The Status of Coastal and Marine Habitats two Years after the Gulf War Oil Spill.

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2 authors, including:

Friedhelm Krupp
Senckenberg Research Institute

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Abdulaziz H. Abuzinada & Friedhelm Krupp (Editors)

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Commission of the European Communities, Brussels
National Commission for Wildlife Conservation and Development, Riyadh

Front cover

The 1991 oil spill killed numerous mangroves by smothering their pneumatophores. Even two years after the oil spill, liquid oil is still seeping from the ground.

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Series editor:
Prof. Dr. Willi Ziegler, Senckenbergische Naturforschende Gesellschaft, Frankfurt a.M.

Editors:
Prof. Dr. Abdulaziz H. Abuzinada, Secretary General, National Commission for Wildlife Conservation and Development, P.O. Box 61681, Riyadh 11575, Kingdom of Saudi Arabia.
Dr. Friedhelm Krupp, Forschungsinstitut Senckenberg, Senckenberganlage 25, D-60325 Frankfurt a.M., Germany.

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PREFACE

H.R.H. Prince Sultan bin Abdulaziz Al Saud
Second Deputy Premier
Minister of Defence and Aviation
Chairman, Board of Directors
National Commission for Wildlife Conservation and Development

The Arabian Gulf embraces a wide range of coastal and marine habitats, including coral reefs, seagrass beds, salt-marshes and mangrove stands. The area supports large populations of residential, wintering and breeding birds, among them cormorants, grebes, waders and terns. The region's rich, and in many respects unique plant and animal life, which has adapted in a most remarkable way to the harsh environment, is of great scientific, educational, economic and recreational value. Conscious of its responsibility towards God's creation, the Government of the Kingdom of Saudi Arabia has always given the highest priority to the protection of these natural resources.

When Iraq waged its war against the region, the Gulf's coastal and marine ecosystems were suddenly put at risk. No one will ever know the exact amount of oil that was deliberately released into this shallow sea, but there is no doubt that the magnitude of the oil slicks was without precedent, creating the largest oil spill in human history. The Kingdom's environmental agencies were at the front line when an immediate response to the oil spill was required. A Wildlife Rescue Centre was established in Jubail Industrial City. The Royal Commission for Jubail and Yanbu (RCJY) provided the facilities and logistical support, while the National Commission for Wildlife Conservation and Development (NCWCD) provided the expertise. The Centre was manned by volunteers from the military and the civilian population.

An oil spill of this size had never been tackled before and international cooperation, the pooling of knowledge and experience, and pragmatic approaches to problem-solving in the field of wildlife conservation became indispensable. The establishment of a Marine Habitat and Wildlife Sanctuary in the area between Jubail and Ras az-Zaur had been suggested long before the war, but following the oil spill disaster, it became an unprecedented challenge. The integrated research and management approach, initiated by the Commission of the European Communities, proved to be the appropriate response to this challenge. It will have a lasting effect on the quality of our environment.

In October 1991 a joint, interdisciplinary team of Saudi Arabian and European scientists took over the facilities of the Wildlife Rescue Centre. These experts have continuously surveyed and monitored the ecological effects of the war over a period of more than two years. In this volume, they are presenting the first results of their research work.

Finally, I wish to extend my sincere thanks to the Commission of the European Communities for their initiative and their continuous support of our endeavour to restore the Gulf environment. Special thanks are due to the Saudi and the international team of scientists for their hard work and their help to secure the survival of the Gulf's unique wildlife.

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INTRODUCTION

The Arabian Gulf environment and the consequences of the 1991 oil spill

Abdulaziz H. Abuzinada & Friedhelm Krupp

THE GULF AND ITS LIVING RESOURCES

The Indo-Pacific Ocean has the highest biological diversity of all seas. The Arabian Gulf, one of its branches, carries this tropical Indo-Pacific flora and fauna far north, but most of its species assemblages are less diverse and the degree of endemism is lower than in other similar marginal seas, such as the Red Sea. The present oceanographic conditions determine the low diversity while the scarcity of endemic species reflects the recent geological history.

The Gulf is an almost enclosed, shallow, epicontinental sea (Plate 1) with an average depth of only 35 m. Its greatest depth does not exceed 120 m. During the Pleistocene glacials, the sea level of the world's oceans dropped by about 120 m, resulting in a desiccation of the Arabian Gulf basin and an eradication of its marine life. The transgression began only 17,000 years B.P., when the Gulf was again colonised by Indo-Pacific flora and fauna. It reached its present level only 7000 years ago (KASSLER 1973). Biota of the Arabian Gulf are thus of post-Pleistocene age, leaving little time for speciation processes.

The Gulf is connected with the Indian Ocean through the Strait of Hormuz. Water circulation through this narrow entrance is restricted. Surface water from the Indian Ocean flows into the Gulf. In a generally counter-clockwise circulation pattern, it moves north-west along the Iranian coast and then turns back south-east along the Arabian shores. Its salinity gradually increases and the heavy, saline water sinks and moves out of the Gulf at the bottom of the Strait of Hormuz. Turnover time has been

Plate 1 a: Map of the Arabian Gulf showing the position of the Jubail Marine Wildlife Sanctuary. (From KULLMANN 1993, courtesy WWF Frankfurt).

Plate 1 b: Detailed map of the study area north of Jubail, Saudi Arabia. (From KULLMANN 1993, courtesy WWF Frankfurt).

estimated at 3-5.5 years (HUNTER 1986). Pollutants are thus likely to remain inside the Gulf for considerable periods of time. Due to the semi-enclosed nature of the Gulf, the tidal regime is rather complex. In most parts it follows a semi-diurnal pattern. The tidal range varies between 0.8 and 4 m.

The Arabian Gulf is flanked by deserts. Besides the scarce rainfall, the only freshwater input is derived from the Shatt al-Arab and the rivers of Iran, but evaporation by far exceeds freshwater influx. In almost all parts of the Gulf salinities are above 40 ppt. In the Gulf of Salwa they may reach as much as 70 ppt. The Gulf region is characterised by a pronounced seasonality and water temperatures at the surface may be as low as 11 °C in winter. In summer they may climb to almost 40 °C. High sedimentation rates result in high turbidity and decreased light penetration. All these factors contribute to a naturally stressful environment.

The present knowledge of the marine ecology of the Gulf is summarised in SHEPPARD et. al. (1992). BASSON et al. (1977) give a detailed account of biotopes of the western Arabian Gulf and JONES (1986) provides a field-guide to the flora and fauna of its shores. On the Arabian side, the shores are shallow and mainly sandy or silty, with very few rocky outcrops (Plate 2). Shoals and sand banks are characteristic of nearshore areas. The intertidal zone, which covers a vast area, has a wide range of habitats, which include mud-, sand-, and rockflats, sand and pebble beaches and tidal creeks. While high summer temperatures and the tidal regime limit the distribution of intertidal macroalgal mats, cyanobacterial mats, salt-marsh and mangrove areas are highly productive ecosystems. Productivity of the water column lies within the expected range of this latitude. Macroalgal beds, seagrass beds and coral reefs are the most productive subtidal habitats.

Compared to other parts of the tropical Indian Ocean, the occurrence of coral reefs is very limited and their development and diversity are rather low. The best developed reefs occur offshore. Some of them support vegetated coral cays (SHEPPARD & SHEPPARD 1991; Fig. 1, Plate 3). In general, most intertidal and marine species assemblages are of low diversity, but abundances of certain species are locally very high. Most invertebrates are still at the beginning of their taxonomic investigation. Fishes are slightly better known. More than 500 species occur in the Gulf (KRUPP 1991), many of which have not yet been reported in the scientific literature. The Gulf hosts important populations of marine turtles, which are possibly genetically isolated from their relatives in other parts of the Indian Ocean.

Fig. 1: Map showing the position of the Gulf offshore islands

The small islands of Jana and Karan off the coast of Saudi Arabia are the primary nesting sites of hawksbill and green turtles (Plate 9). The Gulf region lies on the West Asian Flyway. It is an important refuelling stop on wader migration routes. The offshore coral cays are breeding sites of international importance for several species of terns. Other birds, such as the Socotra cormorant, are more or less restricted to the Gulf region (SYMENS et al. 1993, SYMENS & SUHAIBANI 1993). The Arabian Gulf supports a relatively large number of dugongs and several species of cetaceans.

Although biological diversity is lower than in other parts of the tropical Indian Ocean, the plant and animal life of the Gulf is remarkable in its adaptation to an extreme environment. Under these naturally stressful conditions, many species live at the limit of their range. They are thus particularly susceptible to man-induced changes. With the discovery of the world's largest oil fields a rapid development started. Millions of people migrated to an area which once supported only a small population. The construction of cities and industrial installations required dredging and landfill which destroyed valuable habitats. With an increased demand for fish and shellfish, artisanal and industrial fisheries are constantly expanding and the possibility of overfishing requires attention. The Gulf is also a major source of freshwater and today it has the world's greatest

Plate 2: The Gulf is a shallow, epicontinental sea. Most of its shores are composed of soft, sandy or muddy substrates. Rocky shores, such as at Ras al-Abkhara (= Ras al-Bukhara) in the background are rather rare.

Plate 3: Five tiny islands off the coast of Saudi Arabia are the most important breeding sites of terns and the most important nesting sites of marine turtles in the entire Gulf. They are surrounded by large coral reefs. This photograph shows Kurain Island.

Plate 4: Two years after the Gulf War oil spill many of the oil-impacted shores are still covered by a continuous band of oil and tar.

Plate 5: On most of the beaches the oil penetrated up to 30 cm deep into the substrate. However, in exceptional cases Project members measured up to 50 cm penetration depth. This photograph illustrates the situation in Dawhat ad-Dafi about eight months after the oil spill.

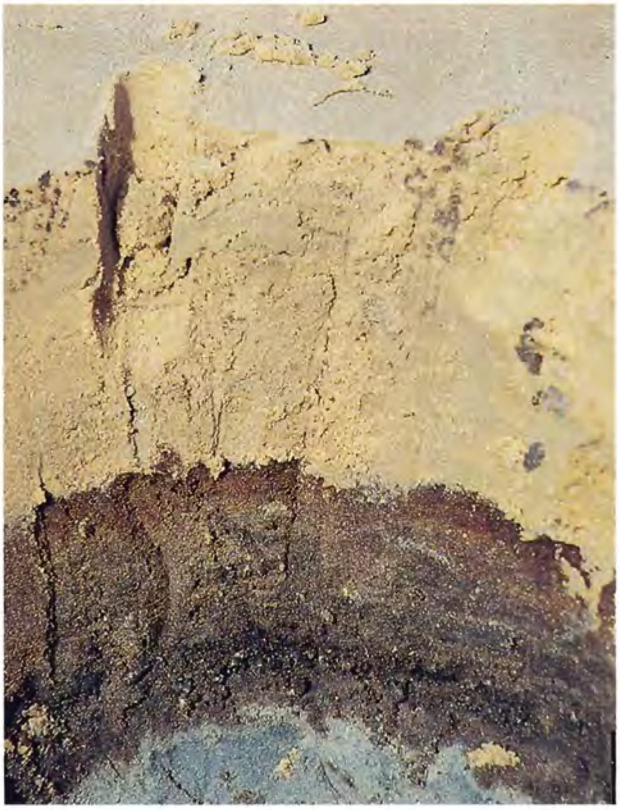

Plate 6: Two years after the oil spill many of the oiled beaches are covered by a new layer of clean sand which covers the oiled sediments. The layer underneath the oil is anaerobic.

concentration of desalination plants. Solid waste and other forms of pollution are a major concern. Natural seepage of oil into the Gulf has been known since ancient times, but after large-scale production started, the level of oil pollution constantly increased. MICHEL et al. (1986) estimated that within 10 years, 1.5 million tonnes of oil are released into the Gulf as a result of normal oil production and transport operations. In their development plans the Gulf countries prepare to cope with such an amount.

THE 1991 GULF WAR OIL SPILL

The largest oil spill in human history hit an environment that was already subjected to natural and man-induced stress. In August 1990 Iraqi troops invaded Kuwait. On 16 January 1991 the Gulf war broke out when the allied air force struck a first blow on Iraqi positions. Allied ground forces entered the war on 25 February and three days later Kuwait was liberated. Between 20 January through May 1991 millions of gallons of crude oil were intentionally released into the Arabian Gulf (SADIQ & MCCAIN 1993). Nobody will ever be able to determine the exact amount of spilled oil. Estimates range from 2 to 11 million barrels, but 6 to 8 million barrels (ca one million tonnes) seems most likely. Driven by the prevailing winds, the oil slick moved south along the Saudi Arabian coast. When the wind direction changed, the oil was washed ashore. Over 700 km of coastline between southern Kuwait and north of Jubail were covered by a continuous band of oil. The islands of Batina and Abu Ali prevented the slicks from drifting further south. Most of the oil accumulated in Marduma Bay just north of these islands.

In many areas, winds combined with extremely high tides carried the oil far inland. The intertidal zone was severely affected, with the upper intertidal being completely inundated with oil (Plate 4). On most shores maximum penetration depths ranged between 2 and 30 cm (Plate 5). In exceptional cases they reached 50 cm, above all where animal burrows carried the oil deeper into the sediment (JONES & RICHMOND 1992). However, only a few months after the spill, the extent of the oil-impacted area was difficult to assess, since much of the oiled sediments were rapidly covered by clean sand (Plate 6).

The mid- and upper intertidal zone lost most of its typical plant and animal communities. The lower intertidal was only partly affected and revealed a patchy pattern of oil contamination (JONES & RICHMOND 1992). The heads of sheltered bays were most severely affected. Large areas of salt-marshes and mangroves along with their associated fauna were killed. Among vertebrates, marine birds suffered most from the spill and oil-covered cormorants struggling to escape from the slick will remain a symbol of this act of ecological terror.

Contrary to earlier predictions, there is no evidence of any large-scale sinking of oil and the damage to subtidal benthic habitats was very limited. Even in Marduma Bay, where heavy oil slicks persisted for more than three months, there was hardly any visible sign of subtidal oiling. Low amounts of oil reached the seafloor after having been attached to suspended sediments, or after erosion of oiled intertidal sediments (JONES & RICHMOND 1992, MICHEL et al. 1993). Macroalgal beds, seagrass beds and coral reefs escaped oil contamination, but fish and shrimp populations obviously were affected (MCCAIN & HASSAN 1993, MATHEWS et al. 1993).

Saudi Arabia, with the help of many countries and international organisations, managed to contain this oil spill. The Meteorology and Environmental Protection Administration (MEPA), the Royal Commission for Jubail and Yanbu (RCJY), the National Commission for Wildlife Conservation and Development (NCWCD), Saudi ARAMCO, the International Maritime Organization (IMO) and several private contractors participated in the oil recovery and wildlife rescue operations. By mid-June 1991, the Kingdom of Saudi Arabia had recovered the record amount of over one million barrels of oil and managed to protect the coastal infrastructures successfully (TAWFIQ & OLSEN 1993). The oil was deposited in interim storage pits where it continued to pose a threat to wildlife until it was completely removed. On Qurma Island immediately after the spill IMO contractors flushed free-floating oil from heavily impacted mangrove areas with low-pressure techniques. The oil was then skimmed and collected for disposal. This clean-up obviously saved numerous mangroves. On Karan 14,000 m^3 of oiled sediment were removed from the shoreline and replaced by clean sand from the interior of the island to allow turtles a pollution-free access to the beaches.

Two years after the war, it is obvious that there are no long-term effects of the oil spill on subtidal ecosystems, such as macroalgal beds, seagrass beds and coral reefs. Fish populations, turtles and marine mammals are in a healthy condition. In the intertidal area the picture is much more complex: The lower eulittoral and the subtidal fringe have largely recovered. The upper intertidal and the supratidal fringe are still covered by an almost continuous band of oil and tar. While limited recolonisation by the original

Plate 7: Two project ornithologists are cleaning an oil-fouled duck at the Jubail Field Research Centre.

plant and animal communities occurs on high-energy sandy beaches and rocky shores (Plate 8, mudflats and salt-marshes in sheltered bays show almost no sign of recovery. Population densities on the impacted shores remain much lower than on unaffected control sites, but in general there is a trend towards recovery with species diversity and population densities increasing (KRUPP & JONES 1993).

THE EC/NCWCD WILDLIFE SANCTUARY PROJECT

The NCWCD is mandated with the conservation and scientific study of Saudi Arabia's biological diversity. The ecological damage caused by the Gulf crisis posed a formidable challenge to which NCWCD responded by setting up an animal rescue centre and launching habitat restoration programmes in conjunction with several other organisations. In February 1991, the NCWCD and the RCJY set up the Wildlife Rescue Centre in Jubail Industrial City, manned by volunteers who were trained by the Royal Society for the Prevention of Cruelty to Animals, U.K. This centre treated more than 1500 birds, besides marine turtles and sea snakes (Plate 7). The survival rate of birds treated in the Centre ranged from less than 10 % for grebes to 60 % for Socotra cormorants. The centre also played an important role in the promotion of public

Plate 8: Desert hyacinths (*Cistanche tubulosa*) grow through a heavily oiled strandline.

environmental awareness (ABUZINADA et al. 1991, ABUZINADA 1993, SYMENS & SUHAIBANI 1993).

The magnitude of this spill required an international response. During the war, the European Community seconded a task force to the concerned authorities in Saudi Arabia. In conjunction with NCWCD, MEPA and King Fahd University of Petroleum and Minerals (KFUPM), an environmental response plan for habitat assessment and remediation, habitat protection and wildlife rehabilitation was drafted. On the basis of this plan, which constituted a comprehensive environmental initiative, the establishment of a "Marine Habitat and Wildlife Sanctuary for the Gulf Region" was suggested. This was an unprecedented challenge, since the area earmarked for protection, the embayment systems of Dawhat al-Musallamiya and Dawhat ad-Dafi, and five offshore islands (Plate 1, Fig. 1), were severely impacted by the oil spill.

The Senckenberg Research Institute of Frankfurt a.M., Germany, in conjunction with an international, multidisciplinary team of ca 40 scientists from six EC countries was commissioned with the implementation of the Project. Coordinated by NCWCD, about 30 Saudi Arabian and Kuwaiti scientists joined the Project which started in October 1991. The facilities of the former Wildlife Rescue Centre were re-equipped to serve as a Field Research Centre. Objectives of the project are:

- To assess the damage caused by the oil spill on coastal and marine habitats and biota
- To develop a methodology for the restoration and enhancement of coastal and marine habitats and biota which could serve as an example for the region
- To assess and document biological diversity and address on a manageable spatial scale the largest possible number of conservation needs, with an emphasis on those requiring urgent attention after the oil spill
- To contribute to an integrated management approach which has a lasting effect on environmental quality in the region

The overall aim of the Project is the restoration and maintenance of the area's biological diversity and productivity (KRUPP & JONES 1993).

The damage caused by the Gulf War has triggered numerous research projects. Before the crisis, our knowledge of the Arabian Gulf environment was very limited, but after the war more studies have been conducted than in the entire period before 1991. The western Arabian Gulf will soon be one of the better known subtropical seas. Several projects were initiated and scientists from all over the world visited the area. However, the disadvantage of short-term studies on such complex issues is that their results are often non-conclusive. The EC/NCWCD Wildlife Sanctuary Project has carried out research, survey and monitoring programmes in the area continuously for over two years and is thus able to provide authoritative information on the effects of the oil spill on habitats, plant and animal communities and the progress of recovery. This volume summarises first results on the environmental effects of the oil spill. A more detailed account of the Pro-

Plate 9: Green turtles mating near Karan Island.
A significant portion of the turtles of the Arabian Gulf nest on the shores of Karan.

ject's activities and scientific results, including conservation aspects, will be published later this year.

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It is with great pleasure that we acknowledge the support the Gulf Wildlife Sanctuary Project by H.R.H. Prince Sultan bin Abdul Aziz Al-Saud and H.R.H. Prince Saud bin Faisal bin Abdul Aziz. Our sincere thanks are due to H.H. Prince Abdullah bin Faisal bin Turki Al-Abdullah Al-Saud for his continuous encouragement. We wish to thank Dr. Abdulbar Al-Gain, President, Dr. Nizar Tawfiq, Vice President of MEPA, and Dr. Ibrahim Alam most sincerely for their cooperation. We are most grateful to the following for help, information and suggestions: Dr. Eugene Joubert, Mr. Muhammad S.A. Sulaym, Mr. Burhan Qari and Mr. Yusef Al-Wetait, NCWCD; Mr. Husni Raziq, Mr. Abdul Halim Al-Momen, Mr. Aziz Al-Omri and Dr. David Olsen, MEPA; Dr. Muhammad B. Amin and Dr. Assad Al-Thukair, KFUPM; Dr. Abdurrahman Al-Shihri and Dr. Abdurashid Nawwab, ARAMCO. We wish to thank Lt.-Col. Abdurrahman Al-Nafie and his staff at the Coastguard, and Captain Saud Al-Balawy and his staff at the Royal Saudi Navy, Jubail, for the help they provided to the project. Prof. Dr. Willi Ziegler, Director of the Senckenberg Research Institute, is gratefully acknowledged for his continued support. At the Commission of the European Communities, Brussels, Mr. Robert Houliston, Mr. Michael Bahr, Dr. Hartmut Barth, Dr. Aristotelis Gavriliadis, Mrs. Rosmarie Reuß and Mrs. Barbara Jeffrey continuously supervised and supported the project. Mrs. Pascale Symens skillfully prepared the scientific and technical drawings in this volume. Finally, our sincere thanks go to the project scientists for their commitment, their hard work and their willingness to take up general project duties far beyond their research and management obligations.

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Environmental effects of the Gulf War on coastal areas north of Jubail - an overview

Hans-Karl Barth & Axel Niestlé

A b s t r a c t: The environmental effects of the 1991 Gulf War on ecosystems in the area between Abu Ali and Ras az-Zaur on the Saudi Arabian Gulf coast are described. The oil was deposited as a thick layer in a narrow, linear strip in the high tide zone. Damage to the fragile vegetation cover of the inland areas was caused mainly by the passage of vehicles during military activities. This has led to a partial remobilisation of sand formerly stabilised in sand sheets and fossil dunes. This reactivating process is self-accelerating and serious effects on the ecosystem in the medium and long-term scale are to be expected.

الآثار البيئية لحرب الخليج على المناطق الساحلية شمال الجبيل، نظرة عامة

هانز كارل بارث واكسل نيرستلة

خلاصة: جرى وصف التأثيرات البيئية لبقعة الزيت على النظم البيئية في المنطقة الواقعة بين جزيرة أبوعلي ورأس الزورعلى الساحل السعودي من الخليج العربي. وقد لوحظ أن الزيت قد تسرب على شكل طبقات سميكة في شريط طولي ضيق بمنطقة المد العليا وأن الأضرار التى لحقت بالغطاء النباتي الهش على اليابسة يعود بشكل رئيسي إلى مرور المركبات خلال العمليات العسكرية مما أدى إلى تحريك جزئي للرمال التي كانت قد استقرت على شكل أسطح رملية وكثبان أحفورية. وهذه العملية النشطة تتسارع ذاتياً وبالتالي فإنه من المتوقع حدوث أثار خطيرة على النظام البيئي على المدى المتوسط والطويل.

INTRODUCTION

In general, semi-desert and desert environments are characterised by a particularly high sensitivity to human activities. The 1991 Gulf War caused an ecological disaster in terrestrial, coastal and marine ecosystems resulting in extensive degradation and a destabilisation of the environmental equilibrium. In the Arabian Peninsula coastal areas were most seriously affected. The stretch of shoreline between Ras az-Zaur and Abu Ali was surveyed by the authors in November/December 1991 and March/April 1993 in order to identify and analyse the environmental impact within this area. Some of the results of these surveys are presented here.

PHYSIOGRAPHY OF THE STUDY AREA

The area under consideration is part of the central coastal lowlands of the Eastern Province of Saudi Arabia (Fig. 1). From its western boundary, marked by the eastern escarpment of the Summan Plateau, the region descends gently to the coastal plains (AL-SAYARI & ZÖTL 1978, BARTH 1980). The coastline is characterised by a wide intertidal zone. Most of the inland area is covered by quaternary sand and gravel deposits with the sandy fraction accumulated in stabilised dunes or sand sheets. These sediments, which are sometimes consolidated as calcretes, occur as beach rock formations or underlie the sand sheets and dunes.

Prominent features in the topography of the area are widely rolling dune systems which are stabilised by a cover of vegetation. Longitudinal sand ridges, representing fossil dunes, stretch in a generally north-south direction. Dune crests rise 20 m above broad interdunal corridors, forming the typical undulations of a transversal dune system. On the periphery of the dunes are sand sheets. The sand in these plains may be up to 10 m thick, covered and stabilised by up to 30 % vegetation cover.

Sabkhas occur in coastal and inland areas. They may cover several hundred square kilometres as is the case for Sabkhat Murair and Sabkhat al-Fasl northwest of Jubail. Salt-marshes have developed in the low-lying, periodically flooded parts of the coastal sabkhas though, in general, the sabkhas are devoid of vegetation. A zone of halophytes may, however, be found along the edge of a sabkha and these give rise to micro-hummocks due to the accumulation of wind-blown sands (Plate 1). Since the prevailing wind direction is north, these "Kuthban" are oriented north to south.

The Eastern Province of Saudi Arabia including the coastal areas of the Arabian Gulf belongs to the arid part of the subtropical belt, which has a Mediterranean type of climate regime (BARTH 1976). Rainfall is very irregular and confined to the winter and early spring. The mean annual rainfall in the study area is 80 to 100 mm. Temperatures rise to more than 40 °C during the months of April through September, whereas values below 10 °C may occur during December through February. Evaporation rates of up to 3000 mm/yr combined with low precipitation are responsible for the high degree of aridity and desert climate of the area. The aridity limits both the vegetation growth and the diversity of plant communities. In general, the diffuse perennial vegetation cover is less than 15 %. The intershrub spaces are bare for much of the year but are occupied for a few weeks by a ground layer of rainy season ephemerals. The total number of species contributing to desert vascular plant biomass is relatively small. The vegetation in the area is described in BÖER & WARNKEN (1992).

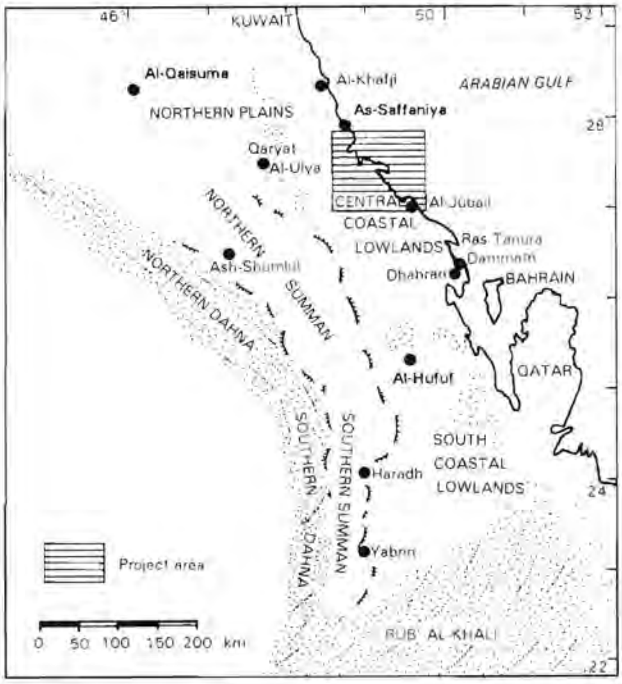

Fig. 1: Physio-geographic regions of eastern Saudi Arabia.

ECOLOGICAL EFFECTS OF THE GULF WAR

Carried by the prevailing currents in the northwestern part of the Arabian Gulf, the oil slicks reached the coastal water of the Project area around mid-March 1991 (Fig. 3). The islands and bays of the study area formed a natural trap for the oil which subsequently accumulated in the embayments in large quantities. Wide areas of the intertidal zone were covered by the oil. Due to the physiographic characteristics of the coast, part of the oil was carried far inland and into some of the sabkhas. The field survey along the coastline, in cooperation with other work in this Project (JONES et al. 1994), showed that the oil coverage in the immediate littoral fringe was restricted almost entirely to the high tide zone. The area of cover was determined by the physiographic zonation. In the upper intertidal zone

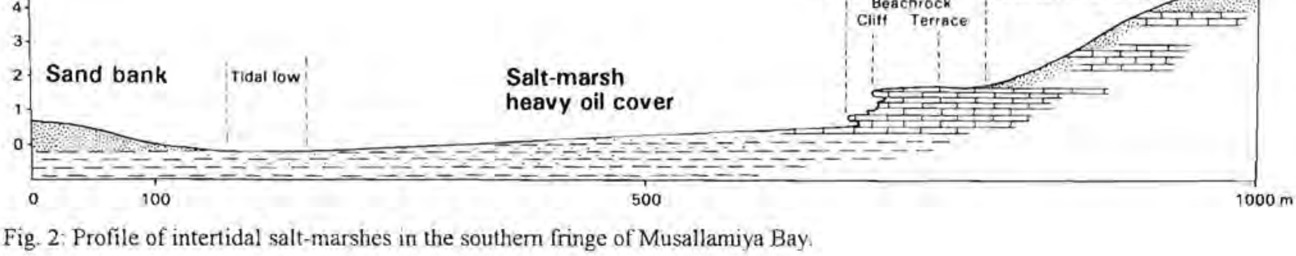

Fig. 2: Profile of intertidal salt-marshes in the southern fringe of Musallamiya Bay.

Plate 1: Coastal sabkha with "Kuthban" in Dawhat ad-Dafi.

it was linear and often patchy, whereas the affected low level areas of the salt-marshes or sabkhas displayed a wide areal cover by the oil. Impermeable tar mats became a semi-permanent feature particularly in the littoral fringe and in the upper eulittoral. However, on rocky shores the oiled layer has started to peel off.

Observation of the spatial distribution and thickness of oil-contaminated sediments leads to the conclusion that, besides the existence of local natural and artificial oil traps, the beaches exposed to the north and the north-east suffered most in terms of the total amount of oil that came ashore. This was due to the prevailing currents and wind directions during the arrival of the oil (Fig. 3).

Measurements of the depth of the oil in impacted sediments indicated a penetration range between 2 and 50 cm. The oil content of sediment samples varied between 5 % and 25 % depending on the topography and texture of the sediments. Usually, a thin layer of residual oil components and algae overlay a completely oiled zone of varying thickness. A partly affected deeper zone was reached by the oil through permeable sands or via animal burrows. In the deepest zone the oil often remained liquid. In some places underlying beach rock prevented deeper penetration of the oil (HAYES et al. 1993).

Below the surface, some horizons of oil residuals were found which almost certainly dated back to earlier spills. Continuous sedimentation either by aeolian or marine processes has covered some of the recently oil-affected beach sediments. The complete spatial distribution and the thickness of these deposits can only be detected by a grid of boreholes.

Additional environmental damage was caused by the Allied Forces. During their assembly prior to the start of the ground campaign against Iraq, a large portion of the northern part of the Project area was used for training and live-fire exercises by infantry and armoured units. The debris from these live-fire exercises are still evident at numerous sites around Musallamiya Bay. The area is widely covered with tracks of vehicles including tanks, and in the stabilised dune fields and flat sand sheets the physical damage to the vegetation is locally quite serious. The continuous degradation of the vegetation and the physical disturbance of the sandy soils has resulted in a marked reactivation of the sand between autumn 1991 and spring 1993. Deflation forms were detected in many places on both the sand sheets and the dune fields. The degree of uncovering of the roots of hummock-forming plants reveals this rapid process in an area where strong winds prevail for about 700-1000 h a year. During the 'Shamal' period

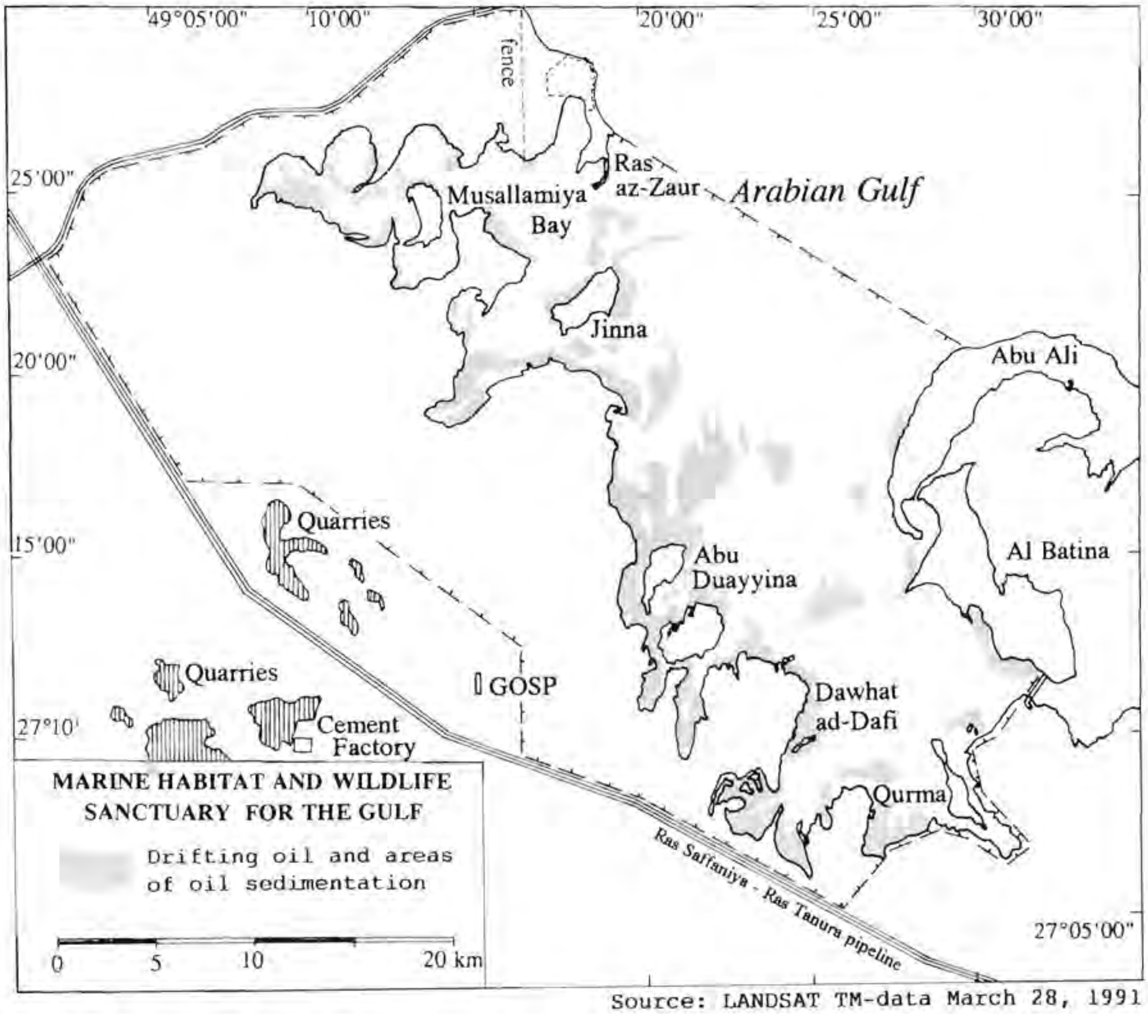

Fig. 3: Drifting oil and areas of oil accumulation in the study area.

between April and September wind velocities may exceed 10 m/sec. The presence of giant sand ripples, sometimes several metres long and about 30 cm high, documents the restoration of some areas as sand sources. New parabolic and/or barchane type dunes can be observed as a consequence of the accumulation of wind-transported sand.

A vegetation cover of 8-10 % is sufficient to reduce aeolian dynamics, thereby preventing large sand movements even during the windy season. Areas with a lower cover must be considered as potential deflation areas during strong winds.

The main damage caused by the oil spill occurred on beaches exposed to the north and in the intertidal salt-marshes and coastal sabkhas. The coverage of oil and residual components on rocky parts of the coast is limited to a narrow linear band in the high tide zone. Thick layers of oiled sediment occur in large areas of the intertidal zone, in salt-marshes and coastal sabkhas. These semi-terrestrial ecosystems are seriously affected not only by the surficial oil deposit but more importantly by the penetration of oil into the sediment.

Both the oil accumulation in the coastal areas and the aeolian processes in the inland areas require extensive countermeasures. The restoration of the original balanced equilibrium in the coastal and terrestrial ecosystems will be difficult.

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Authors' addresses:
Prof. Dr. H.-K. Barth, Universität Paderborn, FB 1 - Physische Geographie/PGS, D-33095 Paderborn, Germany.
Dr. A. Niestlé, Hertzbergstr. 3, D-12055 Berlin, Germany.

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Distribution, species composition and status of the intertidal blue-green algal mats

Lucien Hoffmann

A b s t r a c t: Before the 1991 Gulf War extensive blue-green algal mats covered the intertidal zone, most of which were severely affected by the subsequent oil spill. By mid-1992, areas where the tar layer had been covered by sediment were recolonised. Different types of mats with a marked zonation were observed.

مواقع وجود ابسطة الطحالب الخضراء المزرقة وتركيبة انواعها وحالتها الراهنة

لوسيان هوفمان

خلاصة : قبل حدوث بقعة الزيت كانت ابسطة كثيفة من الطحالب الخضراء المزرقة تغطي منطقة ما بين المد والجزر. وقد تأثر معظم هذه الابسطة الطحلبية بالزيت بدرجة كبيرة، ولكنها عادت لتظهر مرة ثانية بحلول منتصف عام ١٩٩٢م على السطوح الملوثة بالزيت حيث غطت الرسوبيات طبقة القار. وقد لوحظت عدة أنواع من الابسطة الطحلبية المتمنطقة إلى نطاقات واضحة.

Extensive blue-green algal mats covered the intertidal zones in the study area before the oil spill as can be seen from pre-oil-spill satellite images (AL-THUKAIR & AL-HINAI 1993). Different mat morphologies could be distinguished, the most widespread can be described as either folded mats, pinnacle mats, flat mats or polygonal mats (HOFFMANN in prep.). The morphology of these different mat types is related to their species composition and to the environmental factors in which they grow (e.g. tidal regime, drainage, sedimentation rates, degree of exposure to wave action, etc.). The most common taxa in these mats are filamentous blue-green algae belonging to the genera *Lyngbya, Microcoleus, Phormidium* and *Schizothrix*. In some salt-marshes, the heterocystous genus *Scytonema* is also of importance.

Following the oil spill, most of the intertidal mats were severely affected; living mats survived only in the upper intertidal (supralittoral) zone and in some areas protected by physical barriers. In the affected places, the algal mats were either soaked with oil or covered with an oil layer which subsequently solidified to form a more or less thick tar layer. Two years after the oil spill, no sign of blue-green algal growth is observed in the areas where the tar layer is still on the surface and not covered by sediments. Sediment cover seems to be a prerequisite for the recolonisation by blue-green algae. In those parts of the intertidal zone where the tar is covered by a sediment layer, extensive growth of blue-green algal mats occurred in a short time. A marked zonation of mat types was observed, the most important being flat, polygonal, black and orange pinnacle mats. The most common blue-green algal species in these newly established mats are *Microcoleus chthonoplastes* and *Lyngbya aestuarii*. The pinnacle mats (Plate 1) represent a complex laminated microbial ecosystem in which blue-green algae are associated with purple sulphur bacteria. The polygonal mats (Plate 2) play an important role in the cleaning of the polluted coasts. When dry for a long period, these mats curl up at the edges, breaking away from the substrate below and lifting off the tar layer with them, leaving exposed sediment or fresh oil/tar below. This is then open for further weathering, sedimentation and colonisation by the next layer of algal mat and for the recruitment of opportunistic animal species.

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Author's address:
Dr. L. Hoffmann, Université de Liège, Département de Botanique, B. 22, B-4000 Liège, Belgium.

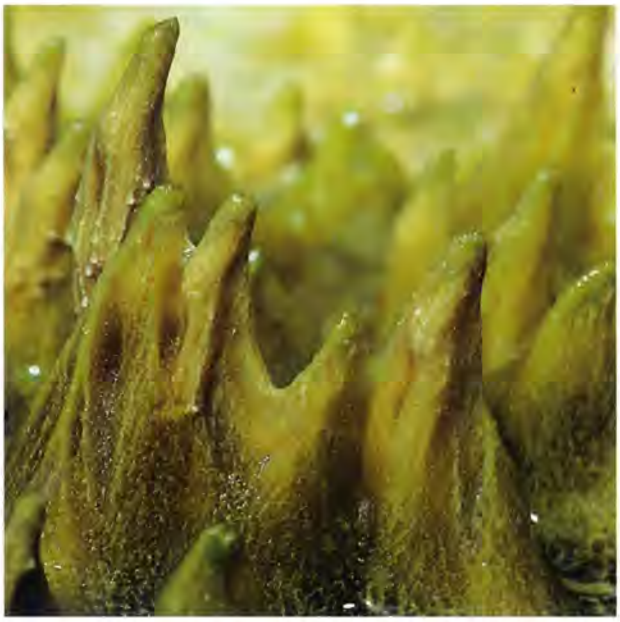

Plate 1: Orange pinnacle mats occur towards the lower edge of the oiled intertidal zone.

Plate 2: Polygonal mats form a continuous belt seaward of the salt-marshes on oiled shores.

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Status of the macroalgae and seagrass vegetation after the 1991 Gulf War oil spill

Olivier De Clerck & Eric Coppejans

A b s t r a c t: The intertidal zone of the Saudi Arabian Gulf coast is almost devoid of macroalgae or seagrasses, even in non-polluted sites. Because of the extreme climatic conditions these plants are restricted to subtidal habitats which have not been affected by the oil spill. Their diversity in the Dawhat ad-Dafi and Dawhat al-Musallamiya area is at least as high as in other similar regions of the Gulf. Their biomass can locally be very high, at least during part of the year. A species list of the Chlorophyta, Phaeophyta and Rhodophyta from the region is included.

حالة الطحالب الكبيرة والحشائش البحرية عقب حدوث بقعة الزيت عام ١٩٩١م

أولفر دوكليرك وأريك كوبيجانز

خلاصة: تخلو منطقة مابين المد والجزر على الساحل السعودي للخليج العربي تقريباً من الطحالب الكبيرة والحشائش البحرية حتى في المواقع التي لم تتلوث. وبسبب الظروف المناخية المتطرفة فإن وجود هذة النباتات يقتصر على بيئات ما تحت المد والجزر التي لم تتأثر ببقعة الزيت وكان تنوعها في منطقتي دوحة الدفي ودوحة المسلمية لايقل عنه في المناطق المماثلة الأخرى من الخليج وقد تكون كتلتها الحية على النطاق المحلي عالية على الأقل خلال فترة معينة من العام. ويتضمن البحث قائمة بأنواع كل الطحالب الخضر Chlorophyta والطحالب البنية Phaeophyta الموجودة في المنطقة.

INTRODUCTION

The seagrasses and macroalgae of Saudi Arabia north of the Jubail area had never been studied from a biological point of view before the 1991 oil spill. The only recent data with which we can compare our results are those of BASSON (1979a, b) on the seaweeds of the Arabian Gulf Coast of Saudi Arabia and those of AL HASAN & JONES (1989) on the marine algal flora and seagrasses of the coast of Kuwait.

MATERIALS AND METHODS

The well pronounced seasons result in a wide range of water temperatures and salinities. The fieldwork was therefore planned for different seasons: 13 - 28 May 1992 (E. Coppejans), 17 July - 20 August 1992 (E. Coppejans & O. De Clerck), 30 October - 14 November 1992 (O. De Clerck) and 19 February - 5 March 1993 (O. De Clerck). Observations and collections were made only in the area of the Jubail Marine Wildlife Sanctuary (between Ras az-Zaur and the north-eastern point of Abu Ali) and were mainly carried out along the continental shore (including Dawhat ad-Dafi and Dawhat al-Musallamiya). The Island of Karan was visited once (August 1992).

These activities were carried out by wading in the intertidal zone at low tide, by snorkelling and by SCUBA diving in the subtidal zone. In this way the following habitats were studied: mangrove stands, salt-marshes, "bare" intertidal sand and mudflats, including tidal channels and shallow sand pools with stone and shell fragments, rocky shores, also including intertidal pools. In the subtidal area the fringing reefs as well as the patch reefs, seagrass meadows and bare sandy areas were also visited. The collected material was either prepared as herbarium specimens or preserved in 4 % formalin with sea water. The preserved samples were used for the anatomical analysis whereas the dried specimens are more useful for the study of the morphological variability of the species (due to ecological factors and to seasonal development). Both approaches are necessary for accurate identifications which were carried out in Gent.

The dried specimens result in a "complete" reference collection which is deposited in the herbarium of the Universiteit Gent (GENT), and a collection containing at least a specimen of every species deposited in the King Fahd University in Riyadh.

RESULTS

The supralittoral and intertidal zones: The intertidal zone (and even the supralittoral fringe) of tropical coasts is generally richly covered by a large number of seaweeds and seagrasses which form distinct zones. The Gulf shoreline of Saudi Arabia is, on the contrary, almost devoid of algae and seagrasses. This is due to the extreme annual fluctuations in temperature and salinity (JOHN et al. 1990, BASSON et al. 1977).

S a l t - m a r s h e s: Large areas of this vegetation have been heavily polluted by the oil spill, but even the non-polluted sites are devoid of any algal growth (except for the extended, thick mats of Cyanophyta). This is confirmed by BASSON et al. (1977). In other tropical regions, algae such as *Vaucheria*, *Enteromorpha* and *Ulva* develop in this biotope. *Ulva* occurs in areas with a higher nutrient level like Tarut Bay but has not been found in the study area.

M a n g r o v e s: Vast surfaces of this shrubby vegetation have also been severely damaged by the oil spill. However, once again the absence of the Bostrychietum, an algal association which is very characteristic on the pneumatophores of mangroves in most tropical areas (COPPEJANS & GALLIN 1989), is not due to the pollution: *Bostrychia* and the associated species of this algal community have never been recorded in the Gulf area. Even the control sites of Tarut Bay, which were not polluted by the 1991 oil spill contain no Bostrychietum. Here the *Avicennia* pneumatophores are generally covered by a layer of blue-green algae, and some of these aerial roots growing in the tidal channels are covered by epiphytic *Chondria dasyphylla*, *Polysiphonia kampsaxii* and *Cladophora nitellopsis* during the cold season.

S a n d y a n d m u d d y c o a s t s: This is the zone where, in other regions of the Indian Ocean, a well-marked zonation occurs for different seagrasses, mixed with some algae (COPPEJANS et al. 1992). On the coastline north of Jubail even the non-polluted areas seem to be completely devoid of any macroscopic vegetation. This is the result of the "scoring" effect of the sun during summer and of the cold temperatures in winter. In the cold season, however, small stones or shell fragments may be covered by *Cladophora*, especially in the shallow tidal pools or tidal channels. Here, even some seagrass (*Halodule*) growth may occur, especially towards low water mark. Shell fragments which were recently washed ashore and stick in the oiled surfaces may also show some *Cladophora* growth in winter.

R o c k y s u b s t r a t e: The upper and middle parts of the intertidal rocks were also almost completely devoid of macroscopic vegetation. In parts of the Indian Ocean this zone is covered by a relatively dense cover of various macroalgae. Here again the extreme climatic conditions prohibit the development of this vegetation in the Gulf region. Deeper rock pools locally have some algal growth: *Cystoseira myrica*, *C. trinodis* and *Hormophysa cuneiformis* are the most characteristic species. Old specimens of these are frequently covered by several epiphytes: *Hincksia mitchelliae*, *Sphacelaria rigidula*, *Jania rubens* and *Fosliella farinosa*. The lower part of the intertidal zone (in fact the infralittoral fringe, between mean and spring low water mark) along sheltered coasts is generally characterised by a dense vegetation of *Digenea simplex*. In shallow pools close to the extreme low water line a relatively rich algal flora was developed, especially in spring, with *Dictyosphaeria cavernosa*, *Cladophora nitellopsis*, *Chondria dasyphylla*, *Laurencia obtusa*, *L. papillosa*, *Polysiphonia opaca*, *Ceramium strictum* and *Hypnea cornuta*. Along exposed coasts (such as Abu Ali) *Cladophoropsis sundanensis* forms cushion-like coverings in the infralittoral fringe.

The subtidal zone: This habitat has not been affected by the oil spill (except for a few restricted areas) and therefore shows the typical vegetation types.

S o f t s u b s t r a t e: Sand and muddy sand substrates are by far dominant in the subtidal zone. They are either bare or covered by seagrasses; *Halodule uninervis* is the dominant species, forming extensive meadows from low water mark down to -3 m. Locally it can be replaced by *Halophila stipulacea* and also by some *Halophila ovalis*. Both of these mainly develop close to low water mark and mainly as colonising species (e.g. shifting sand banks). In a few areas the green alga *Avrainvillea amadelpha* is mixed with *Halodule*. Below -3 m the seagrass cover declines rapidly and another Chlorophyte, *Caulerpa sertularioides*, locally colonises the available space in patches down to -6 m.

H a r d s u b s t r a t e: Fringing coral reefs are fairly well developed along the north-west coast of Abu Ali Island as well as along the east coast of Ras az-Zaur Bay. Shallow patch reefs are distributed over the central area of Dawhat ad-Dafi. They all have a similar and diversified algal flora: their upper surface, close to the water surface, is frequently covered by *Sporolithon molle*. In winter they are largely covered by the cerebriform *Colpomenia sinuosa* and the filamentous *Hincksia mitchelliae*. These species die off in spring; large quantities of loose-lying, decaying specimens of *Colpomenia* are then found in the lagoon of Abu Ali as well as in sheltered subtidal bays around the patch reefs. At the same time the perennial bases of *Sargassum* start forming new annual branches which quite quickly grow into dense bushy vegetations, reaching 1 m in height and locally completely covering the reef. In the summer the annual branches of *Sargassum* are shed and large masses of them are found drifting in patches until they are washed ashore. Together with *Halodule* leaves, drift-wood and other organic material they form a specific biotope at spring high water level with a typical associated fauna. Around Karan this dense vegetation has not been observed, but the stolonoidal stage of *Turbinaria ornata* covers vast areas of the reefs. Along the continental coast vertical and overhanging walls generally have a very colourful and rich flora (especially in spring with huge specimens of *Asparagopsis taxiformis*); at Karan they show large populations of *Lobophora variegata*. *Avrainvillea amadelpha* frequently develops in the coral crevices close to the water surface, mainly at the seaward side of the reefs.

On partly sand-covered, hard substrates between coral heads an algal vegetation develops which is generally dominated by *Hormophysa cuneiformis*, *Cystoseira trinodis* and *Sargassum decurrens*, locally mixed with *Padina gymnospora* and *Dictyota indica*.

Extensive *Sargassum* beds are also present on hard substrates between -4 and -6 m north of Abu Ali. *Dictyopteris membranacea* (a new record for the Gulf) grows extensively on the vertical walls.

Different *Sargassum* species as well as *Cystoseira trinodis* die off towards the summer, leaving the hard substrate rather bare. Hence observations over the different seasons are absolutely essential to understand the annual fluctuations in the biomass of the submerged vegetation.

CONCLUSIONS AND DISCUSSION

The climatic conditions of the supralittoral and intertidal zones are so extreme (especially in summer) that they inhibit macroalgal and seagrass development along the Gulf coast of Saudi Arabia. The oil spill almost exclusively covered these areas and therefore did not influence the algal development. Moreover, some tar-covered rocks of the infralittoral fringe ("Abu Ali slipway") have become completely colonised by *Padina minor*, *Dictyota indica*, *Colpomenia sinuosa*, *Hincksia mitchelliae* and *Spacelaria tribuloides*.

As seaweeds do not have true roots but root-like or discoidal holdfasts by which they can attach themselves to any hard substrate (rock, coral, shells, plants, buoys, ropes, boats and also hardened oil) if the quantity of toxic components is not too high. Moreover their respiration and nutrient uptake takes place over the whole thallus surface and therefore they are partly independent of the substrate quality. Finally as most seaweeds are annual, recolonisation takes place very quickly by spores coming from non-polluted areas.

The preparation of an inventory for the area studied is not yet complete (e.g. most of the smaller epiphytes have still been omitted from the analysis) and identifications are still proceeding, but from the available data it already appears that the seaweed and seagrass vegetation of the area between Ras az-Zaur and Abu Ali is very rich (compared to other regions in the Gulf). Finally the absence of representatives of the genus *Ulva* on the one hand and the very restricted amounts of *Enteromorpha* on the other hand indicate low levels of eutrophication as compared to Kuwait and Tarut Bay where the growth of these species is luxuriant.

SPECIES LIST

Chlorophyta: (20 taxa = 19 species + 1 ecad)
Entocladia viridis Reinke
Phaeophila dendroides (Crouan frat.) Batters
Enteromorpha clathrata (Roth) Greville
Enteromorpha flexuosa (Wulfen ex Roth) J. Agardh
Chaetomorpha aerea (Dillwyn) Kützing
Chaetomorpha gracilis (Kützing) Kützing
Chaetomorpha linum (Müller) Kützing f. *brachyarthra* Kützing
Chaetomorpha mediterranea (Kützing) Kützing
Cladophora cf. *'coelothrix'*
Cladophora koeiei Børgesen
Cladophora nitellopsis Børgesen
Rhizoclonium tortuosum (Dillwyn) Kützing
Cladophoropsis sundanensis Reinbold
Dictyosphaeria cavernosa (Forsskål) Børgesen
Bryopsis hypnoides Lamouroux
Trichosolen sp.
Caulerpa sertularioides (Gmelin) Howe ecad *sertularioides*
Caulerpa sertularioides (Gmelin) Howe ecad *farlowii*
Avrainvillea amadelpha (Montagne) Gepp & Gepp
Acetabularia calyculus Quoy & Gaimard

Phaeophyta: (25 taxa = 24 species + 1 variety)
Feldmannia indica (Sonder) Womersley & Bailey
Feldmannia irregularis (Kützing) Hamel
Hincksia mitchelliae (Harvey) Silva
Sphacelaria rigidula Kützing
Sphacelaria tribuloides Meneghini
Dictyota sp. 1
Dictyota sp. 2
Dictyota indica Sonder
Dictyopteris membranacea (Stackhouse) Batters
Lobophora variegata (Lamouroux) Womersley
Padina gymnospora (Kützing) Vickers
Padina minor Yamada
Nemacystus decipiens (Suringar) Kuckuck
Colpomenia sinuosa (mertens ex Roth) Derbès & Solier
Hydroclathrus clathratus (C. Agardh) Howe
Cystoseira myrica (Gmelin) J. Agardh
Cystoseira trinodis (Forsskål) C. Agardh
Hormophysa cuneiformis (Gmelin) P.C. Silva
Sargassum angustifolium (Turner) J. Agardh
Sargassum binderi Sonder
Sargassum boveanum J. Agardh
Sargassum boveanum J. Agardh var. *aterrimum* Grunow
Sargassum decurrens (Turner) C. Agardh
Sargassum latifolium (Turner) C. Agardh
Turbinaria ornata (Turner) J. Agardh var. *ornata* f. *evesiculosa* (Barton) Taylor

Xanthophyta: (1 species)
Vaucheria piloboloides Thuret

Rhodophyta: (42 species)
Chroodactylon ornatum (C. Agardh) Basson
Erythrotrichia carnea (Dillwyn) J. Agardh
Acrochaetium savianum (Meneghini) Nägeli
Liagora distenta (Mertens) J. Agardh
Asparagopsis taxiformis (Delile) Trevisan
Gelidiella myriocladia (Børgesen) Feldmann & Hamel
Gelidium pusillum (Stackhouse) Le Jolis
Wurdemannia miniata (Sprengel) Feldmann & Hamel
Dudresnaya sp.
Peyssonnelia simulans Weber-van Bosse
Jania rubens (Linnaeus) Lamouroux
Fosliella farinosa (Lamouroux) Howe
Hypnea cervicornis J. Agardh
Hypnea cornuta (Kützing) J. Agardh
Champia parvula (C. Agardh) Harvey
Callithamniae sp.
Anotrichium tenue (C. Agardh) Nägeli
Antithamnion cruciatum (C. Agardh) Nägeli
Centroceras clavulatum (C. Agardh) Montagne
Ceramium codii (Richards) Feldmann-Mazoyer
Ceramium fastigiatum (Wulfen ex Roth) Harvey f. *flaccidum* Petersen
Ceramium strictum (Kützing) Harvey
Crouania attenuata (C. Agardh) J. Agardh
Spyridia filamentosa (Wulfen) Harvey
Hypoglossum sp.
Dasya baillouviana (Gmelin) Montagne
Dasya cf. *corymbifera* J. Agardh
Heterosiphonia crispella (C. Agardh) Wynne
Acanthophora spicifera (Vahl) Børgesen
Chondria collinsiana Howe
Chondria dasyphylla (Woodward) C. Agardh
Digenea simplex (Wulfen) C. Agardh
Herposiphonia secunda (C. Agardh) Ambronn f. *tenella* (C. Agardh) Wynne
Laurencia obtusa (Hudson) Lamouroux
Laurencia papillosa (C. Agardh) Greville
Laurencia patentiramea (Montagne) Kützing
Leveillea jungermannioides (Hering & Martens) Harvey
Polysiphonia crassicollis Børgesen
Polysiphonia kampsaxii Børgesen
Polysiphonia opaca (C. Agardh) Zanardini
Polysiphonia cf. *scopulorum* Harvey var. *villum* (J. Agardh) Hollenberg
Polysiphonia sp.

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Authors' address:
O. De Clerck & Prof. Dr. E. Coppejans, Laboratorium voor Morfologie, Systematiek en Ecologie van de Planten, Universiteit Gent, Ledeganckstraat 35, 9000 Gent, Belgium

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Status and recovery of the intertidal vegetation after the 1991 Gulf War oil spill

Benno Böer

A b s t r a c t: The 1991 Gulf War oil spill caused severe damage to the intertidal vegetation along the Saudi Arabian Gulf coast. Along a 45 km stretch of intertidal mangroves and salt-marshes between Ras az-Zaur and Abu Ali Island, *Salicornia europaea* is almost extinct. Dwarf mangrove (*Avicennia marina*) and salt-marshes dominated by *Arthrocnemum macrostachyum* and *Halocnemum strobilaceum* are severely damaged. *Halopeplis perfoliata* and *Limonium axillare* salt-marshes are relatively unaffected. The natural re-establishment of the vegetation will be protracted unless measures are taken to aid recovery.

حالة الغطاء النباتي
وأستعادتة إلى وضعه السابق في بيئة مابين المد والجزر
عقب بقعة الزيت الناتجة عن حرب الخليج عام ١٩٩١م

بينو بوير

خلاصة: ألحقت بقعة الزيت الناجمة عن حرب الخليج عام ١٩٩١م أضراراً كبيرة بالغطاء النباتي الطبيعي في منطقة مـابين المـد والجـزر على امتداد الساحل السعودي للخليج. وعلى امتداد ٤٥ كم من نباتات الشورة والمستنقعات الملحية لمنطقة مابين المد والجزر بين رأس الزور وجزيرة أبوعلي انقرضت تقريبا نباتات *Salicornia europaea* وقد تضررت بشـكل كبير كـل مـن أشـجار *Avicennia marina* في مناطق نباتات الشورة وكذلك المستنقعات الملحية التي تسود فيها نباتات النوعين *Halocnemum strobilaceum* و *Arthrocnemum macrostachyum*. أما نباتات النوعـين *Limonium axillare* و *Halopeplis perfoliata* فلـم تتـأثر نسبياً. ولذا فإن عملية الأستعادة الطبيعية للغطاء النباتي ستكون طويلة ما لم تتخذ تدابير اضافية لتعجيلها.

INTRODUCTION

Salt-marshes and mangroves are the dominant vegetation types along the Saudi Arabian Gulf Coast (MEPA & IUCN 1989). The 1991 Gulf War oil spill caused severe damage to the intertidal vegetation; according to MEPA (1991) all mangroves had been oiled and only 5 % of the salt-marshes remained unoiled within the oil spill-impacted coastline. Furthermore, that report predicts that it is probable that all the mangroves and salt-marshes north of Abu Ali Island will die. The enormous value of these vegetation types as habitat and detrital food sources for marine organisms as well as their direct and potential value for lumber, firewood and tanning agents has been well documented (ODUM & HEALD 1972, ARONSON 1989, CLOUGH 1993, MANDURA & KHAFAJI 1993, BHATTACHARYA & JANA 1993, UNTAWALE 1993, GLENN & WATSON 1993, LIETH & LIETH 1993, SINGH et al. 1993).

Mangroves commonly trap accumulated oil after spills (LEWIS 1983). The Al-Ahmadi oil spill began on 23 January 1991, and the prevailing winds and high tides brought the oil into the upper intertidal zone, including large areas of mangroves and salt-marshes. The impacts of this 1991 spill were added to those from previous spills (SPOONER 1970, ALI 1990).

MATERIALS AND METHODS

In December 1991 and January 1992 intertidal vegetation types in the study area were mapped using field traverses, a Magellan global positioning system, and the LEKAS geographical information system (BÖER & WARNKEN 1992). The entire area between Ras az-Zaur and Abu Ali Island, including the two embayment systems Dawhat ad-Dafi, Dawhat al-Musallamiya, and the nearshore islands Jinna, Abu Duayyina and Qurma, was investigated by helicopter, boat and car. The state of the vegetation was described in terms of the recovery of affected plants and the establishment of new seedlings.

Individual plants, located in the transition zone between destroyed and healthy areas, were marked with polyethylene strings in order to evaluate the development of the oil-impacted vegetation. Furthermore, 12 mangrove test sites, 25 x 25 m in size, were installed in oil-damaged locations, including both those areas treated with sea water sprinklers soon after the oil spill (on Qurma Island) and those not treated, which retain a bitumen crust on their surface (Khursaniya and Dawhat ad-Dafi). These sites were used for observations of recovery focusing on the growth of new plants and the number of plants that survived the oil spill.

Wooden poles, 2 m long, were dug into the intertidal sediment in order to analyse the zonation of the vegetation. These poles were equipped with a centimetre scale, providing a direct comparison between tidal height measurements and the chart datum as calculated by the Royal Commission for Jubail and Yanbu (RCJY).

Table 1: Zonation of the intertidal vegetation according to the chart datum calculated by RCJY.

Vegetation belt	Intertidal zonation (m above chart datum)	
Avicennia marina	1.30 - 1.70	
Salicornia europaea	1.45 - 1.75	
Arthrocnemum macrostachyum	1.60 - 2.10	
Halocnemum strobilaceum	1.80 - 2.35	and above intertidal
Halopeplis perfoliata	>2.00	and above intertidal
Limonium axillare	>2.00	and above intertidal

RESULTS AND DISCUSSION

In the study area, ca 20 km² of the coastal strip is covered with salt-marshes and mangroves. The only mangrove species present is *Avicennia marina* (Forssk.) Vierh. and it is associated with *Arthrocnemum macrostachyum* (Moric.) Moris et Delponte and *Salicornia europaea* L. The different salt-marsh types are dominated by *Arthrocnemum macrostachyum*, *Halocnemum strobilaceum* (Pall) M.B., *Halopeplis perfoliata* (Forssk.) Aschers. et Schweinf., *Limonium axillare* (Forssk.) O. Kuntze and *Salicornia europaea*. Several other plant species fringe the upper intertidal but the oil did not reach this zone. Only non-sheltered areas frequently covered by high tides have been damaged. Although approximately 30 % of the mangrove, 30 % of the *H. strobilaceum* marsh, 35 % of the *A. macrostachyum* marsh, and almost 99 % of the *Salicornia* marshes died off soon after the oil contamination, more than 50 % of the intertidal vegetation remained

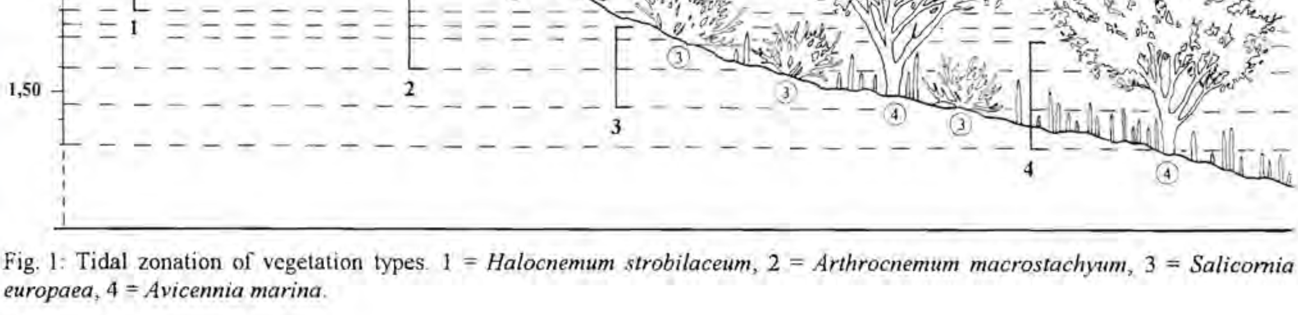

Fig. 1: Tidal zonation of vegetation types. 1 = *Halocnemum strobilaceum*, 2 = *Arthrocnemum macrostachyum*, 3 = *Salicornia europaea*, 4 = *Avicennia marina*.

Plate 1: Devastated mangrove area on Qurma Island.

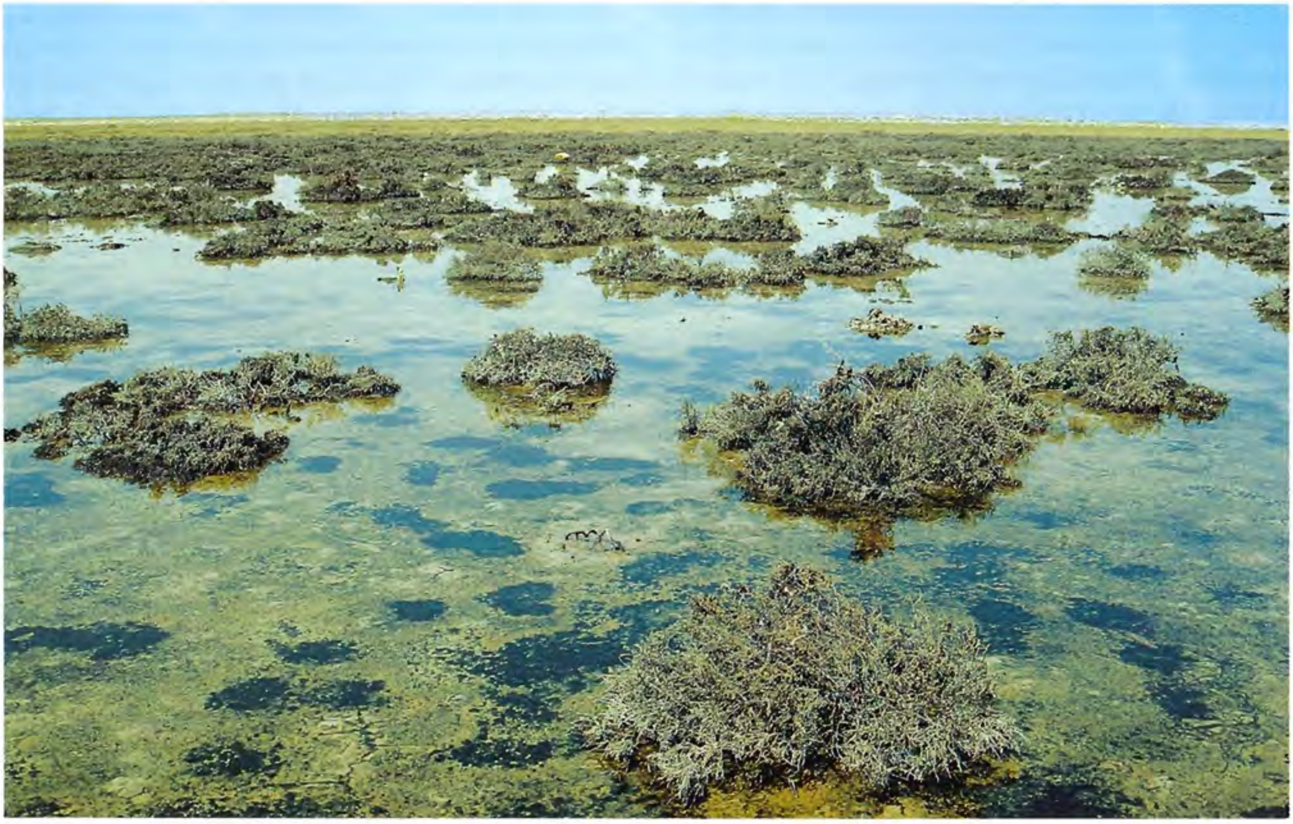

Plate 2: Salt-marsh vegetation killed by the oil spill. A healthy salt-marsh above the high water mark can be seen in the background.

Table 2: Number of living trees in 1992 and 1993, and seeds germinated in 1991 and 1992, in the intertidal test quadrats of Qurma Island, Dawhat ad-Dafi and Khursaniya.

Quadrat	Seeds germinated 1991	Seeds germinated 1992	Living trees 1992	Living trees 1993
Treated with seawater sprinklers:				
Qurma 1	22	0	18	16
Qurma 2	27	0	6	4
Qurma 3	87	0	8	8
Qurma 4	35	0	15	15
Qurma 5	31	0	15	12
Qurma 6	72	3	12	12
Average	45.7	0.5	12.3	11.2
s.d.	26.98	1.22	4.59	4.49
Non-treated; with bitumen crust:				
Khursaniya 1	0	0	31	31
Khursaniya 2	0	0	0	0
Khursaniya 3	0	0	18	17
Khursaniya 4	0	0	8	7
D. ad-Dafi 1	0	0	5	2
D. ad-Dafi 2	0	0	0	0
Average	0	0	3.7	2.8
s.d.	0	0	3.14	2.71

alive and all these plants are flowering and producing fruits. *Limonium axillare* and *H. perfoliata* have not been damaged.

Plate 1 shows a destroyed mangrove area and Plate 2 a devastated *S. europaea* marsh in Dawhat ad-Dafi. The tidal zonation of the different vegetation types is shown in Table 1 and Fig. 1.

The cleaned sites show some signs of recolonisation, whereas the contaminated sites show only dead or sick mangroves and very few plants have germinated (Table 2).

The oil spill clean-up operations in Khalij Marduma (a bay including Qurma Island) were very successful. Oil booms, skimmers and pumps were used to collect the oil from the water surface. Water sprinklers, using sea water under low pressure to rinse off oil from plants and soils, were installed and operated in most parts of the mangroves on Qurma Island between March and April 1991. It is probable that this action prevented further loss of mangrove plants and it may have contributed to their relatively good condition on Qurma Island. The non-cleaned mangrove sites are either naturally well sheltered by the geographical characteristics of their embayment systems and therefore escaped serious contamination, or they are severely damaged by the oil spill.

The degree of pollution varies considerably within the mangrove and salt-marsh communities north of Abu Ali Island. With the exception of the mangroves, the amount of damage correlates well with the height of the plants above chart datum and the location of the intertidal vegetation. The overall situation is complex.

As mangroves and salt-marshes are extremely important coastal ecosystems, the damaged intertidal vegetation should be restored to its pre-oil spill condition. Under natural circumstances it will take a long time before the damaged sites are remediated. MEPA (1991) predicts a decade or more until recovery takes place. With efficient planting techniques including further field experiments it may be possible to restore the damaged sites. Several successful cases of restoration of oiled intertidal vegetation are described in the literature (SENECA & BROOME 1982, GETTER et al. 1984, BROOME et al. 1987). The severely damaged 50-100 hectares of mangroves and the ca 800 hectares of destroyed salt-marshes can and should be restored by breaking up the bitumen layer and replanting.

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Author's address:
B. Böer, Universität Osnabrück, FB 5, Abt. Ökologie, Barbarastr. 11, D-49076 Osnabrück, Germany.

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Intertidal recovery in the Dawhat ad-Dafi and Dawhat al-Musallamiya region (Saudi Arabia) after the Gulf War oil spill

David A. Jones, Iain Watt, Timothy D. Woodhouse & Matthew D. Richmond

Abstract: In order to assess the damage and recovery rate of intertidal habitats after the 1991 Gulf War oil spill, intertidal surveys were carried out between November 1991 and November 1992 in the Dawhat ad-Dafi and Dawhat al-Musallamiya area of the Saudi Arabian Gulf coast. Interim results from these surveys show that the number of species and the number of individuals has increased but they are still lower on the oil-impacted shores than on the control sites. Over this period recolonisation into previously oiled zones has occurred on the more active shores where the tar has been broken up by physical action. The soft-sediment shores have developed extensive algal mats while the upper zones remain heavily tarred preventing recolonisation by typical fauna. Juveniles of the crab *Cleistostoma dotilliforme* and the polychaete *Perinereis vancaurica* have been found settling and living in heavily oiled substrates. Recruitment of species with planktonic larvae is occurring successfully. There is no evidence of lower shore contamination.

استعادة منطقة ما بين المد والجزر لحالتها السابقة في دوحة الدفي ودوحة المسلمية (بالمملكة العربية السعودية) بعد تعرضها لبقعة الزيت من جراء حرب الخليج

ديفيد أ. جونز، إين وات، تيم د. وودهاوس، ماثيو د. ريتشموند

خلاصة : تم إجراء مسوحات لبيئات منطقة ما بين المد والجزر بين نوفمبر ١٩٩١م ونوفمبر ١٩٩٢م.لتقويم الضرر الواقع عليها ودرجة إستعادتها لحالتها السابقة بعد حدوث بقعة الزيت بالخليج عام ١٩٩١م. وقد شملت هذه المسوحات منطقتي دوحة الدفي ودوحة المسلمية على الساحل السعودي من الخليج. وتوضح النتائج الأولية لهذه المسوحات أن كل من عدد الأنواع وعدد الأفراد قد تزايد إلا أنها لم تصل في الشواطيء التي تأثرت بالزيت إلى ما هي عليه في المواقع التي لم تتأثر.

وقد لوحظ خلال هذه الفترة ان إعادة الاستيطان في المناطق التي سبق تلوثها بالزيت قد حدث في الشواطيء التي تم تفتيت القار فيها نتيجة لعوامل طبيعية.

وقد تكونت على الشواطيء الرسوبية الرخوة ابسطة طحلبية واسعة بينما ظلت الطبقات العليا مغطاة بطبقة كثيفة من القار اعاقت اعادة استيطانها من قبل المجموعة الحيوانية الطبيعية للمنطقة. وقد وجدت السرطانات اليافعة من نوع *Cleistostoma dotilliforme* والدودة الحلقية من نوع *Perinereis vancaurica* مستقرة وتعيش في الاوساط كثيفة التلوث بالزيت. كما تم بنجاح اعادة استيطان أنواع الطافيات التي لها يرقات. ولايوجد دليل على تلوث الأجزاء السفلى من الشواطيء.

INTRODUCTION

As a result of the Gulf War oil spill in February 1991, surveys were carried out during November and December of that year to assess the damage caused to intertidal habitats. The study focused on the severely damaged coastlines of Dawhat ad-Dafi and Dawhat al-Musallamiya (Plate 1). JONES & RICHMOND (1992) established permanent transect lines (PTLs) as representative of the habitats present within the impacted zone. To ensure that all the key habitats were included, both physical and biotic data were collected by rapid assessment surveys, and then analysed and used in the selection of the PTLs.

MATERIALS AND METHODS

The biological and physical data for the present study were gathered between November 1991 and November 1992. The aims of the study were to evaluate the loss of biota due to the oil impact, to assess the recovery rate of the intertidal areas and to separate any natural seasonal changes in the biota from those caused by the pollution. Detailed results have been published by JONES & RICHMOND (1992). The present paper summarises these results and describes the current situation in the study area.

Continued monthly monitoring of the established PTLs was carried out in accordance with the methods used during the initial surveys in December 1991. Control sites with similar substrates were located and monitored using identical procedures to determine natural seasonal changes.

The shore was divided into five tidal levels: the littoral fringe, upper eulittoral, mid eulittoral, lower eulittoral, and sublittoral fringe. The mid eulittoral station falls just below the lower edge of the surface oil pollution on each transect. This distance was measured out along a compass bearing from a known point on the shore and noted for accurate replication so as to observe any change in the vertical distribution of oil pollution down the beach. Due to short tidal windows and very small tidal ranges the sublittoral fringe was mostly submerged during the summer months. This study concentrated therefore on the top four stations of the key habitats and key species within those habitats.

RESULTS

Epifauna: Five random replicates of a 1 m^2 quadrat were used to measure the abundance of epifaunal organisms at the four tidal levels. The organisms were then recorded as a percentage cover, or individually counted. Where the substrate was soft, 0.25 m^2 within each quadrat was sifted through by hand for large bivalve molluscs. Unidentified species were collected and returned to the field laboratory for positive identification, or forwarded to the relevant taxonomist.

Settlement panels were established at selected PTLs in order to record the settlement of planktonic larvae from sedentary species such as barnacles and to compare this with settlement occurring on adjacent shores.

Infauna: Three 0.1 m^2 by 15 cm deep cores were taken at selected tidal levels, usually at the mid eulittoral, as this level should record the first changes in biota dynamics on the impacted beach, and at the lower eulittoral to monitor any long-term changes which may be taking place. These cores were sieved through a 1 mm mesh in order to collect the macrofauna which was then preserved in 5-10 % formalin. They were then returned to the laboratory for sorting, identifying and counting.

Temperature and salinity: Temperatures were measured using a digital thermometer and recorded to the nearest degree. Salinities were measured with a refractometer and recorded to the nearest part per thousand (ppt).

It can be seen from Fig. 1 that the PTLs fall into two groups. These are in the north of Dawhat al-Musallamiya and the south of Dawhat ad-Dafi. A habitat description and pollution scale for each PTL is given in Table 1.

In all cases the horizontal level of pollution in the intertidal zone decreased between November 1991 and November 1992. In most cases, by July 1992 a substantial cover of algal mat had developed (see Table 1). Generally, the algal mat cover coincides with the zone impacted by the oil, from high water spring (HWS) tides, to high water neap (HWN) tides (HOFFMANN 1994). The latter usually occurs where the tar mat is thin (2-3 mm) and in many places the algal mat is peeling off. This process also lifts off a layer of tar and in places exposes clean sediment. However, oil leaching from the sediments on rising tides in the upper eulittoral and parts of the mid eulittoral confirms the presence of trapped oil in the sediment below. This oil moves up the beach on each rising tide, consolidates the tar mat and continues to cause mortalities in the recently settled biota.

Plate 1: Heavily oiled upper intertidal zone and strandline at Khalij Marduma six months after the Gulf War oil spill.

Recruitment into soft-sediment areas: There has been an increase in the number of species and the abundance on all the soft-sediment shores. Analysis of the data on key species presence and absence at the PTLs and controls demonstrates, in most cases, a comparable number of species. In many cases, by November 1992, the number of individuals on the lower shores compared favourably with those found at the controls, whereas on the higher shore, tar mats prevented resettlement.

In the very sheltered mud-flat areas, such as at PTL 8, there has been almost no sign of recovery and no resettlement on the upper shores. Here the supra-littoral, littoral fringe and upper eulittoral are dominated by blue-green algal mats. Free oil is still found leaching out of the sediment in the mid eulittoral on rising tides. The combination of this algal mat and tar layer precludes any possibility of settlement by burrowing fauna such as crabs, bivalves or polychaetes, all common to the upper shores of the mud controls. However, the gastropod *Pirinella conica* has increased in abundance in the mid and lower eulittoral at PTL 8 from 337 m^{-2} in November/December 1991 to 856 m^{-2} in November/December 1992, with a peak of 1025 juveniles m^{-2} in August 1992. By November 1992, other species such as *Mitrella blanda* and *Nereis* sp. were appearing, but in very low numbers (ca. 1 m^{-2}).

Recolonisation into previously oiled zones has taken place on other more active soft-sediment PTLs, where the tar has been weathered and broken away through physical action. By October, recolonisation by *Pirinella conica*, *Cerithium scabridum* and *Mitrella blanda* into the upper eulittoral at PTL 1 had begun and by November 1992 PTL 2 had all key species present, but with a lower species abundance.

Plate 2: The polychaete worm *Perinereis vancaurica* colonises the heavily oiled upper intertidal zone. Photograph taken at Qurma Island.

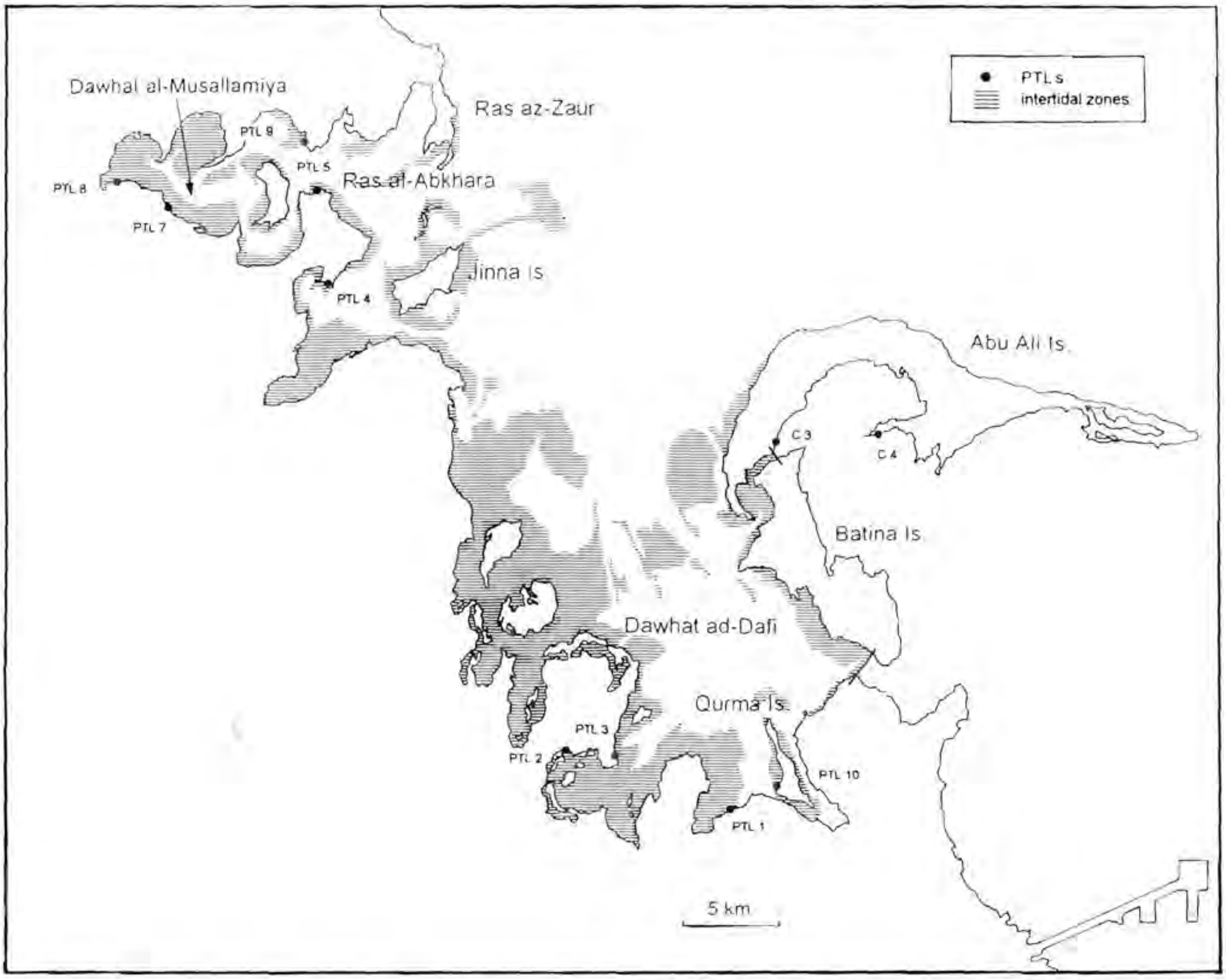

Fig. 1: Map of the area showing the positions of the Permanent Transect Lines (PTLs) and control sites.

Since August 1992, the polychaete *Perinereis vancaurica* (86-320 m^{-2}, Plate 2), newly settled juvenile crabs *Cleistostoma dotilliforme* (100 m^{-2}) and occasionally *Metopograpsus messor* have been found living under the polygonal mat in the oiled layer of most soft-substrate shores. The exceptions to this are the very low-energy shores such as at PTL 8, where *P. vancaurica* did not appear until November 1992, and then only in very low numbers (ca 1 m^{-2}). There was no sign of juvenile *C. dotilliforme*. The numbers of *P. vancaurica* were found to increase towards the middle of the polygonal algal mat zone.

Recruitment into rocky shore areas: By November 1991 most of the tar had already been removed by physical action. The compacted beach rock, a sandy limestone, prevented the oil from adhering as it dried and weathered. By November 1992, tar was only present in the crevices and niches. All the key species found at the rock control were present at PTL 5. Only on the supralittoral and littoral fringe were there differences in species abundance. The population of *Nodolittorina subnodosa* showed a steady increase since December 1991 from 18 to 144 m^{-2} in September 1992, but this population had declined to 48 m^{-2} by November 1992. This species has been found to be "brood protecting" (viviparous, containing as many as 30 young) and therefore can only recruit from a small, patchy population that survived the oiling. Recruitment is therefore lateral and slow, unlike those with planktonic larval stages. These numbers are still low when compared to those at the control (1,235 m^{-2}).

New recruitment and settlement of sedentary animals such as *Balanus amphitrite* and *Pomatoleios kraussi* onto rocky shores has increased since December 1991, from 10 to 60 % coverage per m^2 and 24 to 60 % per m^2, respectively in November 1992. This was also reflected on the settlement

Table 1: Summary of selected intertidal permanent transect lines (PTLs) showing shore types and horizontal changes in tar and algal mats, November 1991 to November 1992. Generally the algal mats appeared in June 1992, and in the case of PTL 1 had disappeared by November 1992. No algal mats on the controls. Pollution scale = 1-10, 10 = Most heavily polluted. Abbreviations: sd = sand; md = mud; mgr = mangrove; n.a. = not available; rk = rock; bld = boulders; fl = flat; poly = polygonal.

PTL Control 1991 - 1992	Shore Type	Vertical tar cover Nov. 1991	Vertical tar cover Nov. 1992	Algal mat cover Nov.1991	Algal mat cover Nov. 1992	Algal mat morph Nov. 1992	Pollution scale Nov. 1991	Pollution scale Nov. 1992
PTL 1	sd md	50 m	12 m	nil	nil	nil	3	2
PTL 2	mgr	20 m	10 m	nil	20 m	fl./ poly	3	2
PTL 8	md	200 m	80 m	nil	80 m	fl	7	6
PTL 5	rk. bld	15 m	5 m	10 m	5 m	fl	3	2
C1	mgr.	nil	nil	nil	nil	nil	n.a.	1
C2	md	nil	nil	nil	nil	nil	n.a.	1
C3	sd	nil	nil	nil	nil	nil	n.a.	1
C4	rk	nil	nil	nil	nil	nil	n.a	1

panels which were completely colonised within one month (June-July 1992) by small *B. amphitrite* and *Euraphia* sp. in densities of 50 to 60 individuals per cm^2. Comparable results were achieved the following month, August 1992. These barnacles remained small, often less than 5 mm in diameter, but settled on top of each other up to a thickness of 2 cm. Predatory gastropods (*Thias* sp. and *Cronia margariticola*) were found on the settlement panels in densities of 1-2 animals per 100 cm^2. By November 1992, the barnacles had suffered 80 % mortality both on the settlement panels and on the adjacent rocky shore.

DISCUSSION

Salinities in the study area were observed to range between 40 and 74 ppt at the height of the summer. These very high salinities were usually found on rising tides. This is possibly due to crystallised salt, formed by evaporation during low tide, being picked up on the rising tide. The salinity in open waters was recorded to be between 38 and 45 ppt. Surface water temperatures were observed to range between 15 and 38 °C. Air temperatures ranged between 5 and 47 °C. Sediment surface temperatures ranged from 28 to 41 °C, increasing by 10 °C on exposed tar surfaces and heavily oiled sediments.

HÖPNER (1991) reported that "a coastal stretch of 775 km is completely polluted between the high and low tide water level" and that this situation is "synonymous with the disappearance of intertidal biological life". Greenpeace (1992) visited the study area in August 1991. They also reported extensive oil cover on the Saudi Arabian coast, "with oil covering the intertidal zone and extending above the high water and below the low water marks at Musallamiya Bay with no sign of living marine life on the shore". However, by December 1991 it was established that the oil had been deposited mainly on the upper shore, essentially between the high water spring tide and the high water neap mark (JONES & RICHMOND 1992). This entire zone was severely impacted.

In contrast to the control sites, all the oiled sites have exhibited growth of blue-green algal mats, usually coinciding with the impacted area of the shore, extending from the high water spring to high water neap tide marks. Blue-green algal mats are common intertidally throughout the Arabian Gulf CLAYTON (1986), and BASSON et al. (1977) noted a negative correlation between the occurrence of algal mat and bioturbation caused by crab and polychaete burrowing. These activities destabilise the surface sediment and, together with grazing pressure, prevent the initial microbial layer of polysaccharide sheaths from establishing. This initial layer helps to stabilise the sediment allowing the algal mat to develop. A likely sequence is that the oil smothers the intertidal biota and creates a stable substrate upon which fine sediment deposits. This facilitates the colonisation of the algal mat. Polygonal mats form directly above high water neaps, where the tar layer is generally thin (2-3 mm). The deposition of fine sediment by tidal action and the subsequent desiccation of this sediment cause the algal mat to shrink and crack into polygonal sections. Eventually they peel off removing a layer of tar which in places exposes underlying clean sediment (HOFFMANN 1994).

After the algal mat has become established, apparently encapsulating the oil and isolating it from the rest of the environment, the grazer *Pirinella conica* rapidly builds up large populations in tide pools and on sheltered parts of the mat. This species appears to be a pioneer settler, common on all the affected soft-bottom shores. An absence of predators and an abundance of food probably encourages this settlement. *Pirinella conica* have been found in high numbers near PTL 1 and on PTL 8 where extensive blue-green algal mats have formed. On examination, the gut content of *Pirinella conica* was found to contain a high content of blue-green algae. The worst conditions are found at PTL 8, at the back of Dawhat al-Musallamiya. This is the most sheltered PTL, with very little wave or current action and together with other such sheltered shores has only shown little reduction in pollution. At PTL 8, a thick rubbery algal mat lines the entire creek system trapping oil and gas. On the other hand more exposed shores such as at PTL 1, have shown a marked reduction in pollution. The oil in the supralittoral has been degraded by photochemical reactions, and in places has adsorbed onto the sediment, forming an oily friable substrate which can be penetrated by air, water and ultimately biota, so encouraging further natural degradation of the oil.

The polychaete *Perinereis vancaurica* and newly settled juvenile crabs such as *Cleistostoma dotilliforme* and *Metopograpsus messor* have been found on PTL 2 and other soft-sediment shores. The burrowing actions of the polychaete may have some influence on breaking down and aerating the sediment. Invariably it is found living at the lower end of the upper eulittoral under the polygonal algal mat in the tar and oiled sediment within the first few centimetres of the surface. It may follow the pollution gradient, as it is most abundant in the middle of the polygonal algal mat zone. Studies on oil-polluted mangroves in Indonesia also found that only a nereid polychaete tolerated such high levels of oil contamination (DUTRIEUX & MARTIN 1989).

Post-larval and subadult *Cleistostoma dotilliforme* juveniles, which as adults live in the supralittoral and littoral fringe, generally require substantial wetting periods, hence normally inhabit the lower, muddy areas of salt-marsh and mangrove creeks. The advent of these polygonal algal mats provide a sheltered zone just above HWN and appear to encourage the resettlement of juvenile *C. dotilliforme*, with apparently no deleterious effect from the oil. However, the success of this resettlement will ultimately depend on the subadults and adults finding suitable conditions on the higher shore for settlement.

The results from the settlement panels and the presence of post-larval individuals on the shore demonstrate that active recruitment of species with planktonic larval stages is occurring successfully.

SOUTHWARD (1978) reported that there were massive predator-prey imbalances with marked oscillations in species population dynamics after the Torrey Canyon oil spill. These oscillations took 12 years before settling back to normal population dynamics. The high mortality in the barnacle population, the decline in the *N. subnodosa* population, the widespread growth of algal mats and the abundance of grazers may indicate the beginning of similar predator-prey oscillations.

The air temperatures, ranging from 5 °C in the winter to 47 °C in the summer and salinities ranging from 38 to 74 ppt in the extensive shallow intertidal areas of the region describe the abiotic factors that must be tolerated by the organisms in the study area. Clean sediment surface temperatures ranging from 28 and 41 °C in many cases are increased by a further 10 °C on the contaminated sediment. This increase in sediment temperature may preclude the resettlement of some species into the area.

On the soft-sediment shores, the settlement of burrowing organisms and the natural degradation of the oil is prevented by thick intractable tar mats which seal off the surface sediments.

Results from November 1992 show the recovery of selected key species on key PTLs, which in turn demonstrate a general trend towards recovery within the impacted area. The number of species and the number of individuals in the impacted zone has increased since December 1991. However, they are still lower than those found on the controls. Although the recolonisation of previously oiled upper shore stations on most sites is encouraging, the area is still under severe stress from the remaining oil and tar mats. The best remedy for this may be their physical removal.

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Authors' address:
Dr. D.A. Jones, I. Watt, T.D. Woodhouse & M.D. Richmond, University of Wales at Bangor, School of Ocean Sciences, Menai Bridge, GB-Gwynedd LL59 5EY, U.K.

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Effects of the 1991 oil spill on the supratidal fringe

Wolfgang Schneider & Ragnar Kinzelbach

Abstract: The upper littoral fringe is the section of the intertidal that was most severely affected by the 1991 oil spill; it is covered by a continuous layer of tar and oiled sediments. Regular visits at 10 permanent transect lines and other localities within the study area revealed that the strandline lost most of its characteristic biota; in spring 1993 there was still no sign of recovery, except on the steep exposed beaches of Abu Ali Island. The strandline communities of non-oiled control sites were studied and major ecological successions and their key/indicator species identified for future monitoring. Recovery of oiled strandlines can only be expected after habitat restoration by artificial cleaning.

حافة منطقة مافوق المد والجزر وتأثيرها ببقعة الزيت لعام ١٩٩١م

ولفجانج شنايدر وراجنر كنزلباخ

خلاصة: كانت الحافة العليا من منطقة مابين المد والجزر هي الأشد تضرراً ببقعة الزيت عام ١٩٩١م. فقد كانت مغطاة بطبقة متصلة من القار والرواسب الملوثة بالزيت. وكشفت الزيارات المنتظمة لعشرة قطاعات دائمية وغيرها من المواقع ضمن منطقة الدراسة بأن القطاع الساحلي فقد معظم مكوناته الأحيائية المميزة. وحتى ربيع عام ١٩٩٣م لم يكن هناك ما يدل على استعادته لحيويته باستثناء الشواطيء المنحدرة المكشوفة لجزيرة أبوعلي. وقد تمت دراسة مجتمعات الحافة العليا للمناكق غير الملوثة بالزيت وتم تعريف التعاقبات الايكولوجية الرئيسية والأنواع الرئيسية والكشافة فيها لغرض الاستعانه بها لأغراض المراقبة المستقبلية. ولايتوقع استعادة القطاعات الساحلية العليا لحيويتها الا بعد عملية إعادة تأهيل صناعية للمواطن الطبيعية فيها.

INTRODUCTION

The oil that was released during the spill in the wake of the Gulf War reached the study area north of Jubail in February 1991. While most of the subtidal and lower intertidal habitats escaped visible oil contamination, the upper intertidal and especially the upper littoral fringe including salt-marshes were severely affected, losing most of their characteristic biota (KINZELBACH et al. 1992, KRUPP & JONES 1993). Situated at the edge of the terrestrial and the marine ecosystems, this transition zone normally exhibits an increased biodiversity as compared to the upper intertidal and the adjoining terrestrial habitats; this is most evident in arid regions with a comparatively poor though specialised terrestrial fauna. Interactions (e.g. on the trophic level) between these two realms are highly complex and not yet fully understood. Even basic information on the taxonomy and the bionomics of species living in or sporadically frequenting the littoral fringe is fragmentary or missing. Therefore a more complex approach, dealing with the typology of the supralittoral and taking into account synecological aspects, such as food chains and energy flow, will be published at a later date. In the following, emphasis is placed on some of the key species of the communities inhabiting the strandline and on the damage caused by the oil spill.

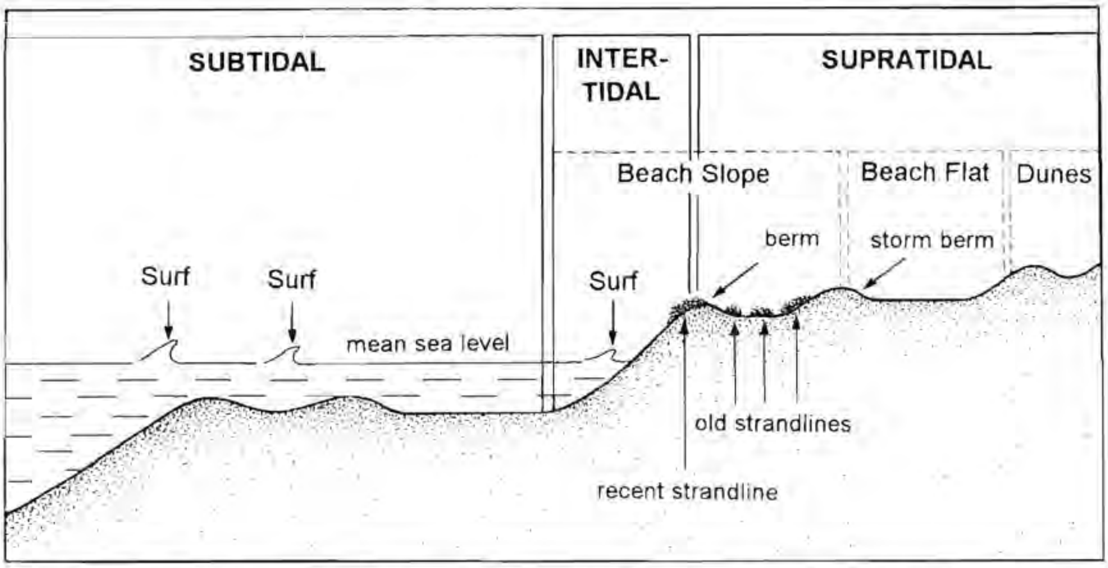

Fig. 1: Schematic sketch of topographic features of an exposed sandy beach on the Saudi Arabian Gulf coast (modified from BASSON et al. 1977; not to scale).

Topography of the upper littoral: The most striking feature of the coast is its extremely low relief. There is an average slope of only 35 cm per kilometre along the eastern shores of the Arabian landmass. The highest coastal elevation in the survey area is Jabal Saduwi (to the west of the inner end of Dawhat al-Musallamiya) at 34 m above sea level. The rest of the coastline is shaped over its entire length by a beach terrace which corresponds to higher Holocene sea levels (PURSER 1973). As a rule, this platform rises only little (0.3-1.0 m) above the highest tide mark. The sea reaches this level only during spring tides or floods.

Most beaches in the Jubail Marine Wildlife Sanctuary are of the low-energy type, preceded by a shallow tidal flat which protects them from wave action. Usually the stranded material is dispersed over the entire tidal flat and consequently only little debris of marine origin is accumulated in front of the beach terrace; PTLs 5 and 6 (PTL: Permanent Transect Lines) are typical examples. Meandering tidal channels with bordering mangrove stands are special semi-terrestrial habitats within the intertidal zone (e.g. at PTL 2).

About 190 out of 460 km of shore (including al-Batina and Abu Ali Islands) are exposed, high-energy sandy beaches. Their morphology (Fig. 1) is very similar to exposed beaches elsewhere, although their slope is less steep and there are tidal flats in front of them. Between the storm berm and the latest berm there is a series of strandlines; after heavy weather old and new material is deposited near the storm berm (e.g. PTLs 5 and 9). It is in this type of "accumulative strandline" that, due to the edge effect, a high species diversity is found.

MATERIAL AND METHODS

In order to assess the damage caused by the oil spill all PTLs (see JONES & RICHMOND 1992) and some newly established control sites were visited and sampled on a regular basis in January 1992, in May/June 1992, in December/January 1992/93, and in March/April 1993. Temperature measurements, in the form of local and/or circadian profiles were taken. Standard methods and devices such as insect nets and sieves of various sizes, Berlese traps, light traps (both white and black light), and UV-lamps were used for collecting.

RESULTS

Strandline as habitat: The strandline is an accumulation of allochthonous debris washed ashore by the surf. In the Project area it consists mainly of marine plants and their epibionts mixed with dead marine animals. The plant debris of exposed beaches is characterised by the predominance of two species, either the brown alga *Sargassum binderi* (Phaeophyta) or the seagrass *Halodule uninervis* (Cymodoceaceae); the two are rarely mixed, their occurrence depending on the subtidal substratum (hard or soft bottoms) and the prevailing currents. Material of terrestrial origin (e.g. leaves, pollen, dead arthropods) is of minor importance; it is blown by wind to the open sea and then transported to the beach. In some places, as along the northerly exposed coast of Abu Ali, the strandline is transformed into a trash-line by the predominance of waste material (e.g. glass, plastics, tins, plywood).

Besides its important role as a food resource, the strandline provides shelter in a generally harsh environment. The surface temperatures of dry beach sand may well exceed 70 °C in summer (BASSON et al. 1977), but even temperatures around 50 °C are lethal to most intertidal organisms. *Phaleria prolixa* (Coleoptera: Tenebrionidae) collected at the beach and exposed to the sun at normal temperatures (42 °C) on beach sand died within minutes. Due to evaporation of retained moisture, temperatures drop dramatically below the strandline and therefore reduce the environmental stress for organisms living there.

Sargassum-strandlines show a high species diversity as they retain moisture for a very long period and are rich in interstitial crevices, offering a variety of microclimates and microhabitats. While surface temperatures of a *Sargassum*-strandline ranged between 27 and 49 °C from 9.00 a.m. to 11.00 p.m., those within the plant mass varied only between 31 and 39 °C (Fig. 2).

In contrast, *Halodule*-strandlines are very poor in species composition; they consist of densely packed, fast-drying flat leaves which leave no space for ventilation, thus preventing evaporative cooling. At PTL 5 the temperature within a seagrass-strandline was 47.7 °C (13.VI.1992; 10.00 a.m.) compared to 37.5 °C in a *Sargassum*-strandline under similar conditions (Fig. 2).

Although as far as food and the temperature regime are concerned, the strandline seems to offer stable conditions, but it is unstable in other regards.

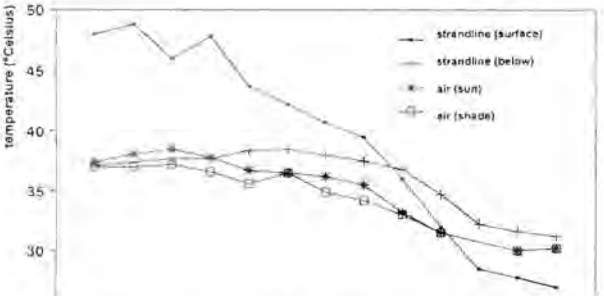

Fig. 2: Circadian temperature profile of a *Sargassum*-strandline on a sandy beach near Jubail (27°05'N 49°35'E, 22.VI. 1992).

The status (e.g. size, extent, position) of the strandline at any given time is a function of the balance between the same forces that are responsible for the removal or deposition of sand - the tides. In general the tidal cycle in the Gulf is semi-diurnal (fide JONES 1986) but its effect on the strandline is not predictable; the tidal range is strongly influenced by such factors as topography and the strength and direction of the winds, resulting in a constantly shifting beach morphology. Therefore a major problem for supratidal animals is to maintain populations at proper tidal levels in order to prevent prolonged submergence or prolonged loss of food and cover.

Strandline communities: As pointed out in the introduction, many species take advantage of the food accumulation and shelter provided by the strandline; most of them are adventitious visitors, but for some this is their normal habitat, where they spend their entire life cycle.

Being a habitat of extreme environmental conditions, the littoral fringe is in some respects very similar to desert habitats (e.g. in the lack of easily accessible freshwater and drastic temperature changes). It is therefore not surprising that the majority of coastal arthropods such as Coleoptera, Isopoda and Chelicerata are specialised members of otherwise typically terrestrial families. These are successful under arid conditions and therefore preadapted to colonise the strandline.

Once the seaweed is washed ashore, the ageing strandline goes through a number of successional stages with characteristic primary consumers. The first species to be found are thalorchestid amphipods. *Talorchestia* aff. *martensii* was the dominant species at the surveyed sites, the taxonomy of which remains unresolved. A second species, *Orchestia platensis*, has been reported from Kuwait (JONES 1986). Provided the strandline's debris keeps wet (e.g. through renewed tidal submergence), the amphipods propagate, exceeding the other community members in both biomass and number of individuals. At the same time coelopid seaweed flies appear (Diptera: Brachycera: Coelopidae) which complete their entire life cycle under the wrack-beds (DOBSON 1976). Although they propagate to astronomic numbers in a very short time, their distribution along the beach is more patchy. As the seaweed is washed further upshore and is no longer reached by every high tide, it becomes dryer. This next successional state is characterised by the predominance of darkling beetles (Tenebrionidae) and isopods. Three species of tenebrionid beetles, *Diphyrrhynchus dilatipennis* (Fig. 3), *Phaleria prolixa* (Fig. 4) (SCHAWALLER 1991, 1993) and *Trachyscelis tenuestriatus* (Fig. 5) are found throughout the year. They occur exclusively under seaweed debris, just within the reach of the highest tides on exposed sandy beaches in association with the terrestrial isopod *Tylos maindroni* (for taxonomy see TAITI & FERRARA 1991). All feed on decaying algae, but as observations show, at least larvae and adults of *P. prolixa* are facultative saprophagous scavengers. On beaches with shingle or rocky sections the ligiid isopod *Ligia pigmentata* is found (clean-up site near PTL 4 and tip of Abu Ali; I. Watt and M. Apel, pers. comm.); species of the genus *Littorophiloscia* can be expected to occur there as well (TAITI & FERRARA 1991).

The tenebrionids and *Tylos maindroni* spend their entire life cycle below the strandline. *Trachyscelis tenuestriatus* and *P. prolixa* were found to hibernate as larvae (different instars) and as adults buried in the sand. Whether they are active at a lower level or overwinter in a state of quiescense or diapause is to be investigated. Pupae have so far not been found but are expected to occur in the same habitat. Newly hatched *Trachyscelis tenuestriatus* were found in the sand below the seaweed at depths of 10 cm.

All these organisms are negatively phototactic, with their main activity period starting just before or after sunset. When exposed to light or otherwise disturbed, they remain for seconds in a state of thanatosis and then start digging themselves into the sand. The darkling beetles make use of their specialised clypeal ridge and the enlarged shovel-like tibiae (Figs 3-5). As they are restricted to the strandlines that are closest to the beach berm, permanent submergence by incoming tides is avoided. Nevertheless occasional submergence by spring tides or during storms is tolerated by both larvae and adults as observations in winter 1992/93 and spring 1993 show.

PARDI (1955, 1958) has demonstrated that the Mediterranean species *Phaleria provincialis* is able to orientate itself along a line perpendicular to its native shore; referring (diurnally) to the sun azimuth it maintains a correct angle of orientation. The direction of movement depends on the animals' physiological condition: specimens that are dehydrated and starved (below an old dry strandline) will move towards the sea and are most likely to find a fresh strandline; others, e.g. after having been submerged, will direct themselves inland. *Tylos latreillii* and *Talorchestia deshayesei* exhibit the same behaviour

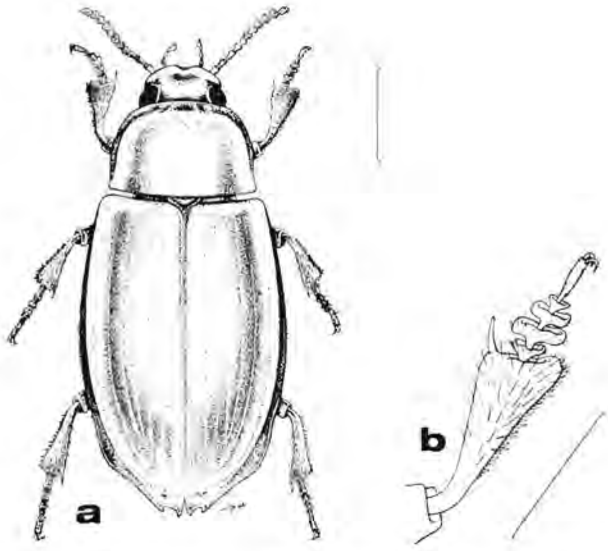

Fig. 3: *Diphyrrhynchus dilatipennis*; a, habitus of female (scale bar: 1 mm), note flattened hind margins and excavations of elytra; b, right foreleg of a male (scale bar: 0.5 mm), note the tarsal dilatations.

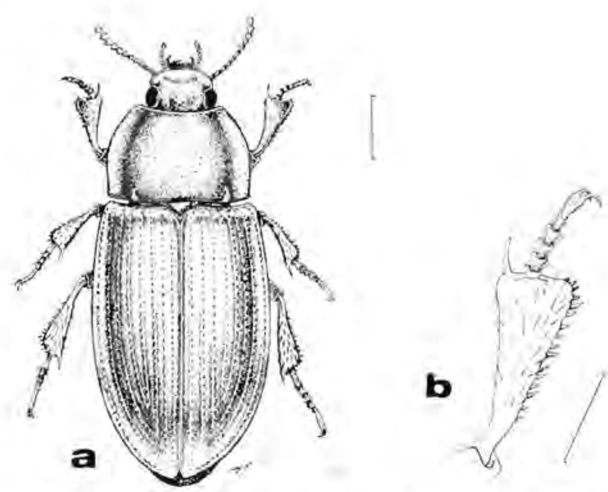

Fig. 4: *Phaleria prolixa*; a, habitus (scale bar: 1 mm); b, right foreleg (scale bar: 0.5 mm).

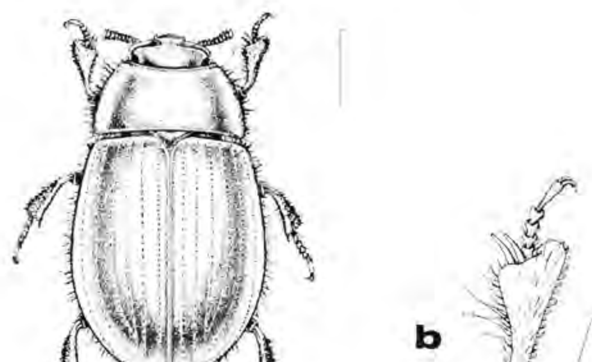

Fig. 5: *Trachyscelis tenuestriatus*; a, habitus (scale bar: 1 mm); b, right foreleg (scale bar: 0.5 mm).

(PARDI 1954, PARDI & GRASSI 1955), and we may assume that this also holds true for the species occurring in the Gulf, including *D. dilatipennis* and *T. tenuestriatus*.

The three tenebrionids were found on all offshore islands visited by us (Karan, Jana and Juraid), indicating that they have effective means of dispersal. *Phaleria prolixa* and *D. dilatipennis* were observed swarming in the dark along the beach and may well reach the islands by active dispersal. In contrast *T. tenuestriatus* has rudimentary hindwings; as with isopods and amphipods it depends on other means of transport, e.g. flotsam or "step by step" dispersal.

Damage by the oil spill: The recent oil spill polluted all of ca. 400 km coastline in the Jubail Wildlife Sanctuary. Most of the oil is found on tidal flats in the upper reaches of low-energy beaches and in accumulative strandlines along high-energy beaches. Even more than two years after the oil spill these areas are still covered by a nearly continuous layer of oiled sand and solid tar, between 0.5 and 400 m wide. In the supralittoral fringe, penetration depth of oil ranges between 2 and 15 cm. While the tar is now being eroded on the rocky shores and at the water's edge on exposed beaches, there is no visible sign of oil/tar degradation in the sand near the beach berm. In most cases the oiled strandline is located at the highest tide mark, now topped with fresh seaweeds. However, this layer, being separated and sealed from the underlying clean substratum by oil, is almost sterile and devoid of higher life. As a consequence, the fresh plant material is drying rather than being decomposed.

DISCUSSION

In the above we have focused on species that spend their entire life cycle within the strandline; they constantly move between the seaweed and the underlying sand, leaving this microhabitat only for dispersal movements or in search of a new wrack-bed when conditions in the old one deteriorate. Some authors (e.g. DOYEN 1976) consider them as "marginally marine", but the terms "strictly coastal" or "strictly littoral" seem to be more appropriate. They form the core of the strandline community, all other visitors depending more or less on them. As presence or absence of these key species reflects the condition of the strandline, they may serve as indicator species.

While they were found at all non-oiled control sites, key strandline species were still absent in spring 1993 at all PTLs visited, except on steep exposed beaches (e.g. along the northern coast of Abu Ali). Here higher tides and a wind-enforced surf established a new and active strandline on clean sand above the uninhabited oiled stripe. As the sandy substratum is not sealed by tar, the habitat of the primary consumers (debris feeders) of the strandline community, the thin layer between the decomposing algal material and the humid sand, is preserved. This clearly demonstrates the potential for recolonisation by recruitment from non-polluted areas outside or from small non-polluted nuclei within the Sanctuary. Although the reclamation of lost territory is favoured by the fact that most organisms of the tidal fringe are r-strategists (producing more offspring than the environment would sustain under undisturbed conditions), recovery can only be expected after the restoration of the strandline habitats by artificial cleaning. Recolonisation will be fast in species with active dispersal, e.g. by swarming flights in *Diphyrrhynchus dilatipinnis* and *Phaleria prolixa*, but much slower in species depending on passive transport such as *Trachyscelis tenuestriatus*, amphipod and isopod species.

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Authors' addresses:

Dr. W. Schneider, Hessisches Landesmuseum, Zoologische Abteilung, Friedensplatz 1, D-64283 Darmstadt, Germany.

Prof. Dr. R. Kinzelbach, Zoologisches Institut der TH, Schnittspahnstr. 3, D-64287 Darmstadt, Germany.

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Effects of the 1991 Gulf War oil spill on the crab fauna of intertidal mudflats in the Western Arabian Gulf

Michael Apel

Abstract: Four transects on muddy shores along the Gulf coast of Saudi Arabia were monitored for intertidal Brachyura (Crustacea: Decapoda) between June and November 1992. Two of these sites had been heavily oiled by the 1991 Gulf War oil spill, the other two had not been affected. The latter showed a rich intertidal crab fauna with five species of Ocypodidae, two Grapsidae, one Xanthidae and one Leucosiidae. A distribution pattern with four major zones was found, each dominated by a different ocypodid species. Most of this fauna was missing or drastically reduced on the oiled sites. Recruitment was observed onto one of the affected sites by *Cleistostoma dotilliforme* and *Ilyoplax frater*, but it remains to be seen if this will result in a permanent resettlement.

تأثير بقعة الزيت عام ١٩٩١م على مجموعة السرطانات في المسطحات الطينية في منطقة ما بين المد والجزر على الساحل الغربي من الخليج العربي

مايكل أبل

خلاصة: تمت مراقبة أربعة قطاعات عرضية في منطقة مابين المد والجزر على امتداد الشواطيء الطينيـة للسـاحل السعودي مـن الخليـج العربي خلال الفترة بين يونيو ونوفمبر ١٩٩٢م وذلك لمتابعة حالة السرطانات قصيرة الذيـل (Brachyura). وكـان اثنـان مـن هـذة المواقع قد تلوث بالزيت بكثافة بسبب بقعة الزيت عام ١٩٩١م، في حين لم يتلوث الموقعان الآخران. وقد تبـين أن الموقعين الأخـيرين يحتويان على مجموعة غنية من سرطانات منطقة مابين المد والجزر مكونة من خمسة أنواع تتبـع العائلـة Ocypodidae ونوعـين تـابعين للعائلة Grapsidae ونوع واحد من العائلة Xanthidae والعائلة Leucosiidae. وقد لوحظ وجود نمط انتشـار ذي أربعـة منـاطق رئيسية يتميز كل منها بسيادة نوع مختلف من العائلة Ocypodidae وكانت معظم هذة المجموعات الحيوانية إمـا غـير موجـودة أو أن أعدادها قد تناقصت بشكل كبير في المواقـع الملوثـة بـالزيت. وقـد لوحظـت عـودة ظهـور أفـراد مـن النوعـين *Ilyoplax frater* و *Cleistostoma dotilliforme* في أحد المواقع المتأثرة بالزيت، ولكن لابد من الانتظار حتى يتضح مـا إذا كـان ذلـك سـيؤدي إلى أعادة الاستقرار بهذة المواقع بشكل دائم.

INTRODUCTION

Brachyuran crustaceans in general and particularly Ocypodidae are important, often dominant, faunal elements of intertidal mudflats along the western coast of the Arabian Gulf. However, surprisingly little is known about species composition, zonation and ecology of the crab fauna in these habitats. BASSON et al. (1977) gave a basic description of the fauna of tidal mudflats along the Saudi Arabian coastline, but most intertidal Brachyura remained unidentified. CLAYTON (1983) and JONES & CLAYTON (1983) described the zonation of the intertidal crab fauna on mudflats in Kuwait, but these results are only partially transferable to the Saudi Arabian coast, since there are major differences in species composition and ecological zonation

Plate 1: Burrows of *Cleistostoma dotilliforme* in the upper intertidal zone near PTL 2.

(JONES 1985). Finally, VOUSDEN (1987) presented some observations on intertidal crabs from the mangroves and mudflats of Bahrain. Quantitative data on the intertidal crab fauna of the Western Arabian Gulf are not available, except for a few density records referred to by BASSON et al. (1977).

This lack of baseline information made it difficult to assess the effect of the 1991 oil spill on the intertidal crab communities and to evaluate the process of recovery. The present study describes the typical species composition and zonation of the brachyuran fauna on unaffected control sites and compares it with similar habitats affected by the 1991 oil spill.

MATERIALS AND METHODS

Between June and November 1992, four transects on muddy shores of the Gulf coast of Saudi Arabia were visited at approximately 6-week intervals. Two of the transects, Control 1 and 2 are

Plate 2: *Macrophthalmus depressus.*

Plate 3: *Metaplax indicus*. (Photograph M. Apel).

located at the northern end of Tarut Bay, which was not affected by the 1991 oil spill. The other two sites are in Dawhat ad-Dafi at the Permanent Transect Line (PTL) 2 and Dawhat al-Musallamiya (PTL 8) north of Jubail (for exact locations see JONES et al. (1993, Fig. 1). Both of the latter sites were heavily oiled in 1991.

All four sites represent the sheltered back end of a bay, where muddy sediments accumulate. The littoral fringe is occupied by a salt-marsh community dominated by *Arthrocnemum macrostachyum*. At Control 2 and PTL 8 this zone ends with a sudden drop in elevation of about 30 cm directly bordering a vegetationless mudflat. Control 1 and PTL 2 have a band of black mangrove (*Avicennia marina)* below the salt-marsh zone.

Along each of these transects at least five stations between spring tide high water and spring tide low water were established, each one representative of a visible change in physical or biological characteristics of the habitat. These stations were sampled taking 2-3 cores each of 0.1 m^2 area and 20 cm depth. The sediment from these cores was sieved through a 1 mm mesh, preserved in 5 % formalin and taken to the laboratory. Here the samples were sorted and all Brachyura identified and counted. At the uppermost station (salt-marsh, above mean high water level) the very consolidated sediment did not allow for coring. Here only burrow counts of the species occurring in this zone, mainly *Cleistostoma dotilliforme*, were made using a 1 m^2 quadrat.

RESULTS

Both control sites have a rich intertidal crab fauna, dominated by Ocypodidae. At both sites five species of this family were present and a zonation with four distinct zones, each dominated by a different ocypodid species, was found (Fig. 1, Table 1). These zones are referred to as salt-marsh or halophytic zone, upper intertidal, mid intertidal, and lower intertidal. There were no wide differences in faunal composition or zonation between the two control sites.

The salt-marsh is dominated by *Cleistostoma dotilliforme*, which builds conspicuous burrows in this zone (Plate 1). Only estimations of the population density of this species based on burrow counts were made. At Site 1 an average of 10, at Site 2 an average of 20 burrows per m^2 was counted, but the total number of individuals per m^2 is probably higher, since juveniles are often found associated with adult burrows (JONES & CLAYTON 1983).

The next zone, the upper intertidal, lies just below the halophyte zone. Here *C. dotilliforme* may still be numerous (up to more than 100 m^{-2}), but mainly occurs as juveniles. The dominant species here is *Paracleistostoma arabicum*, which occurs in densities of up to 600 m^{-2}. Another species of Ocypodidae, *Ilyoplax stevensi*, is also typical in this zone, but does not reach similar densities.

The next clearly marked zone is the mid intertidal. Here, as in the lower intertidal, the sediment

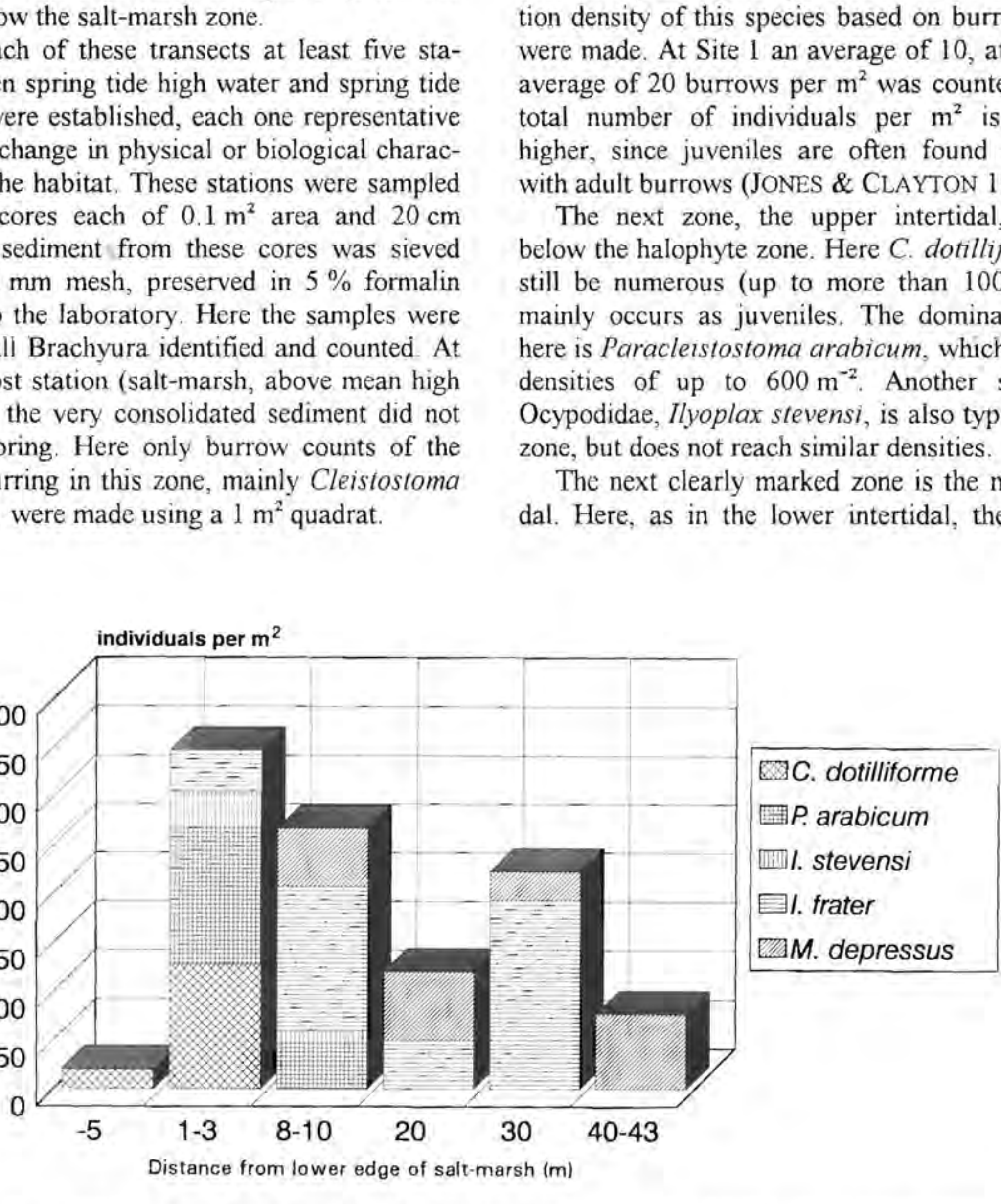

Fig. 1: Densities of ocypodid crabs at Control 1 in November 1993. For Station 1 (-5 m) burrow count, for the other stations densities calculated from 0.1 m^2 cores. -5 m = salt-marsh; 1-3 m = upper intertidal; 8-10 m = intermediate zone (between mangroves); 30 m = mid intertidal; 40-43 m = lower intertidal.

surface never dries out completely at low tide. It is dominated, in terms of abundance, by *Ilyoplax frater* which reaches densities of more than 200 m^{-2}. Also quite common in this zone is *Macrophthalmus depressus* (Plate 2).

The last zone is the lower intertidal. It is dominated by *M. depressus* and no other ocypodid crab is regularly found here. The densities were between 40 (Control 2) and 77 (Control 1) individuals per m^2, but may be underestimated because burrows of larger individuals can be deeper than the 20 cm core depth

Besides these Ocypodidae, two grapsid and one xanthid crab species also occur in the muddy intertidal areas. Their densities are much lower than those of the ocypodid species. *Metaplax indicus*, was quite common (up to 10 ind. m^{-2}) in the mid and lower intertidal at both control sites. Quantitative data on the other species was difficult to obtain, since their abundance was generally below 1 m^{-2}. Present at Control 1 and 2 were *Metopograpsus messor* (salt-marsh, < 1 m^{-2}) and *Eurycarcinus orientalis* (salt-marsh and upper intertidal, < 1 m^{-2}).

Finally, one unidentified species of Leucosiidae was observed quite regularly in the mid and lower intertidal of Control 2, but not at Control 1.

Compared to the control sites most of the crab fauna was missing or considerably lower in density at PTL 2 (Fig. 2). The zonation, which has been described for the control sites was only partly recognisable. The halophyte zone at this PTL was covered with a solid tar layer and only tar-encrusted empty *Cleistostoma*-burrows (≈10 m^{-2}), dating back to the time before the oil spill, were found between dead *Arthrocnemum* bushes. Dead mangroves occur seawards from the salt-marsh and some surviving mangrove trees grow at the same level 20 m away from the transect. From the mangrove level downwards a thick mat of blue-green algae was growing on top of the tarred sediment. This algal mat was partly peeling off, showing a hexagonal pattern (HOFFMANN 1994). It terminated, together with the tar layer, around 30 m seawards from the lower edge of the salt-marsh. However, oil was still present in the sediment, mainly in animal burrows, 40 m down from the salt-marsh zone. At the lower intertidal station (50 m from the salt-marsh) no oil was visible.

In the algal mat zone only one brachyuran species was collected, *C. dotilliforme*. This species occurred in vast numbers in the zone of the peeling algal mats from October 1992 onwards. Of the collected specimens, 90 % were recently settled juveniles, the other 10 % were small subadult individuals with distinct sexual characters but far from adult size

Below the algal mat zone the species typical of the upper and mid intertidal (*P. arabicum, I. stevensi, I. frater*) were found in very limited numbers (< 10 m^{-2}). In the lower intertidal *M. depressus* was present, but did not exceed 10 m^{-2} in density. *Metaplax indicus* (Plate 3), a fairly common predator of

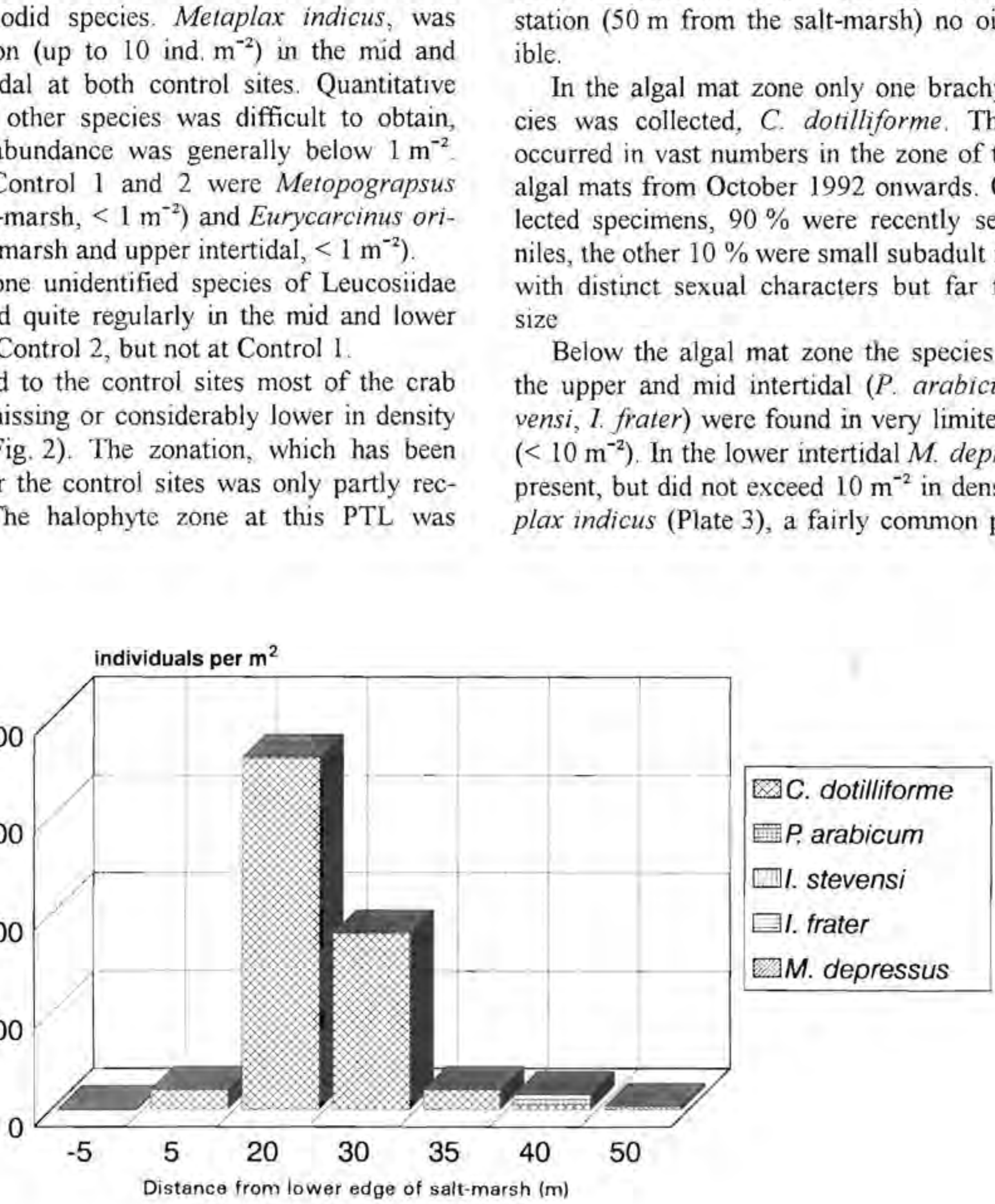

Fig. 2: Densities of ocypodid crabs at PTL 2 in November 1993. For station 1 (-5 m; salt-marsh) burrow count, for the other stations calculated from cores.

Table 1: Typical zonation of intertidal crab fauna on muddy shores on the Saudi Arabian Gulf coast as observed at Tarut Bay control sites.

Zone	Species	Max. density per m^2	Remarks
Salt-marsh	*Cleistostoma dotilliforme*	> 20	Burrow counts
	Metopograpsus messor	< 1	Estimate
	Eurycarcinus orientalis	< 1	Burrow counts
Upper intertidal	*Paracleistostoma arabicum*	600	
	Cleistostoma dotilliforme	130	Many juveniles
	Ilyoplax stevensi	50	
	Ilyoplax frater	200	
	Metaplax indicus	< 10	
	Eurycarcinus orientalis	< 1	
Mid intertidal	*Ilyoplax frater*	250	
	Macrophthalmus depressus	50	Mainly small ind./juv.
	Metaplax indicus	10	
	Leucosiidae gen. sp.	< 10	Only at Control 2
Lower intertidal	*Macrophthalmus depressus*	75	
	Metaplax indicus	10	
	Leucosiidae gen. sp.	5-10	Only at Control 2

the mid and lower intertidal at the control sites, was not observed at all. The same leucosiid species as at Control 2 was occasionally found in the lower intertidal.

At PTL 8 during the whole study not one single specimen of Brachyura was collected and no signs of recolonisation of the mid and upper shore by ocypodid crabs have yet been observed. A solid tar layer completely covers the salt-marsh zone and only tar-encrusted empty burrows of *C. dotilliforme* were present. Their densities were comparable to intact *C. dotilliforme* populations at the control sites, reaching 10-20 burrows m^{-2}. In the upper and mid intertidal, oil is present in the sediment (mainly in animal burrows) and also forms a surface tar layer which was covered by fresh sediment and algal mats. No sign of crab life was found, except in the lower intertidal where no oil was obvious and very scattered burrows of *Macrophthalmus depressus* were observed (< 1 burrow per 25 m^2).

DISCUSSION

The results show clearly that the crab fauna of the muddy shores in the Dawhat ad-Dafi/Dawhat al-Musallamiya area was heavily affected by the 1991 oil spill and has not, as yet, recovered. In particular the fauna of the mid and upper intertidal has been drastically reduced and permanent resettlement in these zones on oiled muddy shores has not yet been observed. Normally these zones are richest in terms of their ocypodid species diversity and abundance (see Table 1), but now these zones are mainly covered with a more or less solid tar layer, which does not allow ocypodid burrowing behaviour or deposit feeding.

On top of the oiled sediments mats of blue-green algae have formed in many places (HOFFMANN 1994). These algal mats consolidate the surface sediment and prevent most burrowing organisms from settling. BASSON et al. (1977) suggested that competition exists between algal mats and an intertidal faunal community characterised by ocypodid crabs and the snail *Cerithidea cingulata*. They observed that algal mats often dominate in places where the habitat has been disturbed. At the present transects the oil has consolidated the sediment and killed most of the fauna of the mid and upper intertidal. This has probably promoted the growth of the algal mats and therefore favoured the algal mat community in those areas hit by the oil. Since the factors which, under undisturbed conditions, control the change from one community to the other are unknown, predictions on the re-establishment of the ocypodid community are difficult to make.

True comparability between the control sites and the PTLs is also difficult to assess. Tarut Bay is known to be an outstandingly productive area (BASSON et al. 1977, KFUPM 1991), due in part to sewage and agricultural water influx. Densities of intertidal organisms may therefore be expected to be much higher in Tarut Bay and lower abundance at the PTLs is not necessarily due to the oil spill.

However, since most of the environmental factors are similar, it can be concluded that the community structure and zonation at the PTLs before the oil spill was similar to Tarut Bay, even though the overall densities might have been lower.

This may explain why the density of *M. depressus* in the lower intertidal is considerably lower at PTL 2 ($< 10 \text{ m}^{-2}$) than at the controls in Tarut Bay ($\geq 40 \text{ m}^{-2}$), even though a qualitative survey in November/December 1991 provided no evidence of a major effect of oil spill impact on the lower intertidal fauna (JONES & RICHMOND 1992, APEL & TÜRKAY 1992). Whether long-term effects of the oil (e.g. reduced fertility) also contribute to this lower abundance is not clear yet, but it should be noticed that at the PTLs not one juvenile *M. depressus* was found during the present study, while at the control sites juvenile *M. depressus* were quite common.

Recruitment from the plankton was observed at PTL 2 for *I. frater* and, in very large numbers, for *C. dotilliforme*. This is encouraging as it indicates that stocks of planktonic larvae exist in this area. If suitable environmental conditions are re-established, recolonisation of this site would be expected.

High densities of juvenile *C. dotilliforme* were observed in October and November on the upper intertidal of PTL 2. On the control sites during these months juvenile *Cleistostoma* were also very common, but densities were much lower. One possible explanation is that the upper intertidal forms a temporary habitat for juvenile *C. dotilliforme* during migration into the halophyte zone. If the latter is not suitable as a habitat due to a solid tar layer, this migration would stop at the upper intertidal level, resulting in abnormally high densities of juvenile *C. dotilliforme* there. Another possibility is the lack of competition, since the normally dominant species (*P. arabicum* and *Ilyoplax* sp.) are missing in the upper intertidal of this site. It therefore remains to be seen if the juveniles of *C. dotilliforme* are able to settle successfully at PTL 2.

Recruitment of *I. frater* was much lower, resulting either from a lower influx of larvae or from adverse environmental conditions at the site preventing larval settlement. Plankton monitoring for decapod larvae in the Dawhat ad-Dafi area which started in October 1992 should provide an answer. This monitoring will supply data on frequency and distribution of brachyuran larvae within the research area and thus will help to evaluate the potential for recolonisation of impacted areas.

No recruitment of any brachyuran species was observed at PTL 8 in Dawhat al-Musullamiya. Here again, either the influx of planktonic larvae is very low or environmental conditions are not favourable for larval settlement.

Many questions regarding the effect of oil on the brachyuran communities still remain open requiring more studies on the different species concerned. The present study aims to provide a base-line for future research concentrating on the biology and ecology of the species inhabiting the affected shorelines. It may be a long time before full recovery of the affected habitats and communities takes place and observation of the succession during this process will provide valuable information about the communities and their components.

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Author's address:
M. Apel, Forschungsinstitut Senckenberg, Sektion Crustacea, Senckenberganlage 25, D-60325 Frankfurt a.M., Germany.

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The impact of the 1991 Gulf War oil spill on bird populations in the northern Arabian Gulf - a review

Peter Symens & Abdullah Suhaibani

A b s t r a c t: The Arabian Gulf is of international importance for breeding and wintering seabirds and wintering and migrating waterfowl. Following the massive oil spill which occurred in 1991, a monitoring scheme to assess possible damage was initiated. During the first months more than 30,000 wintering grebes and cormorants, including the endemic Socotra cormorant (*Phalacrocorax nigrogularis*) were killed by oil-fouling. This represents from 22 % to more than 50 % of the regional populations of the different species. Large numbers of waders were oil-fouled between February and May 1991. The affected intertidal zone along the Saudi Arabian coast was virtually abandoned for the following two years. Although some mortality has occurred, the records indicate that most waders had dispersed from the affected intertidal habitats and that at least a proportion of the oil-fouled waders survived. Since the autumn of 1992, large numbers of waders have reappeared on the previously oiled intertidal areas indicating that recovery is proceeding. The internationally important breeding colonies of terns on the offshore coral islands escaped any serious impact from the oil spills in 1991. The following year a major decrease in breeding success was caused by a lack of prey fish stocks. At the time of writing it is not clear whether the reduction in prey fish populations and the resulting decrease in the terns' breeding success is attributable to the Gulf War oil spill, or caused by natural fluctuations in fish populations.

تأثير بقعة الزيت الناتجة عن حرب الخليج عام ١٩٩١م على مجموعات الطيور في شمال الخليج العربي، مراجعة

بيتر سايمنز وعبد الله السحيباني

خلاصة: يعتبر الخليج العربي ذا أهمية عالمية بالنسبة لتكاثر وإشتاء الطيور البحرية وإشتاء الطيور المائية المهاجرة. وعلى أثر بقعة الزيت الكبيرة التي حدثت عام ١٩٩١م بدأ العمل في برنامج مراقبة لتقويم حجم الدمار المحتمل أن ينتج عن ذلك. وسجلت الأحصائيات خلال الأشهر الأولى نفوق أكثر من ٣٠,٠٠٠ فرد من طيور الغطاس والغاق بما في ذلك الغاق السوقطري *Phalacrocorax nigrogularis* المستوطن وذلك من جراء التلوث النفطي. ويمثل هذا العدد نسبة تتراوح من ٢٢٪ إلى أكثر من ٥٠٪ من المجموعات المحلية للأنواع المختلفة. كما أصاب التلوث أعداداً من الطيور الخواضة في الفترة مابين فبراير ومايو ١٩٩١م. وأصبحت منطقة مابين المد والجزر المتأثرة بالتلوث على أمتداد الساحل السعودي من الخليج مهجورة تقريباً خلال العامين التاليين. وعلى الرغم من حدوث بعض حالات نفوق الا أن مشاهدتنا تشير الى معظم الطيور الخواضة قد انتشرت بعيداً عن منطقة مابين المد والجزر الملوثة وأنه على الأقل هناك نسبة من الطيور الخواضة الملوثة بقيت حية. ومنذ خريف ١٩٩٢م رجعت أعداد كبيرة من الطيور الخواضة الى مناطق مابين المد والجزر التي سبق أن تعرضت للتلوث مما يشير الى أن عملية استعادة هذه المناطق لحيويتها مستمرة.

أما مستعمرات تكاثر الخرشنة ذات الاهمية العالمية على الجزر المرجانية البعيدة عن الساحل فقد كانت بمنأى عن التأثير الخطير لبقعة الزيت عام ١٩٩١م. ولكن حصل انخفاض كبير في نجاح موسم التزاوج خلال العام التالي بسبب النقص في أعداد الأسماك التي تتغذى عليها هذه الطيور. وليس من الواضح في الوقت الحاضر ما إذا كان النقص الحادث في مجموعات الأسماك والتدهور الناجم عنه في نجاح موسم التزاوج لطيور الخرشنة مرده إلى تأثير بقعة الزيت أو إنه نتيجة للتذبذبات الطبيعية في أعداد مجموعات الأسماك.

INTRODUCTION

Although previous quantitative studies on bird populations in the Arabian Gulf are scarce, this region is known to be of international importance for breeding seabirds (e.g. GALLAGHER et al. 1984, ZWARTS 1987, BUNDY et al. 1989) and for wintering and migrating waders (e.g. SUMMERS et al. 1987, ZWARTS et al. 1991). When massive quantities of oil were released into the northern Arabian Gulf in January 1991, it was feared that these important bird populations would be diminished to such an extent that a full recovery would be impossible. At an early stage following this disaster it became apparent that a complete damage assessment was not possible due to the lack of data on the pre-war situation. Therefore a long-term monitoring programme was initiated to gather more baseline information on these bird populations along the northern Gulf coast in Saudi Arabia and to try to assess the long-term effects of the Gulf War oil spill. This paper gives an overview of the results that were obtained between February 1991 and April 1993.

RESULTS

Wintering seabirds: The first obvious victims of the oil spill were wintering seabirds. Counts of dead birds at 82 sites, covering nearly 200 km of coastline between al-Khafji in the north and Jubail to the south, from February to April 1991 revealed a total of 10,243 oil-fouled bird carcasses (SYMENS & SUHAIBANI in press). The majority of these dead birds were: great crested grebes (*Podiceps cristatus*, 20.7 %), black-necked grebes (*P. nigricollis*, 26.6 %), great cormorant (*Phalacrocorax carbo*, 22.8 %) and Socotra cormorant (*P. nigrogularis*, 25.9 %). The remaining 4 % included (in decreasing abundance) gulls, waders, ducks, terns and herons. Extrapolation of this number to the entire affected coastline of Saudi Arabia and Kuwait suggests that at least 30,000 pelagic seabirds died as a direct consequence of oil-fouling in the northern Gulf between February and April 1991. This total number includes a large proportion of the wintering populations of grebes and cormorants of the northern Gulf, as well as important numbers of birds which winter further south in the Gulf and which were caught by the oil while migrating northwards along the Gulf coast to their breeding areas.

It is difficult to define how significant this mortality is at species level, since no accurate pre-war population estimates for wintering seabirds were available for this region. During the winters 1991-1992 and 1992-1993 counts of wintering grebes and cormorants were made along the entire Saudi Gulf coast. These counts indicated that a minimum of 3500 great crested grebes and 5000 black-necked grebes wintered in this area. Whereas the great crested grebe is only a scarce winter visitor to the southern Gulf, the winter distribution of the black-necked grebe reaches the Gulf of Oman and the Arabian Sea (e.g. GALLAGHER & WOODCOCK 1980, BUNDY et al. 1989, RICHARDSON 1990). If the numbers that winter in these parts of the Gulf are similar to those of the Saudi Gulf coast, then the total wintering population of great crested and black-necked grebe in the western and southern Gulf can be estimated at 7000 and 10,000 birds respectively. It is estimated that the Gulf War oil spill killed more than 50 % of this wintering population of grebes. The great cormorant occurs as far south as Oman (GALLAGHER & WOODCOCK 1980, RICHARDSON 1990), though in smaller numbers than in Saudi Arabia. The wintering population of great cormorants along the Saudi Gulf coast was estimated at 15,000 birds in 1991-1992 and 12,000 in 1992-1993. Assuming that this represents half of the population that winters between Kuwait and Oman, then the Gulf War oil spill may have killed 22 to 34 % of this population.

The Socotra cormorant (Plates 1-2) is an endemic bird to the Arabian Gulf and the Arabian Sea. In the northern Gulf, breeding takes place in the late autumn and winter, after which the birds disperse, but the extent of these dispersive movements is poorly understood (e.g. BUNDY et al. 1989). Based on a survey of all breeding colonies of this species in Saudi Arabia, the total population in the Kingdom was estimated at 30,000-35,000 birds in the winter 1992-1993 (SYMENS et al. 1993). Thus the mortality caused by the Gulf War oil spill would represent more than 25 % of that population.

Waders: ZWARTS et al. (1991) tentatively estimated that 260,000 waders winter on the Saudi Arabian Gulf coast and up to four million in the whole Arabian Gulf, and on this basis judged the intertidal zone of the Gulf coast to be one of the world's five major wintering areas for waders. SUMMERS et al. (1987), reviewing the information on status, population size and migration of waders along the West Asian Flyway, showed that all waders wintering in eastern Africa and the majority of those in southern Africa pass through the Middle East on migration, and concluded that the intertidal zone of the Arabian Gulf coast was probably one of the most important stop-over or 're-fueling' areas for migrant waders in the whole West Asian Flyway region.

Plate 1: Adult specimens of the Socotra cormorant (*Phalacrocorax nigrogularis*) on Judhaim Island.

Plate 2: Juvenile Socotra cormorant on Judhaim Island.

Table 1: Number of nests of four species of terns on the northern Arabian Gulf islands in 1991 and 1992.

	Year	Harqus	Karan	Kurain	Jana	Juraid	TOTAL
Sterna bergii	1991	17,80	196	1250	3	0	3229
	1992	15,00	170	2100	2	35	3807
S. bengalensis	1991	16,00	10,154	8710	37	0	20,501
	1992	12,00	14,000	10,000	0	2800	28,000
S. repressa	1991	0	2310	0	5690	930	8930
	1992	0	4800	0	6000	1050	11,850
S. anaethetus	1991	0	11,160	3180	6930	12,730	34,000
	1992	0	17,370	2400	5000	10,000	34,770
TOTAL	1991	3380	23,820	13,140	12,660	13,660	66,660
	1992	2700	36,340	14,500	11,002	13,885	78,427

During the first year following the oil spill, the numbers of migrating and wintering waders in the polluted intertidal zone, representing some 50 % of the total intertidal zone of the Saudi Gulf coast, had decreased by up to 98 % compared to estimated pre-spill levels as given by ZWARTS et al. (1991). This was due to the oil pollution in the intertidal zone and the subsequent loss of food supplies (EVANS & KEIJL in press). LARSEN & RICHARDSON (in prep.) showed that waders disperse away from oiled areas to more sheltered sites and that oiled waders often appear segregated or isolated from non-oiled birds. This behaviour was frequently noted along the Gulf coast where heavily oiled curlews (*Numenius arquata*) were regularly observed singly or in small groups 1 to 5 km inland in the sand dunes, where they foraged on tenebrionid beetles. Large concentrations of waders were only found at non-intertidal wetlands such as temporarily rain-flooded sabkhas and sewage evaporation ponds. Within these flocks, large numbers of birds were oil-fouled, indicating that many of these birds had dispersed away from the oiled intertidal zone. At the sewage evaporation ponds of Jubail in Sabkhat al-Fasl up to 1000 Mongolian plovers (*Charadrius mongolus*) were present in April 1991, of which more than 90 % were oil-fouled (EVANS & KEIJL in press). In April 1992, the maximum count of Mongolian plovers at this site was only 365, none of which were oiled.

Until the autumn of 1992, no concentrations of waders were observed along the affected coast north of Jubail. The only concentrations of waders in the area occurred at the sewage evaporation ponds in Sabkhat al-Fasl in Jubail, where at times nearly 20,000 waders, mainly *Calidris* and *Charadrius* species, were counted between October 1991 and May 1992. These birds spent their entire stay in the region at this site, where they were feeding mainly on the larvae of various chironomid salt flies and ostracods, such as *Heterocypris salinus*.

In October 1992 the situation suddenly changed. Large numbers of autumn migrants reappeared at Sabkhat al-Fasl, but only during daytime. In the evening, all waders left from this site to the oiled intertidal area of Dawhat ad-Dafi where they foraged during the nocturnal low tide and from which they returned to Sabkhat al-Fasl in the early morning to remain there during the diurnal high tide. This change in behaviour indicated that the intertidal fauna in that area was recovering, as was confirmed by WATT et al. (1994). In mid-November 1992 and mid-January 1993, only two years after the oil spills occurred, the total feeding density of waders on the mudflats of Dawhat ad-Dafi reached maximum values of 35 and 32 waders per hectare, representing 76 and 70 % of the pre-war densities recorded by ZWARTS et al. (1991). The recovery for smaller species like dunlin (*Calidris alpina*) and little stint (*Calidris minuta*), which mainly feed on smaller invertebrates such as polychaetes, reached up to 90 %. For species such as redshank (*Tringa totanus*), grey plover (*Pluvialis squatarola*) and curlew, which feed on the larger invertebrates such as crabs, the recovery ranged only from 10 to 34 %. This rate of recovery of wader densities on intertidal areas after the oil spill corresponds very well with results from similar studies on other oil spills. When more than 100,000 barrels of diesel crude polluted 3250 hectares of intertidal flats and salt-marsh at the Medway Estuary in the U.K, wader densities dropped significantly but recovered very well 15 months after the incident (HARRISON & BUCK 1967, 1968; HARRISON & HARRISON 1967). Similarly, CHAPMAN (1985) reported a recovery period of one

Table 2: Numbers of oil-fouled adult terns on Karan, Saudi Arabia, in 1991 and 1992.

Year	n	Proportion of oil-fouled birds		
		lightly oiled	moderately oiled	heavily oiled
1991	16420	3.8 %	0.3 %	0.3 %
1992	11780	0.6 %	1.1 %	1.4 %

to two years for waders and their food supplies on sandy beaches in the Gulf of Mexico after the Ixtoc I oil spill in 1979.

During the initial months following the oil spills, levels of oiling were particularly high in the populations of Mongolian plover, grey plover, broad-billed sandpiper (*Limicola falcinellus*), curlew and Terek sandpiper (*Xenus cinereus*) (EVANS & KEIJL in press; pers. obs.). However, it is impossible to estimate the number of waders that died as a consequence of this oil-fouling. Although dead waders were only rarely found in the affected area, it is assumed that many oiled birds may have died along their migration routes. Ringing studies indicated that oil-fouled waders had significantly lower body weights than unoiled birds, both at the oiled zone in spring 1991 (EVANS & KEIJL in press) and near Riyadh in autumn 1991 (pers. obs.). This decrease in body weight was mostly due to reduced fat reserves and was severe enough to make successful migration and breeding impossible that year. However, birds initially colour-marked at Sabkhat al-Fasl while they were heavily oil-fouled in November-December 1991, have been re-sighted totally clean the following winter (1992/93), indicating that at least a portion of the oil-fouled waders survived.

Breeding seabirds: Breeding seabirds were another important bird group of concern. The offshore islands in the northern Gulf in Saudi Arabia are known to be of international importance for breeding terns, particularly for lesser crested tern (*Sterna bengalensis*) and bridled tern (*S. anaethetus*) (e.g. GALLAGHER et al. 1984, ZWARTS 1987, BUNDY et al. 1989), while swift tern *S. bergii* and white-cheeked tern (*S. repressa*) occur in numbers of regional importance (Plates 3-5). During the breeding seasons of 1991 and 1992 the numbers of pairs of the four breeding species of terns were estimated on the islands Harqus, Karan, Kurain, Jana and Juraid, following the methods used by ZWARTS (1987) in 1986 (see also SYMENS & EVANS in press). The results of this census are shown in Table 1. The colonies of lesser crested tern on these islands are the largest and densest found in the world, and the breeding population on these islands must represent a significant part of the total world population of this species. The large breeding population of bridled terns place the islands among the five most important breeding areas in the world.

It was feared that the terns and their breeding activities could be severely affected by the oil spill. Large numbers of adult terns might be killed through oil-fouling. Oil could be transferred to the eggs by incubating adults and kill the embryo. Research has shown that 10-20 µl of fresh oil on a freshly laid larid egg is enough to kill the embryo (WHITE et al. 1979, LEWIS & MALECKI 1984). Stranded oil on the shore can severely affect the chicks as they gather on the beach. Oil spills can also affect seabird populations through the food chain by damage caused by toxic hydrocarbons to the ecosystems where food resources are produced. Disruption of the breeding cycle of prey fish species could cause a drastic decline in the terns' breeding success. This indirect impact may only become apparent over a longer period.

In both years a large number of adult birds on Karan was checked for oil-fouling. The degree of oil pollution was scored visually as lightly oiled (0-5 % of the total body smothered by oil), moderately oiled (6-33 % of the body) and heavily oiled (more than 33 % of the body) (SYMENS & EVANS in press and Table 2). During the summer of 1991 only small numbers of oiled adult terns were recorded while the few dead oil-fouled terns that were found represented less than 0.2 % of the total adult population. These low numbers can be explained by the fact that the oil from the Gulf War oil spill had disappeared from the open sea and had stranded in the coastal bays by April when the terns returned from their wintering grounds in the Indian Ocean to their breeding areas in the northern Gulf. The larger number of lightly oiled terns in 1991 was probably the result of contact with tar balls while the birds were plunge-diving to catch their prey. Little oil spots were regularly found on all parts of the body, including the underwings and upperparts. In 1992 most of the tar balls of the Gulf War oil spill had stranded and the number of lightly oiled terns

Table 3: The breeding success of terns on Karan, Saudi Arabia, in 1991 and 1992 (n.a. = not available).

	Hatching success (%)		Fledging success (%)		Breeding success (%)	
	1991	1992	1991	1992	1991	1992
Sterna bergii	76	n.a.	n.a.	n.a.	n.a.	33
S. bengalensis	95	n.a.	86	n.a.	82	46
S. repressa	93	45	77	0	72	0
S. anaethetus	94	47	97	37	91	33

decreased correspondingly. The increase in numbers of moderately and heavily oiled terns that year probably reflects the usual, chronic oil pollution that occurs in this region. Moderate and heavy oiling is mostly caused by contact with fresh floating oil. In 1991 there was no floating oil around the islands during the summer, because the oil industry in Kuwait and the northern Gulf was not operational due to the damage caused by the war. In 1992, this industry was again operational and accidental leakage, spilling and transport-related pollution might have caused an increased oil-fouling of terns.

The low number of oil-fouled adult birds resulted in virtually no oiling of eggs by incubating birds. In 1991 a number of chicks were oil-fouled by the tar on the beach rock on Karan, Jana and Juraid, but in general this did not prevent them from normal development to full-grown juvenile birds. Furthermore this problem was very localised so that it had a minimal effect on the total breeding success.

Table 3 gives an overview of the breeding success per species on Karan in 1991 and 1992 (for methodology see SYMENS & EVANS in press). In this table hatching success represents the percentage of eggs from which a chick hatched, fledging success represents the percentage of the total number of chicks that eventually fledged, and breeding success indicates the percentage of eggs that resulted in a chick that fledged. The overall high breeding success in 1991 showed that there was no impact of the oil spills on the breeding activities through poisoning or reduction of their food resources (young pelagic schooling fish, mainly sardines and anchovy). The tempering effect of the soot clouds of the Kuwaiti oil well fires might have had a positive effect on the terns' breeding success by reducing heat stress on adults, eggs and chicks (SYMENS & EVANS in press). In 1992 however, the breeding success was greatly reduced, ranging from only 46 % in lesser crested tern to a complete failure in white-cheeked tern.

The following changes were recorded:

1. many incubating birds abandoned their eggs before they hatched;
2. the growth rate of the chicks was much lower than in the previous year, resulting in a much higher chick mortality;
3. the swift terns preyed upon the chicks of white-cheeked terns to such an extent that not one single chick of the latter species survived for more than three days after hatching;
4. there was a significantly reduced amount of fish brought in by the parents to the chicks;
5. there was an important increase in inter- and intraspecific aggression between birds returning with fish to the colony.

In longer-term monitoring studies on breeding seabirds in other parts of the world, all these phenomena have been attributed to a shortage of prey stock (e.g. DANCHIN 1992, FURNESS 1982, MONAGHAN et al. 1992, UTTLEY 1992). From this it is concluded that in 1992 there was not enough food available for the breeding terns in the northern Gulf to raise their chicks successfully. At the time of writing it cannot be determined whether this shortage is caused by a delayed effect of the oil spill, a decrease in sea temperature due to the soot clouds of the Kuwaiti oil well fires, attributable to the extremely cold winter of 1991-92, a natural cycle in fish populations, or to a combination of these factors.

CONCLUSIONS

The scarcity of pre-war data on distribution, population size, natural fluctuations of populations in space and time, and the lack of base-line data on the ecology and migration strategies of waterfowl populations in the Arabian Gulf region, made any detailed damage assessment of the Gulf War oil spill on these important bird populations virtually impossible at an earlier stage. Surveys on wintering grebes and cormorants during the two winters following the oil spill revealed that the mortality repre-

Plate 3: White-cheeked tern (*Sterna repressa*) near Jana Island.

Plate 4: Bridled tern (*Sterna anaethetus*) on Karan Island.

Plate 5: Part of a breeding colony of the lesser crested tern (*Sterna bengalensis*) on Karan Island.

sented from 22 to 50 % of the regional populations. However, the presence of extremely large numbers of juvenile great cormorants during these winters indicate that the populations are recovering.

Initially, virtually all waders disappeared from the oiled coastline and many birds were oil-fouled, but our observations indicate that most waders dispersed from the affected zone rather than died. Whereas previously it was assumed that most, if not all, heavily oil-fouled waders would die as a consequence of the oil pollution, our observations have proved that at least a proportion of them managed to survive. A strong increase in feeding densities of waders on the affected intertidal areas of Dawhat ad-Dafi since the autumn of 1992 indicates that these traditional feeding grounds are recovering.

Whereas the breeding colonies of terns on the offshore islands escaped any major impact in 1991, a drastic decline in breeding success was noticed in 1992. At present it is not clear whether this decrease can be attributed to the oil spill.

Further monitoring will be necessary to see if any long-term impact of the Gulf War oil spill on these internationally important bird populations occurs and whether full recovery to the pre-war situation can be reached.

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Authors' addresses:

P. Symens & A. Suhaibani, National Commission for Wildlife Conservation and Development, P.O. Box 61681, Riyadh 11575, Kingdom of Saudi Arabia.

Present address: Jubail Marine Wildlife Sanctuary, P.O. Box 11071, Jubail 31961, Kingdom of Saudi Arabia.

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Ecological status of the marine subtidal habitats and the effects of the 1991 Gulf War oil spill, with special reference to soft-substrata communities

Matthew D. Richmond

A b s t r a c t: Surveys of subtidal benthic communities were conducted in February, May/June and October/November 1992 in the bay areas of Dawhat ad-Dafi and Dawhat al-Musallamiya. These local surveys revealed the diversity of marine habitats found elsewhere in the northern Arabian Gulf: coral patch and fringing reefs, seagrass beds, macroalgae-dominated rockflats, and bare sand and muddy seabeds. Detailed analysis of four permanent stations confirmed the rich species composition of the soft-substrata benthic communities as well as a seasonal trend in species numbers and abundance in the infaunal invertebrate community. With the exception of two small, localised sites, there was no visual evidence of oil contamination in the subtidal region.

الوضع الايكولوجي لبيئات ما تحت المد والجزر البحرية وآثار بقعة الزيت لعام ١٩٩١م مع إشارة خاصة لمجتمعات الطبقة السفلى الرخوة

ماثيو رشموند

خلاصة: تم إجراء مسوحات على المجتمعات القاعية لبيئات ماتحت المد والجزر في خلجان منطقتي دوحتي الدفي والمسلمية خلال شهر فبراير ومابين مايو ويونيو، وأكتوبر ونوفمبر ١٩٩٢م.وكشفت هذة الدراسات المحلية عن وجود تنوع في البيئات البحرية مماثل لذلك الموجود في المناطق الشمالية من الخليج العربي.ويشمل ذلك الشعاب المرجانية المتفرقة ومهاد الحشائش البحرية والمناطق الصخرية المغطاة بالطحالب الكبيرة وقيعان البحر الطينية والرملية الجرداء. وقد أكدت الدراسات التحليلية لأربعة من المحطات الدائمة وجود تشكيلة غنية من الأنواع في المجتمعات القاعية السفلى الرخوة الى جانب حدوث اتجاة موسمي في أعداد الأنواع ووفرتها في مجتمع المجموعة الحيوانية اللافقارية. وبإستثناء موقعين صغيرين محليين لم يشاهد أي دليل على حدوث تلوث نفطي في منطقة ما تحت المد والجزر.

INTRODUCTION

Only limited information on the marine ecosystems within the study area exists, although other areas of the northwestern Arabian Gulf have fortunately been investigated and the major habitats of this region of the Gulf have been well described. Such studies have revealed shallow coral reefs supporting rich fisheries (e.g. MCCAIN et al. 1984) and extensive seagrass beds (Plate 1) dominated by *Halodule uninervis* (e.g. COLES & MCCAIN 1990) which are important primary producers and vital to the prawn and other fisheries in the region (BASSON et al. 1977).

The main objectives of this study were (1) to conduct a general survey of the marine subtidal portion of the study area and to identify, and quantify, the extent of the major marine habitats - allowing for the later production of a detailed marine habitat map; (2) to evaluate possible immediate effects of the 1991 oil spill on the subtidal communities and (3) monitor possible long-term effects on benthic communities by regular sampling at selected sites within the study area and control sites unaffected by the spill.

Table 1: Summary of conditions and details of the benthic Subtidal Monitoring Sites (SMSs) and Control sites (C).

Station	Location	Depth (m)	Substrate	Salinity range (ppt)
SMS 1	SW Dawhat ad-Dafi	4	fine sand/ seagrass	47 - 56
SMS 2	Qurma Channel	5	sand/silt	47 - 60
SMS 3	"Pole" Reef	3	sand-shell/ seagrass	40 - 52
SMS 4	"Pole" Reef	0.5	coral reef/ rocky reef top	40 - 52
C 1	Abu Ali central south	1	fine sand/ seagrass	? - 44 - 52 - ?
C 2	Jubail - Field Centre beach	4	sand/silt	? - 44 - ?

MATERIALS AND METHODS

General surveys: During 1992, spot checks on the seabed were conducted at 88 sites within the study area by snorkelling or SCUBA diving. At each site data on water depth, temperature, salinity, substrate type, ecotype and oil pollution were recorded. Latitude and longitude data were ascertained using the Magellan GPS. This "sea-truth" information was continuously added to and was incorporated into a final marine habitat chart of the entire study area with the use of the Geographical Information System (GIS) and refined with information from aerial surveys, satellite images and photo mosaics of the area.

Long-term monitoring: In January 1992, three long-term, Subtidal Monitoring Sites (SMSs) were selected as being representative of the soft-bottom habitats in the study area. One additional station was selected from a hard substrate, reef-top location (SMS 4). These stations were sampled in February (winter), May/June (late spring) and October (autumn) 1992. Difficulty in finding comparable subtidal control sites outside of the study area resulted in two additional "Control Sites" (C1 and C2) being established only in October 1992. Details of these sites are shown in Table 1, with their positions in Fig. 1.

At each of the soft-bottom monitoring sites three 0.1 m^2 cores, 12-15 cm deep, were sampled by SCUBA divers, sieved through a 1 mm mesh and

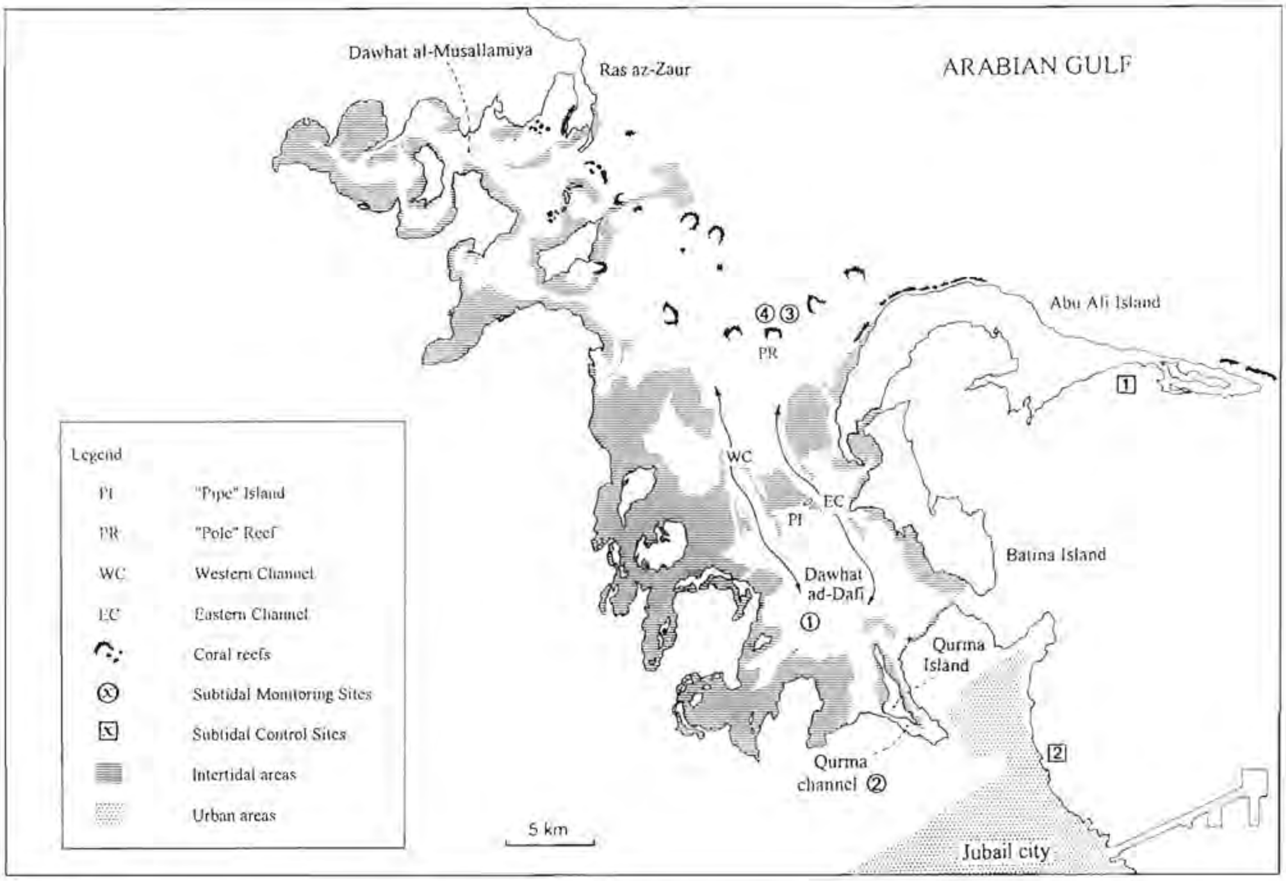

Fig. 1: Preliminary geomorphological chart of the study area with positions of benthic subtidal monitoring sites, coral reefs and intertidal areas (see inset for explanation of symbols).

preserved in 10-15 % formalin solution. All infauna was later sorted and identified to species level where possible. In addition, five 1 m^2 quadrats were used to assess the abundance and percentage cover of epibenthic flora and fauna at the seagrass sites and the hard-substrate monitoring site.

RESULTS

General surveys: The general survey revealed that large areas of the bays of Dawhat ad-Dafi and Dawhat al-Musallamiya are shallower than 1 m (see Fig. 1) and that in general water depth does not exceed 4 m. The "East Channel" and "West Channel" are areas of tidal currents with depths of 4-6 m. Similar depths were found in the dredged areas of "Pipe" Island Channel and around Qurma Island. Only at the northern end of the study area were depths in excess of 8 m found. Water temperature varied considerably within the study area and over the sampling period. The shallowest regions at the landward end of the sheltered bays revealed the greatest fluctuations with Qurma Channel, for example, being coldest in winter at 10-12 °C, warming to 30-33 °C in late spring. Salinity here reached 58 ppt in the winter, dropping slightly in June to 47-50 ppt. At the northern end of the study area, salinity and temperature variations were less marked, with winter salinity of 50-52 ppt dropping to 40-44 ppt in late spring and water temperature varying between 12-15 °C and 30-33 °C over the same period.

Most of the bay areas were found to be soft-bottom biotopes, interspersed by small patches of flat, sandstone pavement and coral patch reefs. Sandy bottom areas shallower than 5 m were normally dominated by *Halodule uninervis* with *Halophila ovalis* and *H. stipulacea* also present (Plate 1). The most developed seagrass beds were common at depths of 3-4 m with the sparsest beds along the shallow intertidal fringe. Other flora of note in the seagrass beds included the green algae *Avrainvillea amadelpha* and *Caulerpa sertularioides*. Large *Pinna* sp. bivalves were common together with sponges and *Phallusia nigra* tunicates. Soft substrate below 5 m depth was predominantly bare. Such depths were found only in the dredged area around Qurma Island and in the 5-6 m deep bay enclosed by the Ras az-Zaur peninsula. The level of exposure to wave action and currents appeared to dictate the level of coarseness of soft-bottom substrates. In shallow and exposed areas coarse sand and shell debris prevailed, commonly around the patch reefs in the north. Finer sands and silt were

Table 2: Summary of mean species numbers, total species number, numbers of individuals, and weight of tar recorded at each monitoring station for each sampling period (data per 0.1 m^2). Standard deviations in parenthesis, NS = not sampled.

Station		January	May-June	October
SMS 1	Mean spp. no.	5 (2)	18 (2)	19 (4)
seagrass	Total spp. no.	7	22	23
	Mean no. individuals	27 (7)	166 (50)	94 (25)
	No tar			
SMS 2	Mean spp. no.	10 (2)	27 (5)	16 (1)
sand/silt	Total spp. no.	15	43	25
	Mean no. individuals	267 (64)	1073 (78)	100 (16)
	Mean tar (g)	0.07	0.7	0.65
SMS 3	Mean spp. no.	16 (3)	22 (9)	43 (8)
seagrass	Total spp. no.	30	42	76
	Mean no. individuals	51 (12)	71 (33)	222 (7)
	No tar			
C 1	Mean spp. no.	NS	NS	29 (4)
seagrass	Total spp. no.			59
	Mean no. individuals			102 (59)
	No tar			
C 2	Mean spp. no.	NS	NS	9 (1)
sand/silt	Total spp. no.			14
	Mean no. individuals			40 (4)
	Mean tar (g)			0.6

more common in the seagrass beds in the south of Dawhat ad-Dafi and western end of Dawhat al-Musallamiya.

Hard substrates tended to be dominated by brown macroalgae, especially of the genera *Hormophysa, Sargassum, Dictyota, Colpomenia* and *Padina* (DE CLERCK & COPPEJANS 1994). On shallow rock-flats, a thin veneer of sand was usually present and the above algae were usually the only forms of sessile marine life. On the reef tops, encrusting, red coralline algae were also present and the urchin *Echinometra mathaei*, the gastropod *Morula* cf. *konkanensis* and the bivalves *Pinctada radiata* and *Spondylus* spp. were especially common. The coral component of these patch and fringing reefs was clearly dominated by *Porites compressa*, with a minimum of seven other genera present. Most reefs revealed good coral cover on the seaward, often northern, face where a near-vertical slope existed from 1-4 m depth. Behind this reef-front the reef top sloped downwards more gently, supporting the community described above, followed by macroalgae-dominated rock which eventually gave way to sand and seagrass. A total of 13 main patch reefs, and two stretches of fringing reef have been identified, with the latter along the northern shore of Abu Ali and along the inshore, western coast of the Ras az-Zaur peninsula. The patch reefs

Table 3: Summary of mean abundances of individuals of the major taxonomic groups, for each soft-bottom monitoring site for each sampling period. Data per 0.1 m^2, standard deviations in parenthesis, NS = not sampled.

Station	Taxa	January	May-June	October
SMS 1	Polychaetes	26 (7)	132 (48)	60 (10)
seagrass	Bivalves	0	10 (3)	2 (0)
	Gastropods	0	2 (2)	27 (12)
	Crustaceans	0.3 (0.6)	23 (26)	4 (3)
	Echinoderms	0	1 (1)	0
	Others	0	0	1 (1)
SMS 2	Polychaetes	9 (2)	192 (38)	32 (8)
sand/silt	Bivalves	60 (38)	328 (18)	25 (8)
	Gastropods	196 (91)	563 (124)	41 (26)
	Crustaceans	0.6 (1)	0.3 (0.6)	4 (3)
	Echinoderms	0	0	0
	Others	0.3 (0.6)	8 (4)	1 (1)
SMS 3	Polychaetes	39 (13)	61 (25)	185 (8)
seagrass	Bivalves	6 (3)	3 (4)	14 (3)
	Gastropods	0.3 (0.6)	0.7 (0.6)	16 (4)
	Crustaceans	2 (2)	2 (3)	1 (2)
	Echinoderms	3 (2)	2 (2)	0.3 (0.6)
	Others	0.6 (1)	4 (1)	6 (3)
C 1	Polychaetes	NS	NS	77 (47)
seagrass	Bivalves			6 (3)
	Gastropods			9 (7)
	Crustaceans			3 (2)
	Echinoderms			0.6 (1)
	Others			6 (2)
C 2	Polychaetes	NS	NS	25 (13)
sand/silt	Bivalves			3 (3)
	Gastropods			10 (9)
	Crustaceans			2 (1)
	Echinoderms			0
	Others			0

rarely exceeded 1 km^2 in the area and the Abu Ali fringing reef, the longest, extended over 8 km (see Fig. 1). Hard substrata deeper than 4 m were found in the "Eastern Channel" and at the northern end of Dawhat ad-Dafi and north of Abu Ali. In the Channel, erect coralline red algae, brown macroalgae, ophiuroids and branching gorgonians were found. On the rock-flats north of Abu Ali, brown macroalgae were again dominant yet small scleractinian corals were also present and at depths below 6 m, ellisellid whip corals were also common (Plate 2).

Long-term benthic community monitoring: Sediment from the two seagrass sites, the Qurma Channel sand/silt station and the two control stations supported varied infaunal communities. Table 2 summarises the infaunal data derived from each station and the weight of tar found for each sampling period. Table 3 presents the mean abundance of the various taxonomic groups in the sediments at all sites.

Data from the soft-bottom habitats sampled since February 1991 revealed an increase in mean species number and individuals from winter to late spring. Samples from the northernmost seagrass bed (SMS 3) had the greatest number of species in autumn, whereas those from the southern seagrass bed (SMS 1) showed little variation from late spring to autumn (see Table 2). The infaunal communities of both seagrass beds were clearly dominated by polychaetes. The sand/silt seabed of Qurma Channel supported an infaunal community dominated by molluscs, in particular the gastropod *Cerithium scabridum*. Mean species numbers were intermediate between those of the seagrass stations in winter and autumn, however, a massive increase in total number of individuals from winter to late spring was observed. In May 1991 this seabed supported a benthic assemblage with a mean number of individuals exceeding 1000 0.1 m^{-2}. In comparison the highest infaunal density from the seagrass beds was only 222 individuals 0.1 m^{-2}. *Cerithium scabridum* accounted for over 60 % of the infauna in Qurma Channel, occurring at densities of over 500 0.1 m^{-2}, with the remainder mostly of the bivalves *Tellina methoria* and *Theora* cf. *opalescens*. Most *C. scabridum* were juveniles less than 4 mm in length. There was an equally dramatic reduction in species number and numbers of individuals from late spring to autumn at the Qurma site. Sediment samples from the seagrass control site (C 1), taken only in autumn, provided mean species number and numbers of individuals intermediary between those of the seagrass monitoring stations (see Table 2), although the community was found to be dominated by polychaetes rather than molluscs. Cores from the bare sand/silt control site (C 2) contained similar infaunal composition to the Qurma Channel sand/silt station.

These data on benthic infaunal species numbers can be directly compared to those provided by COLES & MCCAIN (1990) who sampled benthic communities in the region, from a wider area, using similar methods. The latter, based on a wealth of data, plotted regression graphs demonstrating a clear reduction in density of individuals, and species number, of benthic organisms with increase in salinity. Species number, and abundance in the seagrass beds were slightly lower than that predicted from the plot. The sand/silt Qurma Channel station, with the highest salinity of all stations monitored, provided a mean species number similar to that expected and a mean density of individuals (> 1000 0.1 m^{-2}) five times greater. The presence of such high numbers of juveniles of *C. scabridum* in the seabed of one of the most heavily oiled areas may indicate increased productivity resulting from oil contamination. Contamination by organic matter does not seem likely, since there was a complete absence of representatives of the green algae *Ulva* and *Enteromorpha* in the area (DE CLERCK & COPPEJANS 1994). The high densities of these molluscs would indicate little, if any, detrimental effect to settlement or metamorphosis resulting from oil-derived toxins in the sediment. Chemical analysis of tissue samples from these gastropods and of the sediment itself for straight-chain aliphatic hydrocarbons may reveal anthropogenic inputs. Furthermore, measurement of polyaromatics may reveal oil contamination at sub-lethal levels. Alternatively, it is possible that this area experienced an unusually heavy spat fall of these molluscs.

Monitoring of epibenthic communities on the seagrass beds provided no evidence of significant changes in species composition. However, monitoring of the reef-top site (SMS 4) showed a clear seasonal change in macroalgal dominance which is documented more fully elsewhere (CEC/NCWCD 1992).

Evidence of oil pollution: There has been no observation of deterioration of coral reefs, algal or seagrass beds and evidence of oil in the subtidal region is restricted to two sites. The first is in Qurma Channel (see Fig. 1) where oil accumulated more than at any other site in the entire region and from where approximately 1,000,000 barrels of oil were removed from the western shores, by the end of April 1991. In the centre of the 5 m deep channel a few tar balls have been found in the sediment samples (see Table 2). In addition, a patchy tar layer (0.5-1.5 cm thick) was found along the western shore of the channel, extending from the heavily-oiled intertidal region to a depth of 1.5 m. The second site where oil has been recorded in the subtidal is in a shallow (< 1 m deep), lagoonal seagrass bed inshore of the fringing reef along the north of Abu Ali. Here again, oil accumulated heavily along the shore due to the prevailing winds at the time of the spill. The oil was probably driven into the sediment by wave action during low tide, resulting in a tar layer close to the surface of the sand, through which seagrass was still growing in places. The overall extent of these subtidally oiled shores is less than 5 km. These observations support the suggestion by COLES & MCCAIN (1990) that offshore benthic areas are rarely contaminated by spills in the Gulf and that after the evaporation of most of the volatile compounds, most of the oil residues reach the shoreline. This study has shown that the inshore, subtidal benthic areas are also rarely affected by spills with the bulk of the oil being deposited in the intertidal region. It is of special interest to note that even at the sand/silt control site (C 2), tar balls were also found in the sediment (see Table 2). The presence of oil outside of the area affected by the 1991 oil spill confirms the virtually ubiquitous presence of tar along these shores, as reported by PRICE et al. (1987). These balls were well-consolidated pieces which were most probably also derived from tar-balls washed up on beaches, weathered, then carried back into the water.

Plate 1: Seagrass bed with isolated coral block north of Abu Ali.

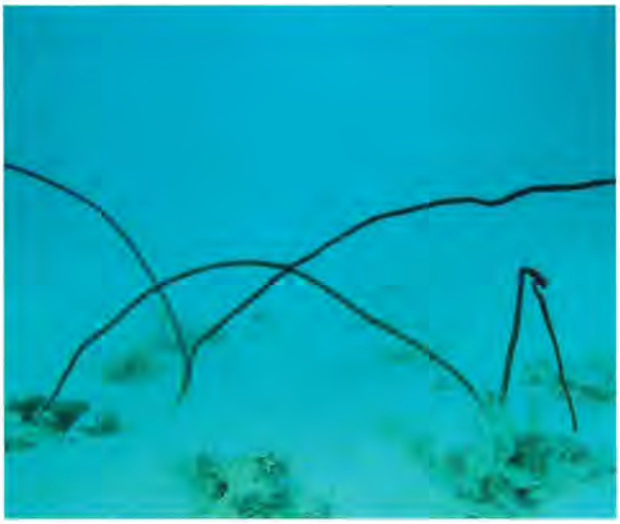

Plate 2: Whip coral area north of Abu Ali.

CONCLUSIONS

In conclusion, the surveys of the subtidal areas within the study area revealed the rich variety of inshore habitats reported in other regions of the Gulf (e.g. BASSON et al. 1977). The fringing reef along the western shore of Ras az-Zaur may be a unique feature of the northwestern Arabian Gulf and should be investigated more thoroughly. Visual evidence of oil pollution in the subtidal was negligible and there was no indication that subtidal marine ecosystems had been detrimentally affected by the 1991 oil spill. The oil which was present, in the form of semi-solid tar, was most probably derived from intertidal sources and not from oil which had sunk in the open water.

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Author's address:
M. Richmond, University of Wales at Bangor, School of Ocean Sciences, Menai Bridge, GB-Gwynedd LL59 5EY, U.K.

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Status of the coral reefs after the Gulf War

Helge Vogt

A b s t r a c t: Selected sections of coral reefs in Saudi Arabia were monitored over a one year period in order to detect any changes that may have occurred as long-term effects of the Gulf War oil spill. In June 1992, 10 permanent transect lines were established; three on inshore reefs in Dawhat ad-Dafi and close to Abu Ali, and seven on offshore reefs surrounding the islands of Karan, Kurain and Jana. Six of these transects were revisited in February 1993 and eight in May/June 1993. A band along each transect, 0.5 m wide and 50 m long, was recorded with a S-VHS video camera. All video pictures were then examined by a computer image-analysis system. Maps of each transect were drawn and the live coral cover calculated. A comparison of the results obtained during the subsequent recordings showed that little change in live coral cover had occurred. During all the periods of fieldwork no abnormal numbers of dead corals were found in any part of the reefs. These findings suggest that no short-term or long-term changes can be attributed to the Gulf War events. Although some reefs in Kuwait show signs of stress and coral bleaching, which may partly be related to the effects of the Gulf War, no such signs were observed on the Saudi Arabian reefs.

الشعاب المرجانية بعد عامين من حرب الخليج

هيلج فوجت

خلاصة: جرت مراقبة مناطق شعاب مرجانية مختارة في المملكة العربية السعودية على مدى عام واحد بهدف الكشف عن أي تغيرات ربما تكون حدثت كآثار بعيدة المدى لبقعة الزيت التي نتجت عن حرب الخليج. في يونيو عام ١٩٩٢م تم عمل ١٠ قطاعات دائمة ٣ منها على الشعاب المرجانية القريبة من الشاطيء في دوحة الدفي بالقرب من أبوعلي و٧ على الشعاب البعيدة عن الشاطيء حول جزر كاران وكرين وجنا. وقد أجريت زيارة أخرى لستة منها في فبراير ١٩٩٣م وثمانية منها خلال مايو–يونيو ١٩٩٣م.

تم تصوير شريط ضيق من كل قطاع بطول ٥٠ سنتيمتر وعرض ٥٠ متر بواسطة آلاة تصوير فيديو VHS ومن ثم جرى فحص كافة الصور بواسطة جهاز كمبيوتر يعمل بنظام تحليل الصور. وتم رسم خرائط لكل قطاع وحصر الغطاء المرجاني الحي. وقد أظهرت مقارنة النتائج المتحصلة خلال التسجيلات المتتابعة حدوث تغيرات طفيفة في الغطاء المرجاني الحي. ولم يلاحظ خلال جميع مراحل العمل الميداني بالمشروع وجود أعداد غير طبيعية لحيوانات مرجان ميتة في أي جزء من الشعاب. وتوحي هذه المعطيات بعدم حدوث تغيرات طويلة أو قصيرة المدى يمكن أن تعزى لأحداث حرب الخليج. وعلى الرغم من أن بعض الشعاب المرجانية على الجانب الكويتي قد ظهرت عليها أعراض اجهاد وابيضاض ربما تعزى جزئياً الى آثار حرب الخليج الا أنه لم تلاحظ مثل هذه الأعراض على الشعاب المرجانية في المملكة العربية السعودية.

INTRODUCTION

The coral reefs in the Arabian Gulf occur in an environment with great extremes of temperature and salinity, as well as high turbidity (SHEPPARD & WELLS 1988). Normal winter water temperatures in the Gulf are amongst the lowest at which coral reefs exist (DOWNING 1985). Intermittent cold periods can lower the water temperatures well below normal conditions (SHINN 1976) and in 1988/89 the lowest temperatures ever recorded in a coral reef area were measured by COLES & FADLALLAH (1991). In these harsh conditions few coral genera are able to survive, the number of species is thus considerably reduced compared with the other regions surrounding the Arabian Peninsula (SHEPPARD & SHEPPARD

Plate 1: Karan Island is a typical coral cay which is surrounded by an extensive coral reef.

1991). Within Saudi Arabian territorial waters, most coral reefs are located offshore (Plate 1) because of temperature fluctuations, high salinities and sedimentation along the coast (BASSON et al. 1977). In some areas salinities may exceed 60 ppt, thus prohibiting the development of coral reefs (SHEPPARD & WELLS 1988). Nevertheless, poorly developed fringing reefs do occur close to the shore, e.g. north of the peninsula of Abu Ali (Plate 2). Offshore, patch or platform reefs range in size between 2 and 31 ha (MCCAIN et al. 1984) and occur abundantly (SHEPPARD & WELLS 1988, Plates 3, 4). However, the best developed and most diverse reefs in terms of species richness are located around six Saudi Arabian islands.

In early 1991, the reef habitats came under serious threat as several million barrels of oil (MCKINNON & VINE 1991) drifted towards the inshore and offshore reefs (MEPA 1991). This oil could have had an impact on the corals by covering and consequently smothering the colonies. In addition, toxic components of crude oil can have a detrimental effect on the viability of coral larvae and may lead to a reduced rate of reproduction of the corals (LOYA & RINKEVICH 1980). Temperature reductions caused by the plume of the Kuwaiti oil fires may also have posed another serious threat to the reefs in the Gulf which are known to live close to their distribution limits.

In order to monitor potential changes in the reefs that might occur as long-term effects, 10 permanent study sites were established on inshore and offshore reefs. Recordings were made at these sites up to three times during periods of fieldwork in July 1992, February/March 1993 and May/June 1993.

MATERIALS AND METHODS

Permanent reference stations (Table 1) in the offshore reefs were set up by placing seven transect lines perpendicular to the shoreline of the islands of Karan, Kurain and Jana. On the inshore reefs, two transects were established perpendicular to Abu Ali Island and one was placed on the reef top of "Pole" Reef, located in the Dawhat ad-Dafi. The 50 m transect lines were tied to corals at intervals of roughly 10 m. The positions of the lines were marked by buoys and their locations recorded by GPS. The same lines were used for fish counts by

Table 1: Percentages of live coral cover of the transect areas.

Transect number	Location	Area	Coordinates (N/E)	July 1992	Feb./Mar. 1993	May-June 1993	SD	max. diff. betw. 2 recs
T 1	Jana	offshore	27°21'39" 49°54'15"	26	27	26	0.27	1
T 2	Jana	offshore	27°22'02" 49°54'45"	26	33	27	3.55	7
T 3	Jana	offshore	27°21'13" 49°53'41"	43	54	50	5.33	11
T 4	Kurayn	offshore	27°38'49" 49°49'09"	32				
T 5	Kurayn	offshore	27°39'16" 49°49'10"	32				
T 6	Karan	offshore	27°43'05" 49°50'12"	38		44	4.72	6
T 7	Karan	offshore	27°42'25" 49°49'28"	13		20	4.85	7
T 8	Pole reef	inshore	27°19'14" 49°25'16"	11	15	3	5.82	12
T 9	Abu Ali	inshore	27°21'05" 49°30'55"	32	32	32	0.00	0
T 10	Abu Ali	inshore	27°21'10" 49°32'21"	14	12	16	2.00	4
Jana reefs average				32	38	34	2.90	6
Inshore reefs average				19	20	17	1.28	3

other team members (KRUPP & MÜLLER 1994) in order to allow for a comparison between specific coral habitats and their fish communities. All underwater work was done by SCUBA diving.

All transects were recorded using a S-VHS-C camera in a handmade underwater housing. In order to obtain defined areas, squares of 50 x 50 cm were placed on the reef. The squares consisted of 21 aluminium bars, which were stretched between two 10 m cords running on either side. This ladder-like structure allowed 20 squares to be placed on the reef at the same time. Once the first 10 m of the transect were filmed with the video system all the squares were rolled onto a plastic tube and then placed on the next 10 m section of the transect. The aluminium bars of the squares also served as scaling bars.

Several video recordings were obtained north of the islands where the prevailing strong northerly winds prevented the time-consuming establishment of transects.

Video image analysis: Images were analysed by using a "Macintosh IIsi" computer with a built-in "Screen Machine" framegrabber card. The "Screen Machine's" hardware and software allowed the display and the storing of video images on the computer system. The digitized images were then used to calculate the coverage of corals by employing the "NIH Image"-programme described by LENNARD (1990).

During the first step of the analysis process the digitized image covering an area of one square was temporarily displayed on the computer monitor. All objects within the squares were then outlined and filled with false colours, thus colour-coding all species and substrate types. All images were then shrunk and fitted into a map form with each sheet containing up to 28 images. This process was conducted for 1525 images with all images being represented in a total of 64 colour-coded maps. On each map the areas covered by species or substrate type were calculated by the use of the "NIH Image"-programme.

RESULTS

In general, live coral coverage (Table 1) ranged from poor to good. In July 1992, it varied from 11 to 43 % with an average of 26.7 %. The live coral cover increased with increasing water depth down to about 6 m. Below this water depth, coral cover gradually became sparse and corals mostly occurred as single colonies.

The average amount of live coral cover was stable during the year of investigation. At Jana Island where three transects were recorded three times, the average live coverage varied only between 32 and 38 %. The two transects at Karan were only recorded twice; between these two recordings, in July 1992 and June 1993, the difference in live coral coverage was 6 and 7 %. No range can be given for the two transects at Kurain because they were recorded only once. At all three inshore reefs the range of variation in the average value for live coral coverage was between 17 and 20 %.

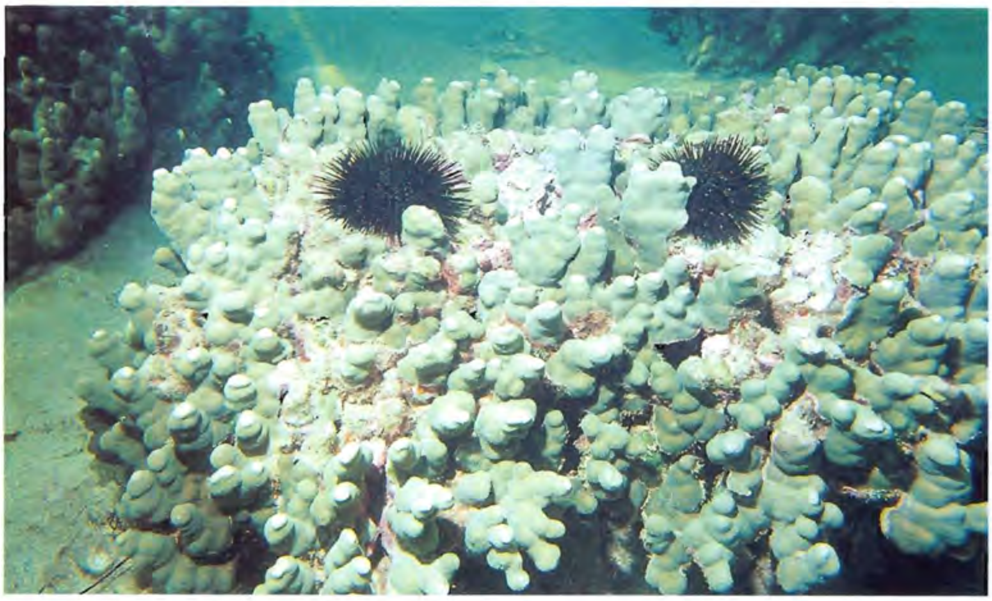

Plate 2: Nearshore reefs are mainly composed of a single species of coral (*Porites compressa*). This photograph was taken at a fringing reef north of Abu Ali Island.

Plate 3: Offshore coral reef at Kurain Island. This reef is dominated by *Acropora*.

Plate 4: An abandoned fishing net causes damage to a coral reef at Kurain Island.

DISCUSSION AND CONCLUSIONS

The results indicate little differences between the recordings of the transects. The maximum difference in live coral coverage between any two recordings along the same transect ranged from 0 to 12 % with standard deviations for all recordings along a transect varying between 0 and 6 % (Table 1). The actual differences are even lower because the data do not always reflect real changes in live coral coverage. Most of the recorded differences are due to seaweeds temporarily overgrowing coral, thus reducing the visible coral coverage, mistakes caused by changing locations of the lines and errors of the recording and analysing system (VOGT 1994).

These figures clearly indicate that live coral cover was not in a state of decline but remained stable, on a poor to good level.

In May 1992, FADLALLAH et al. (1993) found numerous dead coral colonies, corals with tissue degradation or in a state of bleaching in Kuwait. EAKIN et al. (1993) analysed stress bands in coral skeletons in the same area and found that corals, especially from Qi'tat Urayfijan, showed definite signs of stress. Bleaching related to stress and coral mortalities have been observed in earlier years in this area by DOWNING (1985). According to FADLALLAH et al. (1993) and EAKIN et al. (1993) the damage could be partly caused by the effects of the Gulf War and may be related to oil releases, smoke clouds, sewage and pollutant releases. However, natural and anthropogenic stresses may have had synergistic effects.

In November/December 1992, a more comprehensive investigation of the most important coral reefs in Kuwait was conducted by DOWNING & ROBERTS (1993). It showed that only limited mortalities had occurred at the reefs surrounding the islands of Kubbar, Qaru and Umm al-Maradem. At Qi'tat Urayfijan evidence of impact was observed but recovery was well advanced. The authors stress that although effects of the Gulf War may have contributed to the observed mortalities, they may have had only a minor influence compared to other environmental factors.

Personal observations and the findings of ROBERTS (1993), CAVA & EARLE (1993) and Anon. (1993) show that no comparable damage to corals was observed in Saudi Arabian reefs. Occasional findings of bleached *Acropora* specimens are believed to be caused by natural disturbances (Anon. 1993). No visible damage that may be attributed to oil was observed at any part of the reefs. This is despite the fact that the coastlines of the inshore and offshore islands were severely affected by oil.

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Author's address:
H. Vogt, Grüner Brink 3, D-24955 Harrislee, Germany.
Present address: 24 Doddington Grove, Kennington,
GB-London SE17 3TT, U.K.

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The status of fish populations in the northern Arabian Gulf two years after the 1991 Gulf War oil spill

Friedhelm Krupp & Thomas Müller

A b s t r a c t: Fish species were recorded in nearshore areas between Abu Ali and Ras az-Zaur and at four offshore reefs. Compared to other regions of the tropical Indo-Pacific, the number of records (187 species) is low but it exceeds all previous reports from the area. Benthic and demersal species were counted along 12 coral reef transects north of Abu Ali and near the offshore islands of Karan, Kurain and Jana. Despite the oil spill, fish populations in the area were in a healthy condition without any visible signs of oil damage. Recruitment by larvae occurred at normal levels. Species diversities and population densities were within the expected range when compared to pre-war data published in the literature. Distinctly different dominant species occur at nearshore and offshore reefs. The species diversity and population densities are significantly higher at the offshore reefs while the seasonal variation in these parameters is particularly high at the nearshore reefs. During the cold winter of 1991/92 many reef fishes, among them all angelfishes (Pomacanthidae) and butterflyfishes (Chaetodontidae) disappeared from the Abu Ali area, with only juveniles being found the following summer and autumn. During the milder winter of 1992/93 many of these fishes remained in the area and in the summer of 1993 much larger specimens from these two families were present.

حالة مجموعات الأسماك في شمال الخليج العربي بعد عامين من بقعة الزيت الناجمة عن حرب الخليج عام ١٩٩١م

فريدهلم كروب وتوماس مولر

خلاصة: تم تسجيل أنواع الأسماك في المناطق القريبة من الشاطيء بين جزيرة أبوعلي ورأس الزور وفي أربعة مواقع شعاب مرجانية بعيدة عن الشاطيء. وبالمقارنة مع المناطق الأخرى للمنطقة الأستوائية الهند وباسيفيكية، فإن العدد الذي تم تسجيله (حوالي ١٨٠ نوعاً) يعتبر قليلاً ولكنه يتجاوز بشكل واضح حقيقة كل التسجيلات السابقة من المنطقة. وقد جرى حصر الأنواع القاعية ضمن ١٢ قطاعاً للشعاب المرجانية شمال أبوعلي وبالقرب من جزر كاران وكرين وجانا. وعلى الرغم من بقعة الزيت فقد ظلت مجموعات الأسماك بالمنطقة بحالة صحية جيدة ولم يظهر عليها أي أضرار للتلوث النفطي. كما كان ظهور اليرقات بمعدلات طبيعية الى جانب أن درجة تنوع الأنواع وكثافة المجموعات كانت ضمن المستوى المتوقع مقارنة بالمعلومات المنشورة في الفترة السابقة للحرب. وهناك أنواع أخرى مختلفة تماماً تسود بشكل واضح في الشعاب المرجانية القريبة والبعيدة عن الشاطيء. إن درجة تنوع الأنواع وكثافة المجموعات أعلى بشكل ملحوظ في الشعاب البعيدة عن الشاطيء بينما يظهر التغير الموسمي لهذه المؤشرات بشكل واضح في الشعاب القريبة من الشواطيء.

وخلال موسم الشتاء البارد لعام ١٩٩١–١٩٩٢م أختفي العديد من أسماك الشعاب المرجانية ومن بينها كافة أنواع السمك الملائكي (Pomacanthidae) وأسماك الفراشات (Chaetodontidae) من منطقة أبوعلي. وخلال فصلي الصيف والخريف التاليين تمت مشاهدة الأسماك اليافعة فقط أما في خلال موسم الشتاء المعتدل لعام ١٩٩٢–١٩٩٣م فقد بقي الكثير من أنواع هذه الأسماك في المنطقة كما وجدت أفراد أكبر حجماً من أسماك هاتين العائلتين خلال صيف عام ١٩٩٣م.

INTRODUCTION

Fishes of the Arabian Gulf have so far been investigated by relatively few scientists. The most important taxonomic works include BLEGVAD (1944), KURONUMA & ABE (1972, 1986), RANDALL et al. (1978) and AL-BAHARNA (1986). The best reference work for commercial species is FISCHER & BIANCHI (1984). COAD (in press) recently compiled a checklist of the fishes of the Arabian Gulf and the Gulf of Oman in which he lists some 830 species for both areas combined. He states that existing species lists are often contradictory and frequently contain misidentifications. Over 500 species of fishes are known from the Arabian Gulf, and new records are constantly being added. This number is low compared to other branches of the tropical Indo-West Pacific region, such as the Red Sea, where over 1000 species occur. In geological terms, the Gulf has only recently been colonised from the Indian Ocean and its shallowness and environmental extremes limit the number of tropical species able to survive here (KRUPP 1991).

In the Saudi Arabian section of the Gulf two important ecological studies on reef fishes have so far been conducted: MCCAIN et al. (1984) investigated coral reefs and the associated fish fauna in the Manifa - Ras Tanajib area. They recorded a total of 106 species and demonstrated that the depth of the reef base, other physical characters of the reef and seasonality affect fish communities. Two patterns of recruitment were identified with peaks of settlement in spring and autumn. COLES & TARR (1990) conducted the first year-round survey which covered the full annual cycle over a period of two years and provided the most important data on pre-oil spill fish communities in the Sanctuary. In three nearshore areas and at the offshore islands of Karan and Jana they studied fishes along 50 x 2 m transects. The numbers of species and individuals varied depending on location (nearshore or offshore), the level of the reef and season. Depth and temperature were identified as the major environmental factors determining spatial and temporal changes in fish abundance. Unlike MCCAIN et al. (1984) these authors did not find a correlation between live coral coverage and abundance of fishes. Maximum abundances of species and individuals were found in summer and autumn, while minimum numbers occurred during winter and early spring.

During the oil spill only very localised fish mortalities were observed. The largest one occurred around Qurma, where about 1-2 dead fish were found per square metre of beach. Bottom, midwater and surface feeders were among the dead fish and their sizes ranged from 1 cm to 1 m (MEPA 1991). Saudi Arabian fisheries were heavily affected by the war. The war zone was closed to fishery for almost one year. Test fishing in inshore areas that were covered with oil for up to 3 months revealed apparently healthy, edible fish with no petroleum taste (CARPENTER 1992).

In March 1992, KRUPP & ANEGAY (1993) studied fish communities in nearshore subtidal areas north of Abu Ali. Species diversity was similar to pre-war conditions and there were no visible signs of damage from oil pollution. The purpose of the present study was to assess the effect of the oil spill on fish populations and to establish a long-term monitoring programme of reef-fish communities in the Sanctuary area.

MATERIALS AND METHODS

In order to assess species richness and to confirm identifications, a species inventory and a reference

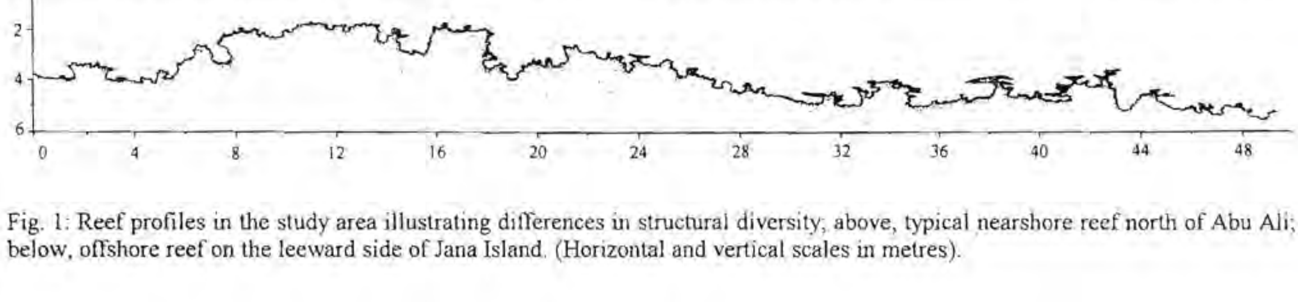

Fig. 1: Reef profiles in the study area illustrating differences in structural diversity; above, typical nearshore reef north of Abu Ali; below, offshore reef on the leeward side of Jana Island. (Horizontal and vertical scales in metres).

collection for the area have been compiled. Fishes were collected by hand nets and experimental trawls. Specimens were obtained from local fishermen on board the fishing vessels in order to record precise locality data. In a few selected localities specimens were collected by SCUBA diving using MS 222 or Rotenone in low quantities for temporarily narcotising the fishes. Underwater photographs of fishes were taken to confirm records and to document live colouration.

In June 1992, nine vertical transects were set up perpendicular to the coastline at depths between 2 and 9 m, two each at Karan, Kurain and north of Abu Ali and three at Jana. In June 1993 three additional horizontal transects running parallel to the coastline were established at Karan on the reef flat (2 m depth), the reef slope (4 m depth) and on a lower reef plateau (6 m depth). For each of these transects, a 50 m nylon rope, marked at 2 m intervals, was fixed to the substrate. Positions were recorded by GPS (Magellan). The same stations were used for coral reef monitoring. Live coral coverage and species compositions are given in VOGT (1994). Survey sites were selected to demonstrate the variability of reefs in the area. However, weather conditions usually did not allow to set up transects at the windward sides of the offshore islands. Each vertical transect was photographed and the reef profile was drawn to scale whilst SCUBA diving (see Fig. 1 for examples). Fishes were recorded by visual counts underwater. All subadult and adult fishes and specimens of > 20 mm in length were recorded in an area of 1 m to each side of the transect line and 2 m above the reef. Species and numbers of specimens were noted on plastic paper. In order to avoid bias, the same observer (F.K.) took the fish counts throughout the study. In June 1992 one count was taken at each offshore transect, followed by three counts each in June 1993 (except for Kurain).

A more detailed study of *Aphanius dispar* (Cyprinodontidae), a species particularly exposed to areas affected by the oil spill, was conducted in the framework of a diploma thesis (MÜLLER 1992). Specimens from oiled areas and unaffected control sites were examined for morphological anomalies and parasitic diseases.

RESULTS

A total of 187 fish species in seven families of Chondrichthyes and 61 families of Osteichthyes have been recorded from the Sanctuary area (Table 1). Several of them represent new records from the Arabian Gulf. Inshore and offshore reefs show distinctly different fish species compositions and abundances. In this survey, 84 species of bony fishes were only found at offshore reefs while 46 species were restricted to nearshore areas. A reef area at the tip of Abu Ali, which in its coral species composition is intermediate between the *Porites compressa* dominated nearshore reefs and the much more diverse offshore coral cays, is inhabited by a larger number of typical offshore fish species than other nearshore reefs. From late spring 1992 and 1993 onward, large numbers of juvenile fishes were present in the area, suggesting normal levels of recruitment from the ichthyoplankton onto the reef.

Pronounced seasonal changes in species richness and abundance of individuals were observed in nearshore areas. In winter 1991/92 most fishes disappeared from the inshore reefs after a sharp drop in water temperature. In January 1992, 12 °C were measured in the central part of Dawhat ad-Dafi and dead fish, among them many *Chaetodon nigropunctatus* and *Pomacanthus maculosus* were washed ashore. Until March, only *Diplodus sargus* was commonly encountered. From April onward, the number of species again increased, with *Lutjanus fulviflamma*, *Acanthopagrus bifasciatus* and *Upeneus tragula* being the first to reappear. Recruitment of *Chaetodon* spp. and *P. maculosus* was observed in summer and autumn. In 1992 neither adult nor subadult Chaetodontidae or Pomacanthidae occurred, while they had been present in autumn 1991. In mid-February, *Aphanius dispar* was abundant in tidal channels on Qurma Island at water temperatures of 11.5 °C.

The winter of 1992/93 was milder than the previous one and the number of species and individuals disappearing from the reefs was much lower. Still, there was a pronounced decline. On 14 December 1992, 16 species with an average of 107 individuals per transect were recorded north of Abu Ali, while 10 days later only 10 species and 81 individuals were present. Besides *D. sargus*, *L. fulviflamma*, *A. bifasciatus*, *P. maculosus* and *Ch. nigropunctatus* were observed throughout the winter. In early March the number again started to increase. The lowest water temperature measured in the study area during that winter was 15 °C.

Of the 187 species recorded from the study area, 71 were encountered at the transects. Only two species, *Chaetodon nigropunctatus* and *Abudefduf vaigiensis* were present at all inshore and offshore transects. Two more species, *Chaetodon melapterus* and *Lutjanus fulviflamma* occurred at all but one stations.

Table 1: Preliminary list of fish species so far recorded in the Jubail Marine Wildlife Sanctuary.

Chondrichthyes

Carcharhinidae
Carcharhinus dussumieri
Carcharhinus leucas
Galeocerdo cuvier
Rhizoprinodon acutus

Dasyatididae
Dasyatis sephen

Myliobatidae
Aetobatus narinari

Pristidae
Pristis zijsron

Rhinobatidae
Rhynchobatus djiddensis

Sphyrnidae
Sphyrna mokarran

Torpedinidae
Torpedo sinuspersici

Osteichthyes

Acanthuridae
Acanthurus sohal
Zebrasoma xanthurum

Apogonidae
Apogon coccineus
Apogon cyanosoma
Apogon taeniatus
Archamia fucata
Cheilodipterus arabicus
Cheilodipterus quinquelineatus

Ariidae
Arius thalassinus

Atherinidae
Atherinomorus lacunosus

Balistidae
Rhinecanthus assasi
Sufflamen albicaudatus
Abalistes stellaris

Batrachoididae
Austrobatrachus dussumieri
Batrachus grunniens

Belonidae
Tylosurus crocodilus

Blenniidae
Ecsenius pulcher
Omobranchus fasciatus
Parablennius opercularis
Petroscirtes ancylodon

Bothidae
Bothus pantherinus
Pseudorhombus arsius

Caesionidae
Caesio lunaris
Caesio varilineata

Carangidae
Alepes macrurus
Alepes melanoptera
Atule mate
Carangoides bajad
Carangoides praeustus
Gnathanodon speciosus
Rastrelliger kanagurta
Scomberoides commersonianus
Seriola dumerili

Chaetodontidae
Chaetodon melapterus
Chaetodon nigropunctatus
Heniochus acuminatus

Chanidae
Chanos chanos

Citharidae
Brachypleura novaezeelandiae

Cyprinodontidae
Aphanius dispar

Clupeidae
Herklotsichthys lossei
Nematalosa nasus
Sardinella gibbosa

Dactylopteridae
Dactyloptena orientalis

Diodontidae
Chilomycterus orbicularis

Echeneididae
Echeneis naucrates

Engraulidae
Stolephorus commersoni

Ephippidae
Platax teira
Platax orbicularis

Exocoetidae
Cypselurus oligolepis

Fistulariidae
Fistularia petimba

Gerreidae
Gerres argyreus
Gerres oyena

Gobiidae
Amblyeleotris periophthalma
Amblygobius albimaculatus
Asterropteryx semipunctatus
Bryaninops sp.
Callogobius sclateri
Cryptocentrus sp.
Cryptocentrus fasciatus
Cryptocentrus lutheri
Eviota guttata
Eviota pardalota
Eviota sebreei
Gnatholepis cf. *scapulostigma*
Gobiodon cf. *citrinus*
Istigobius decoratus
Ptereleotris arabica
Valenciennea sexguttata
Valenciennea sp.

Haemulidae
Diagramma pictum
Plectorhynchus gaterinus
Plectorhynchus pictus
Plectorhynchus schotaf
Plectorhynchus sordidus

Hemirhamphidae
Hyporhamphus sindensis

Labridae
Cheilinus lunulatus
Halichoeres stigmaticus
Halichoeres marginatus
Labroides dimidiatus
Larabicus quadrilineatus

Leptojulis cyanopleura
Paracheilinus mccoskeri
Thalassoma lunare

Leiognathidae
Leiognathus bindus
Leiognathus lineolatus

Lethrinidae
Lethrinus borbonicus
Lethrinus lentjan
Lethrinus microdon
Lethrinus nebulosus

Lutjanidae
Lutjanus argentimaculatus
Lutjanus fulviflamma
Lutjanus quinquelineatus
Lutjanus russelli

Monacanthidae
Stephanolepis diaspros
Paramonacanthus oblongus

Mugilidae
Liza subviridis
Valamugil seheli

Mugiloididae
Parapercis robinsoni

Mullidae
Parupeneus margaritatus
Upeneus sulphureus
Upeneus tragula

Muraenidae
Gymnothorax undulatus
Echidna zebra

Nemipteridae
Nemipterus bipunctatus
Nemipterus japonicus
Scolopsis ghanam
Scolopsis taeniatus
Scolopsis vosmeri

Ostraciidae
Ostracion cyanurus
Tetrosomus gibbosus

Platycephalidae
Grammoplites suppositus
Platycephalus indicus

Plotosidae
Plotosus lineatus

Pomacanthidae
Pomacanthus maculosus

Pomacentridae
Abudefduf vaigiensis
Amphiprion clarkii
Chromis ternatensis
Chromis xanthopterygia
Dascyllus trimaculatus
Neopomacentrus sindensis
Pomacentrus aquilus
Pomacentrus leptus
Pomacentrus trichourus

Priacanthidae
Priacanthus tayenus

Pseudochromidae
Pseudochromis aldabraensis
Pseudochromis linda
Pseudochromis persicus

Rachycentridae
Rachycentron canadus

Scaridae
Scarus ferrugineus
Scarus ghobban
Scarus persicus
Scarus sordidus

Scombridae
Euthynnus affinis
Scomberomorus commerson

Scorpaenidae
Apistus carinatus
Choridactylus multibarbatus
Pseudosynanceia melanostigma
Pterois volitans
Scorpaenopsis cf. *venosa*

Serranidae
Aethaloperca rogaa
Cephalopholis hemistiktos
Epinephelus areolatus
Epinephelus bleekeri
Epinephelus caeruleopunctatus
Epinephelus coioides
Epinephelus multinotatus
Pseudanthias conspicuus

Siganidae
Siganus canaliculatus
Siganus javus

Sillaginidae
Sillago sihama

Soleidae
Pardachirus marmoratus

Sparidae
Acanthopagrus berda
Acanthopagrus bifasciatus
Argyrops spinifer
Cheimerius nufar
Crenidens crenidens
Diplodus sargus kotschyi
Rhabdosargus haffara
Sparidentex hasta

Sphyraenidae
Sphyraena barracuda
Sphyraena jello
Sphyraena obtusata

Syngnathidae
Acentronura tentaculata
Choeroichthys brachysoma
Doryrhamphus excisus
Hippocampus kuda
Trachyrhamphus bicoarctatus

Synodontidae
Synodus variegatus
Saurida undosquamis

Teraponidae
Terapon puta
Terapon theraps

Tetraodontidae
Arothron stellatus
Chelonodon patoca

Trichiuridae
Trichiurus lepturus

Trichonotidae
Trichonotus sp.

Tripterygiidae
Enneapterygius ventermaculus
Helcogramma sp.

Table 2: Fish species occurring at all offshore stations and their mean abundance per transect (mean of 31 counts).

Thalassoma lunare	71.3
Chromis xanthopterygia	67.5
Zebrasoma xanthurum	14.2
Abudefduf vaigiensis	13.0
Pomacentrus trichourus	13.0
Scarus sordidus	11.7
Pseudochromis aldabraensis	9.0
Halichoeres marginatus	8.6
Cephalopholis hemistiktos	6.7
Siganus canaliculatus	6.7
Ecsenius pulcher	5.6
Chaetodon nigropunctatus	5.4
Labroides dimidiatus	2.5
Pomacanthus maculosus	1.8

At the offshore stations, the numbers of species on all transects where three or more counts were taken ranged between 30 and 41 (mean = 34). The lowest number of species recorded in a single count was 19. The two lowest species diversities (30 each) occurred at a vertical transect near Jana where about 50 % of the area were covered by *Pocillopora damicornis* (VOGT 1994), and at the shallowest horizontal transect. The highest species number was found at the deepest horizontal transect on Karan. The average number of individuals per transect ranged between 194 and 412. The two lowest figures (194 and 199) were recorded at the two transects with the lowest species richness. The highest count, however, was taken at a transect near Kurain which had a low species richness. Fourteen species occurred at all offshore transects. They are listed in Table 2.

Species counts taken in 1992 and taken again in 1993 at the same stations showed about the same species compositions but considerable variations in numbers of individuals, without revealing any obvious tendency. Some stations had higher counts in 1992, others in 1993.

The number of species increased with the depth of the transect. At the horizontal transects at 2, 4 and 6 m depth, 30, 37 and 41 species respectively with 199.0, 291.2 and 292.5 individuals (means of three counts) were recorded.

The studies of *Aphanius dispar* did not reveal any morphological anomalies in specimens from oiled areas. There were no significant differences, neither in parasite species composition nor in the degree of infestation, between specimens from affected areas and the control sites (see also MÜLLER 1992).

DISCUSSION

The distribution of benthic and demersal fishes in the Arabian Gulf is rather irregular. The lowest numbers are found on plain mud or sand, where mainly burrowing species occur (Plate 1). Numbers increase in macroalgal beds, seagrass beds and whip coral areas, reaching the highest diversity on coral reefs, which are inhabited by a reduced Indo-West Pacific fish fauna with many elements characteristic of the Arabian region (Plate 2). Unlike more stable tropical marine environment, the Gulf is characterised by a generally low diversity of fish species assemblages, although individual species may occur in very high numbers. Species encountered in low numbers in other areas of the tropical Indian Ocean may form large aggregations in the Gulf, e.g. groups of several hundred *Zebrasoma xanthurum* were frequently seen at the offshore islands.

In previous studies DOWNING (1985) recorded 85 fish species from reefs off Kuwait, SMITH et al. (1987) counted 71 species in reefs near Bahrain, MCCAIN et al. (1984) reported 106 and COLES & TARR (1990) 101 species from reef areas in Saudi Arabian waters. Our records of 187 species from the Sanctuary area compare favourably with these previous studies. However, our list (Table 1) is far from being complete. Several species so far found exclusively nearshore or offshore will certainly later on be encountered in other areas as well. As a result of the survey methods, Chondrichthyes and many pelagic and semi-pelagic Osteichthyes are not yet represented adequately.

The distribution of reef fishes within the area is rather irregular. The location of the reef has a bearing on its fish fauna. Our data confirm previous observations by MCCAIN et al. (1984) and COLES & TARR (1990) that numbers of species and individuals increase with distance from the shore and depth of the reef.

Near the shore, fringing and patch reefs occur in areas where salinities are high and water temperatures vary from 11.5 to 37 °C (COLES & FADLALLAH 1991). Both corals and tropical reef fishes in these areas are living close to their physical limits. In their surveys of nearshore reefs, COLES & TARR (1990) encountered a lack of pronounced size class distributions and concluded that reef fishes migrate to the offshore reefs in winter. This hypothesis must be rejected. Reef fishes migrating over distances between 25 and 70 km of plain sediments, seagrass

Plate 1: The goby *Cryptocentrus lutheri* which lives in association with an alpheid shrimp is frequently found on sandy substrate in the nearshore areas. Photograph taken north of Abu Ali Island.

Plate 2: The sohal (*Acanthurus sohal*) is endemic to the Arabian region. It occurs in the Red Sea, southern Arabia and the Arabian Gulf. Photograph taken near Karan Island.

Plate 3: Abandoned fishing nets keep catching fish. This whitecheek shark (*Carcharhinus dussumieri*) was trapped near Kurain Island.

and macroalgal beds would fall a victim to predators. Population densities at the offshore reefs suggest that all niches there are already occupied, leaving no space for newly arriving specimens from nearshore areas. Our observations strongly indicate that during cold winters many of the typical reef fishes die and that reefs are recolonised from the plankton. Other species probably seek shelter in the coral reef or in adjacent deeper rocky areas during the cold season. Many of the primary reef fish residents may be characterised as "casual" inhabitants of the nearshore coral reefs. Some of them survive during mild winters and reach maturity, but normally they are constantly replaced by new recruits from the plankton when there is plenty of space after the winter denudation.

The number of transects set up so far is still inadequate for a comprehensive classification of fish communities in the area. Another acknowledged bias is posed by the non-random site selection. A series of technical problems was encountered at the transects: Their establishment was time consuming and the lines required regular maintenance and repair. Weather conditions often caused restrictions. The two transects on Kurain were severely damaged by strong tidal currents and counts had to be discontinued in 1993. At the nearshore reefs macroalgal growth temporarily made counts impossible.

BROCK (1982), DE MARTINI & ROBERTS (1982), BORTONE et al. (1989) and others discuss variations and shortcomings of the transect method. Comparisons of our counts with pre-war data from COLES & TARR (1990) posed a number of problems. Their transects were set up at different localities and species compositions vary considerably among sites. These authors also used transects of 2 x 50 m, but counted 5 m above the reef. They thus include many pelagic species, but as ROBERTS (1993) points out, previous studies showed that these cannot be accurately estimated using this method (THRESHER & GUNN 1986). ROBERTS (1993), who conducted a brief survey at some of the Gulf offshore reefs using a modified transect method, covered an area of 4 x 50 m at depths of 3-5 m and counted all species in the water column above the reef surface, excluding transients. Thus, results differed considerably. COLES & TARR (1990) counted 17.0-38.1 species per transect (mean = 28.2), ROBERTS (1993) found an average of 29.3 species per transect. Our counts (mean = 34 species) are slightly higher, but numbers of individuals are usually lower. The most abundant species in our counts on Karan Island is *Chromis xanthopterygia*. This was also the most abundant species found by COLES & TARR (1990) and the second most frequent in ROBERTS' (1993) counts. However, this species is a plankton feeder which tends to venture into the water column far more than 2 m above the reef, thus higher counts were taken by those authors. Our second most frequent species, *Thalassoma lunare*, is more suitable for a comparison, since it is one of the very few species evenly distributed over all levels of the reef (53.3, 55.0 and 54.3 specimens were found at 2, 4 and 6 m levels respectively). They also stick more closely to the reef. COLES & TARR (1990) found an average of 69.7 specimens per transect on Karan and 69.8 specimens on Jana, compared to 62.8 and 59.6 in our counts and 54.0 and 35.3 in ROBERTS' (1993) counts. The latter numbers seem rather low, since that author covered twice the surface (200 m^2 as compared to 100 m^2 in COLES & TARR and in the present study). A comparison of the 10 most common species reveals major shifts in dominance. On Karan transects, only four of the 10 most abundant species encountered by COLES & TARR (1990), were also among the first 10 found by ROBERTS (1993) and in the present survey. Comparing the 10 most abundant species in the two latter studies, there is again an overlap of only five species. These differences in dominance counts indicate considerable fluctuations in abundances which strongly argue in favour of permanent transect lines for long-term studies. A comparison of studies by different authors should largely be restricted to species numbers.

Relative abundances between different surveys cannot easily be compared. In these high-latitude reefs, fluctuations are greater than in more stable tropical marine environments where species numbers are higher and specimens are more evenly distributed. These conditions must be taken into consideration when evaluating fish counts on transects in the Arabian Gulf.

Although MCCAIN & HASSAN (1993) discovered lower levels of ichthyoplankton in areas where there was an oil slick or sheen, no decrease in fish populations was found in the present study. Usually, the number of larvae in the plankton by far exceeds the available space for new recruits in the reef. Species compositions and abundances suggest that benthic and demersal reef fish populations in the Gulf are in a reasonably healthy condition. However, besides the oil spill there are other impacts, e.g. destructive fishing methods require attention (Plate 9).

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Authors' addresses:

Dr. F. Krupp, Forschungsinstitut Senckenberg, Sektion Ichthyologie I, Senckenberganlage 25, D-60325 Frankfurt a.M., Germany. - Present address: Jubail Marine Wildlife Sanctuary, P.O. Box 11071, Jubail 31961, Kingdom of Saudi Arabia.

T. Müller, Schwanheimer Str. 41, D-60528 Frankfurt a.M., Germany.

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Cetaceans of Dawhat ad-Dafi and Dawhat al-Musallamiya (Saudi Arabia) one year after the Gulf War oil spill

Daniel Robineau & Pierre Fiquet

A b s t r a c t: One year after the Gulf War oil spill no evidence was found of any abnormal cetacean mortality in the two bays studied. Furthermore, a small population of humpback dolphins (*Sousa chinensis*) was discovered in this previously highly polluted area, and with reference to what is known on this species in other regions of the world, the number of these animals does not appear to be unusual. This raises the hypothesis that most of the dolphins living in the bays before the spill were able to swim away and escaped the effects of the oil.

وضع دلافين دوحة الدفي ودوحة المسلمية بعد مرور عام على بقعة الزيت الناجمة عن حرب الخليج

دانييل روبنيو وبيير فيكيت

خلاصة: بعد مرور عام على بقعة الزيت الناجمة عن حرب الخليج، لم يتوفر أي دليل على حصول وفيات غير عادية في الدلافين في الدوحتين اللتين جرت دراستهما. وقد تم اكتشاف مجموعة صغيرة من الدلافين محدبة الظهر (*Sousa chinensis*) في هذه المنطقة التي سبق أن تعرضت للتلوث بشكل كثيف. ومقارنة مع ماهو معروف عن هذه الأنواع في مناطق أخرى من العالم فإن عددها لايبدو غير عادي مما يؤيد الافتراض بأن معظم الدلافين التي تعيش في الخلجان قبل حدوث بقعة الزيت تمكنت من السباحة بعيداً عن منطقة التلوث لتفادي آثارها.

INTRODUCTION

As no information was available on the marine mammals of the study area, our investigations, which took place one year after the spill (January, February 1992), had the following objectives:

1. To collect data on marine mammals that frequented the area before the spill;
2. To evaluate the impact of this oil spill on their populations;
3. To collect first hand data on the species that currently frequent the area.

MATERIALS AND METHODS

The field methods used to achieve these objectives were as follows:

1. Searches along the coastline for remains of ancient (individual bones) or recent (more or less complete skeletons and carcasses) strandings;
2. Exploration of the maritime zone by helicopter, boat and from the coast.

We estimate that we have walked along and carefully explored some 40 km of beaches from the level of the tide to the high water mark (Fig. 1). In addition other project participants were asked to look for old and recent strandings when walking along the beaches. Two helicopter flights were carried out on board a Super Puma on 20 and 22 January. During surveys of the surface of the sea, the two side doors of the machine were open, giving the four observers (two on each side) an excellent view of the area overflown. The total length of the transects flown was 235 km (Fig. 1). Flights took place at speeds that varied along different transects (60, 70 or 80 knots), but the altitude was held more or less constant at 150 m; sea state was Beaufort 1 on 20 January and Beaufort 2-3 on 22 January. A number of observations (n = 13) were made on an opportunistic basis by the authors and other project participants, from an inflatable boat used mainly in Dawhat ad-Dafi. Finally, whenever the opportunity arose, we also scanned the coastal waters beyond the littoral zone through binoculars. Two localities were very suitable for this purpose: the cliffs on the west coast of Ras al-Abkhara and the mainland coast along the western channel of Qurma Island (Fig. 1).

RESULTS AND DISCUSSION

Although two observations (three animals) made during helicopter flight on 20 January 1992 over the western part of Dawhat al-Musallamiya may have been of dugongs, this species can not be considered as a normal inhabitant of the area, at least in winter. In fact previous studies (PREEN 1989) were unable to locate this species north of Ras Tanura (some 100 km southwards) during this season.

Boat and aerial observations enable the principal areas frequented by dolphins to be pinpointed (Fig. 2).

Four cetacean species (3 Delphinidae and 1 Phocoenidae) have been identified:

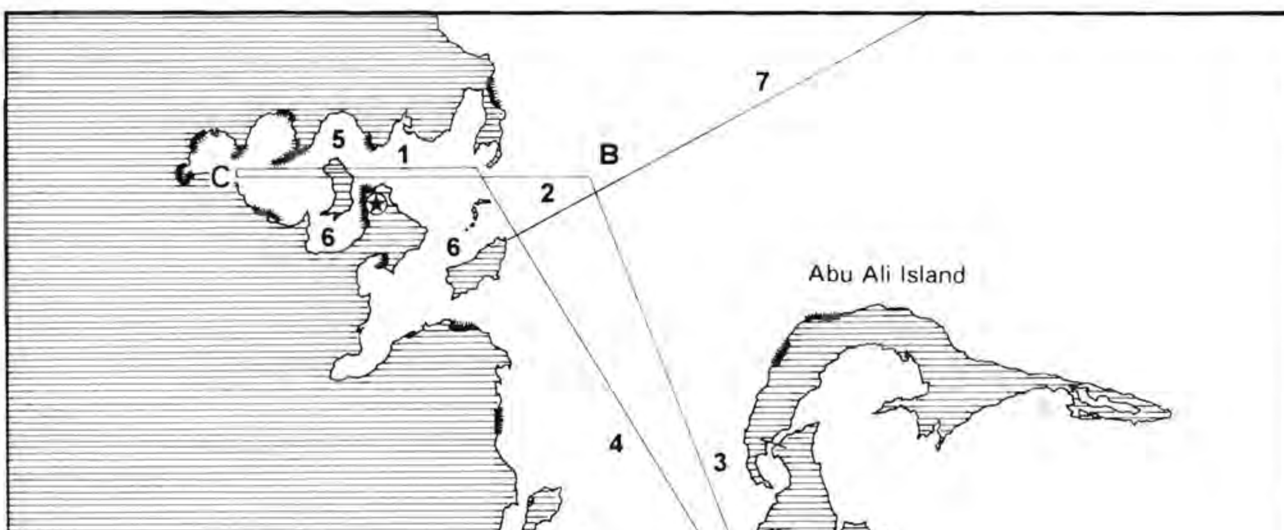

Fig. 1: Coastline explored on foot by the authors (hatching), main localities (stars) from which the coastal waters were scanned and aerial transects (1-6) made in Dawhat ad-Dafi (3 & 4) and Dawhat al-Musallamiya (transects 5 and 6 run for some distance along the coast of Dawhat al-Musallamiya). A: 27°10'N 49°28'E, B: 27°24'N 49°21'E, C: 27°24'N 49°10'E. Areas of boat work were mainly situated between transects 3 and 4 to the level of the northern coast of Abu Ali Island and in the north-east of Dawhat al-Musallamiya.

- Humpback dolphin: *Sousa chinensis* (Osbeck, 1765)
- Bottlenose dolphin: *Tursiops truncatus* (Montagu, 1821)
- Common dolphin: *Delphinus delphis* (Linnaeus, 1758)
- Finless porpoise: *Neophocoena phocoenoides* (G. Cuvier, 1829)

The skeletal material collected consists of: one complete skeleton of a humpback dolphin, two skulls of common dolphins, and skeletal remains from five individual dolphins, the species unconfirmed. In addition three carcasses of recently stranded animals were found on Abu Ali Island, a female humpback dolphin, a young male bottlenose dolphin and a newborn finless porpoise.

From 9 December 1991 to 31 January 1992, only two species were identified at sea: humpback dolphin (12 sightings of some 40 individuals) and bottlenose dolphin (1 sighting of a school of 25 individuals). Finally, a single humpback dolphin was observed from the coast.

The sparse results obtained from the exploration of the coast provide almost no information on the past frequency of cetaceans in the area, nor do they enable any assessment to be made of the impact of the oil spill on their populations.

The lack of success in our investigations might be the result of several factors:

- the existence of large sand-flats along most of the littoral zone, which prevent dead animals from being washed up on the higher part of the littoral,
- in some places a dense carpet of algae and dry phanerogams at the high water mark,
- a coating of oil on the upper part of the beaches.

These different factors combine to conceal the old remains and the more recent ones. However, our lack of success could also be explained if only a small population of dolphins inhabited the area before the oil spill, and if the spill caused no more than a slight mortality among these.

In January, only one species, the humpback dolphin, seemed to frequent Dawhat ad-Dafi and Dawhat al-Musallamiya. The bottlenose dolphin

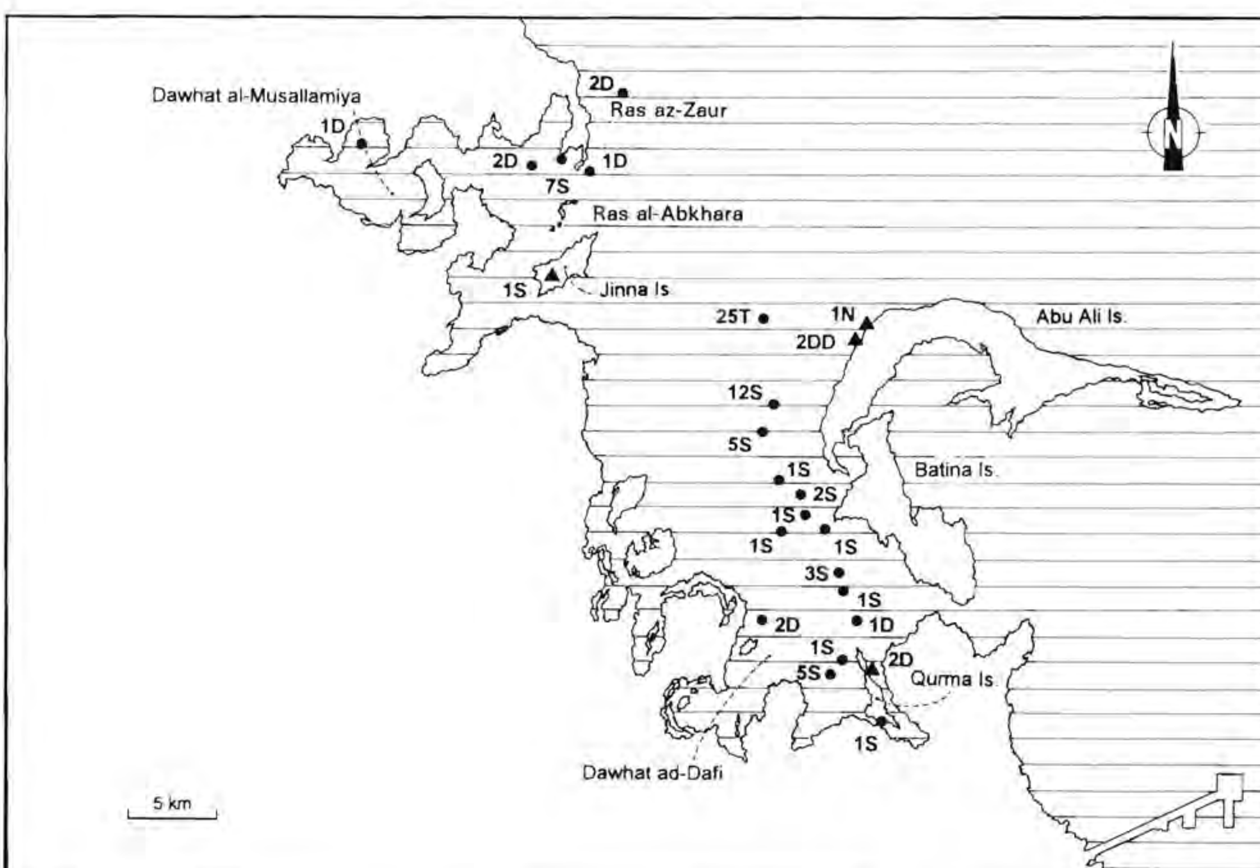

Fig. 2: Sightings (circles) and strandings (triangles) of cetaceans in the Dawhat ad-Dafi and the Dawhat al-Musallamiya from 9 December 1991 to 31 January 1992. D: undetermined dolphins, DD: common dolphins, N: finless porpoise, T: bottlenose dolphins, S: humpback dolphins. The figures refer to the number of specimens.

was only seen once, in December before our arrival, at the northern entrance of Dawhat ad-Dafi. The observations reported in Fig. 2 give a good idea of the areas frequented by these animals. This distribution agrees with what is known of the habits and preferences of these two species, which partition off the littoral area when they co-exist. The humpback dolphin occurs mainly in shallow waters and the bottlenose dolphin more in the open sea (SAAYMAN & TAYLER 1979). The absence of the finless porpoise, according to our sightings, is not surprising as this is a much rarer species (PREEN 1987) and is also difficult to observe. The common dolphin, known only from skulls found on the northern coast of Abu Ali Island, probably lives in more offshore waters.

The regular occurrence in our area, less than one year after the oil spill, of animals like the humpback dolphin which are small range dolphins (SAAYMAN & TAYLER 1979), gives a clear indication that the oil spill was not a fatal incident for the entire population previously living in these two bays.

Furthermore, the number of dolphins (the largest group sighted numbered between 10 and 15 individuals) does not appear unusual if one considers the limited extent of the area that they frequent (reduced to the channels between the extensive sandflats) and the habits of the species (Robineau, pers. observ. in Djibouti and ROBINEAU & ROSE 1984). These elements suggest that the oil spill caused no more than a small mortality among them.

Among recently stranded animals, only one specimen (a young male bottlenose dolphin) was fresh enough to be autopsied. The necropsy did not revealed any obvious lesion or abnormality in thoracic or abdominal organs. The death was probably caused by the presence of trematodes we discovered in the brain.

The hypothesis of only a slight mortality among the dolphins which lived in the area before the oil spill is supported by information provided by other persons who visited the Gulf during or just after the spill. A. Preen, who worked for NCWCD and MEPA during the spill, reported (PREEN 1991) that only one dolphin is known to have died along the north coast of Saudi Arabia. He also mentioned that dolphins continued to live in this area for at least the first three first months of the spill. In March and April 1991 he found 93 carcasses of marine mammals but all were located at least 120 km south of Abu Ali island, mainly in the Gulf of Salwa, and according to him this die-off was not obviously related to the oil spill. Furthermore, in August and September 1991, the MV Greenpeace conducted surveys in the Gulf to assess possible effects of the Gulf War oil spill on cetaceans. Again no dead animals were discovered (HENNINGSEN & CONSTANTINE 1992).

According to NEFF (1990) possible interactions between petroleum and cetaceans are as follows:

1. Physical contact at the surface;
2. Inhalation of volatile compounds above the surface;
3. Accumulation of oil in the organism from solution and dispersion;
4. Ingestion of contaminated food.

Data from other spills in the world suggest that whereas cetaceans can detect (using vision and perhaps echolocation) and may avoid oil, some may enter it without damaging effects (GERACI 1990). This can be explained since oil has no tendency to adhere to the hairless skin of these animals and because the cetacean epidermis is nearly impermeable to the noxious substances in the oil. It seems likely that a small quantity of oil can be inhaled if a cetacean surfaces through an oil slick. On the other hand, though the vapours are very toxic they dissipate rapidly. Because their skin is impermeable to oil and because they do not drink a large volume of sea water, cetaceans will not accumulate much oil from solution and dispersion. Finally, dolphins are active predators that would not normally eat oil-killed fishes. Therefore, on the whole, a spill at sea will affect only a few animals (GERACI 1990).

Nevertheless, as noted by WÜRSIG (1990), some habitats and their residents are more vulnerable than others: "encounters with oil are likely to be prolonged in species that frequent restricted areas such as bays". Ranking from 1 (low risk) to 5 (high risk) cetacean vulnerability to oil, Würsig puts the 'small range Delphinidae' in the high-risk category. However, even with dolphins, like the humpback dolphin, having a limited home range one can expect a certain behavioural flexibility, a search for new areas when customary ones become polluted. One might also speculate that dolphins living in the Gulf have encountered oil spills often enough to avoid contact with oil slicks thereafter. Concerning the small population of humpback dolphins living in the study area, it was probably quite easy for most of them to escape and to reach unpolluted areas because the main oil slick was stopped by Abu Ali Island.

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Authors' address:
Prof. Dr. D. Robineau, P. Fiquet, Museum National d'Histoire Naturelle, CNEMM, Laboratoire d'Anatomie Comparée 55, Rue Buffon, F-75005 Paris, France.

بسم الله الرحمن الرحيم

تقديم

لصاحب السمو الملكي الأمير سلطان بن عبد العزيز آل سعود

رئيس مجلس إدارة الهيئة الوطنية لحماية الحياة الفطرية وإنمائها

يتميز الخليج العربي باحتوائه على مجموعة واسعة التنوع من المواطن الطبيعية الساحلية والبحرية والنظم البيئية الغنية منها الشعاب المرجانية ومهاد الحشائش البحرية والمستنقعات الملحية وتجمعات أشجار الشورة. وتضم هذه البيئات الطبيعية الفريدة مجموعة متميزة من الأنواع البحرية الفطرية النباتية والحيوانية التي تنمو وتزدهر فيها نتيجة لتأقلمها الكامل مع ظروفها البيئية المحيطة القاسية مما يكسبها أهمية خاصة من النواحي الاحيائية والعلمية والاقتصادية والتوعوية والترويحية فهي مورد لاينفذ للتراكيب الوراثية النادرة القادرة على التأقلم مع أشد ظروف البيئة المحيطة قسوة وهشاشة. كما تعتبر المنطقة موئلاً لمجموعات كبيرة من الطيور البحرية المقيمة والمهاجرة شتاء والتي تضم أنواعاً من طيور الغاق والغطاسات والخواضات وطيور الخرشنة.

وانطلاقا من تقدير المملكة العربية السعودية للأهمية البالغة لهذة الثروة الطبيعية المتميزة فقد أولتها حكومة خادم الحرمين الشريفين، أيدة الله، كل أهميتها للمحافظة عليها وانمائها لما فيه مصلحة هذة البقعة الغالية من أرض الوطن.

وقد نتج عن النظام العراقي الغادر على المنطقة في أغسطس ١٩٩٠م أن تدفقت كمية هائلة من النفط إلى مياة الخليج العربي لايمكن تقدير حجمها على وجه الدقة، ولكن تدل أفضل التقارير العلمية المتاحة على أنها من الضخامة بحيث لم يسبق لها مثيل في تاريخ التلوث البحري بالنفط. وكان من نتيجة ذلك أن تعرضت المواطن الطبيعية الحساسة في المنطقة بما تضمه من مجموعات فطرية فريدة، إلى خطر التدمير الشامل من جراء التلوث بالزيت واستدعى ذلك الاستجابة الفورية من الهيئات العاملة في مجال حماية البيئة والمحافظة على الحياة الفطرية المحلية والعالمية للتعامل مع بقعة الزيت لتقليل أضرارها إلى الحد الأدنى الممكن، وإنقاذ المجموعات الاحيائية الفطرية البحرية من تأثيرها المدمر. وكانت الهيئات الوطنية العاملة في هذا المجال في الطليعة حيث قامت باتخاذ كافة الوسائل التقنية والعلمية المتاحة لحصر انتشار الزيت وجمعه والتخلص منه وتم انشاء مركز لإنقاذ الأحياء الفطرية في مدينة الجبيل الصناعية، حيث وفرت الهيئة الملكية للجبيل وينبع مقر المركز وزودته بالمرافق والخدمات اللازمة، وقام خبراء الهيئة الوطنية لحماية الحياة الفطرية وإنمائها بتشغيله وإدارته وتدريب المتطوعين لانقاذ الأحياء الفطرية الذين تدفقوا من كل جوانب الأرض وطنيين ووافدين مدنيين وعسكريين. وخرجت إلى حيز الوجود صورة مشرقة من صور التعاون الدولي لمعالجة هذا التلوث النفطي الذي لم يسبق له مثيل.

وإقتضت ضرورة المحافظة على الحياة الفطرية بالمنطقة إعادة إحياء فكرة إنشاء محمية الخليج العربي للأحياء الفطرية والمواطن الطبيعية في المنطقة الواقعة بين مدينة الجبيل ورأس الزور وهي الفكرة التي كانت قد أقترحت من قبل حدوث هذة الحرب بوقت طويل باعتبارها جزءا من استراتيجية المملكة لحماية الحياة الفطرية فيها. وقد أظهرت الأبحاث المكثفة التي أجرتها دول المجموعة الأوروبية أهمية هذا الاقتراح باعتبار أن إنشاء هذة المحمية يشكل الاستجابة الملائمة الباقية لتحدي التلوث المتكرر المحتمل بالزيت في المنطقة.

وبعد مرور عام على حرب الخليج قام فريق مشترك من علماء المملكة ودول المجموعة الأوروبية بدراسة الآثار البيئية للحرب على المنطقة وحصر نتائجها لمدة تزيد عن العامين وحصلوا على مجموعة من النتائج الأولية القيمة تشكل المادة العلمية لهذا الكتاب الذى يسعدني أن أقدم له.

ويطيب لي أن أعبر عن خالص شكري وتقديري لدول المجموعة الأوروبية على مبادرتها الطيبة وتعاونها المستمر في جهود إعادة تأهيل البيئات الطبيعية للخليج العربي. كما أوجه شكراً خاصاً لفريق علماء المجموعة الأوروبية وعلماء المملكة العاملين في المشروع والذين يمثلون الوجه المشرق المضيء لمستقبل زاهر بإذن الله على جهودهم المضنية التي بذلوها وعلى النجاح الذي تمكنوا من تحقيقه في مهمتهم النبيلة للمحافظة على الحياة الفطرية البحرية الفريدة في الخليج العربي نامية مزدهرة.

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عبد العزيز ابو زنادة وفريدهلم كروب (المحرران)

الوضع الراهن للبيئات الشاطئية والبحرية بعد سنتين من تلوث الخليج

المجموعة الاوروبية ، بروكسل
الهيئة الوطنية لحماية الحياة الفطرية وإنمائها ، الرياض