elements pertaining to Boubyan Island were summarized. Plans specific to Boubyan were covered in more detail.

In the National Physical Plan for the State of Kuwait and Master Plan for the Urban Areas, Boubyan Island was

Fig. 2. Summary analysis of Boubyan Island proposed port sites

designated as having potential for forestry and recreation. The plan identified the lower part of Boubyan as having a forestry potential for a *Tamarix* belt and the upper wetlands as having a potential for development of a mangrove swamp. Additionally, this plan stated that Boubyan Island had a high recreational value area (**Fig. 1**).

The Second Kuwait Master Plan initially did not include the development of a new town in Subbiyah. The following Kuwait Master Plan Review recommended satellite urban centers including Subbiyah New Town. An urban infrastructure is planned for the updated new town of several hundred thousand residents (Municipality of Kuwait, 1997). If the new town project is implemented, it is bound to have an impact on the natural environment as well as future development of Boubyan as a whole. However, as expressed in Issues Report 2KMPR2, the implementation of Subbiyah was likely to prove more difficult than envisioned in terms of timing and the scale of urban development suitable for the planning goal. Master plan reviews, done periodically, have identified parts of Boubyan Island for recreational development, water resource areas, future oil exploration areas, and conservation areas, as well as for resort areas or limited urban growth outside the metropolitan area.

Some selected studies that were assessed in detail and utilized in the Site Planning Inventory analysis are listed in the references at the end of this chapter.

Boubyan Port Study

The Boubyan port study (World Bank and State of Kuwait, 2003) assessed the development feasibility of an international state-of-the art marine port on Boubyan Island. The objective of the study was to make an initial assessment of each of three deep water port sites on Boubyan Island and one site at Umm Qasr. Boubyan was considered as a primary option for developing the new container port. The three alternative sites in Boubyan Island were evaluated as per the subjective and qualitative site evaluation criteria defined in the study.

Ras Al-Gaid (Site 2) was identified as the preferred site location (**Fig. 2**). The volume of traffic identified in Working Paper 3 of the study will require 200 hectares of container terminal facilities. The components will include a wharf/berth area, storage area, gate area and maintenance and repair/auxiliary facility. The proposed concept plan covers an area of approximately 720 hectares.

The preliminary design concept established the basic infrastructure requirements. The infrastructure includes the marine and land side development of the port. Also included are road and train links with Kuwait and Iraq's road and rail network. The proposed concept is based on incremental expansion of the facilities over five phases corresponding to the demand forecast at its base case scenario up to the year 2020.

The site selection conclusions of the study were lacking in addressing detailed environmental impacts, environmental mitigation measures (risk analysis), and ecological assessment studies to substantiate the report's conclusions. (Note: An updated port feasibility study was prepared by Mouchel Parkman in 2004-2005.)

Subbiyah New Town Study

The first phase of the Subbiyah New Town study (Subbiyah Phase I study) was completed in 1985 (Ministry of Planning, 1985). The Phase I study concluded that a population of 100,000 by the year 2000 appeared feasible. Ultimately, the population could be increased to 250,000 by 2005. The second phase of the study (Subbiyah Phase II), completed in 1985, focused on developing physical planning proposals for Subbiyah.

The Subbiyah site, covering 25,000 hectares, is on a peninsula with Kuwait Bay to the south. Urban waterfront development, including a lagoon, is planned for the town center and a linear waterfront park is also planned along the Khor Al-Subbiyah. Thirteen residential districts located between the Zor Ridge and the coastal edge recreation development were planned.

The alternative Subbiyah master plans and waterfront, in addition to the above improvements, proposed a narrow waterfront development across the water channel on a portion of the western shoreline of Boubyan Island along Khor Al-Subbiyah to complement the Subbiyah waterfront development. Nature-orientated recreational and educational uses, such as an aviary and mini drive-in zoo, may be located there to form the nucleus of such a development. Other possible commercial developments may include a special resort with chalets, marinas, and a strip development for private large villas and chalets with private beaches. (Note: An updated Subbiyah New Town Master Plan was prepared by HOK/GC in 2005.)

National Greenery Plan of Kuwait (NGP)

The National Greenery Plan of Kuwait (KISR, 1996) also suggested appropriate sites on the southeastern Boubyan shoreline for coastal park recreation development. In addition, it called for sites of high national environmental and ecological value, such as the tidal channels of northern Boubyan and Warbah Islands, to be preserved under a national open space conservation plan.

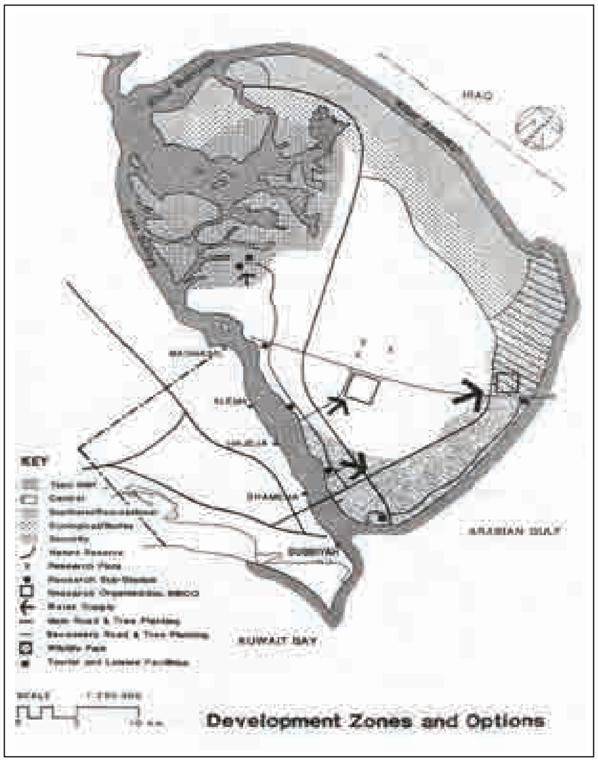

Fig. 3. Previous Boubyan Island Master Plan, 1983

Boubyan Island: Identification of Development Options

The objective of Boubyan Island: Identification of Development Options (Ministry of Planning, 1983) was to generate preliminary proposals for the development of Boubyan Island (**Fig. 3**) national security. The study proposed a range of technically feasible activities for the client's consideration, categorized as follows:

- Research
- Amenity development
- Other development options
- Infrastructural projects

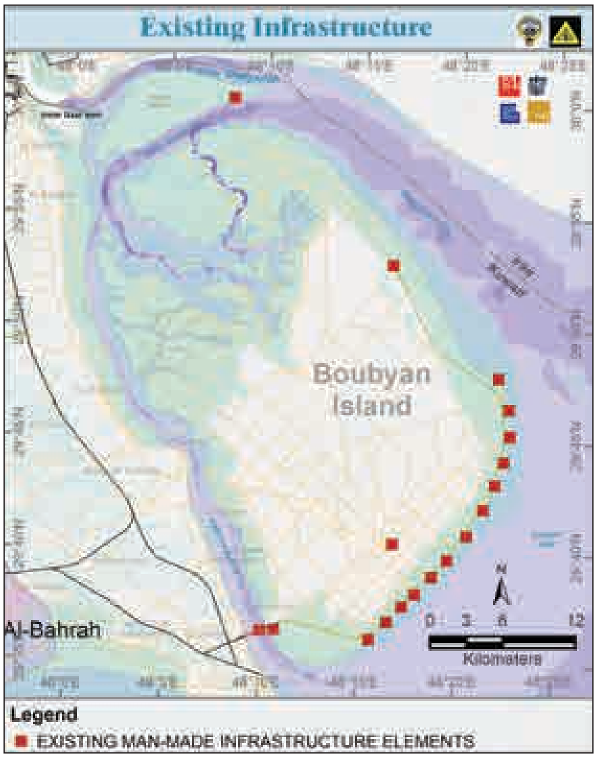

Fig. 4. Existing infrastructure on Boubyan Island

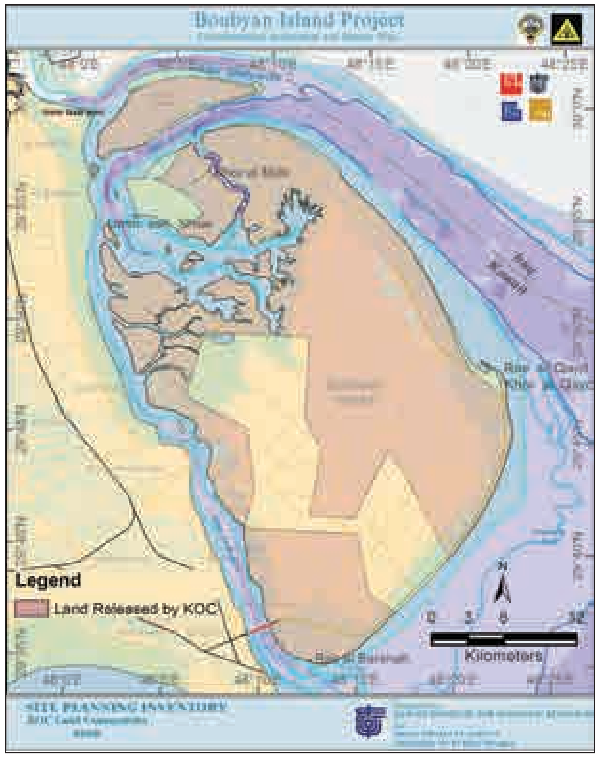

Fig. 5. KOC land concessions map used for constraint mapping phase

Existing Infrastructure

The Boubyan project area is devoid of any significant built infrastructure and development with the exception of some minor military observation posts and scattered southeast coastal defense bunkers (**Fig. 4**). The only current land access to Boubyan Island, and only prominent major existing island engineering structure, is the two-lane Boubyan Bridge, located in the southwest corner of the island (N29 36 16/E48 10 56).

The Kuwait Bay causeway has been delayed, but remains a key link and impact on any development planning activities for Subbiyah New Town and Boubyan Island. The proposed Subbiyah road upgrading project connecting Jahra Motorway Interchange 35 with Subbiyah and the existing Boubyan Bridge has progressed to the issuance of engineering drawing packages (three) for tendering by the Kuwait Ministry of Public Works. The underground waterline infrastructure project paralleling existing road to Jahra from the Subbiyah power station was completed in 2008-2009.

KOC Oil Exploration and Potential Infrastructure

Restricted zones and areas protecting oil rights as defined by the most recent information available from Kuwait Oil Company (KOC) Site Planning Inventory (SPI) map P2T-LU-12 in **Fig. 5** were transferred for use in the constraint mapping phase and final master plan maps.

Archaeology

The Boubyan archaeological review was limited to a literature review only. Preliminary research on the regional archaeology record in the area was initiated in a trip to the British Museum in London. Ancient civilizations, such as Mesopotamian Uruk, Seleucid, Parthian, and Hellenistic, all had footholds in neighboring southern Iraq and Iran. Investigations were conducted with specialized local archaeological experts, focused on historical records and finds in the State of Kuwait and near Boubyan. These investigations assessed the island's archaeological potential, coupled with selected summaries of related key ancient civilizations and Kuwait archaeological findings, and were presented for an overview.

The key findings in this study relating to Boubyan Island archaeological potential, derived from consultation with Mr. Shihab Abdulhamid Shihab, Director of the Department of Antiquities and Museums, Kuwait National Museum, and from documents and papers provided, are summarized as follows.

Archaeological Sites in the Arabian Gulf Region

Around 100,000 B.C., historical studies indicate that the Arabian Peninsula was inhabited by Stone Age man and at that time was heavily populated by animals (**Fig. 6**). The landform contained lakes and savannah. With the excep-

Plate 4. Ziggurat of Ur

Fig. 6. Map of historical archaeological sites in Kuwait

Fig. 7. Regional archaeology influence

tion of the Shat Al-Arab area, the Arabian Gulf was a lowland basin extending from Tigris and Euphrates river estuaries to the Strait of Hormuz until around 15,000 B.C. The inhabitants of the basin then retreated to the higher lands to the north and west due to the expansion of the Strait of Hormuz in that era.

As a result of the continuing settlement along the northwestern and western coastal areas and formation of commercial centers, the Gulf began to assume a strategic importance, linking the established northwest Gulf civilizations (Delmon, Failaka, Magan and Umm Al-Namil) and India.

Other civilizations in the region just north of the Arabian Gulf in southern Iraq (Ur and Uruk, Mesopotamia) (**Plate 4**) and southern Iran also had a rich legacy of settlement and cultural development (**see Fig. 7**).

Prehistoric Culture in Southern Iran (6000-3000 B.C.): From about 6000 B.C. different styles of painted pottery, stamp seals and other objects appear. Early trade between prehistoric cultures is illustrated by small numbers of shells from the Gulf, obsidian from eastern Anatolia, turquoise from northeast Iran and copper from the plateau of southeast Iran. From about 4200-3500 B.C. (Susa A or Susa I period), the site of Susa became the most important settlement and cultural center on the lowland plains of southwest Iran. During the next period (Susa II), covering the second half of the fourth millennium B.C., there is greater evidence for contacts between western and southwest Iran and the late Uruk culture of Mesopotamia.

The Seleucid and Parthian Empires (305 B.C.-224 A.D.): The Achaemenid Empire was inherited by Alexander the Great and his successors. The Seleucids, who ruled Iran and much of the Near East, and the Ptolemies,

Plate 5. Ikarus stone (Failaka)

Plate 6. The Maritime Temple (Failaka)

who ruled Egypt, shared in the control of these lands. Iranian and Macedonian satraps (governors) were employed by the Seleucids to rule Iran from Seleucia-on-the-Tigris, the established capital in Mesopotamia. The Parthians, a nomadic Iranian tribe, seized control of the province immediately east of the Caspian Sea around about 238 B.C. As a result of their expansion of their western frontier to the Euphrates, later Parthian history was characterized by periodic wars with Rome, overland trade and the development of commercial interests in the Gulf.

The Marsh Arabs: Dating back 5000 years, the dense bulrushes and perennial grasses of the southern Iraq marshlands have provided cover and habitat for a unique way of life until their recent draining resulted in a dry, dusty, saline barren desertscape. From Sumerian times, through Sargon, the great Assyrian king, and the Abbasif Caliphate (794-1258 A.D.), the Marsh Arabs have been boating through the narrow winding waterways and small floating islands.

Archaeological Sites in the State of Kuwait

Archaeological Sites in the Kuwaiti Islands: By the second half of the first millennium B.C., the importance of these commercial centers dwindled due to a collapse of the agricultural centers in the Tigris and Euphrates Valleys, India and southwestern Persia, followed by a corresponding setback in maritime activities. At this point, when Alexander the Great conquered the Persian Empire, the Gulf region was revitalized. Alexander was informed of the existence of two islands in the Gulf according to historical accounts. Located a short distance from the estuary of the Euphrates River, the smaller island was partially forested while the other was used for deer and goat grazing. Alexander the Great named this island Ikarus, according to the Greek historian Aristobulus. Archaeological excavations and finds dating back to that historical epoch indicate that Ikarus was the island of Failaka and provided evidence of successful inhabitance by the Persians on both the islands of Failaka and Akkaz (Al-Qurain) from around the first century B.C.

Umm Al-Namil Island: Approximately 1 km from Ras Osharij on the northwesterly side of Kuwait Bay is Umm Al-Namil Island. A Johns Hopkins University report indicated that land along the southern part of the island was more elevated and the basis of old structures and shards dating back to the second millennium B.C. could be detected, with additional scattered shards, including fragments of colored pottery, dating back to several historical periods found in the southeastern part of the island. Evidence of a Portuguese castle overlooking the coast in the southern part of the island, with parts of the castle walls approximately 120 cm high, still remained at the location. A huge number of shards and finds belonging to Islamic civilizations during the seventh and the eighth centuries were unearthed, in addition to archaeological surveys carried out that revealed finds dating back to several historical periods, extending from the Bronze Age to the beginning of the 19th century A.D. The archaeological excavations were carried out at four different sites on the island.

Akkaz Island (Al-Qurain): To the northwest of Shuwaikh port, Akkaz Island is found, with a total area of around 12,000 m^2. Reports indicated the existence of seven archaeological hills and, with exception of the largest one where the archaeological excavations occurred, all of these hills were removed when this island was attached to the Shuwaikh port construction project. Even this hill was not spared some destruction as parts of it were removed in the process of attaching the island to the port while the eastern part of it was destroyed during the Iraqi invasion.

Finds included fragments of bowls made from engraved steatite dating back to the Bronze Age and Islamic coins, according to a UNESCO report. The report submitted by a Johns Hopkins University team in 1973 indicated the finds collected in this island could be traced back to several historical periods, such as Islamic finds dating back to the 17th century A.D., with others imported from the Mediterranean area, dating to the second century A.D., as well as to the period 1500 B.C. Preliminary study of the scattered shards and fragments made from steatite showed that these finds dated back to the period extending between the eighth century A.D. and the second millennium B.C., with other reports indicating that additional shards collected in this island were Bronze Age.

Failaka Island: The second largest Kuwaiti island is Failaka Island, which contains some of the most important archaeological sites in Kuwait (**Plate 5**). It is situated 9 km to the southwest of Boubyan.

In 1958, archaeological excavations were begun on Failaka and continued until 1989, only to be stopped in 1990 as a result of the Iraqi invasion. The excavation works were resumed in 1999 and continued until 2002. The following are the archeological sites classified by historical ages:

I. The Bronze Age Sites
- Saad Hill: F3 (Delmon City)
- Site F6 (The Governor's Palace)
- The Tower Temple

II. The Hellenistic Age Sites
- Said Hill: F5 (The Hellenistic Castle)
- The Lodge Site (F4)
- The Treasure Site
- The Maritime Temple (**Plate 6**)

III. Pre-Islamic Sites
- Al-Qusoor Archaeological Site

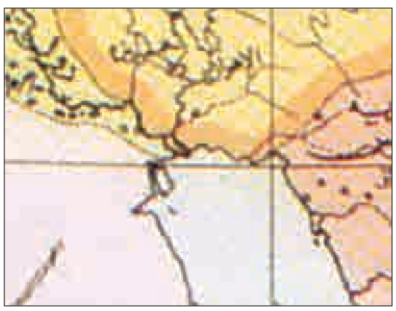

Fig. 8. Map from 1190 (era of Saladin) showing Boubyan Island

Fig. 9. Map (1645-1666) showing navigation channels

Fig. 10. Map (1760-1780) depicting shallowing concept of elongated tidal channels

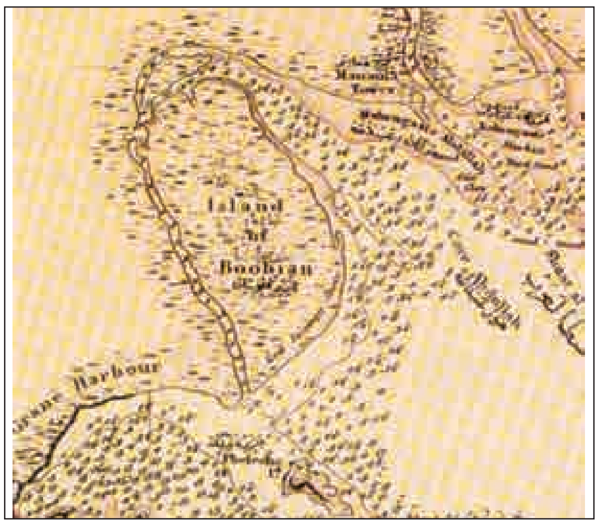

Fig. 11. Earliest map (1821-1829) known to name “Boobian”

Fig. 12. Preliminary assessment of archaeological potential on Boubyan Island

Boubyan Island and Historical Cartography

Boubyan's strategic location at the top of the Arabian Gulf has placed it in the path of ancient navigators following trade routes for hundreds of centuries. A glimpse of selected cartographic recordings reveals evolving shapes and channels as interpreted by various early Islamic traders and European explorers. Dating from the time of Saladin, a map drawn in 1190 depicts present Iraq divided up between the Abbasid Dynasty, Zingo Atabiks, Rabia territory, Artakia state, Bakr territory, and Armanian Shahs. Even from this early time, Boubyan and Kuwait are shown south and outside of this grouping of dynasties (**Fig. 8**).

A map (**Fig. 9**) made by Captain Roobacker of the "Delfshaven" between 1645 and 1666 marks a warning for the shallow areas near the island and the present location of Boubyan Island.The French cartographer Bonne published a map between 1760 and 1780 (**Fig. 10**) illustrating that Faylakah and Kazima (Boubyan) exist within the present Kuwait. Note the elongated tidal channels bisecting the Boubyan area with long intertidal strands. **Figure 11** shows one of the earliest known maps naming present-day Boubyan Island. The map was created by Guysin between 1821 and 1829 and gives new names for some areas both in Arabic and Latin.

Archaeological Assessment of Boubyan Island, Dr. Robert Carter, 2004

In March 2004, an Archaeological Assessment of Boubyan Island was commissioned, headed by Dr. Robert Carter, Co-Director of the British Archaeological Expedition to Kuwait. Methodology included field walking, GPS readings, and sampling for artifacts. The study zone was the southeastern tip of Boubyan (Ras Al-Qayd), identified as site BUB1. In two exploratory trips, no conclusive "temporary Ottoman post" archaeological remains on the ground surface were identified on Boubyan. A pierced gastropod shell was found (similar to artifacts found on man-made shell mounds in the Gulf region) but the overall preliminary conclusion suggests BUB1 is a natural feature and not man-made. The report also suggested that at some future point, in consideration of national historical interests, Kuwaiti authorities may wish to preserve one or several of the 1st Gulf War Iraqi bunkers, even though they do not qualify as archaeological structures by "pre-1960s oil era" criteria.

Archaeological Site, Al-Sabbiyah (Dispatches Magazine Article, 2004)

The H3 Al-Sabbiyah site is located in the inland Jazirat Dubaij edge of north Kuwait Bay near southern Boubyan Island. A magazine article in the local *Dispatches Magazine* (2004 summer issue), titled "The Maritime Legacy of As-Sabbiyah," presents information on the discovery of the earliest archaeological evidence of seafaring in the Middle East. Work by the British Archaeological Expedition to Kuwait has determined that people from the Arabian Peninsula (Kuwait area) and southern Mesopotamia engaged in trade and travel with sophisticated boats over 7000 years ago. The evidence of bitumen-covered reed vessel dismantling, and possibly boat construction or repair activities at the site, is the oldest seagoing boat remains ever found in the region.

Archaeological Potential of Boubyan Island, KISR Study, 2004

The mainland archaeological sites most relevant to Boubyan Island are:

Al-Sabbiyah: This site on the Subbiyah peninsula has two settlement sites 6 to 8 km apart. The first site is a sandy mound comprising more than 30 rectangular structures built of porous stones, covering 2300 m^2. Excavation works at the second site uncovered circular wells built of stones, a probable station on the ancient caravan

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Table 1. Boubyan Project Map Index (Data Theme Maps)

KISR Project	Number	Map Title & Map Subtitle
GIS/SPI	P2T-BM-01	BASE MAP
	P2T-BM-02	BASE MAP - KISR Data Collection Zones
Env. Measurements	P2T-EM-10	ENVIRONMENTAL MEASUREMENTS - Env. Meas. Data Collection Points
	P2T-EM-11	ENVIRONMENTAL MEASUREMENTS - Key Meteorological Data
	P2T-EM-12	ENVIRONMENTAL MEASUREMENTS - Dust Accumulation Rates
	P2T-EM-13	ENVIRONMENTAL MEASUREMENTS - Sand Accumulation Rates
	P2T-EM-14	ENVIRONMENTAL MEASUREMENTS - Air Pollution (passive samples)
Geomorphology	P2T-GI-10	GEOMORPHOLOGY - Data Collection Points
	P2T-GI-11	GEOMORPHOLOGY - Units Classification
	P4T-GI-11a	GEOMORPHOLOGY - Units Classification w/Interpreted Topo Overlay
	P2T-GI-12	GEOMORPHOLOGY - Marine Flooded Areas & Inland Drainage Pattern
	P4T-GI-12a	GEOMORPHOLOGY - Marine Flooded Areas & Inland Drainage Pattern w/ Interpreted Topo Overlay
	P2T-GI-13	GEOMORPHOLOGY - Inland Drainage Patterns
	P4T-GI-13a	GEOMORPHOLOGY - Inland Drainage Patterns w/Interpreted Topo Overlay
	P4T-GI-14	GEOMORPHOLOGY - Erodibility Map
Topography	P2T-TP-10	TOPOGRAPHY - Master Plan Contour Map 0.5 m Contour Interval
	P2T-TP-11	TOPOGRAPHY - Existing Infrastructure
	P4T-TP-12	TOPOGRAPHY - Digital Elevation Model (0.5 m Contour Interval)
Vegetation	P2T-FL-10	TERRESTRIAL FLORA - Vegetation Transect Data Points
	P2T-FL-11	TERRESTRIAL FLORA - NDVI Map (vegetation enhanced image)
	P2T-FL-12	TERRESTRIAL FLORA - Vegetation Biodiversity
Wildlife	P2T-FA-10	TERRESTRIAL FAUNA - Transect Observation Point
	P2T-FA-11	TERRESTRIAL FAUNA - Bird Migratory Observations (by season)
	P2T-FA-12	TERRESTRIAL FAUNA - Migratory Bird Breeding
	P2T-FA-13	TERRESTRIAL FAUNA - Migratory Bird Foraging Observations
	P2T-FA-14	TERRESTRIAL FAUNA - Resident Bird Breeding/Nest Density
	P2T-FA-15	TERRESTRIAL FAUNA - Resident Bird Foraging Observations
	P2T-FA-16	TERRESTRIAL FAUNA - Rare Bird Species Observations
	P2T-FA-17	TERRESTRIAL FAUNA - Invertebrates, Mammals, Reptiles
Fisheries	P2T-MK-10	MARINE ECOLOGY - Data Collection Stations
	P2T-MK-11	MARINE ECOLOGY - Water Chemistry
	P2T-MK-12a	MARINE ECOLOGY - Key Commercial Species - Gill Net Catch Data - Summary
	P2T-MK-12b	MARINE ECOLOGY - Key Commercial Species - Gill Net Catch Data - Saboor
	P2T-MK-12c	MARINE ECOLOGY - Key Commercial Species - Gill Net Catch Data - Zobaidy
	P2T-MK-13a	MARINE ECOLOGY - Fisheries Trawl Catch Data - Summary - Numerical
	P2T-MK-13b	MARINE ECOLOGY - Fisheries Trawl Catch Data - Summary - Biomass
	P2T-MK-13c	MARINE ECOLOGY - Fisheries Trawl Monthly Catch Composition - Numerical
	P2T-MK-13d	MARINE ECOLOGY - Fisheries Trawl Monthly Catch Composition - Biomass
	P2T-MK-13e	MARINE ECOLOGY - Key Commercial Species - Fisheries Trawl Catch Summary - *M. affinis* (Shrimp)
	P2T-MK-13f	MARINE ECOLOGY - Fisheries Forage Species - Numerical & Biomass Density
	P2T-MK-14a	MARINE ECOLOGY - Marine Mammal Observations - *Sousa* (Dolphins) - Observation by Season
	P2T-MK-14b	MARINE ECOLOGY - Marine Mammal Observations - *Sousa* (Dolphins) - Monthly and Water Body Distribution
	P2T-MK-14c	MARINE ECOLOGY - Marine Reptile Observations - *Hydrophis* (Sea Snake) - Observation by Season

	P2T-MK-14d	MARINE ECOLOGY - Marine Reptile Observations - *Hydrophis* (Sea Snake) - Monthly and Water Body Distribution
	P2T-MK-15	MARINE ECOLOGY - Zooplankton
Soils	P2T-SL-10	SOIL ASSESSMENT - Data Collection Points
	P2T-SL-11	SOIL ASSESSMENT - Soil Type Distribution
Site Planning Inv.	P2T-LU-10	SITE PLANNING INVENTORY - Data Collection Points
	P2T-LU-11	SITE PLANNING INVENTORY - Visual Aesthetic Quality
	P2T-LU-12	SITE PLANNING INVENTORY - KOC Land Concessions
	P4T-LU-13	SITE PLANNING INVENTORY - Road & Access Network
	P4T-LU-14	SITE PLANNING INVENTORY - Shaded Relief Map (0.5 m Resolution)

Other Subconsultant info in Database		
Sematco	**Number**	**Map Title & Map Subtitle**
Geotech	P2T-GE-10	GEOTECHNICAL - Borehole Points

roads. Shards collected at these sites dated back to the early, middle and late Islamic periods.

Ras Al-Qayd: The Turks established a short-term depot/camp here in 1902.

Boubyan Island historical relevance is summarized below:

- Boubyan's strategic location at the top of the Arabian Gulf placed it in the path of ancient navigators following trade routes for centuries.
- Studies of the Arabian Gulf basin indicate that the Gulf was a dry basin until 15,000 B.C. and Boubyan Island was surrounded by water only since 4000 B.C.
- The island played a vital role in sea transportation 3000 B.C. The island was considered to be the first commercial station for ships sailing from the south of Al Rafidayn to the civilization centers in the Arabian Gulf area, particularly during the epoch until 1000 B.C. It is assumed that sailing during such period used to be near the coastlines due to the small size of the ships and boats at that time.
- It is likely that the commercial sailing route near the coast going from the south of Kuwait to the south of Al Rafidayn passed through the western bank of Al Subbiyah, which separates Boubyan Island from the mainland.
- An ancient commercial land route from Kuwait going to Al Basra passed though the following areas: Al Jahrat (Al Jahraa), Umm Deira, Al Subbiyah Palace (Qasr Al Subbiyah), Arafjiyah, Al Sabriya, Umm Qasr (Kuwaiti part, where there is fresh water) and then to Safwan.
- It is thought that Boubyan Island shared historical relationships with the other islands in Kuwait Bay.

The study recommended further field investigation and archaeological survey of Boubyan Island, to clarify its historical role, if any, in establishing the human civilization during the various historical periods already in evidence in the adjacent island and mainland archaeological sites (**Fig. 12**).

Completely ruling out any archaeological potential on Boubyan Island at this stage is possibly premature. However, the likelihood of significant findings of preserved structures based on current research and field archaeological assessments is very low. The possibility of artifacts or sunken boats preserved in the Khor Al-Subbiyah, Khor Abdullah, or other offshore mud areas could be higher, due to the centuries old historical trading route activities thought to have occurred in the waters surrounding Boubyan. Any future coastal development work on Boubyan requiring excavation or trenching should, at the least, notify proper government authorities if any suspected artifacts are uncovered.

Data Management and GIS Mapping

Overall Boubyan Project Mapping

Support and assistance to aid in the establishment of a KISR-based Boubyan project database management system with an overall integrated GIS mapping component were provided under the scope of the project and a digital share file to catalog all project-related photo images was developed. A total of 36 desktop study data reference GIS base maps (**Table 1A**) were prepared as well as one overall project GIS base map layer.

Table 1A. Phase 1 Desktop Study Data Reference GIS Base Map List

Map Title	Theme Titles	Map Scales
Land Use	Local Plans (Previous)	50,000
Land Use	Regional Plans (Proposed)	100,000
Land Use	Recreation and Open Space	50,000
Land Use	Regional Archaeology Influence	100,000
Land Use	Kuwait Archaeology	100,000
Land Use	Existing Infrastructure/Current Development	50,000
Land Use	Site Planning Inventory Survey–Land and Visual Character	50,000
Land Use	Demographics/Population	100,000
Base Map	Data Collection Zones	50,000
Environmental Measurements	Field Survey Data Collection Stations	50,000
Environmental Measurements	Meteorology - Wind Roses at Subbiyah	50,000
Geology	Geotechnical - Borehole Survey	50,000
Geology	Geological Formation	100,000
Geology	Geotechnical Zones - Subbiyah	100,000
Geology	Groundwater Locations	50,000
Geology	Geomorphology	100,000
Soils	Survey Points	50,000
Soils	Reconnaissance Soils	50,000
Terrestrial Flora	Vegetation Survey Plan	50,000
Terrestrial Flora	Native Vegetation Zones	50,000
Terrestrial Fauna	Wildlife Survey Plan	50,000
Geomorphology	Shoreline Detail	50,000
Marine Environment	Biotope Mapping	50,000
Marine Environment	Invertebrate Zooplankton	50,000
Marine Environment	Ichthyoplankton	50,000
Marine Environment	Water Chemistry - Salinity/Temperature/Dissolved Oxygen (Dames and Moore, 1983)	50,000
Marine Environment	Water Chemistry - Nutrients (Dames and Moore, 1983)	50,000
Marine Environment	Fisheries (Dames and Moore, 1983)	
Marine Environment	Current Data (Dames and Moore, 1983)	50,000
Marine Environment	Faunal Observation	50,000
Marine Environment	Field Survey Monitoring Stations (KISR)	50,000
Marine Environment	Water Chemistry Dec .1979 to May 1980	50,000
Marine Environment	Bathymetry	50,000
Terrestrial Fauna	Breeding Birds Literature Review	50,000
Land Use	Topography	50,000

Database Reporting for Specific Mapping Units

The field data notes were processed and entered into the Boubyan Information System Environmental Planning (BISEP) GIS via the digital Site Planning Inventory (SPI) Field Survey Data Collection Form and checked through database quality control standards. High, medium, and low existing visual quality judgments were entered based on criteria and parameters defined in the SPI Database Reporting section and utilized in production of the map units specific to the project SPI studies.

Data Theme Maps Output

The SPI project completed responsibilities for the development and production of a comprehensive set of graphic data theme map outputs, used to interpret the KISR scientific field program results for the HOK/GC planning team. The field observation data from the KISR and other joint venture subconsultant projects were interpreted and incorporated by the SPI cartographic team into a series of geo-referenced field survey and environmental baseline thematic maps. The project updated data theme sets, comprised of a total of 53 maps, were produced as shown

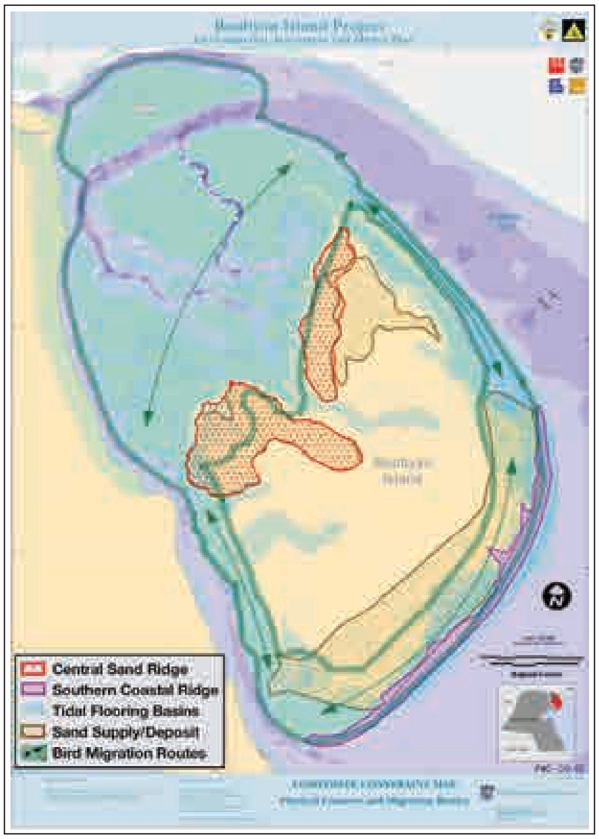

Fig. 13. Sample composite constraint map

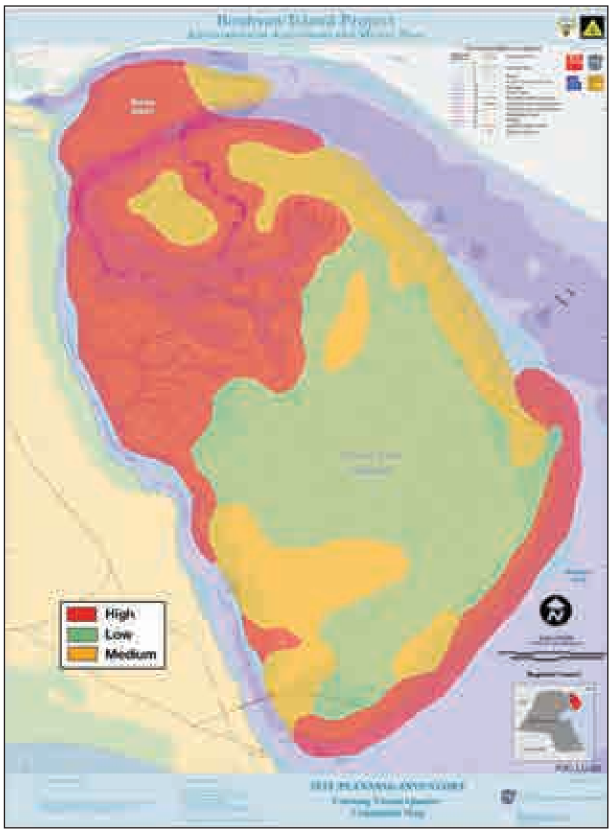

Fig. 14. Sample constraint map of Site Planning Inventory

in the data theme map list in **Table 1**, with five of the maps specific to SPI themes. Once data classifications were defined and developed by the project leaders and BISEP staff, a variety of data conversion methods were undertaken to generate the final GIS layers that formed the basis for the data theme layers and maps. Data conversion methods and associated tasks included scanning, image rectification, on-screen digitizing, attribution of geospatial data and geographic coordinate conversion to generate the maps.

Data Theme Map Use and Applications

To facilitate understanding the interaction of various disciplines in the assessment of habitats and sensitive areas, selected readings and results from the three transect lines developed early in the field programs allowed for interpretation of comparative data from common observation points or common area coverage data theme layers. An early concept GIS map series included a transect line that was expanded into a transect zone (3 km to either side of the centerline), which allowed the inclusion of a broader range of multi-disciplinary observation and/or sampling points for interpretation and valuation of the interrelationships of the individual disciplines associated with the landforms.

The data theme layers and maps served as an early planning tool and as a foundation for the constraint map development. The SPI provided a set of draft constraint maps based on preliminary interpretations of map themes and emerging trends, to support the HOK/GC team environmental assessment work and alternative option planning studies. The final map set was reviewed and used in the updating of the final constraint maps.

Beyond the immediate project needs, the final data theme maps or layers can form the basis for future Boubyan Island resource management and monitoring programs and be utilized as a valuable baseline reference source for any site-specific future detailed environmental assessment studies or development projects that may occur on the island.

Constraint Maps

A detailed set of 21 constraint maps were developed from interpretations of the biota, geomorphologic, and ecological trends resulting from the field investigation conclusions and mapping products. The constraint map themes were derived from joint interactions, meetings and workshops with the project team, especially Mouchel Parkman environmental assessment specialists. The maps were accompanied by a text outline and explanation that covered the intent behind the delineations, the project associated with the map information, the data theme map sources utilized in generating the constraint maps, and key assumptions upon which the maps are predicated. The general purpose of all of the constraint maps was to convey the relative importance of various island areas, features or processes and to provide an analysis tool for the planners and assessment team's decision.

Constraint Map Development Process

The constraint map development process included the following steps:

Constraint Map Source: Evaluation of 53 data theme maps delineating field investigation results and assessments combined with supplemental map analysis tools including aerial photography, remote sensing imagery, master plan topography contour map, and the KISR Guide for Land Features of Boubyan Island.

Data Interpretation and Zonation: Utilized data trend summaries, conclusions, and zonation assumptions interpreted from geo-referenced data. The KISR Boubyan project manager, cartographic specialists, and GIS staff met individually with each of the project leaders to determine relevant data required from the project database. These data were extracted from the database as decision support for the delineation and classification of constraint areas. Database queries were developed to extract field data and extracted data were mapped to facilitate interpretation by the project leaders.

Development of Constraint Maps: Including map manipulations, graphic delineations, and map intent summaries. Once the interpreted constraint zonation areas, polygons or directional trends were evaluated by the project leaders and the KISR cartographic specialist team, these geospatial features were digitized and attributed accordingly and then placed on the existing map base for final review. Modifications in the form of adjustments to boundaries or feature attributes were made, when necessary, prior to final map production.

Constraint Map Output: A set of 21 interpreted constraint maps were utilized in the alternative planning options, environmental assessments, and evaluations of the preferred land use concept and final master plan concept. A sample of the overall project composite map is shown in **Fig. 13** and a sample constraint map specific to the SPI work is shown in **Fig. 14**.

Field Survey: Site Planning Inventory

Comprehensive site planning inventories typically identify a full range of key site investigations based on variations in landform, land cover, land use, hydrological features and processes, aesthetic resources, terrestrial vegetation and habitat communities, cultural history, marine elements, and meteorological influences that give regions and sites distinctive characteristics. In this case, specific detailed field surveys were being executed in other KISR and other subcontract projects that included biological assessments (marine, terrestrial flora and fauna) and physical element studies (geology, geotechnical, geomorphology, topographic survey, groundwater, soils, environmental measurements and meteorology). The remaining site inventory elements on Boubyan and Warbah Islands included: manmade influences (circulation roads, tracks, any located historical elements, and military security structures), land character classification (landforms and landscape setting), and existing visual quality (viewsheds, key views, and visual resources).

The related survey data were observed, catalogued, and documented to formulate field baseline status for significant landforms and visual quality for the purpose of being applied to the environmental impact assessment, mapping, and planning activities. Impact levels on the established visual and landscape resources resulting from proposed alternative developments were identified for evaluation, modeling, or simulation strategies to be applied by the planning team. Specific land use plan alternatives and associated mitigation options for sensitive habitats and strategies for the preservation of significant landscape character sites were discussed in the final master plan.

The overall approach and rationale generated baseline studies with the aim of describing, classifying, and evaluating existing natural landscape features and aesthetic (primarily visual) qualities within and surrounding Boubyan and Warbah Islands. Particular attention was given to the sensitivity and ability of the landscape units, viewsheds, and existing ecosystems to accommodate change. The length of the Phase 2 field survey was 12 months, with an emphasis on gathering representative data and images in each primary landform zone seasonally. An attempt was made to gather a reasonable amount of field input by the time Phase 3 planning activities start up to accommodate the schedule overlap in project phases.

The main objectives of the FA038C SPI Field Survey are to:

- Review Phase 1 reconnaissance trips and site selection activities;
- Define a plan and methodology for implementation of land character and visual assessment studies; and
- Conduct a 12 month (four seasons) field survey focusing on existing visual quality and landscape character assessment.

Table 2. Coast Guard Trip GPS Data

Grid	Description	Symbol	Position	Altitude	Depth	Proximity
1	Main Coast Guard	Waypoint	N29.72069 E48.10135	-0.1	NA	12
2	Small Island	Waypoint	N29.76116 E48.09968	-1.2	NA	18
3	Large Inlet	Waypoint	N29.80887 E48.06551	-0.1	NA	6
4	Army Post	Waypoint	N29.87465 E48.01717	1.2	NA	19
5	Dolphin	Waypoint	N29.93103 E48.01550	-0.1	NA	23
6	Northern Inlet	Waypoint	N29.96212 E48.11052	-0.3	NA	27
7	Beach Head Visit	Waypoint	N29.90067 E48.13636	-0.1	NA	28
8	Warbah Coast Guard	Waypoint	N29.99320 E48.11135	-1.4	NA	32
9	Small Inlet - Warbah	Waypoint	N29.96862 E48.04884	-0.8	NA	22

Field Reconnaissance

The SPI team visited the islands seven times between August 2003 and the end of January 2004. Two trips were to the northern Boubyan and Warbah Island waterway channels while the remaining five were terrestrial trips, covering the accessible roads in the summer seasons and the only accessible main road in the winter. The purpose of the trips was to identify areas to focus land character and visual interest activities.

Preliminary observation and photo-recording of information relating to the islands' locating setting, general physiographic characteristics, important views, circulation, and linkage elements (island vehicular and marine access, circulation roads, tracks, pedestrian trails, etc.) and existing uses were initiated during these reconnaissance trips. The information was used to make a preliminary field site survey plan.

The following initial SPI field observations were made:

- Preliminary visual environment (terrestrial area)
- Terrestrial circulation: Road conditions (dirt tracks) and features were noted and preliminary classifications were made; seasonal weather impacts and access were experienced and noted
- Waterway circulation: Initial Coast Guard trips to northern Boubyan tidal channels and Warbah Island

Preliminary Visual Environment

The overall dominant visual experience of the southern portion of the Boubyan Island landscape is of an endless flat desert plain and its interface with sky and water in different scales and forms. At ground view and eye level, discernible topographic prominences or topographical enclosures are non-existent. The visual experience of the distant horizon in all directions gives a feeling of visual endlessness; views in all directions generally extend unobstructed up to the horizon.

The major scenic/visual units of the southern and central Boubyan landscape include:

- The endless flat plain of the interior desert sabkha with some limited vegetation stands.
- The exceptions are the coastal beach edges along the Arabian Gulf (Khor Abd Allah) and Khor Al-Subbiyah in the south and east sides of Boubyan with a more dense vegetation strand. Narrow bands of lush green marsh vegetation occur at isolated pockets of tidal wetlands along these southern and eastern coastline zones.

The dominant visual experience of the northern portion of Boubyan Island was quite different. While no more than 4 to 4.5 m in height above the high tide line, distinct and interesting topographical forms in the visual ground plain cut from the tidal action of the inland waterway network. These forms (delineated in the shaded relief map of this area) become more pronounced at the low tide stage. In general this region presents differing views from every angle.

The major scenic/visual units of the northern Boubyan and western Warbah landscape include:

- The maze of dynamic tidal waterways that dominate these zones in both islands.
- The lush green marsh vegetation in narrow shoreline bands associated with the wetlands occurring in these zones.

Table 3. Updated Environmental Survey Manual for SPI

Program	**Site Planning Inventory**
Component	Landscape & Visual Interest Assessments
Organization	KISR
Team Leader	Eng. Robert H. Grina, Senior Landscape Architect
Key Personnel	M. Belt, Cartographic Specialist D. Parkinson, Cartographic Specialist
Key Program Cross Links	2a. Vegetation 1e. Geomorphology Micro Landforms
Sampling:	
- Locations	76 geo-referenced sites. Co-located with vegetation and other program sites.
- GIS Base Map Reference No.	*P2T-BM-02, P2T-LU-10 & P2T-LU-11*
- Frequency	Once. Repeat visits at 3 locations to assess seasonal variations.
- Schedule	*Variable*
- Methodologies	Methodology for land character and visual assessments adapted based on international best practice, e.g., UK Landscape Institute "Guidelines for Landscape and Visual Assessment" and US Department of Transportation & Federal Highways "Visual Impact Assessment." Photo views will be recorded from various directions to characterize the study area. Key view features will be recorded. GPS location of all observation sites to be recorded.
Data Components/Parameters	Land character descriptions as per SPI Field Survey Forms definitions.
Analyses	
- In Situ	N/A
- Laboratory	N/A
- Data Processing Time	N/A
Quality Management	Checked by team leader

Table 4. Summary of SPI Field Visits for Data Collection to Boubyan and Warbah Islands (August 2003 to November 2004)

Date	**Study Site**	**KISR Zones**	**Event Nos.**	**Activity Notes**	**Vehicles**
Phase 1					
August 10, 2004	Boubyan	A, D	1.001 to 1.004	Visual Survey, Site Office Selection	4 WD
October 13, 2004	Boubyan/Warbah	E, F	1.005 to 1.012	Visual Survey	Boat
Phase 2					
March 1, 2004	Boubyan	A, B, D	2.001 to 2.010	Visual Survey	4WD
March 16, 2004	Boubyan	A, B	2.011 to 2.014	Visual Survey	4WD
March 23, 2004	Boubyan	A, E	2.015 to 2.019	Visual Survey	Boat
March 29, 2004	Boubyan	B, C, D	2.020 to 2.032	Visual Survey	4WD
April 13, 2004	Boubyan	A, B, D	2.033 to 2.035	Visual Survey, Site Office Install	4 WD
May 12, 2004	Boubyan	B, D	2.036 to 2.040	Visual Survey	4WD
May 20, 2004	Boubyan	C, D	2.041 to 2.042	Visual Survey	Hovercraft
May 24, 2004	Boubyan	C, E	2.043 to 2.044	Visual Survey	Hovercraft
May 25, 2004	Boubyan	C, E	2.045 to 2.046	Visual Survey	Hovercraft
June 12, 2004	Boubyan	A, C	2.047 to 2.051	Visual Survey	4 WD
August 1, 2004	Boubyan	C, E	2.052 to 2.055	Visual Survey	Boat
Sept. 15, 2004	Boubyan/Warbah	E	2.056 to 2.058	Visual Survey	Helicopter
Sept. 26, 2004	Boubyan/Warbah	C, E, F	2.059 to 2.064	Visual Survey	Helicopter
Total no. of field trips: 2 trips (Phase 1) + 13 trips (Phase 2) = 15					

Terrestrial Circulation (Phase 1: Reconnaissance)

Initial preliminary road descriptions included observations for the following major dirt tracks:

Road No. 1 (Bridge to Oil Well Head—48 km): This road originates at the Boubyan side of the bridge at the old army checkpoint and runs along the Arabian Gulf (eastern side of Boubyan Island).
Ras Al-Barshah Road: This dirt track to Ras Al-Barshah hugs the beach along the southern shoreline.
Road No. 4: The coastal desert track runs along the Khor Al-Subbiyah waterway.
Waterway Circulation: Coast Guard trip (**Table 2**).

Field Program

A comprehensive field survey program, focusing on existing visual quality, was implemented. The SPI survey program and related fieldwork covered the duration from August 2003 to November 2004. A full review of the original SPI field program plan and methodology was conducted in March 2004 through meetings with Mouchel Parkman management and technical representatives. Any modifications related to the Environmental Baseline Field Manual were monitored during the SPI fieldwork stages and updates were reported. A final copy of the SPI Environmental Manual sheet is shown in **Table 3**.

Summary of Field Trips

A total of 15 separate field trips to the project area (Boubyan and/or Warbah Islands) were conducted and recorded by the SPI team to gather visual assessment data and for project-related purposes (**Table 4**). Thirteen field trips (encompassing 64 events and 171 photographs) were made to the selected visual survey points. Also, supporting data from two field trips (consisting of 12 events and 50 photographs) were utilized to enhance the visual survey coverage. GIS data theme map P2T-LU-10 delineates the final SPI survey project data collection points (event numbers) related to the SPI field survey. Coverage points collated by KISR study zones are on map P2T-BM-02.

A reduction of planned multiple visits to some sites was the only minor program adjustment. This was offset by an overall increase in island area coverage and doubling the observation points (36 to 76), resulting from the availability of more innovative means of access. This included devising an access program via hovercraft and helicopter to previously inaccessible regions to supplement the land vehicle and boat field trips.

Site work at the event locations included the recording of global positioning system (GPS) points along with directional photographic documentation activities related to site settings, landscape character classifications or subunits through recording of typical and special landform features or processes, land cover (vegetation or otherwise), and any noticeable existing land use. Field data notes from the observation points covered qualitative elements such as:

- The visual environment and identification of key views for visual assessment, viewshed, and existing visual quality;
- Potential sensitive ecological landscapes and habitats; and
- Potential areas sensitive to increased levels of future development.

Database Reporting

The field data notes were then processed by the SPI team and entered into the Boubyan Information System Environmental Planning (BISEP) GIS via the digital SPI Field Survey Data Collection Form and checked. Entry form criteria and definitions were modified from international visual quality standards by the SPI planning team experts to relate specifically to the Boubyan Island project. Subsequent evaluations of site characteristics and the aforementioned criteria parameters were used to develop high, medium, and low existing visual quality judgments, with representative photographic samples of each of the three levels.

Field Trip Observations

Descriptions of the major scenic/visual units of the Boubyan and Warbah Island landscapes observed for each of the field trips (located by KISR study zones) are provided in the following visual environment summaries.

Visual assessment information is also incorporated in the SPI data theme maps from two trips conducted on August 10 and October 13, 2004.

Trip No. 1 (P2) (Events 2.001-2.010)/March 1, 2004

- **Road No. 4 (Zone A):** The dirt track heading north from the Boubyan Bridge parallels the waterway, Khor Al-Subbiyah (on the west), and is breached by sporadic swales draining the flooded inland areas (to the east) during the wet season. The topography in the area is flat, with long vistas in all directions. Key views are of the landside west coast of Khor Al-Subbiyah and the typical tidal mudflat landscape with pockets of sandy coastal vegetation, extending north and south along the Boubyan (eastern) shoreline of the waterway, Khor Al-Subbiyah. On the landward side of the dirt track is typical desert landscape of sabkhas, characterized by sparse or no vegetation. The major seasonal drainage stream (N29 43 118, E48 08 499) causes access problems during the wet months. Marine life presence in the intertidal mudflats, along with birds associated with the mudflats and intermittent vegetation communities, suggest a habitat of some value in this area.

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- **Road No. 1/Bridge to Oil Well Head—48 km (Zones A, B, and D):** This dirt road originates at the Boubyan side of the bridge, angles across to 10 km to within a few hundred meters of the Gulf coast edge, and runs along the Arabian Gulf to the north. The road surface is compacted and the surrounding topography is generally flat except for locally undulating areas along the Gulf. Belts of intermittent to dense coastal vegetation occur along the Arabian Gulf side, providing higher visual interest. The inland side of the road has long uninterrupted vistas and is characterized by low sabkha depressions typically flooded between November and March/April. Sparse, sporadic vegetation growth to the west is visible from the road, with lower scenic value than the coastal side. Military concrete defense bunkers constructed approximately 2 km apart remain along the southeastern coastline up to the military post (from km10 to km33). A sandy beach and spit run along the shoreline of the Kuwait Naval Security observation base camp. A salt lake is a prominent feature north of the entrance to the army camp facility. In the northern section of the road (east side) along the Khor Abd Allah, the topography is flat, consisting of continuing dry season salt-crusted flats with remnant debris from tidal flooding. There are some remnants of previously stacked ordnance/ammunition boxes and shell casings. Blown-up ordnance pits are located at the end of the road. An oil well head (appears to be abandoned) with a concrete pad is at the terminus of the road, with views of monotonous flat sabkha to the south and west. This is the only access road during winter months. Even then, the road is dangerous as vehicles can get stuck in mud if driven before the road dries out after each rain or if driven through flooded drainage swales bisecting the road (events 2.004-2.007, P2 006-013).
- **Ras Al-Qayd (Zone D):** This unique and scenic habitat area includes a sand spit terminus, a salt marsh wetland, tidal mudflats, sandy beach areas, and a tidal inlet waterway as well as one of Boubyan's most highly diverse vegetation resources growing on the coastal peninsula running south to the military outpost. The water channel is dynamic as the width and size vary with the marine tidal changes. Active bird-related migration, nesting and foraging characterize this area, along with high quality and extremely diverse scenic resources (events 2.007-2.010, P2 014-021).

Trip No. 2 (P2) (Events 2.011-2.014)/ March 16, 2004

- **Boubyan Bridge/Southside Landing (Zone A):** Mudflats extending north and the shelly, sand beach formations to the south define the landforms around this concrete landing structure. Major views of Boubyan Bridge and the Subbiyah power plant dominate the site. Abandoned military hardware from the 1990 Gulf War was stockpiled a short distance from this site.
- **Ras Al-Barshah (Zone A):** A densely vegetated wetlands area with a tidal mudflat and sea-induced flooding channel influences this rich habitat area. The width of the waterway varies with the tide (very narrow at places during high tide). There is a dominant view of the Subbiyah power plant across the Khor Al-Subbiyah to the west and views of the open Arabian Gulf to the southeast, including Failaka Island on a high visibility day. The topography is flat except for the gentle slope towards the Khor Al-Subbiyah. The dominant salt marsh vegetation, lush with shades of green, lines the Ras Al-Barshah tidal waterway in narrow bands and widens in the undulating flooded areas. The low marsh is surrounded by elevated terrestrial grounds supporting some of the highest zones of plant species diversity on the island. Bird migration along with some nesting and foraging are associated with this habitat area. These elements all combine to create some of the highest valued scenery on the island (event 2.012, P2 028-030).
- **Road No. 1/Boubyan Bridge to Ras Al-Qayd (Zones A, B, and D):** Seasonal flooded areas were photographed, with high points creating inland islands, generating moderately interesting views. Some scattered and sporadic salt-tolerant vegetation to the west of the road was observed. For a description of Ras Al-Qayd, see trip no. 1 (P2) (events 2.013-2.014, P2 031-034).

Trip No. 3 (P2) (Events 2.015-2.019)/ March 23, 2004

- **Northern Boubyan-Tidal Channels (Zones A and E):** The dominant visual experience of the northern portion of Boubyan Island is quite unique. While no more than a few meters in height above the high tide line, distinct and interesting topographical forms in the visual ground plain are cut from the dynamic tidal action of the inland waterway network. These forms become more pronounced at the low tide stage. In general, this region presents differing views from every angle. The major scenic/visual units of the northern Boubyan and western Warbah landscape include the maze of tidal channels in both islands and the lush green marsh vegetation in narrow shoreline bands associated with the channel and small khor wetlands. During high tide conditions, the boat trip touched on two islands in Khor Ath-Thala'ab and stopped in a wetlands habitat on the northern landside of Boubyan Island. As this was a spring season study trip, the small islands and channel shorelines were characterized by evidence of bird nesting and intense foraging activities. High quality scenic views of birdlife and vegetation reveal the rich and undisturbed habitat areas associated with the small islands and shorelines in this part of Boubyan. During the return trip, a view down the open Khor Al-Subbiyah towards the non-descript mainland provided relatively less visual interest.

Trip No. 4 (P2) (Events 2.020-2.032)/ March 29, 2004

- **Ras Al-Qayd—Transect Zone I (Zones B, C and D):** The concept of the transect zones is to provide a number of common points on the island for comparative readings and data interpretation from all KISR environmental field projects. Ras Al-Qayd Transect Zone I extends from the shoreline at the Ras Al-Qayd area to the peripheries of an inland low area and ephemeral water feature to the west, a distance of about 5 km. Eleven terrestrial transect GPS observation points were taken, with selected stations photographed for SPI work. Between the Ras Al-Qayd near coastal belt and the inland extremities of the zone, several micro landforms were identified. These include sabkhas of different morphologic features, recent flood patches, drainage basins and aeolian landforms creating visual values ranging from high to low from the near coastal belt to the large expanses of flat and barren inland desert.
- **South Central Boubyan—Transect Zone II (Zones B and C):** GPS points were taken at 12 terrestrial observation points for geomorphology and other field project assessment purposes. SPI utilized selected points for photos delineating major changes in land cover (events 2.025-2.032, P2 073 -086). Transect Zone II extends in a north-south direction from offshore of the central portion of the southern coast of Boubyan Island, through the shoreline belt, to the peripheries of an inland low area (ephemeral lake) at a distance of about 10 km. The Transect Zone II centerline, which extends parallel to a desert track, running in an almost north-south direction, intersects with the Boubyan main road at 14 km from Boubyan Bridge. The different landforms are recorded along the transect, including sandy beaches, beach ridges, foreshore sabkhas, sabkhas, drainage basins, water ponds (ephemeral lakes), and aeolian landforms. The variety in micro land features provides descending high to low visual interest inland from the coastline until the barren sabkha flats. Transect Zone II also includes one additional marine sampling station offshore to link marine data. (Note: Transect Zone III runs north-south along road no. 4, paralleling Khor Al-Subbiyah in KISR study zone A, and SPI visual data was obtained from selected common points during the first Phase 1 field trip.)

Trip No. 5 (P2) (Events 2.033-2.035)/ April 13, 2004

- **Ras Al-Qayd Military Post/Site Office—33 km (Zone D):** A field trip to Boubyan was conducted to supervise access, transport, and placement of the prefabricated site office units adjacent to the Ras Al-Qayd army post. One visual assessment was made at a south coast site, with shoreline vegetation and sandy beach providing high value scenery.

Trip No. 6 (P2) (Events 2.036-2.040)/ May 12, 2004

- **Southeastern Shoreline (Road No. 1—5 km to Oil Well Head—48 km) (Zones B and D):** A 30 km stretch of pristine southern coastal terrain and beaches was the focus of this field trip. After observing some intermittent vegetation clumps and indicators of seasonal flooding around the 5 km point, four representative shoreline sites (km13, km19, km27 and km29) were photographed and assessed for visual quality. These high visual value areas are characterized by long north-south sloping sandy beach vistas and open Arabian Gulf views of dark turquoise water to the east. To the west are nearshore vegetated belts with sand hillocks interrupted by natural drainage swales or large open mudflat beds. This coastal habitat strip of Boubyan Island requires only some minor military debris cleanup to provide an existing high value scenic resource.

Trip No. 7 (P2) (Events 2.041-2.042)/ May 20, 2004

- **Central and Northeast Boubyan—First Hovercraft Trip (Zones C and D):** The KISR hovercraft research program, organized by SPI for KISR Boubyan projects, provided the availability of hovercraft to penetrate previously inaccessible interior island areas in three separate photographic forays related to SPI and visual survey work. The first SPI hovercraft trip recorded northeastern interior land, indicating some high ground with vegetated hillocks providing a moderate level of scenic interest surrounded by low, relatively flat sabkha areas of low visual interest. Minefields on the northeast of the khors precluded hovercraft observation in that area.

Trip No. 8 (P2) (Events 2.043-2.044)/ May 24, 2004

- **Central Boubyan—Second Hovercraft Trip (Zones C and E):** The second SPI hovercraft trip observed north central interior lands just below and reaching to the northern tidal zone khors. Low, barren mudflats and sabkha areas subject to intermittent tidal inundation dominated the inland topography of this part of the island with monotonous views, contrasting with the rich shoreline habitats of the khors with lush vegetation strips, active birdlife, and diverse coastal views.

Trip No. 9 (P2) (Events 2.045-2.046)/ May 25, 2004

- **Central and Northwest Boubyan—Third Hovercraft Trip (Zones C and E):** The third SPI hovercraft trip, with an operation base near Khor Al-Subbiyah, recorded interior land views ranging between the northwestern and central portion of the island. These flatlands provide views of a bleak and non-descript terrain stretching for kilometers in all directions. The khor shoreline provided high value scenic habitat vistas.

Trip No. 10 (P2) (Events 2.047-2.051)/ June 12, 2004

- **Central Boubyan—Inland Dirt Tracks/East-West (Zones A and C):** A terrestrial field trip to Boubyan followed the inland dirt tracks from Ras Al-Qayd to the higher ground with the inland bunker and the KISR weather station, penetrating large areas of barren interior sabkha, and returning to the main dirt road just before the bridge. Sparse vegetation and some micro surface drainage landforms were observed only in the southwestern edge of the interior sabkha, offering moderate visual interest, while the broad, dry central and eastern mudflats were characterized by a distinct visual absence of life. At ground view and eye level, discernable terrain elevation changes or topographic prominences are nonexistent. The visual experience of the distant horizon in all directions gives a feeling of visual endlessness; views in all directions generally extend unobstructed up to the horizon. The sabkha surface is very treacherous in the central part of the island and other low-lying areas as the thin dry crust disguises a persistent saturated thick mud layer underneath, even in the driest summer months.

Trip No. 11 (P2) (Events 2.052-2.055)/ August 1, 2004

- **Northeastern and Northern Boubyan (Zones C and E):** Another boat field trip to Boubyan was conducted in the peak summer months to record views in the northeastern coastline and the khors of the northern tidal zone. The trip revealed more high value scenery associated with the shoreline vegetation and wildlife habitat. Minefields were observed inland from the coast (approximately 2 to 3 km) in the barren sabkha of northeastern Boubyan, which was of lower visual quality.

Trip No. 12 (P2) (Events 2.056-2.058)/ September 15, 2004

- **Northern Boubyan—First Helicopter Trip (Zone E):** The first of two helicopter trips around Boubyan and Warbah Islands provided aerial view photos to augment the previous ground level images of the project areas. Selected shots increased visual quality interpretation in the more remote areas, specifically the interior land in the northeastern corner of Boubyan, the land mass between Khor Al-Milh and Khor Ath-Thala'ab and the southwestern extremity of the northern tidal zone khor systems.

Trip No. 13 (P2) (Events 2.059-2.064)/ September 26, 2004

- **Central and Northern Boubyan and Warbah—Second Helicopter Trip (Zones C, E, and F):** The second helicopter trip around Boubyan and Warbah Islands revealed views and details of barren interior island land surfaces, panoramic shots of the Khor Boubyan and western Warbah tidal channels and wetlands and the flooded terrain at the southern limits of the northern tidal channel zone. These selected aerial shots from the two helicopter trips greatly increased landform understanding and visual quality interpretation in the more remote project areas.

Alternatives and Master Planning Processes

The overall goals and objectives of this work were:

- To provide interpretations and clarifications regarding technical field survey results and initial environmental assessment interpretations for use by the client team (HOK/GC and Mouchel Parkman) planning and design teams in creating land use alternatives and the final master plan concept;
- To provide edited overall KISR project reviews and commentary on the client master plan concept;
- To provide issue-specific commentary on the master plan concepts; and
- To provide a framework for sustainable island resources management planning.

Joint Venture Master Plan, August 2005

Figs. 15 and 16 show the master plan (August 2005 version) that was reviewed by KISR. The detailed review of the master plan concept was conducted in the context of the various SPI elements. The resultant effects of implementing the designated master plan concept land uses are summarized below.

Design Issues

Research Station and Educational Amenities: The research station should be located near the interpretive center and the Ras Al-Barshah environmental preserve for a closer relationship to the visitor center (including native plant demonstration gardens and testing/production facilities), with water channel access for constructed wetlands and additional interpretive opportunities. (If located too close to the transport corridor, the research station/visitor center complex would be in a position to be a receptor of negative railway and traffic noise and negative visual

Fig. 15. Boubyan Island Master Plan (August 2005 version)

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Fig. 16. Boubyan urban expansion (August 2005 version)

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impacts.) Also, any marine or biological research monitoring of the northern tidal protected area would have to be by boat launch, so the location should have a small dock and access to Khor Al-Subbiyah. The research facility and visitor center complex could provide a sustainable "green architecture" model utilizing traditional cooling systems and solar, wind, or other renewable energy resources (**Fig. 17**).

The engineered wetlands will provide additional new avifauna habitat area, linking the research center with the boat pier and creating an "outdoor nature classroom." The man-made wetlands area will serve public awareness, nature education, and wetlands mitigation research needs and will be accessed by a system of elevated boardwalks with viewpoints, observation towers, bird hides, and interpretive signage.

Environmental Issues

Visual Quality: The master plan concept land uses will not disturb the internal views of the northern tidal channel views as long as human intervention is tightly controlled, and ecologically engineered roadway afforestation belts or greenery buffer zones should increase visual quality as a background for views to the south. The scenic value along the southeastern coastline will be enhanced by an eco-resort landscape corridor development and the addition of habitat tidal salt marsh improvements. In this plan, the visual integrity of the Ras Al-Qayd peninsula and Ras Al-Barshah salt marsh scenic habitats is preserved. Recreation elements proposed (golf courses, eco-campgrounds, etc.) will improve the visual quality value of their immediate surroundings. The proposed lake system separating Subbiyah expansion from Boubyan can also increase scenic value and habitat opportunities in a rather bleak part of the island.

Architectural Visual Controls: Long-distance views are commonplace on Boubyan Island due to the island's flat topography. This provides an opportunity for low visual impact architectural solutions and controls to maintain the visual quality in the highest value scenic resource areas. With the enforcement of proper low-rise height restriction requirements, most of the land uses are likely to have little impact on the distant island views. The exceptions would be the port area crane towers and possible Subbiyah New Town expansion, which may require taller elements impacting island-wide horizon views.

Landscape Screening—Transport Corridor and Secondary Road Network: The transport road must be fenced to act as a barrier preventing unauthorized human intrusion and the buffer should utilize earth berming and/or other screening devices that reduce visual and noise disturbance. To remain consistent with sustainability goals,

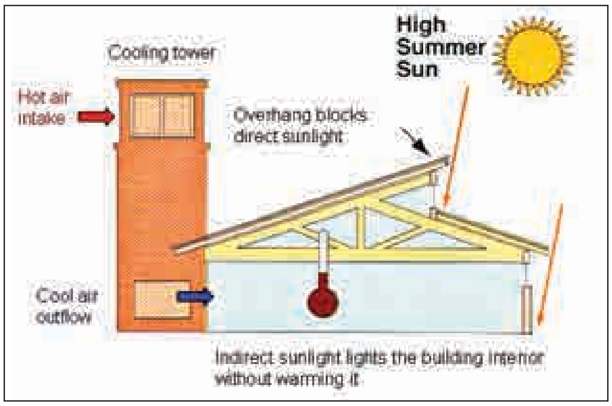

Fig. 17. Research and visitor center should be energy efficient (National Park Service, USA)

linear masses of naturalizing trees (requiring only rainfall after establishment) can be planted adjacent to the transport corridor road and/or rail right-of-ways for environmental and safety considerations. Localized environmental benefits from roadside mass tree plantings act to reduce headlight glare, provide sand abatement, and filter undesirable airborne sediments. Along the southeast coast road and other island secondary road right-of-ways, naturalizing tree masses should be planted to act as a buffer and to enhance habitat and shade cover. Non-sustainable road planting should only be permitted at major island roadway nodes (i.e., bridge approaches, Boubyan Urban Expansion junction, port entry, etc., designated for future return effluent water service) or in site-specific developments (road networks for resorts, interpretive center, etc.) and urban area streetscape projects. All island road designs (permanent and temporary roads) should also address potential marine surface flooding impacts and allow for the continuation of natural geomorphological processes across road alignments. Berming can also provide localized improved soil conditions for landscape buffer elements.

Noise Element Assessment: There are currently no noise disturbance elements on Boubyan Island. Noise pollution will increase with the implementation of the master plan concept land uses. Both temporary and permanent noise sources (traffic, marine and land recreation vehicle noise, cargo vessels, construction equipment, etc.) will be generated from construction activity, port operations and dredging, the transport corridor, hotel development, lake dredging, and development of the Boubyan Urban Expansion area with its associated infrastructure projects. Planning and development criteria governing all of these activities and projects (as well as other projects impacting Boubyan) should protect identified island conservation and habitat receptor areas designated as "noise sensitive" zones with appropriate buffering measures and noise control ordinances. A policy of the master plan should call for environmental noise exposure guidelines and assessments in specific environmental impact projects addressing decibel level standards, controls, and monitoring procedures to assist in ameliorating or abating noise element problems. Even sensitive receptors within the Subbiyah and Boubyan urban expansion fabric such as libraries, residential areas, schools, parks, and open space require location consideration, mitigation, and/or buffering from major highways and business park/industrial uses.

Night Light Glare Pollution: A by-product of the land uses proposed in the master plan concept is night light/ glare pollution generated from intensive, high density urban development. The Subbiyah New Town development would have a major impact in this regard on Boubyan, as would the port project to a lesser extent. The pristine night skies of the habitat areas need some protection in this regard and any potential for astronomical observation resources could be compromised without proper controls. The master plan should recommend the adoption of appropriate ordinances to control sources of light that adversely affect a defined dark skies conservation zone. Recommendations for street and building lighting controls (limiting candlepower output, type of lighting, etc.) in both Subbiyah and Subbiyah expansion, the port, and other island developments on Boubyan are ways to lessen the impacts of potential night light glare pollution. A minimum 25 km radius zone (from the center of Boubyan Island) should be imposed that would be subject to lighting controls to preserve nighttime skies.

Road Protection and Sand Abatement Systems: The design of fencing and afforestation systems for the transport corridor (port road and railroad) should include sustainable design and engineering solutions. Close proximity of the road and rail tracks will be more economically efficient and prove easier to protect with a common integrated system. Utilizing an ecomat product with native grasses and shrubs (requiring only rainfall), an effective sustainable sand abatement system can be established along targeted sand and wind corridors in the transport corridor with long-term economic benefits. For optimum sand stabilization, the control system should be planted between the railway and the northern security fence. Sand movement is generally higher in the western half of the island but site-specific monitoring and Environmental Impact Assessments will be required to determine the most effective planting areas.

Land Use Planning Issues

Military Uses: Military security needs, while not specifically designated in the master plan concept, are likely to be a part of any final master plan solution. These passive security and observation needs can be accommodated but any physical military training activities with all-terrain military vehicle maneuvers, live-fire weapons exercises, and ordnance dumping, which would pose public safety problems and have strong negative impacts on the island's ecological and physical processes, should definitely be moved off the island to other locations.

KOC Oil Exploration and Potential Infrastructure: KOC land concessions and released lands were delineated on map P2T-LU-12. All proposed developments within KOC unreleased lands will likely require notification and coordination with KOC interests, so major plan elements should avoid these areas as much as possible.

Suburban Encroachment and Boubyan Urban Expansion: The implementation of a proposed lake separating the urban expansion from the rest of Boubyan is necessary as a physical barrier to restrict urban sprawl and to reduce environmental impact (separating introduced predators [e.g., cats] from nesting bird areas).

Cultural Issues

Archaeology: While no significant archaeological resources have been identified on Boubyan Island to date, it is important to consider the discovery of local mainland (Subbiyah area) archaeological evidence indicating that people from the Arabian Peninsula (Kuwait area) and southern Mesopotamia engaged in trade and travel with sophisticated boats over 7000 years ago. Construction activities (dredging, trenching, excavating, etc.) that could threaten any potential significant artifacts or sunken vessels should have procedures for identification, notification, and resource protection measures for discovery, or disturbance, of any significant findings.

Existing Military Bunkers: An existing island military bunker could hold potential as a designated war museum site to convey recent national or historical stories of conflict related to the area.

Sustainability Issues

Boubyan Island Sustainability Management Plans: While the large scale of Boubyan allows for ample planning and development opportunities covering a range of diverse land uses, many of the marine and terrestrial ecosytems are fragile and interrelated. The effects of the various proposed land uses need to be assessed with respect to the impact on island-wide ecosystems and physical processes to maintain overall island sustainability. This can be accomplished through policies in the master plan defining preliminary requirements and general criteria for site-specific Environmental Impact Assessments during the design and engineering stages of each proposed land use development. In addition, master plan policies should mention the need for conservation and resource management plans and programs for the island both in local and regional contexts. KISR is currently preparing native vegetation management plan criteria for the island. Detailed specific management plans for vegetation as well as wildlife and marine habitats can be prepared by KISR at the request of government agencies in the future.

Note that management plan process, issues, and organization structure suggestions (i.e., proposed Kuwait Protected Lands Agency) presented in the KISR Phase 3 Interim Report 4 were incorporated in the updated comprehensive KISR Phase 4 Support Report: Resource Management Planning Process and Framework (see summary herein).

Environmental Impact Assessment (EIA): As a key component of any land and resource management plan, the monitoring of environmental impacts will be vital in assessing changes to baseline conditions and prescribing timely adjustments to the plan in response to findings. Environmental assessment procedures will need to be coordinated with any legislation governing the EPA and be aligned with current EIA reporting guidelines.

Sustainable Road Fill Material: KISR has a large volume of bioremediated treated oil lake by-product suitable for road base fill. The availability and use of this tarcrete by-product should be explored for use in the major earthworks and road construction projects proposed for Boubyan.

Constructed Wetlands: These environmental friendly landscapes can be engineered and integrated with eco-resort open spaces, transition areas and linkages to enhance greenbelt and wildlife corridors.

Open Space Greenery Concept: Planting of urban greenbelt or open space corridors should be "desert xeriscape" with lower water requirements. Treated wastewater generated by the permanent established Boubyan Urban Expansion population could be the source and should provide an adequate supply for properly designed drought-tolerant landscapes.

Suggested Plant Materials: A preliminary list of sustainable salt-tolerant native plants has been suggested to use in rehabilitation of disturbed areas of Boubyan Island as well as for most of the island-wide open space and transition area greenery needs. Availability of large quantities of native species could be a concern (see production nursery comment below). Also, a general list of ornamental plants which require imported soil and water with low salts was provided. These should be limited to specific urban infrastructure, urban streetscapes and resort project landscape sites to avoid introduction of any invasive species to the island ecosystem. (KISR also provided a preliminary plant palette list; see **Table 5**.)

A reliable supply of native plants and halophytic species for major island development projects should be an early priority for any sustainable landscape planning on the island. Necessary infrastructure needs should be allocated to the designated site in the master plan. Demonstration gardens with educational native and sustainable planting displays should be adjacent to the production nursery grounds.

Bicycle Path System and Kuwait Bicycle Club: A bicycle path and trail system should be considered in the Boubyan Master Plan to provide for more sustainable transportation options on the island and accommodate needs of the existing Kuwait Bicycle Club. Linkages are suggested in the eco-resort section and south coast road right-of-way to encourage alternative transport uses.

Island-wide Regional Trail System with Interpretive Elements: The master plan should incorporate a regional day-use trails system linking to eco-resorts, education facilities, Boubyan Urban Expansion open spaces, public beaches, campgrounds, and public access areas in preserves.

Production Nursery: A proposed large-scale production nursery is a key master plan element in the island's development and makes economic, logistic and horticultural sense. On-site island production of plant materials will greatly decrease shipping and delivery costs as well as provide locally "hardened-off" plants. The nursery will ensure a reliable supply of suitable native plants and halophytic species for major island development projects such as the port and transportation corridor development, the Boubyan lake development, resort areas, interpretive and research center project, and island ecosystem rehabilitation projects. The required infrastructure needs of the planned nursery should be allocated to the designated site in the design development stage of the island infrastructure. The nursery project is envisioned with both a retail section for the horticultural needs of future island residents and a large wholesale component for commercial landscape project demand, as well as servicing government program indigenous planting requirements for island revegetation projects. Demonstration gardens with educational native and sustainable planting displays are planned to be an integral part of the nursery complex. Emphasis on production of native plants and naturalizing drought-tolerant species will also contribute to island water demand reduction and water conservation.

Equestrian Trails and Center: An equestrian trail system should be considered in conjunction with a regional trail plan, along with an equestrian center for rec-

Table 5. Preliminary Plant Lists

Plant List A
Naturalizing Plants (natives and/or halophytes, for salt marsh vegetation restoration or coastal/sabkha transitional areas):
Botanical Names
Acacia pachyceras
Acacia podalyriifolia
Atriplex spp.
Avicennia marina
Atriplex leucoclada
Baccharis halimifolia
Ficus glomerata
Lycium sp. *Shawii*
Nitraria retusa
Phragmitis australis
Salicornia europaea
Salsola spp.
Senecio desfontainei
Sporobolus spp.
Seidlitzia setifera
Tamarix aucheriana
Zygophyllum simplex

Plant List B
Ornamental Plants (requiring fresh water and imported soil):
Botanical Names
Trees
Acacia arabica
Acacia salicina
Albizzia lebbeck
Azadirachta indica
Callistemon viminalis
Casuarina equisetifolia
Conocarpus lancifolius
Dalbergia sissoo
Eucalyptus microtheca
Olea europaea
Parkinsonia aculeata
Pithecellobium dulce
Prosopis chilensis
Prosopis juliflora
Tamarix aphylla
Vitex agnus
Ziziphus spina-christi

Palms
Chamaerops humilis
Phoenix dactylifera
Washingtonia filifera
Washingtonia robusta

Groundcovers
Atriplex semibaccata
Carissa grandiflora "Boxwood Beauty"
Carissa grandiflora "Prostrata"
Gazania splendens
Ipomoea pes-caprea
Mesembryanthemum sp.
Pennisetum setaceum
Ruellia californica
Sesuvium portulacastrum
Wedelia trilobata

Shrubs
Atriplex canescens
Atriplex lentiformis "Breweri"
Atriplex nummularia
Bougainvillea spp.
Carissa grandflora
Cassia artemisioides
Clerodendrum inerme
Conocarpus lancifolius
Jasminum sambac
Leucophyllum frutescens
Tecoma stans
Thevetia peruviana

Turf
Cynodon dactylon cvs "Tifgreen"
Paspalum vaginatum
Stenotaphrum secundatum

reation and interpretive opportunities as well as historic cultural ties. Camel riding facilities could be integrated within the complex.

Campgrounds: Campground concepts should incorporate sustainability concepts and utilize composting toilet systems which convert 95% of toilet wastes into water vapor and CO_2 (with the remnant turned into stabilized compost that can be used as soil amendment). Use of these elements will also reduce infrastructure demand. The campground could provide options for three different hierarchies of campsites ranging from primitive to water only to water and electricity connections. Other campground elements to consider include: a mosque or prayer shelter facilities, general store, ranger station, outdoor (natural) interpretive amphitheater area, maintenance storage, day-use picnic area along with shade shelters, and refuse collection area. All major campground areas including campsite groupings should be defined and screened with mounding and planting. Also, pathways and camp roads could be lit with solar power.

Regarding cultural issues, shared restroom facility clusters (separate men's and women's facilities) can be maintained and kept clean assuming that there will be on-site control and management (ranger supervision and maintenance programs).

Table 6. Matrix for Different Land Use Activities

Environmental Elements	Activities for Preferred Concept	Environmental Reserve (RA)	Protected Water Reserve	Environmental Reserve (CPA)	Managed Water Habitat	Greenbelt Afforestation Zone	Intertidal Mudflats & Buffer	Port	Free Trade/Light Industry Zone	Dredged Material Holding Area	Port Transportation Corridor	Sabkhas Restrictive Access	Boubyan Urban Expansion	Lake Boubyan	South Coast Resorts	Subbiyah New Town
Environmental Measurements	Air pollution	1	3	1	4	4	4	4	4	4	4	4	4	4	4	4
	Groundwater	1	4				5	4	4	4	3	4	5	5	5	5
	Sand accumlation	1	3	1	0	0	4	1	0	0	4	1	1	1	4	4
	Tidal processes	2	4	1	4	4	5	4	4	4	0	4	5	5	5	5
	Inland terrestrial processes	1	3	1	2	2	4	2	2	2	3	3	1	1	4	4
	Dust fallout	1	5	1	5	5	3	5	5	5	5	5	1	2	4	5
	Coastal geomorphology	1	3	1	4	4	5	4	4	4	0	2	5	5	5	5
	Coastal erosion	1	3	1	5	5	3	5	5	5	0	2	5	5	3	3
	Coastal sediment transport	1	3	1	5	5	5	5	5	5	0	2	5	5	5	5
	Soil erosion (terrestrial)	2	2	1	5	1	5	5	1	3	3	4	3	3	1	1
	Soil deposition (terrestrial)	4	5	1	5	1	5	5	5	3	4	2	3	3	1	1
Vegetation	Microbiology	4	2	4	3	4	4	3	3	3	3	2	3	3	3	3
	Plant cover	4	2	4	3	4	4	3	3	3	3	2	3	3	3	3
Wildlife	Terrestrial wildlife	5	5	3	5	2	1	1	1	1	1	1	2	2	3	1
	Coastal wildlife	5	5	4	5	3	1	1	1	1	1	1	2	2	1	1
	Bird migratory path	5	5	5	5	3	2	3	2	2	4	2	2	3	2	2
	Bird nesting	5	5	5	5	4	5	4	1	2	4	1	2	2	3	1
Fisheries and Oceanography	Hydrodynamic regime	3	1	5	5	5	5	5	2	5	4	1	4	3	2	4
	Bathymetery	3	1	5	5	5	5	5	4	5	4	1	4	1	1	4
	Flood pattern	5	1	5	5	5	5	5	4	5	4	1	3	1	1	4
	Sediment quality	5	1	5	4	4	4	4	2	5	4	1	3	1	1	3
	Fisheries	5	1	5	5	5	5	5	2	5	3	1	4	1	1	4
	Shrimp	5	1	5	5	5	5	5	2	5	3	3	4	1	1	4
	Plankton	5	1	5	5	5	5	5	2	5	3	3	3	1	1	3
	Marine mammals and reptiles	5	1	5	5	5	5	5	2	5	3	3	4	1	3	4
	Eutrophication	5	1	5	5	5	5	5	3	5	3	3	5	5	3	4
	Productivity	5	1	5	5	5	5	5	3	5	3	3	4	3	2	4
	Water quality	5	1	5	5	5	5	5	3	5	3	3	4	4	3	4
	Salinity	4	1	4	3	3	3	3	2	3	2	2	1	1	1	1
Soil Assessment	Gypsic Aquisalid	5	5	1	1	2	1	1	1	1	5	3	5	5	4	5
	Typic Aquisalid	5	5	1	1	2	1	1	1	1	5	3	5	5	4	5
	Typic Torriorthent	5	5	1	1	2	1	1	1	1	3	3	3	5	4	5
Site Planning Inventory	Historical elements	1	1	1	1	1	2	2	2	2	1	1	2	1	2	1
	Landscape setting	5	3	1	1	1	5	3	3	3	3	1	5	4	5	2
	Visual quality	5	3	2	2	2	5	4	4	4	4	3	5	5	5	2
	Noise pollution	5	5	4	4	2	4	1	1	1	1	2	3	4	5	2
	Military activities	5	5	3	3	3	5	2	2	2	3	3	5	5	5	3

Table 7. Zonal Assessment of Environmental Impacts for the Activities Based on Master Plan Concept

Area	Importance of the Area	Type of Activities	Expected Impacts	Magnitude without Mitigation	Mitigation Measures	Residual Impacts
Northern Boubyan	Ecologically very sensitive breeding and nesting area of internationally important birds.	No direct activity. Indirect activities like dredging and excavation works for port construction.	Impact to birds and wildlife due to noise and vibration from nearby areas.	Negative change (-B)	Avoid work involving high noise during nighttime. Continuous noise monitoring is recommended during construction and operation of dredging, excavation, transportation and other port activities.	Slight negative impact (-A) may remain
Boubyan Urban Expansion	Connecting site for Subbiyah New Town and port. Presence of khor habitats and bird breeding.	Link bridge. Excavation, dredging, erection of pillars. Road construction. Dumping of waste and sands. Construction of Subbiyah urban township.	Disappearance of breeding birds and marine shrimps. Changes the marine water quality and sediment quality. Disturbance to marine biota. Attracts terrestrial animals like rats, mice, etc., which are predators for ground nesting birds.	Significant negative (-C)	Development of alternate area for birds with same natural environment. Introduction of mangrove plantation in the alternate site to benefit birds and marine habitat. Proper plan for dumping and disposal of waste materials. Strict control of human access to sensitive bird migration and nesting area.	Slight negative impact (-A) will remain on marine water quality
Port and industrial zone	Easy access to nearby countries to advance trade. Bird nesting and migratory route.	Construction activities. Dredging of navigation channels. Excavation and erection of engineering structures. Marine transportation.	Increase in economy and employment. Affects freshwater influx. Disturbance to bird migratory route and nesting grounds. Change in marine water and sediment quality. Reduces marine population. Changes the soil characteristics. Increase in noise and vibration.	Significant positive (C) Significant negative (-C)	Sensitive coastal area in the northern island and Ras Al-Gaid should be screened from fishing and boating. Proper plan for minimizing the impact on coastal flora, fauna and endangered marine species. Proper plan for disposal/reuse of dredged material. Monitoring of coastal water quality is essential.	Slight negative impact (-A) will remain
Southern coast	Recreation and tourism.	Construction of hotels, chalets, roads and other amenities.	Eliminates vegetative and productive area for terrestrial habitats to some extent. Changes in the long shore drifts. Eliminates bird migratory route.	Negative change (-A)	Proper lining with native greenery can make up for this loss.	No impact (N) will remain
Ras Al-Qyad and Ras Al-Barshah	No direct activity is involved.	Construction activities in nearby areas.	Noise pollution, air pollution and human interference affect bird migration and nesting.	Negative change (-A)	Activities involving high noise and other disturbances are suitably planned, considering the migratory path and nesting season of birds. The protected area should be separated with proper fencing to protect from encroachment of other predators.	Birds may get adapted to the new environment after construction, but slight negative impact may remain
Port transporation	Protects from encroachment to the northern island.	Introduction of a new bridge.	Disturbance to birds and other coastal wildlife.	Slight negative change.	Avoid traffic sound at nighttime and during nesting seasons. Proper conservation measures to minimize sound and air pollution.	Slight negative impact (-A) may remain

Table 8. Activity-Based Impact of the Selected Master Plan Concept

Activity	Major Impact Components	Type of Impact	Recommended Mitigation
Environmental reserves, managed water habitat, protected water reserve	Vegetation, terrestrial and coastal wildlife, birds, coastal water and sediment quality, fisheries and marine production, visual quality, noise pollution, soil deposition.	Positive impacts. Any development in the reserves would significantly hinder birdlife.	If properly protected, these areas can have positive impacts on the environment; however care should be taken to avoid destruction of vegetation. Precaution to minimize noise at night.
Boubyan Urban Expansion	Groundwater, tidal processes, coastal geomorphology-erosion and sediment transport. Bird foraging and migration. Eutrophication, water quality, soil characteristics, visual quality and noise.	Major impacts on bird population due to the increase of rats and mice (predators of birds) and hunting by residents. Negative effect on community health can also be expected.	Groundwater monitoring, preventing coastal erosion, water quality monitoring in lake and beach area, arrangement for soil drainage system, proper wastewater treatment and provision for proper medical facilities (hospitals) within the island. Enforcing regulation for private bird hunting. Disposal and treatment of garbage from residential area should be effective to avoid pest problems.
Port transportation corridor	Air pollution, dust fallout, bird migration and nesting, soil characteristics, noise pollution.	Significant impact on birds. Noise pollution will be greater.	Proper control of traffic and noise. Development of buffer zone and monitoring of sound pressure.
South coast resorts	Coastal erosion, bathymetry and flood pattern, eutrophication.	Significant impact	Preventing coastal erosion by ground greenery and water quality monitoring.
Port	Air pollution, noise pollution, dust fallout, bird migration and nesting, soil characteristics, coastal erosion and sediment transport, coastal hydrodynamics, flood pattern, coastal water quality and fisheries.	Natural and anthropogenic waste disposal, oil spillage, discharge of ballast water, use of anti-fouling material sewage contaminate water, increase in air pollution from industrial stacks and traffic movement.	Sensitive coastal area in the northern island and Ras Al-Gaid should be screened from fishing and boating. Proper plan for minimizing the impact on coastal flora, fauna and endangered marine species. Advance identification of location for stationary installations such as underwater cables, pipelines and outfalls in such a way that they are away from navigation channels. Use of efficient dredging equipment to reduce water turbidity. Physical and chemical analysis of water and sediment before and during construction to design proper monitoring mechanism to minimize impact. Limiting dredging activity during critical spawning and prespawning periods and a detailed management plan for dredging and disposal of dredged materials. Emergency contingency plan to minimize accidents during transport.
Subbiyah New Town	Air pollution, groundwater, soil characteristics, dust fallout, coastal geomorphology and sediment transport, and coastal water quality.	Significant impact	Preventing coastal erosion through proper conservation methods, water and sediment quality monitoring, groundwater monitoring, arrangement for soil drainage system, proper wastewater treatment and planned provision for proper medical facilities (hospitals).
Free trade zone/ light industry	Air pollution, groundwater, dust fallout, coastal processes and bird migration to some extent due to noise from increased traffic and industrial works.	Significant impact	Proper air quality monitors and groundwater monitoring. Avoid major noise-producing work at night. Proper management of industrial waste.
Dredged material holding area	Transportation and storage of dredged materials. Air pollution in summer changes soil characteristics.	Moderate impact	Proper conservation methods for disposal/reuse of dredged material. Monitoring the quality of dredged material.
Intertidal mudflats and buffer	Impact on intertidal biota (oyster reef, snails and fiddler crabs) and vegetation due to construction activities in the nearby area.	Negative impact	All construction activities (excavation, dumping and vehicular transport) should be planned away from the intertidal zones. The area should be free from oil contamination. Fencing and restricted access can be enforced.

Initial Environmental Evaluation Report

Background

The Initial Environmental Evaluation (IEE) study was aimed at assessing the environmental impact on Boubyan Island based on the environmental measurements executed during the project studies through Rapid Impact Assessment Matrix (RIAM) and Strategic Environmental Assessment Matrix (SEAM) for the proposed major land uses covered under the preferred master plan concept, which was revised to the final master plan (August 2005). From the RIAM results, it can be concluded that various aspects of the construction and operation phase of activities involved in the Boubyan Island Master Plan will result in a range of major, significant, moderate and slight negative impacts on the existing ecosystem of Boubyan Island and, in many cases, significant positive changes for the biological components. The environmental components affected due to the activities of selected concepts are of immense importance as far as the biodiversity of Kuwait is concerned. Recommendations and follow-up actions to be implemented during construction and operation activities were also included in the IEE section. All the detailed input required by the RIAM model for the Site Planning Inventory elements are shown in **Table 6**.

The roles of KISR were:

- To assess the potential impact during construction of the designated project elements
- To study the severity of the proposed uses in the allocated area (i.e., worse case scenarios)
- To suggest special mitigation measures to reduce expected problems
- To identify the residual impacts in term of:
  - Time frame (long term, temporary, no impact)
  - Extent (local/regional)

The IEE study work scope was divided into the following components:

- A summary of the revised scope of work and a description of the preliminary matrix structure for review by the project leaders.
- Application of the developed matrix to the master plan concept primary land uses as made available by HOK/GC to KISR. The objective was to provide backup valuation support and reference for strategic environmental assessment studies carried out by the joint venture team, particularly Mouchel Parkman.

Recommendations

The results of the IEE value weight scoring process are summarized in **Tables 7 and 8**.

Boubyan Island Resource Management Planning Process

Background

KISR prepared overall guidelines and objectives for a process to develop a long-term resource management plan for the Boubyan Island Project. The project leader's role was to provide strategic input, editing and technical coordination in developing a framework and process for such a document.

KISR contacted the International Union for the Conservation of Nature (IUCN), represented by the Regional Office for West and Central Asia and North Africa (WESCANA RO) Protected Areas Program, to provide advice on the framework for the island's management planning with regard to the international standards and guidelines for areas of significance for biodiversity conservation. This cooperative task took place in early July 2005.

Objectives for the resource management planning process report were to:

- Assess and evaluate the potential for recognition of the biodiversity of Boubyan Island at the international level.
- Develop the framework of the site's management planning process with a set of interim management recommendations.
- Discuss specific function and qualification justification of Boubyan wetlands salt marsh area under Ramsar definitions.
- Provide technical advice with justification on the classification category of the protected areas according to international procedures.
- Provide recommendations on ecotourism and the sustainable use of biodiversity taking into account the current draft master plan option for Boubyan Island.
- Provide ideas on how research programs can be integrated with public education programs on biodiversity.
- Provide recommendations on stakeholders' involvement and capacity building.

This report described and summarized the recommendations and ideas for the management planning process of the island based mainly on the master plan option and the conservation zoning plan which were developed based on the joint venture consultancy master plan environment assessment policies in conjunction with KISR.

General Recommendations of Resource Management Planning Process Report

Ecotourism Development: The master plan option suggested an upmarket tourism development arrangement for Boubyan to serve as a main economic element of the island's development. The proposed vision for tourism development needs to respect the island's landscape, especially in the general use or development zones. This includes the development of large resorts, golf courses, freshwater pools and water sports.

Without strong contracts and sensitive designs, the tourism development projects could have major negative impacts on the fragile biodiversity of the island. To minimize the preventable impacts of tourism on the integrity of ecosystems, habitats and species, the highest possible measures of mitigation and control need to be put in place prior to, during and after the development of any tourism infrastructures and services. Ecotourism opportunities need to be stressed to preserve the island's biodiversity.

Also, a proper tourism impact monitoring program should be developed and implemented at all stages of tourism development. A plan for site information and interpretation needs to also be put in place to inform visitors of the island's values and guide them on the code of behavior and conduct while on the island. Tourism's direct and indirect contribution to the conservation of the island's biodiversity should be incorporated in all policies and regulations for tourism development. A more in-depth analysis needs to be undertaken to tackle the tourism development sector and assess its opportunities and threats under IUCN's international guidelines.

Capacity Building and Training: Capacity building and training need to be integrated in all management interventions on the island. Local and national capacities need to be enhanced whenever possible to maximize benefits derived from the island's development to the local and national economy.

The points below are the main recommendations specific to the management planning process in terms of capacity building and training:

- The formulation of a management team responsible for the implementation of the management plan is of immediate importance. This will allow the team to join the development process at an early stage, which will enhance their understanding of the project's context and history.
- Undertake an in-depth training needs assessment exercise for all personnel involved in the management of the protected areas.
- Based on the needs assessment, the development and implementation of a comprehensive capacity building and training program for all those involved in the site's management.
- Training programs should adopt an "on-the-job" training approach focusing on enhancing practical knowledge and skills.
- Regional expertise should be utilized whenever possible in the training programs to facilitate regional cooperation and enhance cultural compatibility and technical relevance.

Follow-up Actions

Extracted from the technical report, the following are the proposed follow-up actions in regard to the management planning and implementation processes for Boubyan and Warbah Islands to which the KISR team of experts could provide further technical assistance to Kuwait and relevant government agencies:

1. The development of the full management plan for Boubyan and Warbah Islands including the public consultation process.
2. The development of the legal framework for the islands under the proposed legislative arrangements.
3. The development and implementation of the capacity building and training program for the on-site management teams.
4. The development and implementation of a follow-up plan for the designation of the islands under international conventions and criteria including IUCN Protected Areas Categories, MAB Program, IBAs and Ramsar Convention.
5. The development of a tourism master plan for the island including visitor management systems and business and marketing plans.

Wetlands Visitor Center & Research Complex Concept Design

This Boubyan Island project site selection was based on the land use designation for a Wetlands Visitor Center & Research Complex as specified in the recently completed Boubyan Island Master Plan. The site area is 12 hectares in size located adjacent to the Khor Al-Subbiyah inlet to the proposed Lake Boubyan water feature. Boubyan New Town is across the waterway to the north, with future marina facilities and resort hotels directly across the water from the visitor center. The visitor center site will be comprised of an enhanced coastal wetlands habitat with approximately 300 m of mudflat and nabhka shoreline and an open waterway connection. Facilities will be developed on elevated areas (minimum 6 m above sea level) generated from wetlands site excavation fill and partially on pilings, to allow the natural tidal flow processes to flow and develop habitat near the buildings. Primary view orientation over the constructed wetlands and Khor Al-Subbiyah/Lake Boubyan will range from the northwest and to the northeast. Ingress and egress from the wetlands complex is from a designated spur road with controlled access for shuttle buses, autos and delivery/service. There

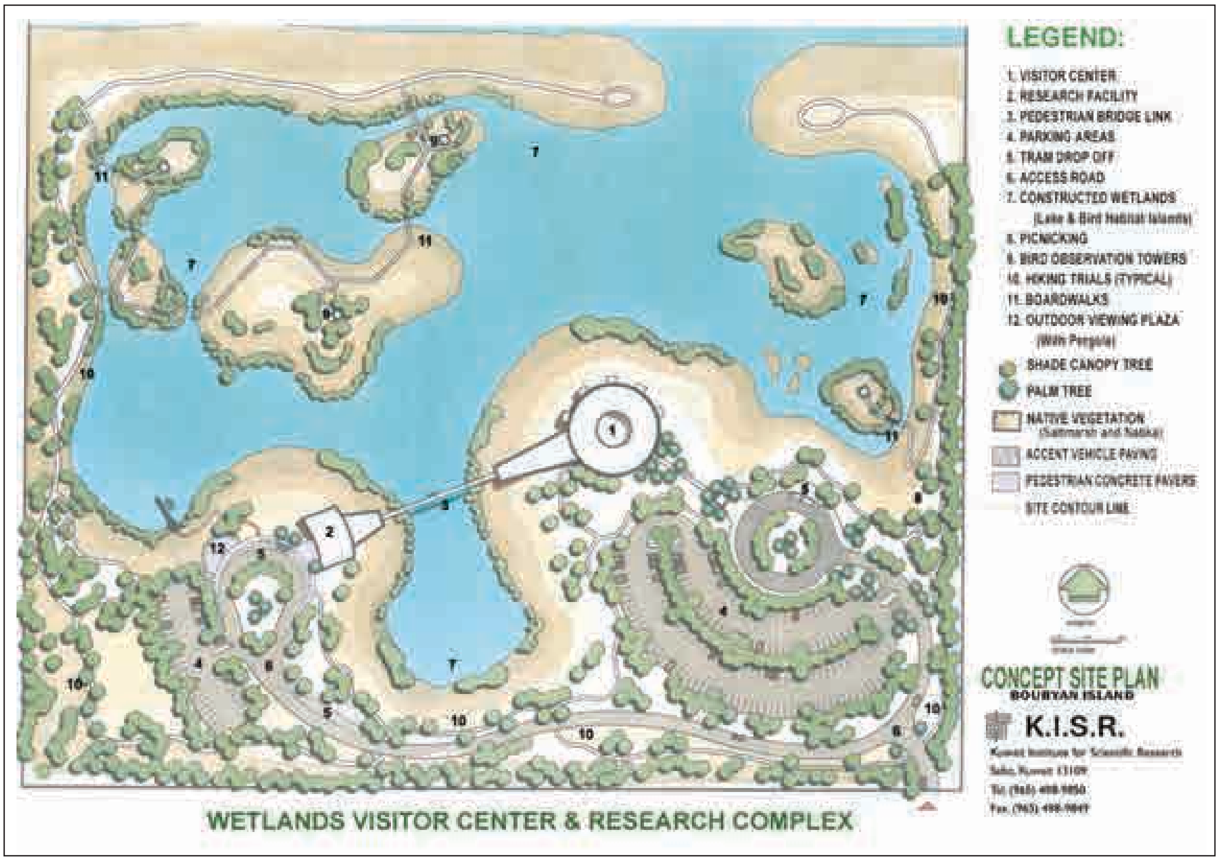

Fig. 18. Wetlands Visitor Center & Research Complex concept site plan

is a planned vehicle day parking area (90 spaces) at the visitor center and an additional parking lot (24 spaces) at the research facility, with tram drop-off stations at both points. A main entry plaza walkway axis goes to the visitor center and an elevated pedestrian bridge over a small bay connects the visitor center with the research facility. A site pedestrian walkway system (with portions designed for handicap access) connects to parking and picnic areas as well as a site trail system that feeds to natural wetland paths, outdoor interpretive exhibits, observation towers, and constructed elevated walkways in sensitive habitat areas. Tree-planted berm separation buffers screen parking lots from buildings and wetlands. The primary objectives for the development are to provide both public education awareness exhibits (indoor and outdoor) of wetlands habitat integrated with park research and administrative services support facilities (**Figs. 18 to 23**). Site-sustainable design solutions included:

- Emphasis on indigenous wetland halophytic plantings throughout the constructed wetland environs.
- Use of naturalizing introduced drought-tolerant plants limited to provide functional tree cover.
- Supplemental shoreline stabilization and enhanced bird habitat in the developed site areas.
- Native dirt-stabilized pathways; special parking lot and walkway paver designs allowing percolation.
- Capture of site runoff water for irrigation use and incorporation of a native garden area and nature trails with educational interpretive exhibits.

Boubyan Island Westlands Visitor Center & Research Complex Description

The visitor center building is accessed via an entry portico and gently rising ramp to reach its elevated site position. The building complex overlooks a constructed wetlands park consisting of native salt marsh plantings and a naturalizing tree canopy buffer, offering habitat and research opportunities. The first building contains an exhibition hall basement emulating an underground bird's nest with exhibition area, offices, and services. The first floor (main entry level) has an exhibition hall with viewing balconies and a theater. The visitor center building is connected by a bridge to the research complex. The research complex consists of laboratories, offices, acclimatized bird-viewing pod and observation terraces. The connecting bridge spans an inlet of the constructed wetlands and its height accommodates the dynamic tidal changes associated with the Boubyan Island coastline (**Fig. 24**). **Tables 9 and 10** show the visitor center and research facility space planning

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Fig. 19. Wetlands Visitor Center & Research Complex view to the north

Fig. 22. Wetlands Visitor Center & Research Complex view to the northeast

Fig. 20. Wetlands Visitor Center & Research Complex view to the southwest

Fig. 23. Wetlands Visitor Center & Research Complex view to the northwest

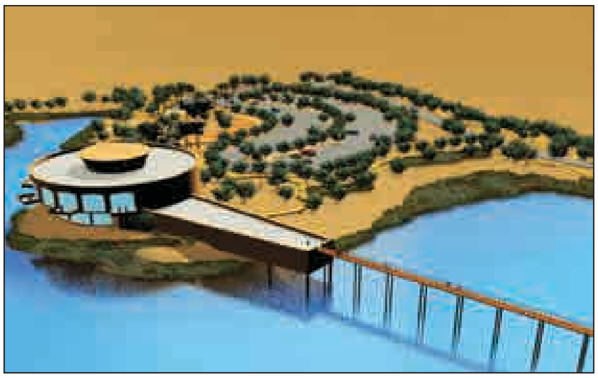

Fig. 21. Wetlands Visitor Center & Research Complex view to the southeast

developed from KISR criteria. Overall site external building-related elements include: entry portico structure, pedestrian connection bridge, roof view terraces and decks, solar tile wall panels, cooling tower intakes, roof skylights, and outdoor plaza with shade trellis.

Facility-Related Sustainable Design Solutions

Building Material and Energy Control: The 1 m thick wall infill consists of hay bales (a new innovative sustainable building technology for Kuwait) with adequate concrete structure of columns, beams, and foundation slab. All walls have wire mesh cladding with lime plastering. The plastering technique using natural materials is a traditional regional architectural finish (**Fig 25**).

The south elevation of the exhibition building has minimum openings to reduce heat. There are wind catchers and solar panels facing to the south side of the building. The bird observatory platform has external and internal wide windows to expose the view of the building. The south elevation wall of the lecture hall is modified by integrating solar cells to maximize the sun exposure for energy. The research laboratory is half above and half below grade to minimize heat gain and energy requirements.

Table 9. Visitor Center Space Planning

Exhibit hall with foyer/multi-media discovery display area, viewing area, information area, sales (1256 m^2)	Offices, staff, mechanical and storage room (121 m^2)
Auditorium/lecture room for 120 people (370 m^2)	Prayer room (30 m^2)
Men's and women's restrooms (57 m^2)	Tea room (30 m^2)
Total interior building area = 1864 m^2	

Table 10. Research Facility Space Planning

Research exhibit/viewing area (146 m^2)	Offices, mechanical and storage room (394 m^2)
On-site laboratories (287 m^2)	Tea room (22 m^2)
Viewing pod (182 m^2)	Prayer room (34 m^2)
Men's and women's restrooms (57 m^2)	
Total interior building area = 1122 m^2	

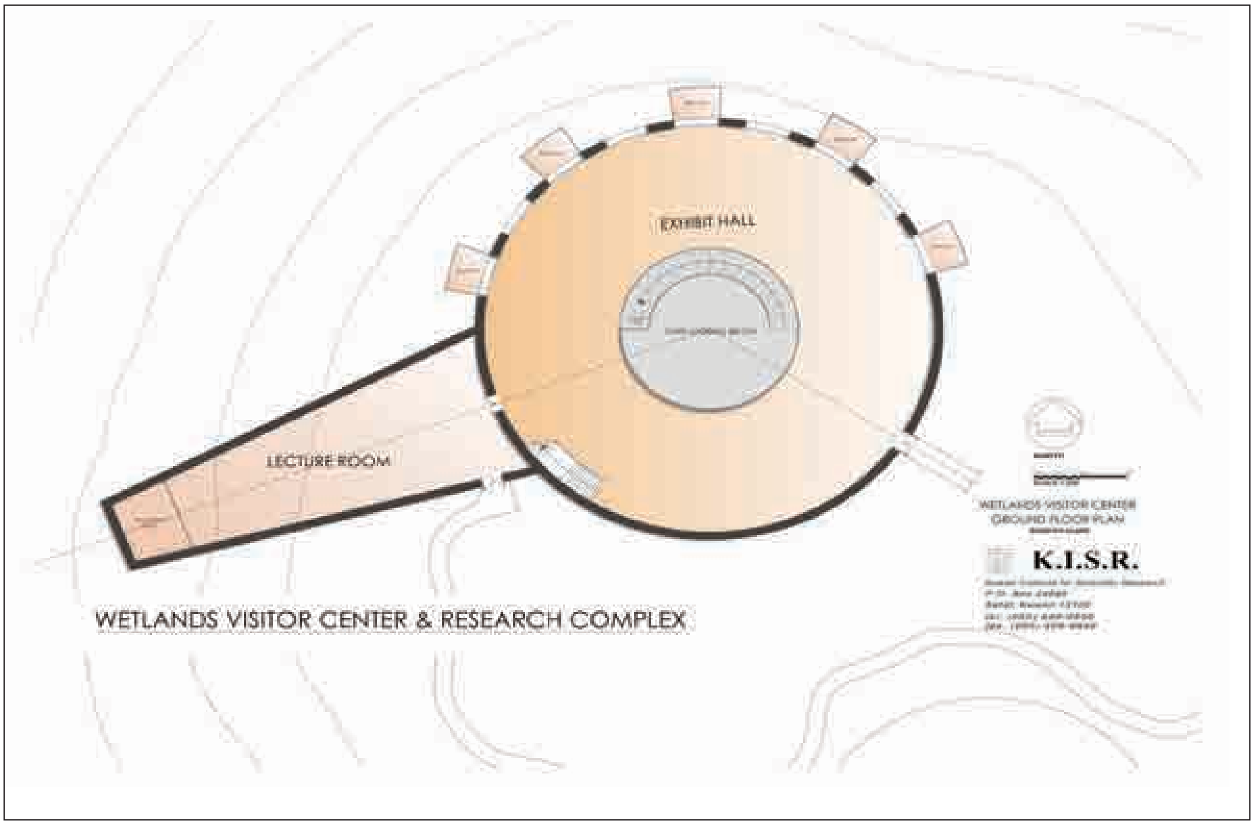

Fig. 24. Wetlands visitor center ground floor plan

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Fig. 25. Wetlands visitor center interior viewing area

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Ecology and Environment of Boubyan Island in Kuwait

Isolated in the northwestern corner of the Arabian Peninsula, Boubyan Island remains intact with natural resources enriched by the fresh water from the Euphrates and Tigris rivers.

This book represents the most comprehensive database on the Island provided by the Kuwait Institute for Scientific Research (KISR) based on field studies from 2004 to 2006. It includes hundreds of images and illustrations with scientific information related to: habitats, geomorphology, air quality, soil and topography, wildlife and vegetation, weather and marine life, environmental impact assessment and sustainable master planning for future development. Incorporating a diverse range of scientific and ecological planning expertise, this work provides a foundation and background for an integrated, environmentally driven development approach to sustain the island's natural systems and processes.

"This scientific analysis conducted on Boubyan and Warbah Islands provides strong justification for decision makers to conserve the habitats and biodiversity of these islands. This has resulted in the establishment of the Mubarak Al Kabeer Marine Reserve in the north of Boubyan Island, covering about 60% of its total area."

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ISBN: 978-99966-37-08-7
90000
9 789996 637087

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