Open Research Online

The Open University's repository of research publications and other research outputs

Phytoplankton ecology and production of the Red Sea off Jiddah, Saudi Arabia

Thesis

How to cite:

Shaikh, Essam Abid (1982). Phytoplankton ecology and production of the Red Sea off Jiddah, Saudi Arabia. PhD thesis The Open University.

For guidance on citations see [FAQs](#).

© 1981 The Author

<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Version of Record

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.21954/ou.ro.0000fca2>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

D 42872/82

UNRESTRICTED

PHYTOPLANKTON ECOLOGY AND PRODUCTION OF THE RED SEA

OFF JIDDAH, SAUDI ARABIA

VOLUME 1

by

ESSAM ABID SHAIKH B.A., M.Sc.

College of Oceanography

King Abdulaziz University, Jiddah, Saudi Arabia

A Thesis

Presented to

The Faculty of Science

of

The Open University

(In Two Volumes)

In partial fulfilment of requirements

for the degree of

Doctor of Philosophy

October, 1981

© Essam Abid Shaikh, 1981.

1 of submission: 1-11-81
2 of award: 24-3-82

ProQuest Number:27777232

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent on the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.

ProQuest 27777232

Published by ProQuest LLC (2020). Copyright of the Dissertation is held by the Author.

All Rights Reserved.

This work is protected against unauthorized copying under Title 17, United States Code
Microform Edition © ProQuest LLC.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

IN THE NAME OF GOD

MOST MERCIFUL, MOST BENEFICENT

BLESSINGS OF ALLAH MAY BE UPON

OUR MESSENGER MOHAMMED

AND HIS COMPANIONS AND HIS UMMAH

*Saudi Arabian
National Mission
In Canada
Bank Street Suite 1144
Toronto Ontario M5T 1P6*

المملكة العربية السعودية
وزارة التعليم العالي
الكتب التعليمي بكندا

4th September, 1981.

Attention:

Members of Senate, The Open University
Dr. M.E. Varley, Department of Biology, The Open University.

As required according to "Schedule M to the General Regulations", and "Rules relating to the Submission of Dissertations and Theses for Higher Degrees", (Pages 45-46, Postgraduate Prospectus and Student Handbook 1982, Section Ph.D.12).

I hereby declare and state that no part of the material contained in my thesis entitled

"Phytoplankton Ecology and Production of the Red Sea off Jiddah, Saudi Arabia",

which I have submitted to The Open University in partial fulfilment of the Ph.D. degree, has been submitted by me to this or any other University for any degree. In addition, no part of this thesis has been, or will be submitted by any other candidate to any other University for any degree.

I further declare that none of the material contained in my thesis is yet published, but that preparations for publication are being made.

TELEPHONE : (613) 237 3550

TELEX NUMBER 053-4865 CABLE ADDRESS ELMIAH

ABSTRACT

PHYTOPLANKTON ECOLOGY AND PRODUCTION OF THE RED SEA OFF JIDDAH, SAUDI ARABIA

Essam A. Shaikh, M.Sc.
The Open University, 1981

Supervisor: Dr. M.E. Varley
External Supervisor: Dr. J.C. Roff

The Red Sea, being a landlocked, semi-enclosed body of water located in an arid zone where evaporation is far in excess of precipitation and run-off, offers a unique ecosystem from the tropical region. During 1977-78 off Jiddah, physical, chemical and biological data were collected at an eutrophicated inshore Sharm station and a relatively unpolluted offshore station. The prevailing high temperatures, high salinity and lack of land drainage resulted in highly stratified dense waters with little or no vertical admixture. There was not always an abundant supply of nutrients in these waters but, due to monsoonal activity, domes of high phosphate, silicates, nitrates and ammonia were noticed both in the offshore and inshore waters. Biological production, measured as phytoplankton cell numbers, chlorophyll a and primary production, also increased usually with a time-lag between the nutrients and production. Depending on the monsoonal currents, periodic recruitment and exchange of Red Sea component, Mediterranean component,

Nile estuarine component and Indo-Pacific components of phytoplankton takes place. The annual phytoplankton cycle follows a bimodal pattern with the peaks of production coinciding with the activity of the monsoons.

The magnitude of production was higher in the offshore waters and the production in the study area was higher than in several temperate and tropical waters. The high carbon assimilation ratios suggest a high efficiency of photosynthesis characteristic of sun-adapted phytoplankton. Based on the photosynthetic production, it is speculated that a rich fishery potential exists in the Red Sea.

ACKNOWLEDGMENTS AND DEDICATIONS

To acknowledge all those who made it possible for me to complete this work would be impossible, and they know themselves well.

The spirit of my departed father, to whom perfection and aspiration to the best was the goal of a lifetime dedicated to the betterment of mankind, was always and will remain a motivating force.

To Shaikh Muhammed Mutawalli Sharawi, whose guidance and example-setting will always be a most enriching and determining factor in my life.

To Dr. Abdullah Nasseef, whose friendship is more real than many brotherhoods.

To Dr. Naieem Dewidar, whose supervision and constant help and understanding made it possible for me to bring this work to light.

To Dr. Margaret Varley, whose patience, understanding and guidance were vital for the direction of this work.

To Dr. John Roff, who made it possible for this work to come together and be meaningful, and whose impatience made the conclusion of this work a reality.

To all my associates, colleagues and friends at King Abdulaziz University, to whom I owe a great deal of success in my practical life which is consequently reflected in this work. Especially to the man who knows the Red Sea better than the palm of his own hand, Mohammed Sayeed, who was with me from the first day and who, along with his colleagues, helped a great deal in collecting the data, maintaining the boats and made sure I was always in the right location.

To Angela and Rosemary, without whose unfailing dedication, hard work and sleepless nights I could not have come through with this.

Last but not least, to those who are affecting my daily life without whom my world is not enriched: Sadaga, Abdulwahab, Fatma and Suad Shaikh, Hassan and Nawal, Hamoud and Thuraya, Samir, Osama, Tariq, Huda, Shaikha and Hadeel. And to my mother, without whose constant support and prayer this would not have come this long and hard way.

TABLE OF CONTENTS

VOLUME ONE
Page

LIST OF TABLES	vi
LIST OF FIGURES.	vii
LIST OF APPENDICES	xii
PREFACE AND SUMMARY	xiii
INTRODUCTION	1
DESCRIPTION OF STUDY AREA	7
Geography and Location	7
Climatic Conditions	8
Circulation Pattern in the Red Sea	9
Land-drainage and Pollutants in the Jiddah area	10
MATERIALS AND METHODS.	14
Sampling Programme	14
Physico-Chemical Methods	16
1. Temperature	16
2. Salinity	17
3. <u>In situ</u> Density (σ_t)	17
4. Sea Water Transparency	17
5. Dissolved Oxygen	18
6. Oxygen Saturation	18
7. pH	18
8. Alkalinity and Total Carbon Dioxide	19
9. Soluble Reactive Phosphorus (SRP)	19

Table of Contents. Continued.

	Page
10. Reactive Silicate (SiO_2)	19
11. Nitrite (NO_2)	19
12. Ammonia (NH_3)	19
Biological Methods	21
1. Qualitative and Quantitative Examination of Phytoplankton	21
2. Species Diversity Index	22
3. Photosynthetic Pigments	22
4. Carbon Assimilation	24
Statistical Methods	26
RESULTS	28
Physico-Chemical Data	28
1. Temperature	28
2. Salinity	30
3. Density Structure	32
4. Transparency	35
5. Dissolved Oxygen	36
6. Soluble Reactive Phosphorus	38
7. Silicate	40
8. Nitrite	42
9. Ammonia	44
10. Relationships between Salinity, Silicate and Phosphate	45
Biological Data	46
1. Seasonal Composition of The Major Groups of Phytoplankton and Diversity Indices . .	46

Table of Contents. Continued.

	Page
2. Quantitative Abundance of Phytoplankton . . .	49
3. Seasonal Species Composition.	53
4. Phytoplankton Pigments	62
5. Primary Production	65
6. Carbon Assimilation Ratios ($\text{mgC}:\text{mgChla}^{-1} \text{ hr}^{-1}$).	68
7. Inter-relationships of Physico-Chemical and Biological Data	70
DISCUSSION	71
The Physico-Chemical Environment	71
Phytoplankton Ecology	81
1. Biogeography of Phytoplankton	82
2. Phytoplankton Succession	90
3. Factors influencing Phytoplankton Production	91
4. Magnitude of Phytoplankton Biomass and Cell Densities	96
5. Magnitude of Primary Production	97
6. Duration Range and Amplitude of Primary Production	99
7. Annual Phytoplankton Cycle and Production Estimates for the Red Sea	100
SUMMARY AND CONCLUSIONS	105
REFERENCES	110
TABLES	122
FIGURES	148

Table of Contents. Continued.

	VOLUME TWO
	Page
APPENDICES	1
Figure 10 (Repeated)	150
Figure 11 (Repeated)	151
Figures 6 to 9 and 13 to 24 TRANSPARENCIES	REAR POCKET

LIST OF TABLES

Table	Page
1. Climatic data at Jiddah based on observations for the period 1966-1976	122
2. Maxima and minima of physico-chemical variables at the Sharm and offshore stations	123
3. Seasonal phytoplankton abundances (cells l^{-1}) and percentage composition of major groups at the Sharm station	123
4. Seasonal phytoplankton abundances (cells l^{-1}) and percentage composition of major groups at the offshore station	127
5. Maximum and minimum values of biological variables and parameters at the Sharm and offshore station .	130
6. Correlation matrix (Pearson's r) of chemical and biological variables and parameters at the Sharm station ($n \geq 64$; $P < 0.05$; * not significant) .	131
7. Correlation matrix (Pearson's r) of chemical and biological variables and parameters at the offshore station ($n \geq 65$; $P < 0.05$; * not significant) .	132
8. Comparison of inorganic phosphate values ($\mu\text{g-at l}^{-1}$) from some selected regions	133
9. Comparison of silicate values ($\mu\text{g- t l}^{-1}$) from some selected regions	134
10. Comparison of nitrite values ($\mu\text{g- t l}^{-1}$) from some selected regions	135
11. Comparison of ammonia values ($\mu\text{g- t l}^{-1}$) from some selected regions	136
12. Composition of phytoplankton blooms in the Red Sea	137
13. Comparison of abundance of phytoplankton cell numbers from selected regions (cell nos l^{-1}) . . .	138
14. Comparison of chlorophyll <u>a</u> ($\mu\text{g l}^{-1}$) from selected regions	140

List of Tables. Continued

	Page
15. Comparison of primary production (C_{14} method) from selected regions	141
16. Comparison of carbon assimilation ratios (mg C mg Chl a^{-1} hr $^{-1}$) from selected regions . . .	143
17. Comparison of duration, range and amplitude of primary production during major phytoplankton blooms in selected regions	145
18. Period of occurrence of phytoplankton blooms in the Red Sea area	147

LIST OF FIGURES

Figure	Page
1. The Red Sea showing major geographic features	148
2. Study area showing location of inshore (Sharm) and offshore stations	149
3. Showing the major coastal features of the City of Jiddah	150
4. Lithography and sediment types around Sharm-Obhur	151
5. Monthly mean wind velocities (nautical miles per 24 hrs) for the Red Sea area. Compass vectors indicate frequency of direction and sum to 100%	152
6. Seasonal temperature distribution at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	153
7. Seasonal temperature distribution at the offshore station. (TRANSPARENCY IN REAR POCKET-TO OVERLAY Figure 11)	154
8. Seasonal salinity (‰) distribution at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	155
9. Seasonal salinity (‰) distribution at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	156
10. Seasonal density (σ_t) distribution at the Sharm station	157
11. Seasonal density (σ_t) distribution at the offshore station	158
12. Seasonal changes in Secchi disc visibility at the Sharm and offshore stations	159
13. Seasonal distribution of dissolved oxygen at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	160

List of Figures. Continued.

Figure	Page
14. Seasonal distribution of percent (°/°) oxygen saturation at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	161
15. Seasonal distribution of dissolved oxygen at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	162
16. Seasonal distribution of percent (°/°) oxygen saturation at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	163
17. Seasonal distribution of soluble reactive phosphorus ($\text{PO}_4\text{-P}$) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	164
18. Seasonal distribution of soluble reactive phosphorus ($\text{PO}_4\text{-P}$) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY FIGURE 11)	165
19. Seasonal distribution of reactive silicate (SiO_2) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	166
20. Seasonal distribution of reactive silicate (SiO_2) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	167
21. Seasonal distribution of nitrite (NO_2) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	168
22. Seasonal distribution of nitrite (NO_2) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	169
23. Seasonal distribution of ammonia (NH_4) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10)	170
24. Seasonal distribution of ammonia (NH_4) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11)	171
25. Salinity (°/°) - reactive silicate (Si) relationships and water masses in the study area	172

List of Figures. Continued.

Figure	Page
26. Seasonal distribution of reactive silicate: soluble reactive phosphorus ratios at the Sharm station	173
27. Seasonal distribution of reactive silicate: soluble reactive phosphorus ratios at the offshore station	174
28. Seasonal composition of the phytoplankton by major groups at the Sharm station	175
29. Seasonal variation in diversity indices of the phytoplankton community at the Sharm station, for surface (0) and 30 m depths, and total water column	176
30. Seasonal composition of the phytoplankton by major groups at the offshore station	177
31. Seasonal variation in diversity indices of the phytoplankton community at the offshore station, for surface (0), 100 m and 200 m depths, and total water column	178
32. Seasonal abundances of phytoplankton cells by major groups at the Sharm station	179
33. Examples of vertical distributions of the major phytoplankton groups at the Sharm station	180
34. Seasonal abundances of phytoplankton cells by major groups at the offshore station	181
35. Examples of vertical distributions of the major phytoplankton groups at the offshore station	182
36. Seasonal profiles of chlorophyll <u>a</u> concentration at the Sharm station	183
37. Seasonal profiles of chlorophyll <u>b</u> concentration at the Sharm station	184
38. Seasonal profiles of chlorophyll <u>a</u> concentration at the offshore station	185
39. Seasonal profiles of chlorophyll <u>b</u> concentration at the offshore station	186
40. Seasonal variations in vertical profiles of carbon fixation (primary production rate) at the Sharm station.	187

List of Figures. Continued.

Figure	Page
41. Seasonal variations in vertical profiles of carbon fixation (primary production rate) at the offshore station	188
42. Integral primary production rates at the Sharm and offshore stations	189
43. Carbon assimilation ratios ($\text{mgC mg Chl}\underline{\text{a}}^{-1} \text{ hr}^{-1}$) at the Sharm station	190
44. Carbon assimilation ratios ($\text{mgC mg Chl}\underline{\text{a}}^{-1} \text{ hr}^{-1}$) at the offshore station	191

LIST OF APPENDICES

Appendix	VOLUME TWO	Page
1A. PHYSICAL, CHEMICAL AND BIOLOGICAL DATA Sharm station		1
1B. PHYSICAL, CHEMICAL AND BIOLOGICAL DATA offshore station		8
2. PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH, 1977-1978 Sharm station - Abundance in cells/l (Van Dorn bottle collections)		15
3. PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH, 1977-1978 offshore station - Abundance in cells/l (Van Dorn bottle collections)		49
4. PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH, 1977-1978 (Van Dorn bottle collections and plankton hauls) Sharm Station . . .		86
5. PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH, 1977-1978 (Van Dorn bottle collections and plankton hauls) offshore station . .		106
6. TAXA LIST OF ALL GENERA AND SPECIES IDENTIFIED FROM THE RED SEA, 1977-1978		129
7. ADDITIONS TO THE PHYTOPLANKTON TAXONOMIC LIST FOR THE RED SEA FROM THE PRESENT STUDY		138
8. REFERENCES USED IN COMPILING THE PHYTOPLANKTON SPECIES LIST IN THE REGION OF JIDDAH 1977-78 . . .		143
9. DIVERSITY INDICES FOR DIATOMS AND DINOFLAGELLATES IN THE REGION OF JIDDAH (Sharm station) DURING THE PERIOD NOVEMBER 1977 TO OCTOBER 1978		146
10. DIVERSITY INDICES FOR DIATOMS AND DINOFLAGELLATES IN THE REGION OF JIDDAH (offshore station) DURING THE PERIOD NOVEMBER 1977 TO OCTOBER 1978 . .		148

PREFACE AND SUMMARY

Although the Red Sea has been important to the Arabs in their commerce since medieval times its oceanographic significance remained unrecognized until the Austrian Expedition Pola in 1895. Modern oceanography in the Red Sea region is in its infancy even today. Systematic investigations on the hydrography, plankton production and fishery production extended over a long period are not available.

In the last decade, the threat of increasing oil pollution, industrial and urban effluents and other manmade perturbations to the coastal marine ecosystems was recognized, and several marine science activities were initiated in the Red Sea area. At Jiddah, Saudi Arabia, King Abdulaziz University added an "Institute of Marine Sciences".

The present study was carried out during 1977-1978, while at King Abdulaziz University. Observations were made on a regular basis at two stations: an inshore station which receives pollutants, and an offshore station which is relatively unpolluted.

The results of this study are presented in this thesis and can be summarised as follows:

After a general introduction, a brief account of the study area is given, including a description of circulation patterns in the Red Sea. Methodology employed in this study is also presented. Data on temperature, salinity, density, transparency, dissolved oxygen, inorganic phosphate, silicate, nitrite and ammonia are presented and discussed. The semi-enclosed nature of the Red Sea, in an arid zone where the evaporation is far in excess of precipitation and run-off, is reflected in the hydrographical conditions of the Red Sea. Nutrients such as phosphates, silicates and nitrites appear to be at a low level which could be attributed either to lack of input through rainfall and land drainage, or to rapid utilization by phytoplankton, or both.

Based on their abundances, four categories of phytoplankton were recognised: (a) those common in the inshore and offshore waters during the major bloom, (b) those common during the minor bloom, (c) those common to the major and minor bloom, and (d) those restricted to either of the blooms.

Based on the biogeography of 163 phytoplankton taxa, 10 floral elements were recognised in the study area. Succession patterns of the major phytoplankton groups: diatoms, dinoflagellates, and blue-green algae are discussed. Statistical correlations between physical, chemical and biological data are also presented and discussed.

A comparison of the magnitude of phytoplankton biomass, determined as cell numbers and chlorophyll a, with other temperate and tropical seas is made; the values obtained in

this study compare favourably with those reported from other tropical waters.

Primary production data (carbon-14 method) showed a bimodal peak distribution with a two month time lag between the inshore and offshore waters. Primary production and carbon assimilation rates in the study area compare favourably with some of the high values from tropical and temperate waters.

Based on the duration, range and amplitude of primary production, it is concluded that Red Sea waters resemble some of the other productive tropical seas.

Employing several conversion factors and assumed transfer coefficients, the primary production from the whole Red Sea has been converted to tertiary production. The calculated potential annual tertiary production from the Red Sea is between about $5-9 \times 10^6$ tons of fish which is higher than the fish landings reported by FAO.

In the light of the present data, the possible scope of future investigations in the Red Sea area is briefly discussed.

INTRODUCTION

Biological oceanographic studies on phytoplankton and primary organic production have been much more extensive in temperate and sub-Arctic seas than in tropical waters. Ryther (1963), Platt and Subba Rao (1973), Parsons and Takahashi (1973), Fogg (1975), Cushing (1978), and Dunbar (1979) have presented excellent reviews on this subject. Recent investigations of Ryther et al. (1966), Ryther and Menzel (1965), El-Sayed and Turner (1977) and Qasim (1977) have shown that contrary to earlier beliefs, the magnitude of primary production in tropical and sub-tropical waters can be as high as that of temperate and sub-Arctic seas. Conclusions drawn from temperate and sub-Arctic waters cannot be uncritically applied to tropical seas; there is a clear need at this time to examine differences and similarities between temperate and tropical systems.

One interesting sub-tropical area which has received relatively little biological attention is the Red Sea. Hydrographic investigations in the Red Sea were first carried out by the Austrian Expedition Pola in 1895 and subsequently a number of expeditions carried out investigations. Although the physical and chemical oceanography of the Red Sea has been extensively reviewed by Morcos (1970), biological oceanography has received far less attention.

Marine biological studies in the Red Sea area date back to 1895 when the Pola expedition collected information on planktonic crustacea such as the Copepoda, Ostracoda and Amphipoda (see Halim 1969). Other zooplankton groups, including the Euphausiacea, Mysidacea, Sergestidae, Tomopteridae, Chaetognatha and planktonic larvae were also studied by Ammiraglio Magnaghi (1923-24). The German Deep Sea Expedition Valdivia and the John Murray Expedition (1933-34) have also collected information on microplankton, medusae and copepoda. The review of Halim (1969) gives details on the species distribution of zooplankton; he concluded that, contrary to the general impression, the variety and abundance of the standing crop of zooplankton in the Red Sea is high. Halim (1969) is of the opinion that, during the northeast monsoon the largest number of species are transported into the Red Sea from the Gulf of Aden, and during hot summer months the epipelagic species sink to deeper levels.

Ponomareva (1968) observed that out of 22 species of euphausiids of the Indian Ocean, 10 are present in the Red Sea, and most of them are transported from the Gulf of Aden. The pteropod fauna (Frontier 1963) and pelagic tunicate fauna (Fenaux 1973) appear to be rich in the Red Sea and Gulf of Aden when compared to the Persian Gulf. In general, there is a predominance of the tropical Indo-Pacific zooplankters in the Red Sea. Cohen (1973) and Steinitz (1973) concluded that the Red Sea has a large element of Indo-Pacific fish fauna with distinct areas of endemism; the percentage of

endemic species increases in a northerly direction. The fish fauna of the Red Sea is richer than that of the Persian Gulf.

Fishelson (1973a, 1973b) reviewed the earlier work on the coral reef tables in the Red Sea. In the Gulf of Aqaba and the Gulf of Suez along the shallow sub-tidal region, fringing type corals predominate and two species of Millepora (M. dichotoma and M. platyphyla) constitute about 40% of the total reef formers. Fishelson (1973a) postulated that a high level of species diversity is maintained by prevention of overcrowding due to desiccation during periods of extreme low water, and by the regeneration capacity of the corals. The frequent oil spills and phosphate dust that stimulate the growth of the algae, seem to cause a high mortality of the corals in the Gulf of Aqaba (Fishelson 1973b).

Distribution of the majority of species in the coral reef communities seems to be determined by the light intensity (Schuhmacher 1973) on the coasts of Eilat, Dahab, Sharm el Sheikh and Aqaba on the Jordanian coast. Loya (1972) also observed a depth-dependent species ensemble of various corals.

Biomass of the zoobenthos is about 50g m^{-2} in the southern part of the Red Sea and consists predominantly of seston feeders (60 to 90%) such as flat urchins, holothurians, bivalves and amphipods, while the detritus feeders (e.g. polychaetes such as Maldanidae), contribute only about 5g m^{-2} , (Neyman and Kondritskiy 1974). Such an oligotrophic zoobenthos was attributed to the prevailing high temperatures ($>11^{\circ}\text{C}$) at the bottom. In the Red Sea region there are three

main fisheries of economic value: pelagic or midwater fisheries consisting of sardines, anchovy, mackerel and barracuda; demersal or bottom fisheries consisting of a great variety of species; and the shrimp fishery represented by species of Penaeus, (Botros 1971). The total annual catch is about 5.3×10^5 metric tons (FAO 1978) whereas the annual potential yield of the demersal fishery alone is considered to be at least 6.0×10^5 metric tons (Gulland 1970).

The review by Halim (1969) showed that phytoplankton studies in the Red Sea were mostly qualitative in nature. There was a paucity of diatoms during the warm season (March - May) and a maximum of 62 species was recorded during the winter months (November-February). There were only 13 species recorded south of 20°N. Dinoflagellates were in greater abundance than diatoms except in February, and consisted of 20 tropical species several of which were strictly Indo-Pacific. Discoloration of Red Sea waters by Trichodesmium erythraeum has also been mentioned.

Other phytoplankton studies available were made in the vicinity of the Suez Canal. Dowidar (1974) recorded 273 species and grouped them into Mediterranean, tropical and Indo-Pacific species; about 90% of the Suez Bay species are common to the Mediterranean. In Lake Maruit, a eutrophicated lake in Egypt, Aleem and Samaan (1969) recorded 64 taxa and a high magnitude of phytoplankton production. Recently Spanier et al. (1979) observed in the Gulf of Elat (Aqaba) a greater biomass and productivity during the winter (December-March) than during the rest of the year (April-November), when production and biomass were poor. Primary

production increased towards the coral reefs and Red Sea proper.

In the Gulf of Aden, the trophic layer (the layer with the largest quantity of algae) reached to about 25 m and occurred during November to February; the quantity of algae depended on the depth of the thermocline (Savich 1971). Thus a period of maximum growth of phytoplankton between November and March appears to be a common feature of the studies of Halim (1969), Spanier et al. (1979) and Savich (1971).

The Red Sea provides a unique area of study in the tropics because of:

- (a) partial isolation from the open ocean which puts it in the category of landlocked seas;
- (b) absence of river flow and only scant rainfall;
- (c) evaporation loss, in excess of 210 cm yr^{-1} which is made up by inflow of waters through the Straits of Bab-el-Mandeb;
- (d) variable wind-driven and monsoon currents.

Due to oil pollution, increases in industrial and organic effluents and speculative or urban development of the coastal areas, marine ecosystems of the Red Sea area are seriously threatened (UNESCO 1976). It must be remembered that for a proper development and management of the resources and environment of the Red Sea, a sound knowledge of the physical, chemical and biological oceanographic aspects of the area is necessary.

Although several marine science activities were initiated

in recent years, a multi-disciplinary programme for studying the Red Sea is almost non-existent. The marine biological station at Ghardaga, Egypt has been reopened as the "Institute of Oceanography and Fisheries, Ghardaga, Red Sea, Egypt". Sudan established an "Institute of Oceanography" in 1971 at Port Sudan and a marine biological station belonging to the University of Khartum at Swakin in 1973. At the University of Jordan, Amman, a marine science programme was started in 1973. At Jiddah, Saudi Arabia, King Abdulaziz University added an "Institute of Marine Sciences". The Arab League Educational, Cultural and Scientific Organisation (ALESCO) in 1974 recognised the need to have a cooperative regional programme for "Environmental Studies of the Red Sea" and it is hoped that this area will be intensively studied.

The present study was carried out while at the Institute of Marine Sciences, recently started by the King Abdulaziz University, and the present thesis, though preliminary, constitutes the first of its kind from this geographical region. This study was undertaken to investigate:

- a) the physico-chemical and planktological cycles at an inshore station (Sharm station) and an offshore station,
- b) whether any qualitative and quantitative differences in the phytoplankton exist at these two stations,
- c) how the magnitude of primary production at these two stations is governed by physico-chemical factors,
- d) whether any local effect of pollution can be discerned, and
- e) the potential fisheries production of the Red Sea as estimated from its primary production.

DESCRIPTION OF STUDY AREA

Geography and Location

The Red Sea (Figure 1) extends southeastwards from Suez for 1932 km to the straits of Bab-el-Mandeb, which connects with the Gulf of Aden and the Indian Ocean via a 100 m deep sill. It is 306 km wide at its maximum breadth in the southern sector, has a surface area of 440,000 km², a mean depth of 524 m, and a maximum depth of 2920 m.

The reef-studded shelves of the Red Sea are less than 50 m deep and drop off abruptly to about 500m deep. The distances from the shore to the 200 m and 500 m depth contours are about 2 km and 5 km respectively. A narrow central trough with depths more than 1500 m is a salient feature. An island, El-Ketaah which is about 10 km off Sharm-Obhor is formed from a submarine pinnacle rising from depths exceeding 700 m. Such submerged elevations are common and support heavy algal and coral growth.

The area of study is shown in Figure 2; it includes both the neritic and oceanic provinces of the central Red Sea in the vicinity of the city of Jiddah. The city is located between latitudes 21°15'N and 21°45'N and extends for about 35 km along the coast from Petramean in the south (Figure 3) to Sharm-Obhor in the north. The coast-line is fringed by almost continuous flats of reefs which at certain places,

particularly in the south, have developed into small shallow lagoons (see Figure 3). The depth of water over the reefs varies between a few centimeters and two meters, and causes navigational hazards. In the shallow coastal areas calcareous rocks and thick coral formations predominate; moving away from the coast, the bottom is mostly covered with muddy sand or mud deposits (Figure 4).

Climatic Conditions

During June, July and August, the southwest monsoon season, the winds are generally NNW and NW, and are directed towards the Gulf of Aden (Table 1). During this period, winds are usually weak. During the northeast monsoon season (October-May), the winds are northerly and are stronger.

Air temperatures range between a low of 28.5°C during January to a high of 37.5°C during July. The temperature steadily increased during January through July, and from August onward decreased gradually. The difference between the mean daily minimum temperature and mean daily maximum is about 10°C (Table 1).

There is very little precipitation at Jiddah and it is restricted to the period October to May. During the southwest monsoon, precipitation is almost nil.

There is a high level of radiant energy available throughout the year (Table 1), peaking in June and being lowest in December. Neumann (1952) calculated an annual evaporation of 211 cm from the Daedalus reef area (25°N, 35°E) of the Red Sea.

Circulation Pattern in the Red Sea

Geometric features, tides, monsoon winds, change in density of the waters, evaporation and cooling are some of the factors influencing the circulation pattern in the Red Sea. Morcos (1970) presented a detailed discussion on this subject and what follows is a brief summary of the salient features of circulation in the Red Sea. In a narrow rectangular basin like the Red Sea, when winds blow the surface water will be driven at an angle of 45° to the right of the wind direction (because the area is located in the northern hemisphere) and an "Ekman spiral" develops. This has two components, one in the direction of the wind and the other to the right of the direction of the wind. Because of its narrowness, in the Red Sea, the first component will gain momentum while due to the latter, piling up of water continues. During the two reversing monsoons, contrasting features in circulation are noticed as follows.

During the summer months, May through September, when north northwest winds blow along the axis of the Red Sea, surface waters are transported along the African coast with greater frequency and increased velocity. Seasonal changes in the wind patterns for the southern Red Sea area are summarised in Figure 5.

Along the African coast, surface water gets piled up while water from depths moves upwards in an easterly direction; this causes upwelling along the Arabian coast. As the surface waters are driven towards the south, an outflow from the Red Sea into the Indian Ocean takes place

Over the sill at the straits of Bab-el-Mandeb. However, because of the narrow sill, some of the water accumulated at the sill sinks and a bottom current develops and moves upwards in the northern part of the Red Sea. Newmann and McGill (1962), based on a more recent study, concluded that during early summer the water outflowing over the sill originates in the surface layer as a result of evaporation and cooling. They further reported an inflow of a third intermediate layer of waters in between the outflowing surface waters and northerly bottom current.

During winter, when the south southeast winds blow over the southern half of the Red Sea, surface waters are transported along the Arabian coast during December through to February. Their frequency and velocity are both high during the winter months. As the waters are piling up on the Arabian coast, sub-surface deep waters upwell on the African coast, a reversal of summer conditions. As the south southeast winds affect only the southern half of the Red Sea, at about 20°N two circulations converge, causing the surface water to sink. This sinking in turn causes an upward movement of water just north of the sill.

Land-drainage and Pollutants in the Jiddah area.

Five sources of land-drainage and pollutants can be identified:

- (a) oil pollution,
- (b) domestic wastes and sewage (city of Jiddah),
- (c) domestic wastes and sewage (Sharm-Obhor area),
- (d) fish wastes,

(e) de-salination plant inputs.

(a) Figure 3 shows the location of the oil refinery at Petramean in the southernmost region of Jiddah. Petroleum oil and oil products which leak during loading and unloading operations and through washing of the oil tankers are the chief pollutants.

(b) To the north of the Petramean area lies the Islamic seaport, which contributes to oil pollution through marine transportation. Additionally, during the pilgrimage season several thousands of pilgrims arrive by sea and stay in the City of Pilgrims. Domestic sewage and wastes are directly discharged into nearshore waters, causing heavy pollution in this area. A preliminary survey showed that the inshore waters contained as high as 88×10^3 coliform bacteria per ml of sea water during the pilgrimage season.

(c) Sharm-Obhor is a creek about 10 km long, located about 30 km north of Jiddah. Its breadth ranges between <200 m and >800 m. It has a maximum depth of 55 m near the mouth where it joins the Red Sea, and its average depth in the middle is about 30 m. The shores near its mouth are mostly rocky, with thick coral formations (Figure 4). In the central and northeastern regions, gently sloping beaches with scattered coral formations predominate. The Obhor area is a popular summer resort for the people of Jiddah, and in recent years many hotels and houses have been built on either side of the Sharm to accommodate the increasing population. Effluents which include domestic wastes and sewage are discharged directly into the Sharm without any treatment and these are

a source of eutrophication. Like the Islamic seaport, the waters of the Sharm are highly polluted and contain large numbers of coliform bacteria.

(d) To the north of the City of Pilgrims, the main fishing harbour and fish market of Jiddah are located (Figure 3). Fish wastes, decaying fish, and the sewage of metropolitan Jiddah are directly discharged into nearshore waters, which results in organic enrichment.

(e) To meet an ever-increasing demand for fresh water, the supply authorities have established a de-salination plant at about 20 km to the north of Jiddah (Figure 2). The de-salination plants Jiddah I and Jiddah II have the following characteristics:

	Jiddah I	Jiddah II
1. Length of valve for pumping sea water	Artificial gulf on shore	85 meters
2. Depth of pumping valve (m)	4	9
3. Daily quantity of water pumped (m tons)	0.40×10^6	0.74×10^6
4. Salt content of sea water (%)	39 - 40	39 - 40
5. Sea water temperature (°C)	24 - 32	24 - 32
6. Quantity of blow down water/day (m tons)	0.02×10^6	0.69×10^6
7. Salt content of blow down water (%)	44.6	46.7
8. Temperature of blow down water (°C)	38	35

Thus it is clear that 1.14×10^6 metric tons of water are pumped daily from the sea, of which 0.71×10^6 metric tons are returned from the desalination plants as blow down.

The blow down water affects the environment in two ways:

1) The temperature of the blow down water is about 10°C higher than the intake water. On average this difference between blow down and intake will be higher during winter than during summer.

2) The daily desalination of 0.43×10^6 metric tons of sea water would increase the salt budget of the adjoining sea by about 18×10^3 kg of salt. These environmental perturbations would be expected to be reflected in the physico-chemical and biological cycles in the nearshore waters.

MATERIALS AND METHODS

Sampling Programme

As one objective of this study was to compare the nearshore eutrophicated coastal waters with further offshore waters, several inshore and offshore stations were initially sampled. Analysis of the data revealed no substantial differences in measured variables within the seven inshore or within the six offshore (approximately 4 - 7 km) stations. In view of constraints of time and physical resources, and in order to broaden the scope of the study, it was therefore decided to restrict sampling to one inshore station and one offshore station (Figure 2).

Physical, chemical and biological oceanographic observations were made on a regular basis at these two stations of differing trophic status. The inshore station, referred to as the Sharm station (Figure 2) had a depth of approximately 40 m, and was sampled on 20 occasions during the period 28 March 1977 and 25 October 1978. The offshore station was located about 7 km seaward off the Sharm, and had a depth of approximately 200 m. It was sampled on 13 occasions from 2 November 1977 to 25 October 1978.

At the Sharm station the following variables were measured: temperature, salinity, dissolved oxygen, hydrogen ion concentration (pH), alkalinity and total carbon dioxide,

soluble reactive phosphorus (SRP), reactive silicate (SiO_2), nitrite (NO_2), ammonia (NH_3), chlorophylls a and b, and rate of photosynthetic carbon assimilation (C_{14}). Values of sigma-t (σ_t -density), oxygen percent saturation, and carbon assimilation ratios ($\text{mgC mgChla}^{-1} \text{ hr}^{-1}$) were calculated from these variables. Depths sampled included 0, 5, 10, 15, 20, 25, and 30 m. In addition, Secchi disc readings were obtained and phytoplankton species were enumerated from at least three depths and their diversity indices were calculated.

At the offshore station, the same variables were measured at 0, 25, 50, 75, 100, 150 and 200 m and the same calculations were made from these variables. All samples were taken either with a 1 litre Nansen bottle or 6 litre Van Dorn bottles. Actual depths of sampling were corrected for "wire angles" when necessary.

Physico-Chemical Methods

1. Temperature

Surface temperature was measured by immersing a mercury thermometer in the upper 30 cm layer of surface water, and allowing it to stay for at least 2-3 minutes. The temperature was read to the nearest 0.01 degree Celsius. In the upper 75 m, temperature was measured using a Schmidt thermometer fitted to a Nansen bottle. It was also allowed to stay for not less than 3 minutes at the required depth, and the temperature was measured to the nearest 0.01 degree Celsius. For sub-surface layers below 75 m, temperature was measured by the use of both protected and unprotected reversing thermometers fitted to the reversing bottle. The bottle was allowed to stay at least 3 minutes at the required depth before reversing. Readings obtained by the reversing thermometers were corrected according to procedures outlined in Sverdrup, Johnson and Fleming (1942). The depth of reversal was corrected by using the unprotected reversing thermometer when there was a wire angle. Otherwise, i.e. when there was no wire angle as in calm weather, it was sufficient to measure the length of this wire, and the error in this case would be negligible (Sverdrup et al. 1942)

2. Salinity

Since an inductive salinometer that could cover the high salinity values usually found in the Red Sea was not available, salinity was calculated from chlorinity values. Chlorinity was estimated by the titration method of Knudsen (Strickland and Parsons 1972). The silver nitrate solution was standardized periodically against standard sea water with a chlorinity of 19.376‰ prepared at the Institute of Oceanographic Science at Wormley, Surrey, U.K. From each sample, triplicate titrations were made and the average was calculated. Corresponding salinities from the chlorinities were read from Knudsen's tables (Oxner 1962).

3. In situ Density (σ_t)

In situ density (σ_t) was calculated from the salinity and temperature data at each depth according to the formula of Matthews (1932).

4. Sea Water Transparency

A 30 cm diameter weighted Secchi disc was lowered on a graduated ropeline. The average of the depth of disappearance, and on raising the disc, of its reappearance was recorded.

5. Dissolved Oxygen

The dissolved oxygen was determined by the classical Winkler procedure. Sea water samples were drawn gently into 300 ml BOD (Biological Oxygen Demand) bottles and all precautions were taken to avoid trapping any air bubbles. A volume of water at least equal to the volume of the BOD bottle was allowed to overflow from the top of the bottle and then the bottle was stoppered. Subsequent procedures and titrations followed methods outlined in Strickland and Parsons (1972).

6. Oxygen Saturation

Percentage oxygen saturation was calculated from oxygen content, temperature and salinity according to the formula of Weiss (1970).

7. pH

pH values were determined with a glass electrode using a Tacussel U9N pH meter, with a precision of ± 0.1 units. Samples were read immediately after collection and temperature corrections were applied where necessary to obtain in situ pH values. pH readings were taken solely for the purpose of calculating C^{14} uptake rates.

8. Alkalinity and Total Carbon Dioxide

For alkalinity determinations, water samples were drawn into polyethylene bottles and tightly stoppered. Experimental procedures were as detailed by Strickland and Parsons (1972). Total carbon dioxide in the samples was calculated according to Strickland and Parsons (1972), based on the total alkalinity, salinity, initial temperature, pH and the temperature at which the pH was measured. The values of total carbon dioxide so determined were used only for the primary production calculations.

9. Soluble Reactive Phosphorus (SRP)

Sea water samples for the determination of soluble reactive phosphorus were stored frozen until analysis. Determination was carried out on samples brought to room temperature according to the method of Strickland and Parsons (1972). Extinctions of solutions were measured in 10 cm path cells using a Pye-Unicam SP 500 UV Spectrophotometer.

10. Reactive Silicate (SiO_2)

Samples for the determination of reactive silicate were stored frozen until analysis. Determination was carried

out on samples brought to room temperature according to the method of Strickland and Parsons (1972). Extinctions of solutions were measured in 10 cm path cells.

11. Nitrite (NO_2)

Determination was carried out according to the method of Strickland and Parsons (1972). Extinctions of solutions were measured in 10 cm path cells.

12. Ammonia (NH_3)

Determination was carried out according to the method of Strickland and Parsons (1972). Extinctions of solutions were measured in 10 cm path cells.

13. Because of lack of equipment when this study was carried out, nitrate (NO_3) was not measured.

Biological Methods

1. Qualitative and Quantitative Examination of Phytoplankton

On each sampling day, at each station net tows for phytoplankton were made using a 50 cm mouth diameter plankton net of 64 μm mesh. Surface horizontal tows were made at each station at a speed of about one meter^(e) per second for about 15 minutes. Additionally, at each station a vertical haul from 50 m to the surface was made. The plankton concentrates were drained into glass bottles and preserved in 4% neutral formalin. These net samples were used only for qualitative studies concerned with species identification.

For quantitative studies, sea water collected with modified Van Dorn bottles was used. One litre of the sample was preserved with 4% neutral formalin and sedimented for at least 48 hours. The supernatant was gently siphoned off and a concentrate of about 50-100 ml was obtained. The concentrate was transferred to labelled glass bottles to which some more 4% neutral formalin was added to make up a known volume. Cells were counted at magnifications of 280X and 560X using Utermöhl's technique (Utermöhl 1958), under a Wild Heerbrugg M40 inverted microscope. From each sample 2 aliquots

were drawn and counted and average cell numbers calculated. On several occasions, especially during phytoplankton blooms, it was necessary to dilute the samples. Final cell numbers were calculated taking into consideration concentration and dilution factors. Cell numbers are expressed as cells litre⁻¹ of sea water. Single non-chain forms were counted as individuals; for colonial forms such as Trichodesmium, each filament was counted as an individual.

Taxonomic references included: Cleve-Euler (1951), Steidinger and Williams (1970), Wood (1963), and Dowidar (1976 and unpublished). Taxonomic nomenclature followed the above references. A complete list of taxonomic references is given in Appendix 8.

2. Species Diversity Index

A diversity index, expressed as information (D in "bits") per individual (Margalef 1957) was calculated from the formula:

$$D = -\sum_{i=1}^N p_i \log_2 p_i$$

where: D is the diversity

N is the total number of individuals

$p_i = n_i/N$, the proportion of the collection belonging to the i^{th} species.

3. Photosynthetic Pigments

Using a 6 litre modified Van Dorn bottle, water samples

were collected from pre-determined depths. The sample was mixed well and strained through a nylon mesh with a pore size of 300 μm to remove any larger zooplankters. Two litres of the screened sample were drawn into a polyethylene bottle and 0.2 ml of 1% magnesium carbonate solution was added. The samples were stored in darkness in a cooler on board the vessel. Soon after arrival at the laboratory on the same day of collection, photosynthetic pigments were determined following the procedure outlined by Strickland and Parsons (1972).

A two litre water sample was filtered through a Millipore filtration unit fitted with a 47 mm diameter (0.45 μm pore size) Millipore AA filter. In some cases when the filter was clogged due to excessive particulate material, it was necessary to complete the filtration using a second filter. In this case both filters were used for extraction. Filters were extracted in 8 mls of 90% acetone and allowed to stand in darkness in a refrigerator for about 24 hours before reading. Using a Pye-Unicam SP 500 UV Spectrophotometer, extinctions of the extracts were read against 90% acetone at 7500, 6650, 6450 and 6300 $\text{\AA}$ in 10 cm path cells.

Concentrations of chlorophyll a and b were calculated using Richards and Thompson equations (1952) (see Strickland and Parsons 1972):

$$\text{chlorophyll } \underline{a} = 15.6 E_{6650} - 2.0 E_{6450} - 0.8 E_{6300}$$

$$\text{chlorophyll } \underline{b} = 25.4 E_{6450} - 4.4 E_{6650} - 10.3 E_{6300}$$

Pigment concentrations are collected and reported as $\mu\text{g litre}^{-1}$

(or mg m^{-3}).

It was realised that the extinction coefficients in these equations would yield low estimates (Humphrey 1978), by as much as 23% for chlorophyll a. When comparing the Red Sea waters with other geographical areas or when comparing assimilation numbers ($\text{mg C mg chl a}^{-1} \text{ hr}^{-1}$) with those of other regions, chlorophyll a values should have been corrected using the following equations (Humphrey 1978):

$$\text{chlorophyll } \underline{a} = 0.766 \times \text{chl } \underline{a} + 0.005 \times b + 0.005 \times C$$

$$\text{chlorophyll } \underline{b} = -0.049 \times \text{chl } \underline{a} + 0.891 \times b + 0.059 \times C$$

Since the second and third terms of the chlorophyll a equation are small compared to the first term, their effect on recalculation of chlorophyll a is negligible. Consequently, the corrected chlorophyll a value will be 0.766 times that obtained from the Richards and Thompson equation (Humphrey 1978). In this study this correction ($\times 0.766$) was made.

4. Carbon Assimilation

The carbon- 14 tracer technique (Steemann Nielsen 1952) was employed to determine the photosynthetic carbon uptake rates. To a sample of sea water with a known quantity of total carbon dioxide, a known quantity of radio-active carbon ($\text{NaHC}^{14}\text{O}_3$) was added and the sample was incubated in situ for 6 hours under ambient light levels. After incubation, the samples were filtered, the filters were washed, dried and their radio-activity determined. The uptake of carbon was calculated and expressed as $\text{mgC m}^{-3} \text{ hr}^{-1}$.

During the study only in situ incubations were carried out. At each station a plastic buoy was tied to a rope and the rope was held taut by anchoring a heavy weight at the bottom. Pre-screened (<300 μm) sea water samples described earlier, were used. About 125 ml of water were drawn into a 150 ml BOD bottle and the contents of one ampoule of $\text{NaHC}^{14}\text{O}_3$ (4 microcuries) were added and the bottle stoppered. After mixing the contents gently, the bottles were tied to a rope and suspended from a plastic buoy at the same depth from where the sea water was obtained. At each depth 2 light and 1 dark bottles were incubated for 6 hours, generally from 0800 hours to 1400 hours.

Following incubation, the bottles were hauled, arranged according to depth in a wooden box, and were protected from light. The samples were filtered at the sea station, Institute of Oceanography, King Abdulaziz University. Using a filtration apparatus and Sartorius membrane filters of 0.2 μm pore size, samples were filtered under gentle suction. The filters were washed with filtered sea water, sucked dry and were serially numbered. These filters were then stored in plastic cups and stored in a refrigerator. Determination of the activity of the filters was carried out by the International Agency for Carbon-14 Determination, Horshølm, Denmark, which also supplied the ampoules used in this study. Carbon uptake was calculated as follows:

$$\text{mgC m}^{-3} \text{hr}^{-1} = \frac{\text{CPM}(a) \times \text{mgC/l}(c) \times 1.05(d) \times 1.06(e) \times 10^3(f) \times K_1}{\text{CPM}(b)}$$

where: a is the activity of the filter

- b added activity from the ampoule
- c total carbon content mgC l^{-1} in the sea water
calculated by $\text{mgCO}_2 \times \frac{12}{44}$
- d correction for isotopic discrimination (+5%)
- e correction for respiration (+6%)
- f conversion of mg l^{-1} to $\text{mg m}^{-3} = 10^3$
- K_1 correction for incubation time = 1/hrs of incubation.

It should be added that the activity of the filter from the light bottle is corrected for the dark uptake of carbon-14. No corrections for reassimilation of recently labelled (carbon-14) products were made. Corrections for isotopic discrimination (+5%) and respiration (+6%) are similar to those usually used by several investigators.

Statistical Methods

Differences between the means of variables or parameters (at the surface and 25 m depths) at the Sharm station and the offshore station were tested using Student's "t" test. Pearson's correlation coefficients were also calculated between the variables or parameters at the inshore and offshore stations to test for relationships.

Analysis of variance between means by month and means by depth (therefore with unequal sample sizes) was carried out for different variables and parameters. Computational methods for the statistical analysis are the same as detailed in Sokal and Rohlf (1973). All computation was carried out with

"Stalib" APL programmes in the Computer Centre at the
University of Guelph, Ontario.

RESULTS

Physico-Chemical Data

The complete data set is presented in Appendix 1, and maximum and minimum values are summarized in Table 2.

1. Temperature

SHARM:

The temperature pattern followed a distinct seasonal cycle, (Figure 6). Lowest temperatures (26° - 27°C) were observed during northern hemisphere winter months, i.e. December through March, following which temperatures increased. Highest summer temperatures were reached in August and September, and remained high during the fall. A minimum temperature of 25.10°C was observed at 20 m on 11/4/78 and a maximum of 32.20°C at the surface on 29/8/78 (Table 2). Due to the shallow water column at this station any changes at the surface tended to be transmitted throughout the water column.

Temperature gradients remained very weak and the waters were almost isothermal during December to March and during June

to September, suggesting little horizontal advection of water. During the summer months vertical temperature gradients at this station rarely exceeded 2°C; a maximum vertical gradient of 4.3°C was noted on 15/8/77.

OFFSHORE

A seasonal cycle of water temperatures was also evident at this station, (Figure 7). During the winter months, December through March, temperatures were low and a gradual warming was noted during the summer months. Temperatures remained high during the ^{autumn}(fall). A maximum of 31.50°C was observed at the surface on 10/8/78 and a minimum of 22.10°C at 200 m on 25/10/78 (Table 2).

A comparison with the nearshore station (Figure 6) shows several similarities such as the isothermal nature of the upper layer during winter, and developing thermal stratification after April. The temperature gradient between the surface and 100 m layer was 1.4°C during August. During November and January, this gradient was only 0.8°C - 0.9°C. The lowest vertical temperature gradients between the surface and 200 m were recorded as 3.5°C from December to January. Thus, the water column at this station never becomes isothermal although effective winter mixing down to about 100 m occurs. Below 100 m, water temperatures were fairly constant at 23° - 24°C from February to November, and at 150 m, they were almost constant year round at about 23°C.

2. Salinity

SHARM:

The salinity distribution at the inshore station is shown in Figure 8. A minimum value of 38.40‰ was noticed at the surface on 30/4/77 and a maximum of 39.98‰ at 15 m on 2/11/77 (Table 2). The high salinity values during the summer months of June-August result from excessive evaporation. The relatively high surface salinity values in January and February were probably due to mixing of oceanic Red Sea water piling up on the Arabian Coast during the southeast monsoon. Variations in salinity values were also noticed in the sub-surface layers and generally followed events at the surface. However, during the summer months following excessive evaporation at the surface, salinity at 5 m may be lower than that of overlying waters (Figure 8).

The annual average salinity at the surface and 5 m are 39.20‰ and 39.05‰ respectively. At 10 m it was 39.23‰, at 15 m, 39.36‰ and at 30 m, 39.26‰. The relatively high salinity at 10-15 m depths can be attributed to a sub-surface water current originating probably at the extreme east end of the Sharm and flowing westerly towards the sea. Near the bottom, an eastward current with salinity similar to that of the surface layer of the adjoining Red Sea region enters the Sharm (Dowidar, personal communication).

OFFSHORE:

The season distribution of salinity in the offshore waters is shown in Figure 9. A maximum of 40.54‰ was noticed at 200 m on 31/1/78 and a minimum of 38.80‰ at 25 m on 10/7/78 (Table 2). In the upper 50 m layer the salinities were always about 39.0‰ except during November, February and July when values <39.0‰ were encountered.

These low values are hard to explain and cannot be attributed to the Sharm water because the salinity of Sharm water was >39.10‰. Also, the run-off from land or the amount of effluents from Jiddah area are insignificant at the offshore station and thus dilution can be ruled out. The average salinity values for 50 m, 100 m and 200 m depths were 39.38‰, 39.88‰ and 40.32‰, respectively. Variations in salinity below 100 m were not pronounced. During January, the water column from 0 to 150 m was almost isohaline, exhibiting a difference of only 0.28‰, again suggesting effective winter mixing to this depth.

3. Density Structure

SHARM:

The pattern of density distribution in the nearshore waters is shown in Figure 10. A minimum value of 24.214 was calculated for 29/8/78 at the surface and a maximum of 26.678 was calculated for 30 m on 25/1/78 (Table 2). Pronounced changes in the density were observed only in the top 10 m layer, which could be attributed to: (a) run-off from land, (b) discharge of effluents (November-March), and (c) surface warming during summer (April-September). Between 10-15 m, high density water (25.00-26.50) was observed most of the year; this represents the outflowing Sharm water.

As stated earlier (Dowidar, personal communication), this water originates near the eastern shallow end of the Sharm as a result of sinking surface water. Due to evaporation, the surface water has a higher salinity and hence higher density and results in periodic density inversions, e.g. October-November 1977.

OFFSHORE:

Density structure in the offshore waters is shown in Figure 11. Density ranged between 24.441 at the surface on 10/7/78

and 28.397 at 200 m on 31/1/78 (Table 2). Based on vertical density characteristics, three layers could be recognized:

(a) An uppermost layer with σ_t values ranging from <25.00 to 26.50 and affected by seasonal temperature and salinity changes. The effect of temperature variations on density was more pronounced than salinity. The lower boundary of this layer extended to about 50 m.

(b) An intermediate layer with σ_t values ranging from <26.50 to 27.50. Seasonal temperature and salinity variations were rather gradual and equally affected the density structure. This layer extended vertically to about 100-150 m.

(c) The lowermost layer, where the variations in neither temperature nor salinity were pronounced. It extended from about 100-150 m to the bottom. σ_t values range from 27.00 to <28.50.

Formation of these three layers appeared to follow a seasonal pattern, thus during winter (December and January) the first two layers were present. In the top layer (100 m) winter cooling affected the density structure, and at greater depths salinity changes were important. A distinct third layer was, however, absent. During spring a top, intermediate and bottom layer, with boundaries at 50, 150 and 200 m respectively, were noticed. The top layer is formed as a result of seasonal surface warming, and the intermediate layer is formed of water with lower temperature than that which prevailed during winter (Figure 7).

During summer, transitional conditions from spring to summer occurred, and during June the lower boundaries of the

three layers were relatively established at 50, 100 and 200 m respectively. During autumn, two well-defined layers, an upper layer of 75 m thickness with a pronounced decreasing temperature gradient, and a second layer between 75 and 200 m, with nearly constant salinity and decreasing temperature, were noticed as in October. During November, due to surface cooling, the temperature gradient in the top 100 m was limited, and an increase between 100 and 200 m in salinity was the important factor.

4. Transparency

The transparency characteristics of the inshore Sharm and offshore waters are compared in Figure 12. Inshore, Secchi disc readings ranged from 10.0 m on 14/2/78 to 25.0 m on 20/6/78 (Table 2). In the offshore waters, the range was between 22.0 m on 10/7/78 and 32.0 m on 27/6/78 and 2/11/78 (Table 2). During November through February, the transparency of the inshore waters decreased slightly following which it increased steadily until June, except for a drop during April-May. During July through October, the waters became more turbid.

Offshore waters were less turbid than the Sharm waters, and in general, offshore Secchi readings were almost twice those inshore. The higher turbidity of Sharm waters could be attributed to the presence of quantities of terrigenous material brought about by land run-off and effluents, and also to biogenic material such as plankton. Although the offshore waters were more transparent, the seasonal patterns of transparency showed some similarities between inshore and offshore waters. As it is well known that Secchi disc readings are subject to errors such as time of observations, angle of sun's rays, cloud cover and human error, these readings will be considered as representing only the relative degree of water transparency.

5. Dissolved Oxygen

SHARM:

The seasonal distribution of dissolved oxygen in the inshore waters is shown in Figure 13. The oxygen content ranged from $2.10 \text{ ml O}_2 \ell^{-1}$ at 30 m on 28/5/78 to $4.72 \text{ ml O}_2 \ell^{-1}$ at 15 m on 15/8/77. The oxygen content was usually between $4.0-4.25 \text{ ml} \ell^{-1}$ and did not show any marked seasonal variations except for "domes" (here used in a spatial-temporal sense) of low oxygen values during May-June 1978. Complete absence of oxygen was never observed.

The Sharm waters are nearly saturated in their oxygen content (Figure 14). The oxygen saturation values ranged from 46.6% to 110.2% (Table 2). Domes of low saturation waters were observed during April-May 1978.

OFFSHORE:

Considerable seasonal variations in the oxygen content occurred of the offshore waters (Figure 15). Table 2 shows that the values ranged from $1.85 \text{ ml O}_2 \ell^{-1}$ at 200 m on 22/2/78 to $4.80 \text{ ml O}_2 \ell^{-1}$ at surface on 25/10/78. In the top layer (<50 m), the oxygen content was about $4.0-4.5 \text{ ml} \ell^{-1}$ and did not show any marked seasonal changes. Thus, the pattern is similar to that observed in Sharm waters. Also, formation of domes of

low oxygen content was noticed during May-June.

Below 50 m, there were marked changes in the oxygen content. With increasing depth, there was a marked decrease in the oxygen content. The isopleths showed formation of distinct domes of low oxygen ($2.5-3.0 \text{ ml O}_2 \ell^{-1}$) during February-March, May-June and September. In the offshore waters, changes in oxygen saturation were also more marked (Figure 16). Values ranged from 38.5% at 200 m on 22/2/78 to 114% at the surface on 25/10/78. Domes of low saturation values were observed during February-March, May-June and September.

It may be generalized that the surface waters at both stations are usually saturated or almost saturated with oxygen but that absolute oxygen concentrations are low. This can be attributed to high temperatures, high salinity and little freshwater input. Organic matter contributed through the sewage and effluents will deplete oxygen through biochemical oxygen consumption, but no data are available to determine the biological oxygen demand.

While discussing the density structure, it was pointed out that density in the uppermost layer (<50 m) and intermediate layer (<100 m) are mostly affected by the temperature-salinity relationships. Figure 16 shows that below 100m, the offshore waters are undersaturated in their oxygen content; this is probably partly due to lack of direct exchange with the atmosphere and partly due to low photosynthetic activity at these depths. Some of the low oxygen saturation domes could be the result of intrusion of oxygen-depleted water into the area of study, particularly in the May-June 1978 period.

6. Soluble Reactive Phosphorus

SHARM:

The seasonal distribution of soluble reactive phosphorus in the inshore waters is shown in Figure 17. On several sampling days, phosphate was undetectable ($<0.01 \mu\text{g-at}$) and reached a maximum of $0.76 \mu\text{g-at PO}_4 - \text{P l}^{-1}$ on 14/3/78 at 15 m (Table 2). During winter, there was a general increase in phosphate, reaching a maximum during March in the surface waters. This increase could be attributed to lower biological activity following the peak in December (see section on Biological Data - 5. Primary Production). Following this, the phosphate concentrations decreased rapidly in the top 10 m to reach a minimum during October, which is probably due to increased biological activity during the summer months. At sub-surface levels there were domes of relatively high phosphate values during May-June, September-October and November, probably the result of sub-surface intrusions of nutrient rich Sharm water, or in situ nutrient regeneration.

OFFSHORE:

The seasonal change of soluble reactive phosphorus in the offshore waters is shown in Figure 18. The range here was

quite high, with a minimum of $0.01 \mu\text{g-at}_\ell^{-1}$ at the surface on 25/10/78 and a maximum of $1.46 \mu\text{g-at}_\ell^{-1}$ at 75 m on 11/4/78 (Table 2). Except during April, phosphorus values in the top 100 m were fairly constant ($\sim 0.2 \mu\text{g-at}_\ell^{-1}$) and showed little seasonal variation. Such a constant low value could be attributed to the assimilation of phosphorus being in a steady state with its supply.

During April, there was a rapid increase of this nutrient when it reached maximum values. Figure 18 shows the formation of a dome of high phosphorus during February at about 150-200 m, and the concentrations of phosphorus rapidly increasing into April, when high levels extended almost to the surface. Reasons for these high levels of phosphorus in April are not clear. They could be due to in situ remineralization of phosphorus following the crash of the peak in primary production which occurred in January-February (see section on Biological Data - 5. Primary Production). After April, there was a rapid decrease in this nutrient which could be attributed to renewed biological assimilation.

7. Silicate

SHARM:

The seasonal distribution of silicate in nearshore waters is shown in Figure 19. The values ranged between $1.09 \mu\text{g-at}\ell^{-1}$ at the surface on 25/1/78 and $7.40 \mu\text{g-at}\ell^{-1}$ at 30 m on 15/8/77 (Table 2). In the top 10 m, silicate concentrations were low and showed little variation. When compared to winter (November-December) values, the concentrations decreased during spring, which could be attributed to utilization by diatoms. During June-July (1978) months, domes of high silicates were noticed at sub-surface levels. During August 1977, unusually high concentrations of silicates were observed in the surface waters which was not the case during 1978.

For coastal waters which, in general, have high silicate concentrations, the values from the Sharm station are low; this must be mainly due to the low discharge of freshwater into the Sharm.

OFFSHORE:

The seasonal distribution of silicates in the offshore waters is shown in Figure 20. The values ranged from $0.98 \mu\text{g-at}\ell^{-1}$ at the surface on 23/9/78 to $4.69 \mu\text{g-at}\ell^{-1}$ at 200 m on

31/1/78 (Table 2). The distribution pattern was similar to that of phosphorus with very little seasonal variation with values $<3.0 \mu\text{g-at l}^{-1}$ in the top 100.

Such constant silicate values suggests the possible existence of a steady state system where consumption and replenishment rates are equal. During April and August, domes of higher silicate levels taking their origin from 100-200 m depths were noticed. A comparison with inshore values shows that the offshore waters are more impoverished in silicate. Lack of admixture of freshwater accounts for such low silicate levels.

8. Nitrite

SHARM:

The nitrite nitrogen distribution in the inshore waters is shown in Figure 21. On several occasions, there was total depletion of this nutrient at the surface; the maximum value recorded was $0.65 \mu\text{g-at } \ell^{-1}$ on 18/7/78 at the surface (Table 2). On a seasonal basis, values during winter, i.e. November to January months, were uniformly low in the water column ($< 0.2 \mu\text{g-at } \ell^{-1}$) and the values steadily increased during spring and summer to reach a maximum ($> 0.6 \mu\text{g-at } \ell^{-1}$). Later, a decrease in nitrite was observed during autumn and winter.

OFFSHORE:

The seasonal distribution of nitrite in the offshore waters is shown in Figure 22; values ranged between $0.01 \mu\text{g-at } \text{NO}_2 - \text{N } \ell^{-1}$ at the surface on 28/5/78 to $3.25 \mu\text{g-at } \text{NO}_2 - \text{N } \ell^{-1}$ at 200 m on 11/4/78 (Table 2). When compared with nearshore waters, this nutrient was in greater abundance offshore, and exhibited a strong seasonal pattern. During winter, values were about $0.3 \mu\text{g-at } \ell^{-1}$, followed by a decrease during spring. There was no surface accumulation of nitrite during the summer

and autumn, however, domes of high nitrite values were observed during April-May and September and October and reached from 50 m to the bottom.

9. Ammonia

SHARM:

The seasonal distribution of ammonia in the inshore waters is shown in Figure 23. Ammonia was undetectable at 5 and 10 m on 29/8/78; a maximum of $3.54 \mu\text{g-at}\ell^{-1}$ was observed in the surface layer on 11/4/78 (Table 2). There was no marked seasonal change in ammonia distribution. During winter (November-January) and spring (February-March), concentrations were between $1.0\text{--}2.0 \mu\text{g-at}\ell^{-1}$ and were almost uniformly distributed. In April, there was a sudden increase throughout the column ($>3.0 \mu\text{g-at}\ell^{-1}$) followed by a rapid decrease during the summer months.

OFFSHORE:

The seasonal distribution of ammonia in the offshore waters is shown in Figure 24. There was complete depletion of this nutrient in the surface waters on 28/5/78 and the maximum of $3.90 \mu\text{g-at}\ell^{-1}$ was observed at 200 m on 21/4/78 (Table 2). In the top 100 m, there was little seasonal variation in ammonia and the values were constant at about $1.0 \mu\text{g-at}\ell^{-1}$. However, during March-April, the ammonia content doubled.

Below 100 m ammonia concentration was generally high (2.0-4.0 $\mu\text{g-at } \ell^{-1}$) during winter (November-February) and spring (March-April). During the summer months (May-September), values were uniformly low (<1.0 $\mu\text{g-at } \ell^{-1}$) throughout the water column. Domes of high values of ammonia were observed near the bottom during February-April and in October.

10. Relationships between salinity, silicate and phosphate.

The relationships between salinity, silicate and phosphate have been used to indicate water mass origins or relative biological nutrient requirements.

Relationships between salinity and silicate (both stations combined) and between silicate and phosphate (Sharm and offshore stations) are presented in Figures 25, 26 and 27 respectively. These relationships will be examined further in the Physico-chemical environment section of the Discussion.

Biological Data

1. Seasonal Composition of the Major Groups of Phytoplankton and Diversity Indices

SHARM:

The seasonal composition of phytoplankton groups in the inshore waters at the Sharm station is shown in Figure 28. Diatoms, dinoflagellates and blue-green algae were represented, with diatoms constituting the bulk of the phytoplankton during most of the year except for May, June and October. During May and June, the blue-greens were dominant, and during October dinoflagellates were dominant. The appearance of blue-greens was limited to the summer months of May, June and July, whereas dinoflagellates and diatoms were present year round.

The diversity index (Figure 29) at the Sharm station ranged from 0.92 at 20 m during October to 4.56 at the surface in April. The general seasonal trend is for higher diversities in the early part of the year until April and again in August and September, with much lower values in October and variable values during the summer (May-July). Diversity indices for diatoms and dinoflagellates separately are tabled in Appendix 9.

OFFSHORE:

The seasonal composition of phytoplankton in the offshore waters is shown in Figure 30. There is a close similarity between inshore and offshore waters in the seasonal composition of phytoplankton. Diatoms were present all year except during October, and they dominated the phytoplankton community at the offshore station year round except for June and October. Dinoflagellates were also present year round, but only dominated the community in October as at the Sharm station. Blue-green algae were present as small proportions of the total phytoplankton crop in several months, but only reached significant proportions from May to August, and were dominant only in June. Again, this closely resembles the situation observed at the Sharm station.

The diversity index (Figure 31) at the offshore station ranged from 0.65 at 100 m in October, to a maximum of 4.62 at 100 m in July. The general seasonal trend is similar to that of the inshore station although there is much variation. Higher diversities were again generally observed early in the year and again in August and September, with much lower values in October and variable values from April to June. Diversity indices for diatoms and dinoflagellates separately are tabled in Appendix 10.

The low diversity indices at both stations in October clearly reflect the predominance of a few species of dinoflagellates. The low values during the summer months reflect the dominance of blue-green algae.

2. Quantitative Abundance of Phytoplankton

SHARM:

Cell numbers ranged from only 10 l^{-1} at 40 m on 20/8/78 to 69,755 l^{-1} at the surface on 25/1/78 (Table 3). The phytoplankton community showed a distinct bimodal distribution with a primary peak in January 1978 and a smaller secondary peak in late May (Figure 32). Although both diatoms and dinoflagellate contributed to the primary January peak, diatoms were far more abundant. The third apparent peak in August may be due simply to spuriously low cell counts on July 25 (c.f. Figure 34 - offshore station).

The abundance of major groups (number of cells l^{-1}) during the peak periods can be summarized from Table 3 as follows:

	<u>Primary Peak</u>	<u>Secondary Peak</u>
Date	25 Jan 1978	28 May 1978
Total maximum	69,755	12,920
Average for water column	31,120	7,439
Diatoms maximum	68,435	8,030
Dinoflagellates maximum	1,320	1,690
Blue-greens maximum	Nil	4,500

During the primary peak 53 taxa of diatoms, 14 taxa of dinoflagellates and 1 chrysophyte comprised the cell counts

(based on Van Dorn collections), (Appendix 2), and a total of 65 diatoms, 44 dinoflagellates and 1 chrysophyte species were present (based on Van Dorn collections and plankton net hauls combined) (Appendix 4). During the secondary peak, 9 taxa of diatoms and 11 taxa of dinoflagellates together with blue-green algae comprised the cell counts (based on Van Dorn collections) (Appendix 2); a total of 33 diatom and 28 dinoflagellate species in addition to the blue-greens were present (based on Van Dorn collections and plankton net hauls combined), (Appendix 4).

In the vertical plane, dinoflagellates, diatoms and blue-greens exhibited marked variations with depth (Figure 33, Table 3). During periods when diatoms and dinoflagellates comprised the dominant flora, they were most abundant in the top 5 m, their numbers generally decreasing with depth. During the summer months, when blue-greens were most dominant, in the top 5 m they constituted more than 60% of the phytoplankton population.

OFFSHORE:

Total phytoplankton cell numbers at this station reached a maximum of 24,860 cells ℓ^{-1} in surface waters on 27/12/77 (Table 4). On 25/10/78 cell numbers were low throughout the water column, and phytoplankton were not noted in the deeper waters. Phytoplankton abundance in offshore waters followed a bimodal distribution with a primary peak during December and January and a secondary peak in July (Figure 34). The

seasonal cycle of phytoplankton abundance is thus very similar at the two stations, but the primary peak offshore occurred about three weeks earlier. The summer peak of abundance for blue-greens and dinoflagellates occurred in July and for the diatoms, in late August.

The abundance of the major groups (number of cells μ^{-1}) during the peak periods can be summarized from Table 4 as follows:

	<u>Primary Peak</u>	<u>Secondary Peak</u>
Date	27 Dec 1977	10 July 1978
Total Maximum	24,860	15,920
Average for water column	9,571	6,102
Diatoms maximum	24,250	7,180
Dinoflagellates maximum	610	3,320
Blue-greens maximum	Nil	9,650

During the primary peak 27 taxa of diatoms and 18 taxa of dinoflagellates comprised the cell counts (based on Van Dorn collections) (Appendix 3), and a total of 50 diatom and 31 dinoflagellate species were present (based on Van Dorn collections and plankton net hauls combined) (Appendix 5). During the secondary peak 28 taxa of diatoms and 30 of dinoflagellates, together with blue-green algae, comprised the cell counts (based on Van Dorn collections) (Appendix 3); a total of 32 diatom and 44 dinoflagellate species in addition to the blue-greens were present (based on Van Dorn collections and plankton net hauls combined) (Appendix 5).

In the vertical plane, the phytoplankton groups exhibited marked variations with depth (Figure 35), except during

October (Table 4). Diatoms constituted the bulk of the cell counts and were most abundant in the top 100 m (Table 4). During May to July, blue-greens were most abundant in the surface waters (60-80%) and during October, only dinoflagellates were noted (Table 4).

3. Season^{al} Species Composition

A total of 283 taxa of phytoplankton (including 10 sub-species or varieties) have been recognized and identified from collections at the two stations. Seasonal species lists at the Sharm and offshore stations are presented in Appendices 4 and 5 respectively. A wide variety of taxa was present at both stations. The complete species list with authorities is presented in Appendix 6.

In the Bacillariophyta, 137 species (including 6 varieties) belonging to 48 genera were identified, together with a further 21 taxa (exclusive of the monospecific genera) of uncertain specific status (referred to as spp.). In the Dinophyta, 110 species (including 4 sub-species and varieties) were recognized, belonging to 27 genera; in addition a further 13 taxa (exclusive of the monospecific genera) of uncertain specific status (referred to as spp.) were noted. In the Chrysophyta a single species was observed and in the Cyanophyta the single genus Trichodesmium (not separated into species) was observed.

Based on their seasonal distribution, the phytoplankters can be grouped as:

- A - those common to inshore and offshore waters during the major bloom,
- B - those common to both inshore and offshore waters during the minor bloom,

C - those common to both major and minor blooms

D - those restricted to only one of the blooms

A. During the major bloom, the following taxa were common to the inshore and offshore waters:

Diatoms

Bacteriastrum delicatulum

B. hyalinum

Chaetoceros affinis

C. atlanticus

C. coarctatum

C. compressus

C. didymum

C. Lauder

C. peruvianum

Climacodium fraunfeldianum

Guinardia flaccida

Nitzschia closterium

N. longissima

N. seriata

Planktoniella sol

Rhizosolenia alata

R. bergonii

R. calcar-avis

R. delicatula

R. fragilissima

R. hebetata

R. imbricata
R. Shrubsolei
R. Stolterfothii
R. styliiformis
Streptotheca thamesis

Dinoflagellates

Amphisolenia bidentata

Ceratium arietinum

C. carriense

C. contrarium

C. declinatum

C. furca

C. fusus

C. kofoidii

C. macroceros

C. massiliense

C. teres

C. trichoceros

C. tripos

Diplopsalis lenticula

Exuviaella spp.

Goniodoma polyedricum

G. sphaericum

Gonyaulux polygramma

Peridinium divergens

P. oceanicum

P. trochoideum

Prorocentrum micans

Pyrophacus horologium

B. The following taxa were common to the offshore and inshore waters during the minor bloom:

Diatoms

Chaetoceros curvisetum

Guinardia flaccida

Hemiaulus hauckii

Leptocylindrus danicus

L. minimus

Nitzschia closterium

N. delicatissima

Rhizosolenia alata

R. bergonii

R. calcar-avis

R. delicatula

R. Stolterfothii

Dinoflagellates

Ceratium breve

C. candelabrum

C. contrarium

C. declinatum

C. furca

C. fusus

C. kofoidii

C. massiliense

C. pentagonum

C. teres

C. trichoceros

Dinophysis caudata

Exuviaella spp.

Goniodoma polyedricum

Gonyaulux polygramma

Ornithocerus spp.

Peridinium brochii

P. spp.

P. divergens

P. granii

P. steinii

P. trochoideum

Peridinopsis asymmetrica

Prorocentrum micans

C. Of the above, the following species were common to both major and minor peaks.

Diatoms

Chaetoceros affinis

C. compressus

Guinardia flaccida

Nitzschia closterium

Rhizosolenia alata

R. bergonii

R. calcar-avis

R. delicatula

R. stolterfothii

Dinoflagellates

Ceratium contrarium

C. declinatum

C. furca

C. fusus

C. kofoidii

C. massiliense

C. teres

C. trichoceros

Exuviaella spp.

Goniodoma polyedricum

Gonyaulux polygramma

Peridinium divergens

P. trochoideum

Prorocentrum micans

D. The following were restricted to one of the blooms as shown:

Primary bloom Diatoms

Bacteriastrum delicatulum

B. hyalinum

Chaetoceros atlanticus

C. coarctatum

C. concaviformis

C. convolutus

C. didymum

C. lauderi

C. peruvianum

Climacodium fraunfeldianum

Nitzschia longissima

N. seriata

Planktoniella sol

Rhizosolenia fragilissima

R. hebetata

R. imbricata

R. shrubsolei

R. styliiformis

Streptotheca thamesis

Primary bloom Dinoflagellates

Amphisolenia bidentata

Ceratium arietinum

C. carriense

C. macroceros

C. tripos

Diplopsalis lenticula

Goniodoma sphaericum

Gonyaulux polygramma

Peridinium oceanicum

Pyrophacus horologium

Minor bloom Diatoms

Chaetoceros compressus

C. curvisetum

Hemiaulus hauckii

Leptocylindrus danicus

L. minimus

Nitzschia delicatissima

Minor bloom Dinoflagellates

Ceratium breve

C. candelabrum

C. pentagonum

Dinophysis caudata

Ornithocercus spp.

Peridinium brochii

P. cerasus

P. divergens

P. granii

P. steinii

Peridinopsis asymmetrica

4. Phytoplankton Pigments

SHARM:

Chlorophyll a concentrations in the inshore waters ranged from 0.07 to 1.83 mg m⁻³ on 18/7/78 and 25/1/78 respectively (Table 5). Seasonal variations in chlorophyll a in the water column are shown in Figure 36. During the winter months, December and January, chlorophyll a reached a maximum in the top 10 m and decreased with depth. During February-May the values in the top 10 m were lower, but there was an increase at sub-surface (>10 m) levels. From the 28th of June values at the surface registered an increase. Subsequently, there was no marked variation in the chlorophyll a values.

Chlorophyll b values ranged between 0.03 and 1.42 mg m⁻³ (Table 5). Comparison of chlorophyll b (Figure 37) profiles with those for chlorophyll a show close similarity. Maximum chlorophyll b values were observed during December-January in the top 10 m. Following this, there was an increase or accumulation of this pigment at depths greater than 10 m until the 28th of May, and in surface waters until the 20th of June. There was an increase in its concentration in surface waters again in September. Thus, it may be concluded that these algal pigments showed a bimodal (or trimodal?) peak distribution with a major peak during December-January, and a minor peak during

May-June months.

OFFSHORE:

Chlorophyll a concentrations in the offshore waters ranged from 0 to 2.25 mg m⁻³ and chlorophyll b from 0 to 1.86 mg m⁻³ (Table 5). Chlorophyll a concentrations were generally low in the surface waters during October-November. During December there was a sudden and rapid increase at 75 m (Figure 38). The surface layers (0-25 m) next showed an increase in chlorophyll a, with a peak occurring on February 22nd. A second peak in surface waters was reached in June and July. Subsequently chlorophyll a levels in the surface waters declined concurrently with a substantial sub-surface increase at 75 m in September. Seasonal variations in chlorophyll b were similar to those of chlorophyll a (Figure 39). Values were low during October-November, and maximum concentrations were observed at 75 m during December. From January until April 11th, the values gradually increased in the top 25 m. On April 21st, surface values decreased, but the values at about 75 m increased. During May to September, values in the surface layer remained fairly high.

A comparison of chlorophyll a levels in the inshore and offshore waters shows certain similarities (Figures 36, 38 and 37, 39). At the offshore station, a very distinct sub-surface chlorophyll maximum layer developed in December. At the Sharm station, although there is a sub-surface maximum (e.g. April, May and July), this probably represents an

"accumulation" of pigments by sinking from surface waters, and this may also be occurring in September in the offshore waters.

There is general evidence at both stations of approximate seasonal bimodality, with the lowest chlorophyll values between the maxima occurring in October-November at both stations. At the Sharm station, the second seasonal minimum occurred in March, and at the offshore station, it occurred in April. Generally, the inshore waters had slightly higher levels of chlorophyll a than the offshore waters. This was especially true of the surface waters during December and January, which is consistent with the data on numerical abundance of phytoplankton at this time.

5. Primary Production

SHARM:

Seasonal variations in primary production profiles are shown in Figure 40. Primary production rates ranged from $0.31 \text{ mg C m}^{-3} \text{ hr}^{-1}$ at 20 m during August, to $6.34 \text{ mg C m}^{-3} \text{ hr}^{-1}$ at the surface on 21/4/78 (Table 5). The maximum integrated production rate of $199.84 \text{ mg C m}^{-3} \text{ hr}^{-1}$ was observed on 27/12/77 and the minimum was $29.16 \text{ mg C m}^{-2} \text{ hr}^{-1}$ on 29/8/78 (Table 5).

In general, production was high in the surface waters and decreased with depth, as evident from the profiles for November to October. The seat of maximum production was often at about 20 m except from late April to August when it was at the surface (Figure 40).

OFFSHORE:

Seasonal variations in primary production profiles at the offshore station are shown in Figure 41. On several occasions primary production was undetectable in deeper waters; it reached a maximum of $9.40 \text{ mg C m}^{-3} \text{ hr}^{-1}$ at the surface on 10/7/78. The maximum integrated production of $206.13 \text{ mg C m}^{-2} \text{ hr}^{-1}$ was measured on 10/8/78 and the minimum of 25.45

mg C m⁻² hr⁻¹ on 28/5/78. In the offshore waters, the highest rate of production was generally at the surface from March to September and in November, and at 25 m during October, January and February. Production seems to have started at 75 m during December, and gradually surfaced, where it attained a maximum similar to the chlorophyll a pattern.

The annual cycle of integral production (mg C m⁻² hr⁻¹), shows several interesting features (Figure 42). In the inshore waters, production rapidly increased during winter to reach a maximum during December.

In the offshore waters, the corresponding seasonal maximum was not attained until February. Following this, production declined at both stations into May when minimum values were observed in offshore waters. Although the decline in production was similar from January to May, actual production was higher inshore than offshore. From May onwards, production offshore rapidly increased to reach high levels during July-August. Increase in inshore production was not as dramatic as in the offshore during June-July. Interestingly, minimum values were observed in the inshore during August, when production was at its peak offshore. Following this, production values registered an increase and were similar, both in the inshore and offshore waters, during October.

The annual cycle of production at the offshore station thus appears to be strongly bimodal with two peaks of almost equal integrated rates in February and July-August. The annual cycle at the Sharm station seems to precede events offshore by about two months, but no clear second peak of

production in autumn is evident. Rather, two smaller spring-summer peaks in April and June occur to give a possible trimodal annual cycle.

6. Carbon Assimilation Ratios ($\text{mg C mg Chl } \underline{a}^{-1} \text{ hr}^{-1}$).

SHARM:

The pattern of seasonal variation in carbon assimilation ratios is shown in Figure 43. These ratios, which are a measure of the photosynthetic efficiency of the phytoplankton, ranged from 1.21 at 30 m during July to 14.57 at 5 m during February (Table 5). This range excludes the very high values (at the surface during July and similar high values at 10-20 m during October), as they appear to be suspect. Chlorophyll a values on those days were very low, and could have resulted in these high suspect values. The great majority of ratios lay between 1 and 10. In the inshore waters, photosynthesis was efficient during November and December at sub-surface levels (20-30 m), (Figure 43). Photosynthetic efficiency steadily increased throughout the column and ascended to the surface to attain a maximum during March. The efficiency continued to be reasonably high (~6) in the top 5 m, and reached a second maximum during July. There was increased photosynthetic efficiency in the whole column during October.

OFFSHORE:

The seasonal pattern of variations in carbon assimilation ratios at the offshore station is shown in Figure 44. The great majority of ratios about 75 m lay in the range of 0.5 - 7, but ranged from 0.11 at 75 m during January to 17.70 at the surface during October (Table 5).

The pattern suggests that efficient functioning of photosynthesis began at sub-surface levels (about 25 m) during January and reached the surface. However, it did not last long, as evident by the low assimilation ratios during February to June. From June, the photosynthetic efficiency increased rapidly and reached a maximum during August. In the vertical plane photosynthesis was efficient down to 75 m. This was followed by low efficiency during September. Again during October, the phytoplankton carried on photosynthesis effectively, as evident by the high assimilation ratios throughout the column.

Figure 44 also shows that from 50 m to 100 m, during the period November to July, photosynthetic efficiency was extremely low, whereas in the inshore waters photosynthetic efficiency continued to be high, even near the bottom, generally throughout the study period.

7. Inter-relationships of Physico-Chemical and Biological Data

In order to avoid lengthy description and repetition of these findings, the inter-relationships of the data presented above will be considered in the Discussion Section following.

Correlation matrices summarizing relationship between measured variables and derived parameters at the inshore (Sharm) and offshore stations, is presented in Tables 6 and 7.

DISCUSSION

There are very few bodies of water similar to the Red Sea i.e. which are landlocked, semi-enclosed and located in an arid zone where evaporation is far in excess of precipitation and run-off. Because of the uniqueness of the Red Sea and paucity of data from neighbouring seas, a comparison of the present data with that from other bodies of water becomes difficult. However, such comparisons will be made wherever feasible in order to place the present findings into some reasonable ecological perspective. The objectives of this discussion are therefore:

- (i) to interpret as far as possible the physico-chemical and biological data obtained, their interactions and significance to primary production
- (ii) to place these findings into perspective by comparison with previous biological oceanographic research.

The Physico-Chemical Environment

To the south of Jiddah in the Red Sea, and in the Indian Ocean, the reversal of the monsoon wind system is a dominant oceanographic force. During November-February under the influence of the ~~nor~~theast monsoon, it appears that oceanic

Red Sea water piles up on the Arabian Coast, gets cooled and mixes downward. The relatively high surface salinity values in January and February probably reflect this effect. During the Southwest monsoon period, May to September, surface waters warm up and some stratification is noticed. Although any evidence for upwelling of colder sub-surface waters is lacking, a distinct seasonal inclination of isotherms, isohalines and isobars is very evident at the offshore station (see Figures 7, 9, 11). This effect does not extend to the inshore Sharm station some 7 km away.

It may well be that Jiddah lies at the approximate limit of influence of the monsoon reversal, at least with respect to upwelling. The tendency for surface waters to upwell here during the summer will also be resisted by higher summer temperatures causing lower densities (Figure 11). In view of this apparent lack of outside influence (i.e. upwelling due to monsoon influence) attention will now focus on the local relationship between variables.

Pearson correlation coefficients between the various parameters are given in Table 6 for Sharm (inshore) waters and in Table 7 for offshore waters. Between the inshore and offshore waters, certain correlations were similar.

Significant positive correlations existed between advancing season (month) and temperature, depth and density, salinity and density, density and phosphate, oxygen and temperature, oxygen and oxygen saturation and temperature, phosphate and ammonia and silicate and depth.

Of these correlations, those between advancing season and temperature, increase in density with increase in salinity, increase of phosphate with an increase in density, increase in oxygen saturation level with oxygen concentration, increase of ammonia with an increase in phosphate and an increase of silicate with depth are obvious.

It is clear that with an increase in depth both density and nutrients increased, particularly in the offshore waters (Table 7). The increase of the nutrients at these depths could be either due to lesser utilization of nutrients below the euphotic zone or due to regeneration of nutrients or both. It is well known that a wide range of biogenic materials such as the siliceous diatoms, radiolarians and other sestonic material sinks in the water column where regeneration of inorganic phosphorus, silicon and nitrogen takes place. In landlocked basins, due to restrictions on the exchange of bottom water, accumulation of nutrients results. Such an accumulation of silicates and inorganic phosphates in basins was reported by Richards (1958) and Richards and Vaccaro (1956).

The correlations between temperature and oxygen saturation were positive and significant both in the inshore and offshore waters. This is clearly a reflection of increased oxygen utilisation in deeper, cooler waters due to processes of nutrient regeneration. The supersaturation values in surface waters can clearly be ascribed to oxygen production by photoautotrophic organisms. Such simple explanations are, however, not always adequate and departures from expected

correlations between temperature and dissolved gases, e.g. oxygen and carbon dioxide, are often recorded. For example, on the west coast of India, during April, May and June, high oxygen concentrations were recorded despite poor phytoplankton crops and high temperatures (Subrahmanyam 1959; Kasturirangan 1957).

Significant negative correlations existed between depth and temperature, temperature and density, depth and oxygen, oxygen and density, oxygen saturation and phosphate, and temperature and phosphate, both in the inshore and offshore waters. These correlations are generally expected and consistent with findings from research in other bodies of water.

Temperature and all nutrients were negatively correlated in the offshore waters, which shows that as the temperature decreased in deeper waters, there is an increase in nutrients. As stated earlier, increase in the subsurface nutrients results from lower utilization of nutrients and from regeneration.

There have been several accounts to show that the relative fertility of ocean waters can be understood by comparing the available nutrients. Table 8 summarizes the inorganic phosphate concentrations in some selected regions. Phosphate concentrations noted in the present study are comparable to records from the Gulf of Aqaba (Klinker et al 1978), Gulf of Elat (Levanon-Spanier et al. 1979, Sournia 1977) and the N.E. Arabian Sea (Radhakrishna et al. 1978). Grasshoff (1969) and Hansen et al (1968) recorded higher values in Red Sea waters than those recorded during this study. There was not always an abundant supply of this nutrient in these waters

as indicated by low values such as 0 and $0.01 \mu\text{g-at l}^{-1}$. These low values could be attributed to the lack of input of phosphate through rainfall and land drainage.

Phosphate concentrations at the inshore station did not show a clear seasonal cycle. Although some features could be seasonally related to biological activity, there was no correlation to biomass (chlorophyll a) or to rate of production (Table 6). Overall, the seasonal distribution of phosphate was "episodic", with several high peaks of phosphate occurring at depths of 10-15 m. This is probably a consequence of periodic sub-surface pollution from the Sharm-Obhur area.

Offshore, the seasonal cycle is clearer, with a single peak in phosphate occurring in April. This was possibly a consequence of breakdown and remineralisation of phosphorus after the peak in primary production. Overall there was a significant negative correlation between phosphate and biomass (chlorophyll a) and production (Table 7).

Silicate values recorded during the present study are comparable with those reported earlier from the Red Sea area (Klinker et al. 1978, Hansen et al. 1968, Grasshoff 1969, Sournia 1977. See Table 9). When compared to the Bay of Bengal, Baltic waters and the Black Sea, which receive large quantities of freshwater, silicate concentrations in the Red Sea are quite low. These low concentrations can be attributed to lack of freshwater input. Besides freshwater inputs, replenishment of silicates takes place through regeneration from diatom frustules (Hart 1934, Cooper 1952, Harvey 1955) and

liberation of this nutrient from bottom muds (Hendey 1951).

In estuaries and coastal waters where there is considerable admixture of freshwater, low salinity together with high silicate values are used as indicators of incursion of freshwater (Nash 1947). In landlocked basins and fjords, because of slow dissolution of diatom shells, Grasshoff (1975) reasoned that silicates would behave in a conservative manner and therefore could be used in the identification of water masses. Grasshoff (1975), based on a silicate-salinity diagram, identified four water masses in the Red Sea. They are:

- A. 35.1‰ S, 29 $\mu\text{g-at Si l}^{-1}$,
- B. 36.8‰ S, 0 $\mu\text{g-at Si l}^{-1}$,
- C. 40.6‰ S, 3 $\mu\text{g-at Si l}^{-1}$,
- D. 38.16‰ S, 14.5 $\mu\text{g-at Si l}^{-1}$.

From the present data a silicate-salinity diagram was constructed (Figure 25), from which three main water masses can be identified as follows:

- I is the surface water of the Sharm, relatively rich in silicates (3-7.4 $\mu\text{g-at Si l}^{-1}$) and salinities (39-39.7‰),
- II is the Red Sea water with intermediate values of silicates (0.5-5 $\mu\text{g-at Si l}^{-1}$) and salinities from 39.8-40.5‰, and
- III is Bab-el-Mandeb water with low silicates (1-3 $\mu\text{g-at Si l}^{-1}$) and lower salinities (38.4-39.7‰).

Although the range of silicates in the present study is comparable to that observed by Grasshoff, the present salinity

values range from 38.4 to 40.5, whereas those of Grasshoff ranged from 31.5 to 40.6. For this reason, the water masses I, II and III do not readily correspond to water masses A, B, C, and D identified by Grasshoff. Water masses II and III could correspond to water masses C and D identified by Grasshoff. Water mass C originates from the Red Sea and D is the Red Sea water after it has cascaded down into the Gulf of Aden (Grasshoff 1975).

Nitrite values during the present study are comparable to those reported earlier from the Red Sea (Deuser et al. 1978, Hansen et al. 1968, Grasshoff 1969) (see Table 10). When compared to the N.E. Arabian Sea (Radhakrishna et al. 1978) or the Straits of Bab-el-Mandeb (Grasshoff 1969), the present values were low. Levanon-Spanier et al. (1979), and Sournia (1977), who also encountered low nitrite values in the same geographical area, are of the opinion that nitrogen (NO_2 , NO_3 - N) is the major nutrient limiting primary producing in the Red Sea. This hypothesis of nitrogen limitation is widely held for other ocean areas.

It is necessary to point out that during this study, nitrates could not be determined and therefore we have to rely on the findings of Deuser et al. (1978) who furnished evidence for denitrification in adjacent geographical regions, i.e. the Persian Gulf and the Gulf of Oman. It is assumed that some denitrification also takes place in the study area, which leads to reduction of nitrate to nitrite. This in turn may result in a lower level of primary production, except in the blue-green algae which can fix atmospheric nitrogen.

In the offshore waters, two maxima of nitrite concentrations were observed; one of these was usually in the surface waters, i.e. euphotic layer, and the second maximum was in the deep layer ~200 m, i.e. below the euphotic zone. In this respect, these findings are similar to those of Gilson (1937) who reported two nitrite maxima. The offshore waters have more nitrite than nearshore waters. This could be either due to excretion of extracellular nitrite by phytoplankton as suggested by Vaccaro and Ryther (1960), or due to bacterial nitrification, or both. Grasshoff (1969) contends that the high nitrite values at the entrance to the Red Sea, where turbulent mixing takes place, are due to excretion by phytoplankton.

Maximum ammonia values observed during this study are comparable to those reported by Grasshoff (1969) from the Red Sea (Table 11). They are quite high when compared with values from the Gotland Deep and Oslo Fjord (Grasshoff 1975).

In the nitrogen cycle, the first step in the nitrification process is the formation of ammonia by bacterial decay of dead organic matter, excretion of ammonia by animals and photochemical oxidation of organic matter by solar ultra-violet radiation. Although some nitrogen is also contributed by river water and rain water, Morcos (1970) rules out such a possibility in the Red Sea. Some nitrogen is fixed by the blue-green alga Trichodesmium, but there are no estimates on rates for the Red Sea region. Ammonia is oxidized to nitrite and finally to nitrate. Thus Harvey (1955) demonstrated a succession in the production of ammonia, nitrite and nitrate

nitrogen peaks in the sea water. Comparison of ammonia values (Figure 23) with nitrites (Figure 21) shows that in the inshore Sharm waters there was no clear succession of ammonia and nitrite peaks. However, in the offshore waters (Figures 24 and 22), there was a succession of peak values of ammonia and nitrite. Domains of high values of ammonia were observed at 100-200 m during February-April and high values of nitrites occurred during April-May.

The silicate to phosphate ratio in temperate waters is generally around 20:1, (Sverdrup et al. 1942). During this study, the ratio varied between <5 and >20 in the Sharm waters (Figure 26) and from <5 to >40 in the offshore waters (Figure 27). Comparison of these figures shows that in the inshore region, ratios were low, increased with depth and gradually increased during January and June. In the offshore waters, the ratios were higher decreased with depth and gradually increased from March until August. Such anomalies could be attributed to several factors, among them:

1. differential requirements for these two nutrients by phytoplankton groups in the water (Redfield 1934), and
 2. differences in the rate of re-solution of either nutrient.
- It is possible that in the inshore Sharm waters, re-solution of phosphate from phosphorite phosphates in the bottom sediments takes place as considered by Grasshoff 1969; this would explain the lower silicate:phosphorus ratios inshore.

A balance sheet for nutrient salts in the Red Sea is given by Morcos (1970), which shows that annually 153×10^6 tons of

phosphate, 1275×10^3 tons of nitrate and 1120×10^3 tons of silicates are lost through the outflow from the Red Sea. As discussed by Morcos, balancing the budget by contribution of nutrients from rivers as in the Mediterranean Sea, is not possible in the Red Sea. The suggestion of Hassan (1962), that irrigation water from land after being used may be diverted into the Red Sea, with a view to reduce the loss of nutrients, merits consideration.

Phytoplankton Ecology

One of the main objectives of this study was to investigate the factors that govern phytoplankton ecology and primary production in the study area, which is unique due to its semi-arid nature and monsoonal currents. As the magnitude of production is dependent on the abundance of phytoplankton biomass, it will be necessary to examine the factors that account for the distribution and seasonal succession of phytoplankton.

Earlier it was stated that certain groups of phytoplankton organisms were common to inshore and offshore waters, or to the major and minor blooms of phytoplankton. Restriction of a few species to either of the seasonal blooms was also mentioned. A biogeographical consideration of the phytoplankton species should give an insight into the origin and source of recruitment of phytoplankton in the area of study. It is proposed first to consider the biogeography of the phytoplankton of the study area and then to discuss the succession and quantitative abundance of phytoplankton. This will be followed by a discussion of physico-chemical factors that control the magnitude of primary production.

1. Biogeography of Phytoplankton

For the present purposes, the approach of Smayda (1958), Hasle (1976) and Guillard and Kilham (1977) was followed, which is based on physical features such as temperature and water movements. A phyto-geographical consideration of species associations such as that of Thorrington-Smith (1971) would be more revealing; however, this cannot yet be attempted for want of sufficient data on the distribution of each species.

In the present study, a total of 283 taxa of phytoplankton were recognised; this included 249 species or monospecific genera and a further 34 recognisable, but not fully identified, taxa. Included in the total were 110 recognised species, or monospecific genera, and a further 13 taxa of dino-flagellates. Halim (1969), in his review, lists only 88 dinoflagellate species from the Red Sea. The present study has added a total of 87 species of diatoms and dinoflagellates to the taxonomic list of phytoplankton in the Red Sea (Appendix 7).

The phytoplankton populations in this area can be compared with those of Thorrington-Smith (1971), who carried out a numerical investigation of phytohydrographic regions in the West Indian Ocean. Thorrington-Smith, based on a cluster analysis of the 237 species, recognised 11 different floral elements. The species encountered during the present study conform to these floral groups as follows:

1. Southwest monsoon floral element

Gossleriella tropica

Rhizosolenia styliformis

Rhizosolenia alata

Schroderella delicatula

Chaetoceros affinis

^w
Ginardia flaccida

2. Equatorial sub-surface based floral element

Bacteriastrum hyalinum

Rhizosolenia hebetata

Chaetoceros affinis

Rhizosolenia alata

Planktoniella sol

Dactyliosolen mediterraneus

Chaetoceros peruvianum

Thalassionema nitzschioides

Nitzschia closterium

Chaetoceros danicus

Chaetoceros atlanticus

Nitzschia seriata

3. Predominantly pre-southwest monsoon floral element

Thalassiothrix fraunfeldii

Rhizosolenia calcar-avis

Chaetoceros messanensis

4. Floral elements from fluctuating conditions
Chaetoceros affinis
Dactyliosolen mediterraneus
5. Equatorial undercurrent floral element, April-May
Podolampas spinifera
Ceratium teres
Rhizosolenia hebetata
Thalassiothrix longissima
Hemiaulus hauckii
Oxytoxum scolopax
6. Floral element with distribution centered on 5°S
Prorocentrum gracile
Ceratium tripos
Chaetoceros decipiens
7. Floral element 7
No representatives from the study area
8. Floral element 8
Fragilaria oceanica
Rhizosolenia imbricata
Rhizosolenia bergonii
Ceratium furca

9. Floral element from southern side of the equatorial undercurrent in April-May

Ceratium vultur

Peridinium trochoideum

10. Floral element from regions of fluctuating conditions

Ceratium extensum

Rhizosolenia alata

Thalassiothrix mediterranea

Chaetoceros atlanticus

Climacodium fraunfeldianum

Ceratium fusus

Ceratium declinatum

Ceratium pentagonum

Ceratium tripos

Chaetoceros laciniosus

Chaetoceros dadayi

Rhizosolenia Stolterfothii

Ceratium Kofoidii

Ceratium trichoceros

Chaetoceros affinis

Leptocylindrus danicus

Ceratium carriense

11. South-Equatorial current-based floral element

Asterionella japonica

Ceratium extensum

Rhizosolenia alata

Thalassiothrix mediterranea

Chaetoceros tetrastichon

Chaetoceros atlanticus

Climacodium fraunfeldianum

A comparison of the distribution of phytoplankton during this study with that of Halim (1969) shows certain common features as follows:

1. Commonly abundant in the Red Sea

Hemidiscus cuneiformis

Striatella delicatula

Rhizosolenia calcar-avis

Rhizosolenia Shrubsolei

Rhizosolenia alata

Guinardia flaccida

Thalassionema nitzschioides

Bacillaria paradoxa

2. Diatoms found only to the south of 20°N

Chaetoceros tetrastichon

Streptotheca thamesis

Striatella delicatula

Thalassiothrix longissima

3. Mediterranean component

Ceratium massiliense

Peridinium trochoideum

4. Indo-Pacific component
Ceratium egyptiacum
5. Strictly tropical but absent from Mediterranean
Ceratium breve
Ceratium reflexum
Ceratium vultur

In addition to the two species listed as Mediterranean components, a comparison of the present study with that of Guillard and Kilham (1977) shows the following Mediterranean species in the study area:

Thalassiothrix fraunfeldii
Nitzschia seriata
Nitzschia delicatissima
Rhizosolenia calcar-avis
Chaetoceros decipiens
Asterionella japonica
Chaetoceros affinis
Chaetoceros decipiens
Ceratualina bergonii
Dactyliosolen mediterraneus
Rhizosolenia Stolterfothii
Thalassionema nitzschioides
Leptocylindrus danicus
Thalassiosira subtilis
Ceratium breve

Ceratium contortum

To the Indo-Pacific group listed by Halim (1969), occurrence of the diatom Biddulphia pelagica should be added. A few species from the Adriatic Sea (see Guillard and Kilham 1977) were also found in the Red Sea, for example Bacteriastrum hyalinum, Chaetoceros curvisetum, and Thalassiosira decipiens.

During the present study, the following species considered as tropical (Smayda 1958, Sukhanov 1969) were also present:

Planktoniella sol

Gossleriella tropica

Similarly, species listed as cosmopolitan were also present:

Chaetoceros compressus

Leptocylindrus danicus

Prorocentrum micans

Thalassiothrix fraunfeldii

Nitzshia seriata

Nitzschia delicatissima

A few species recorded from the estuarine Nile plankton (Halim 1976b) were also recorded during this study. These include:

Nitzschia longissima

Chaetoceros affinis

Thalassionema nitzschioides

Asterionella japonica

Peridinium trochoideum

Thus, in the study area a wide variety of phytoplankton groups, each ^{characteristic of} ~~originating from~~ a different water mass, were present. For example, from the tropical Indian Ocean, phytoplankters from equatorial sub-surface waters, the equatorial under current boundary, the south equatorial current and sub-surface tropical waters were present. In addition to the flora ^{characteristic of} ~~restricted to~~ the Red Sea, flora from the adjacent water bodies were also present as evident from the Mediterranean, Adriatic and Nile floral components. Periodic recruitment and exchange of phytoplankton in and out of the Red Sea could account for such a diversity of phytoplankton groups.

An examination of Appendix 5 shows that during the south-west monsoon season, i.e. June-August, the offshore waters have several phytoplankters listed above as Mediterranean and estuarine Nile components. It is possible that due to the southerly flow of the Red Sea waters and incursion of waters from the Mediterranean and Gulf of Suez, a recruitment of Mediterranean and Nile estuarine phytoplankton takes place at this time, which bloom under favourable hydrographic conditions.

During the northeast monsoon, December to June, with the peak activity during January-February, offshore oceanic waters from the Indian Ocean enter the Red Sea. Examination of Appendix 5 shows the presence of the equatorial sub-surface floral element, south-equatorial current based floral element and Indo-Pacific component. It is likely that these floral elements are brought into the Red Sea along with the offshore oceanic waters.

In view of the paucity of data on qualitative and quantitative seasonal abundance of phytoplankton from other areas in the Red Sea, it is not yet possible to establish any phytoplankton as indicators of different water masses. The significance of such studies is recognised and the need to carry out extensive surveys is pointed out here.

2. Phytoplankton Succession

In general in the Red Sea area, winter populations are dominated by diatoms, and summer populations have representatives of diatoms, dinoflagellates and cyanophytes (Table 12). During the northeast monsoon season (December-June) there was no succession of diatom and dinoflagellate peaks at either the inshore or offshore station; however blue-green algae became dominant or co-dominant at both stations in May and June. During the southwest monsoon season (July-November) there was a succession of dominance from diatoms to dinoflagellates and back to diatoms at both stations.

Such a seasonal pattern of succession in the major algal groups and their component species is often observed not only in temperate waters, but also in tropical and polar seas (Lebour 1917, Raymont 1963). The precise sequence of factors responsible for this ecological succession is still not clear, although the variables probably involved are apparent.

Off the Madras coast, where environmental conditions are rather stable, no succession of blooms of diatoms and

dinoflagellates was found. In the Egyptian Mediterranean delta, which experiences natural environmental perturbations, a succession was reported by Aleem and Dowidar (1967).

3. Factors influencing Phytoplankton Production

Because of several unique features of the Red Sea, i.e.: semi-enclosed body of water, location in an arid zone with little run-off from land, and seasonal reversal of the monsoon effect, it might be expected that factors governing phytoplankton production could be different from those in temperate seas. Although ambient nutrient levels in the study area were often low, photosynthetic production was high over the whole year. It is reasonable to assume that light was never a limiting factor especially since some of the highest rates of production coincided with the lowest seasonal levels of solar radiation. The bimodal pattern of production at the offshore station is very reminiscent of the "typical" pattern in temperate seas, with the exception of the earlier commencement of the first "spring" bloom. The unimodal (or possibly trimodal?) sequence of seasonal production at the inshore station is rather similar to that of Narragansett Bay (described by Smayda 1957). Pratt (1965) and Martin (1965) analysed the temporal relationships between phytoplankton and zooplankton in Narragansett Bay, and convincingly argued that the decline of the autumnal zooplankton population, and consequent release from grazing pressure, allowed the winter blooming of phytoplankton to occur. Unfortunately,

no zooplankton data is yet available for the present study area, but the trophic interactions^c of phyto-and zooplankton seem to be a logical step for future study. The spring blooming in temperate waters is usually ascribed to a reduction in depth of the upper mixed layer, and development of the seasonal thermocline (Sverdrup 1953). There is no such convincing relationship at the Sharm station. At the offshore station, the February peak of production does correspond to the onset of seasonal stratification. However, the second peak of production here corresponds to the height of seasonal stratification (June-July). This does not correspond to the typical pattern in temperate waters where the autumnal bloom usually coincides with partial disruption of the density discontinuity layer.

This thesis represents the first work of its kind to be carried out in the study area. From the data collected here, no comprehensive explanation of the seasonal patterns of production observed can be advanced. It is worthwhile, however, to consider further some of the correlations obtained.

Reference to Tables 6 and 7 shows the correlation matrix for the inshore Sharm station and offshore waters respectively. In the inshore waters the correlations between depth and cell numbers and depth and C^{14} uptake were negative. Similarly in the offshore waters, the correlations between depth and all biological variables were negative, this is consistent with the general pattern observed by several researchers. With an increase in depth, the light energy available for phytoplankton decreases exponentially (Sverdrup et al. 1942)

and limits phytoplankton growth and production.

In the inshore waters, the correlation between temperature and species diversity index was negative and significant, whereas in the offshore waters the correlation between temperature and all biological variables were positive and significant. In the offshore waters, with an increase in temperature there is an increase in phytoplankton growth which is very difficult to explain. Comparison of inshore and offshore temperature structures (Figures 6 and 7) shows no marked differences in their pattern, yet the winter-spring peak of production offshore was delayed by about two months (Figure 42) and annual production was higher than inshore. It appears that in the offshore waters there must be some factor other than increased temperature which stimulates phytoplankton growth. Alternatively, some factor at the inshore station inhibits production during June to August.

Nutrients such as phosphate, silicate and nitrogen compounds are essential for the growth of the phytoplankton. Due to assimilation during periods of active growth, the nutrients will be depleted and a negative correlation results between nutrients and phytoplankton (Atkins 1923, Harvey et al. 1935, etc.) Such a correlation was not obvious in the inshore Sharm waters. Only in the offshore waters were negative correlations at a significant level noticed between phosphate and chlorophyll a, chlorophyll b, C^{14} uptake and assimilation ratio, also between nitrite and species diversity index and between ammonia and C^{14} uptake.

Again, the reasons for these differences in relationship between nutrients and biomass or production at the two stations is difficult to explain and requires further investigation. The salient differences between the two stations are clearly: the later timing of the winter-spring bloom offshore, and the lack of a late summer-early autumn bloom at the inshore station.

Comparison of inorganic phosphates (Figures 17, 18) with annual primary production (Figure 42) shows that domes of high phosphate values occurred first, followed by an increase in primary production. Thus, nutrient domes at the Sharm station were observed during October, February, May and July, and the primary production increases were during November, April, June and October respectively. In the offshore waters, also, such a time lag between the formation of nutrient domes and phytoplankton production can be seen. High phosphate levels were noticed during December-January and during April, while production was high during January-February and July-August.

A similar time lag was noticed between other nutrients, such as silicates, nitrites and ammonia, and phytoplankton production in this area. Unfortunately, data on the most important inorganic nutrient - nitrate, is lacking here.

There is evidence to show that, for tropical phytoplankton at least, the rate of nutrient regeneration is more critical than the instantaneous nutrient concentrations. Both the rate of consumption of phosphate (Volkovinskiyi, 1974) and its rate of regeneration (Maksimova, 1972) are faster in tropical

than in temperate waters.

Marine phytoplankton is widely regarded as nitrogen limited, with both NH_3 and NO_3 as significant sources. Recently, Harrison (1980) has provided a review of nutrient regeneration, contrasting the contributions of bacterial regeneration of NO_3 and zooplankton regeneration of NH_3 . It seems clear that we shall not be able to fully understand seasonal cycles of primary production until attention focuses more heavily on nutrient kinetics. Thus, simultaneous information on: the seasonal dynamics of zooplankton grazing and excretion of NH_3 , bacterial regeneration of NO_3 , and advective-diffusive processes is required (Harrison, 1980).

Amongst the biological variables, correlations between assimilation number and species diversity index, chlorophyll a and chlorophyll b were negative and significant in the inshore Sharm waters. In the offshore waters the correlation between assimilation number and species diversity index was also negative and significant, similar to that of the inshore waters. Such a negative significant correlation between assimilation index and species diversity index supports the principle of Margalef (1978) that increasing species diversity index is associated with a decrease in production per unit biomass (= assimilation number). This is equivalent in fact to an increase in maturity of the plankton community. This negative correlation may also indicate the significance of detrital biomass to this ecosystem as proposed by Platt and Subha Rao (1970).

Other biological variables, such as cell numbers and species diversity index, chlorophyll a, chlorophyll b, and C^{14} uptake, were positively correlated at a significant level and are self-consistent.

It should be remembered that the nanoplankton have not been enumerated during this study. Although their contribution to biomass and total chlorophyll a values may be small, they may account for over 50% of annual production (Malone 1980). Thus even though cell numbers of blue-greens, diatoms and dinoflagellates may be low, primary production rates may still be high if nanoplankton are abundant.

4. Magnitude of Phytoplankton Biomass and Cell Densities

Phytoplankton biomass determined as cell numbers and chlorophyll a showed great variations during the study period. The inshore waters of Sharm had higher cell numbers than the offshore waters. This is consistent with the general pattern of abundance of phytoplankton, as, for example, in the coastal waters and shallow ponds in the Cape Hatteras to Nantucket area (Smayda 1973). Table 13 shows that the cell numbers in the study area compare favourably with those reported from some adjacent waters such as the Suez Canal (Dowidar 1976), and some temperate waters like Aomori Bay (Kokubo 1932), Georges' Bank (Riley 1941), Block Island Sound (Riley 1952), and regions off Cape Cod and off Bermuda (Smayda 1973). However, in some of the waters adjacent to the Red Sea, such as the Gulf of Aden (Savich 1969),

Egyptian Mediterranean (Halim et al. 1976a), (Aleem and Dowidar 1967), and the Arabian Sea (Kuzmenko 1977), cell densities are decidedly higher.

Phytoplankton biomass in terms of chlorophyll a also showed a wide range with generally higher values in the inshore Sharm waters. Table 14 shows that the magnitude of chlorophyll a was comparable to that observed in the N.E. Arabian Sea (Radhakrishna et al. 1978). In the adjacent waters such as the Red Sea (McGill and Lawson 1966 and Gulf of Elat (Sournia 1977 and Levanon-Spanier et al. 1979) chlorophyll a values were lower than those reported in this study. A comparison with those values from the inshore waters on the west coast of India (Dehadri and Bhargava 1972; Bhargava and Dwivedi 1976) or with temperate waters (Henry et al. 1977), Peruvian waters (Koblentz-Mishke and Semenova 1977), Southern North Sea (Gieskes and Kraay 1977), St. Margaret's Bay (Platt and Subba Rao 1970) and Chesapeake Bay (Loftus et al. 1972) shows that the chlorophyll a values are lower in the study area (Table 14).

5. Magnitude of Primary Production

Primary production in the study area showed higher values in offshore waters than in the inshore Sharm waters. This is valid either on a volumetric basis ($\text{mg C m}^{-3} \text{ hr}^{-1}$) or on an areal basis ($\text{mg C m}^{-2} \text{ hr}^{-1}$). The values measured in the study area are higher than most of the values given in Table 15. Thus, the values in the Red Sea (Yentsch and Wood 1960),

Gulf of Elat (Sournia 1977; Levanon-Spanier et al. 1979), North Arabian Sea (Kuzmenko 1973), Goa Estuary (Bhattathiri et al. 1976), North Eastern Arabian Sea (Radhakriska et al. 1978), Cochin backwaters (Qasim et al. 1969) are lower when compared to those reported in the present study. The present values are also higher than those from some temperate waters such as the Beaufort Channel (Williams and Murdoch 1966), and Chesapeake Bay (Flemer 1970), (Table 15).

Carbon assimilation ratios in the offshore waters are higher than inshore. Table 16 shows that a high range of values was observed in the study area. The values are higher than those for the Gulf of Elat (Levanon-Spanier et al. 1979), Red Sea (Yentsch and Wood 1960; Khemeleva 1970), inshore waters of the Arabian Sea (Radhakrishna 1969), Cochin backwaters (Qasim et al. 1969), Caribbean Sea (Malone 1971), Gulf of Thailand (Subba Rao 1965), Indian Ocean (Saijo and Takesue 1965) and Gulf of Panama (Smayda 1965). In its efficiency, phytoplankton in the study area is comparable to the Fladen Ground (Steele and Baird 1961) and to the Woods Hole area (Yentsch 1965) as evident by the high assimilation numbers. Overall, the high carbon assimilation ratios from the present study suggest a high efficiency of photosynthesis characteristic of "sun-adapted" phytoplankton.

In the surface waters of the Red Sea a north to south increase in the chlorophyll a was reported by Khemeleva (1970). In the north the concentration was 0.14 mg m^{-3} , 0.24 in the central region and 0.40 in the south. A similar north to south gradient in the photosynthetic rate was also observed

by Khemeleva (1970). Thus it was $0.31 \text{ mgC m}^{-3} \text{ hr}^{-1}$ in the north, 0.71 in the central region and 3.42 in the southern waters. The corresponding assimilation numbers were 3.91, 4.14 and $7.01 \text{ mgC mg Chl a}^{-1} \text{ hr}^{-1}$ which suggest a southward increase in the photosynthetic efficiency in the Red Sea.

6. Duration, Range and Amplitude of Primary Production

In addition to the assimilation numbers already discussed, the functioning of any ecosystem in time can be judged by a comparison of the duration, range and amplitude of primary production following Cushing's (1975) method.

Cushing (1975) described the production cycle as a bell-shaped curve, symmetrical at its peak, so that the magnitude can be described as the amplitude. The duration is the time interval between initial and terminal phases. It should be pointed out that comparison of amplitudes of phytoplankton cycles based on primary production measurements should be preferred to that based on biomass measurements, if one is interested in the functioning of the system. It is well known that several abiotic factors such as Langmuir convection cells (Loftus et al. 1975), convergence of water masses (Pomeroy et al. 1956), differential motion of surface and bottom waters (Tyler and Seliger 1978), vertical advection (Winters et al. 1975) and tidal front formation (Pingree et al. 1975), and biotic factors such as positive phototaxis and diurnal migration (Selinger et al. 1970, 1971) generate a patchyspatial and temporal distribution of phytoplankton.

Under such conditions, precise determination of the amplitude and duration of a growth cycle will require sampling at frequent intervals. To resolve any discrepancies in the amplitude determinations based on biomass, in the present study, primary production measurements were used. It should be also added that production measurements integrated under a unit surface area are used in preference to individual volumetric rates ($\text{mg C m}^{-3} \text{ hr}^{-1}$) as the former seem to fall in a limited range.

The duration of production (Table 17) is 8 weeks in the inshore and offshore waters, but the amplitude in the inshore was 2.6 whereas it was 4.8 for the offshore waters. Observations from the Gulf of Elat (Levanon-Spanier et al. 1979) are comparable to the present study.

In the Gulf of Elat, the duration was 8 weeks and the amplitude was 5.7. With respect to the amplitude and the range of production, the present observations are similar to those from Lake Edku (Samman 1974) and Cochin backwaters (Qasim et al. 1969). The magnitude and amplitude of production in the study area compare favourably with some of the highly productive waters such as the Peruvian upwelling area (Beers et al. 1971), coastal tropical Pacific (Sorokin 1973) and west coast of India (Radhakrishna 1969).

7. Annual Phytoplankton Cycle and Production Estimates for the Red Sea.

In the study area the annual phytoplankton cycle follows a bimodal pattern with a major peak between December and

February, and a minor one between August and October. Although this is similar to the bimodal production cycle reported from temperate waters (see Cushing 1975), there appears to be a difference in the time of occurrence of the peaks. Even within the study area, there is a time lag between the inshore and offshore waters.

Table 18 shows that in the Red Sea, a bi- or tri-modal distribution pattern seems to be the rule, with regional differences in the occurrence of the peaks. While discussing the physiogeography and circulation pattern, it was pointed out that the northeast monsoon is active during December-February and the southwest monsoon during June-August. The two peaks of phytoplankton production offshore coincide with the activity of the monsoons. Several authors (Humphrey 1972; Subba Rao 1974; Halim 1969; Cushing 1971; Qasim et al. 1978) have elaborated on the dependence of the primary production cycle on the monsoonal activity in the Indian Ocean. Although the production cycle in the study area follows a bimodal pattern (clearly at least at the offshore station), and related possibly to the two monsoon events, nevertheless unlike other areas, i.e. the Bay of Bengal and the west coast of India, neither of the peaks in the Red Sea results from enormous land run-off.

The mean production for the Sharm station is calculated at $82.46 \text{ mg C m}^{-2} \text{ hr}^{-1}$, and for the offshore station $96.30 \text{ mg C m}^{-2} \text{ hr}^{-1}$. These production rates are about the same as for 'young' surface water and newly upwelled productive waters

(Steeman Nielsen 1963). Assuming 12 hours sunshine per day average, corresponding annual production rates are $361 \text{ gC m}^{-2} \text{ yr}^{-1}$ for inshore Sharm waters, and $422 \text{ gC m}^{-2} \text{ yr}^{-1}$ for offshore waters. These rates are rather high and favourably compare with the 44 - 423 ($207 \text{ gC m}^{-2} \text{ yr}^{-1}$ average) calculated from Humphrey (1972) or the $>180 \text{ gC m}^{-2} \text{ yr}^{-1}$ (second group) given by Cushing (1971). An average value of $392 \text{ gC m}^{-2} \text{ yr}^{-1}$ for this study area shows that production is comparable with that of upwelling zones ($300 \text{ gC m}^{-2} \text{ yr}^{-1}$) generalised by Ryther (1969). In this respect, it is interesting to have recorded these high values despite the absence of demonstrable upwelling related to monsoon reversal.

Since the observations on primary production in the Red Sea are very few, and may not be representative of the various regions, any calculations on the total annual areal production of the Red Sea will be subject to revision. However, from the present data the upper and lower limits of primary production can possibly be established. Caution is warranted for upper values in view of the probable pollution influence in the Jiddah area which will stimulate primary production.

Assuming a mean annual production of 392 gC m^{-2} and an area of 438,000 sq. km., the total annual production for the whole Red Sea will be:

$$392 \times 438,000 \times 10^6 = 171.7 \times 10^6 \text{ tons C yr}^{-1}$$

If the mean production is assumed as 196 gC m^{-2} (50% of the above calculated 392 gC m^{-2}) then the total annual production for the Red Sea will be $85.8 \times 10^6 \text{ tons C yr}^{-1}$, and this may

be considered as a lower limit of primary production.

From these upper (171.7×10^6 tons C yr^{-1}) and lower (85.8×10^6 tons C yr^{-1}) estimates it is interesting to speculate on the effect of photosynthetic production, and its possible relation to local fisheries. In calculating the tertiary production from the primary production, several approximations and assumptions have been made based on the procedures of Cushing (1971) as follows:

- (i) The estimate of carbon production has already been raised by a factor of 1.45 to correct for losses (Nielsen 1964; Goldman 1968), in data supplied by the International Agency for C^{14} Determination.
- (ii) From primary to secondary production an ecological transfer coefficient of 7.23% is used (a lower estimate from the Arabian Sea from Cushing 1971). There is little information on efficiency of energy transfer between secondary and tertiary levels, but a nominal figure of 10% is used here. Therefore, tertiary production is given by:

$$171.7 \times 10^6 \times 0.0723 \times 0.1 = 124.14 \times 10^4 \text{ tons C yr}^{-1}$$

- (iii) To convert this figure to wet weight of fish the conversion factor of carbon/wet weight (13.5%) is used (see Cushing 1971; Vinogradov 1953). Therefore the upper estimate of fish production is given by:

$$124.14 \times \frac{100}{13.5} \times 10^4 = 9.19 \times 10^6 \text{ tons wet wt yr}^{-1}$$

- (iv) A lower estimate of fish production will be half this figure viz: 4.59×10^6 tons wet wt yr^{-1} .

Cushing's (1971) estimate of potential fish production for the Arabian Sea with an area of 131,000 sq. km. is 2.50×10^6 tons wet wt yr^{-1} . This compares very favourably with the present estimates on an areal basis. However, the current fish landings from the area are about 0.53×10^6 tons annually (FAO 1978) which is low compared to the above estimates.

In calculating the tertiary production from primary production, and equating this to potential fisheries yield several approximations are made. The composition of the third trophic level is not completely known. It includes predatory copepods and other planktonic predators as well as clupeid fishes. However, as treated by Cushing (1971) these animals (with the exception of plankton eating fish and molluscs) are included in the secondary trophic level.

It must be remembered that the contribution of seaweeds and corals to overall production is not included in these calculations. Contributions from both these sources could be significant as indicated in recent reviews by Michanek (1975) and Muscatine (1980). Production by the extensive coral reefs of the Red Sea (Fishelson 1973a, 1973b) especially could be a significant contribution. Thus the fishery potential of the area would seem to be high and worthy of closer review.

SUMMARY AND CONCLUSIONS

During the present study observations were carried out on a regular basis at two stations; an inshore (Sharm) station that receives pollutants, and an offshore station that is relatively unpolluted.

Due to the influence of the southwest monsoon, during November-February surface water gets cooled and mixes downwards while during the northeast monsoon, surface water gets warmed up and this leads to some stratification.

Evaporation in excess of dilution results in high salinity of the waters in this region. Density inversions were also observed in the inshore waters. In the offshore, three density layers could be recognised (a) an uppermost layer with density values between 25.00 and 26.50 extending down to the 50 m level; (b) an intermediate sub-surface layer with values from 26.50 to 27.50 extending down to 100 m depth, and (c) a bottom layer with densities between 27.00 and 28.50 extending below 100 m. Formation of these three density layers followed a seasonal pattern.

Transparency of the offshore waters, judged by Secchi disc readings, was almost twice that of the inshore station. The higher turbidity of the Sharm waters is attributed to the biogenic material of terrigenous origin.

From data on the oxygen concentration and oxygen saturation values it is generalised that near surface waters are often saturated but rarely super-saturated. Prevailing high temperatures, high salinity, little freshwater input, biological oxygen demand and density stratification seem to account for any under saturation of oxygen.

In the inshore waters domes of high phosphate values were observed during May-June, and September-November, while in the offshore waters such domes were present during February to April. Domes of high silicate values were observed during June-July in inshore waters and during April and August offshore. Due to lack of inflows of silicate-rich freshwater, silicates were in general impoverished in this region.

Nitrite nitrogen was in greater abundance offshore than in the Sharm waters, where there was occasional total depletion of this nutrient. In the inshore waters, domes of high nitrite values were observed during September and November, while in the offshore waters they were observed during April-May and September. Ammonia concentration reached higher levels at the offshore station, but both stations showed some seasonal variation.

In general, with increase in depth there was an increase in nutrients which could be either due to lower utilisation of these nutrients below the euphotic zone, or due to rapid regeneration.

Nutrient levels in the study area are in agreement with those reported in the Gulf Region but are generally low when compared to other seas that receive large quantities

of freshwater. This results in various anomalies of silicate-phosphate ratios and certain interesting salinity-silicate relationships in the Red Sea.

Based on the salinity-silicate ratios three water masses:
I surface water ($3-7.4 \mu\text{g -at Si l}^{-1}$; $39-39.50\text{S}^\circ/\text{oo}$);
II Red Sea water ($0.5-5 \mu\text{g -at Si l}^{-1}$; $40-40.5 \text{S}^\circ/\text{oo}$);
III Bab el-Mandeb water ($1-3 \mu\text{g -at Si l}^{-1}$; $38.5-39.5 \text{S}^\circ/\text{oo}$)
were recognised.

The phytoplankton cycle followed a bimodal peak distribution with a primary peak during January and a secondary peak during summer; in the inshore waters this was during May while in the offshore it was during July. There were several similarities between the nearshore and offshore waters in respect of phytoplankton abundance:

During the major peak 49 species were common to these two stations; 36 species were common to the minor bloom; 23 species commonly bloomed in these two regions during major and minor peaks. However, 29 species were restricted to the major peak and 17 species to the minor peak.

Both stations were dominated by diatoms during the northeast monsoon season, and no successional patterns were evident. A succession from diatom to blue-green to dino-flagellate dominance was recorded at both stations from April to October. Although blue-greens were most dominant during May and June, they were present offshore until September.

A biogeographical consideration of the phytoplankton observed during the study showed the presence of several floral elements: (1) southwest floral element (2) equatorial

sub-surface element (3) pre-southwest monsoon element (4) equatorial undercurrent element (5) south-equatorial floral element and floral elements from fluctuating conditions. The phytoplankters based on their abundance can be recognised as a Red Sea component, a Mediterranean component, an Indo-Pacific component, a Nile estuarine component and a tropical component, which suggests that periodic recruitment and exchange of phytoplankton takes place in the study area.

The distribution pattern of chlorophyll a resembled that of numerical abundance of phytoplankton. Inshore waters had one subsurface chlorophyll maximum while the offshore waters had two subsurface maxima. When compared to temperate waters chlorophyll a values in the study area were low, but agreed well with those previously reported from the Red Sea region.

The annual primary production cycle followed a bimodal pattern with a time-lag of 2 months (earlier) between the inshore and offshore waters. Production in the offshore waters was higher than that in the Sharm waters. The magnitude of production in the study area was higher than several temperate and tropical waters.

A high range of carbon assimilation ratios was recorded both in the inshore and offshore regions; values were generally higher in the latter. In both regions, efficient functioning of photosynthesis began at subsurface levels (~25 m) and ascended to the surface. The carbon assimilation ratios in the study area were comparable with those in the adjacent seas or from the temperate waters.

The duration of a production cycle was about 8 weeks both

in the inshore and offshore waters; the amplitude of production was 2.6 and 4.8 in the inshore and offshore respectively. The duration and amplitude of production compare favourably with some of the highly productive temperate and tropical seas. The production cycle appears to be triggered by the activity of the monsoons in this region. The earlier blooming of phytoplankton in the inshore Sharm waters could be due to the availability of some growth triggering agents, such as humic substances.

Assuming an annual production of 392 gC m^{-2} for the whole Red Sea area (438,000 sq. km), the total annual photosynthetic production was calculated as 171.7×10^6 tons C yr^{-1} . Using several transfer coefficients and conversion factors it is calculated that this production would be equivalent to between about 4.6 and 9.2×10^6 tons wet weight of fish which is considerably higher than the currently reported FAO fish landings.

REFERENCES

- Aleem, A.A. and N. Dowidar. 1967. Phytoplankton production in relation to nutrients along the Egyptian Mediterranean coast. *Stud. trop. Oceanogr. Miami* 5: 305 - 323.
- Aleem, A.A. and A.A. Samann. 1969. Productivity of Lake Maruit, Egypt: Pt. II - Primary Production. *Int. revue ges. Hydrobiol.* 54: 491 - 527.
- A.L.E.S.C.O. 1974. cited in: UNESCO. 1976. Marine Sciences in the Gulf area. UNESCO technical papers in marine sciences 26: 1 - 66.
- Ammiroglio Magnaghi. 1923-1924. cited in: Halim, Y. 1969. Plankton of the Red Sea. *In: Oceanography Marine Biology*, Barnes, H. (Ed.) pp. 231 - 276.
- Atkins, W.R.G. 1923. The phosphate content of fresh and salt waters and its relationship to the growth of algal plankton. *J. Mar. Biol. Ass. U.K.* 14: 119 - 150.
- Beers, J.R., M.R. Stevenson, R.W. Eppley, and E.R. Brooks. 1971. Plankton populations and upwelling off the coast of Peru, June 1969. *Fish Bull.* 69: 759 - 876.
- Bhargave, R.M.S., and S.N. Dwivedi. 1976. Seasonal distribution of phytoplankton pigments in the estuarine system of Goa. *Ind. J. Mar. Sci.* 5: 87 - 90.
- Bhattathiri, P.M.A., V.P. Devassy, and R.M. Bhargava. 1976. Production at different levels in the estuarine system of Goa. *Ind. J. Mar. Sci.* 5: 83 - 86.

- Botros, G.A. 1971. Fishes in the Red Sea. *Oceanog. Mar. Biol. Ann. Rev.* 9: 221 - 348.
- Cleve-Euler, A. 1951. Die diatomeen von Schweden und Finland. *Bibliotheca Phycologica* Band 5. Reprint 1968, 3301 Lehr. Verlag Von J. Cramer, New York, Stockholm.
- Cohen, D.M. 1973. Zoogeography of the fishes of the Indian Ocean. pp. 451 - 463, In: *The biology of the Indian Ocean*. Zeitzschel, B. (Ed.) Springer-Verlag, Berlin. 549 pp.
- Cooper, L.H.N. 1952. Processes of enrichment of surface water with nutrients due to strong winds blowing on to a continental slope. *J. Mar. Biol. Ass. U.K.* 30: 453 - 464.
- Cushing, D.H. 1971. Upwelling and production of fish. *Adv. Mar. Biol.* 9: 255 - 334.
- Cushing, D.H. 1975. *Marine Ecology and Fisheries*. Cambridge University Press, Cambridge. 278 pp.
- Dehadri, P.V., and R.M.S. Bhargava. 1972. Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental factors along the central West Coast of India. *Mar. Biol.* 17: 30 - 37.
- Deuser, W.G., E.G. Ross, and Z.J. Mlodzinska. 1978. Evidence for the rate of denitrification in the Arabian Sea. *Deep-Sea Res.* 25: 431 - 455.
- Dowidar, N.M. 1974. The phytoplankton of the Mediterranean waters of Egypt. 1-A check list of the species recorded. *Bull. Inst. Ocean. and Fish. A.R.E.* Vol. 4: 321 - 344.
- Dowidar, N.M. 1976. The phytoplankton of the Suez Canal. *Acta Adriatica, Institut Za Oceanograpyie I* Vol. XVIII no. 14: 239 - 256.
- Dowidar, N.M., S.A. Raheem El-Din, and A.A. Aleem. 1976. Phytoplankton populations in the region of Obhur (Jiddah, Saudi Arabia). *Oceanography Depart., Faculty of Science, King Abdulaziz University, Jiddah, Saudi Arabia*. (Unpublished manuscript).
- Dunbar, M.J. 1975. Productivity of marine ecosystems. pp. 27 - 31 In: *Productivity of world ecosystems*. Proc. Symp. National Acad. Sci., Washington, D.C.: 27 - 31.
- El-Sayed, S.Z., and J.T. Turner. 1977. Productivity of the Antarctic and tropical/subtropical regions: A comparative study. pp 463 - 503. In: M.J. Dunbar (Ed.) *Polar Oceans Conference, Arctic Institute of North America*.

- FAO. 1978. 1977 Yearbook of fishery statistics. FAO fisheries series. 44: 323 pp.
- Fenaux, R. 1973. Appendicularia from the Indian Ocean, the Red Sea and the Persian Gulf. pp 409 - 414, In: The Biology of the Indian Ocean. Zeitzschel, B. (Ed.) Springer-Verlag, Berlin. 549 pp.
- Finenko, Z.Z. 1978. Production in plant populations. In: Marine Ecology, Vol. IV. Dynamics. pp 13 - 88. O. Kinne (Ed.) John Wiley and Sons, New York.
- Fishelson, L. 1973a. Ecological and biological phenomena influencing coral-species composition on the Reef Tables at Eilat (Gulf of Aqaba, Red Sea). Mar. Biol. 19: 183 - 196.
- Fishelson, L. 1973b. Ecology of coral reefs in the Gulf of Aqaba (Red Sea) influenced by pollution. Oecologia 12: 55 - 67.
- Flemer, D.A. 1970. Primary productivity in the Chesapeake Bay. Chesapeake Science 11: 117 - 129.
- Fogg, G.E. 1975. Primary productivity. In: Chemical Oceanography, Vol. 2 pp 386 - 453. J.P. Riley and G. Skirrow (Eds.) Academic Press, New York.
- Frontier, S. 1963. Zooplankton recolte en Mer d'Arabie, Golfe Persique et Golfe d'Aden II Pteropodes-systematique et repartition. Cah. ORSTOM Oceanogr. 6: 233 - 254.
- Gieskes, W.W.C., and G.W. Kraay. 1977. Primary production and consumption of organic matter in the Southern North Sea during the spring bloom of 1975. Neth. J. Sea Res. 11: 146 - 167.
- Gilson, H.C. 1937. The nitrogen cycle. John Murray Exped. 1933-34, Sci. Repts. V.2, No. 8: 21 - 81.
- Goldman, C.R. 1968. The use of absolute activity for eliminating serious errors in the measurement of primary productivity with C_{14} . J. du Conseil, Cons. Perm. Int. Explor. Mer. 32: 172⁴ - 179.
- Grasshoff, K. 1969. "Meteor" Forschungsergebnisse, No. 6, Physik und Chemie des meeres, Gebruder Borntraeger, Berlin: 76 pp.
- Grasshoff, K. 1975. The hydrochemistry of landlocked basins and fjords. In: Chemical Oceanography, Vol. 2. pp 456 - 597. J.P. Riley and G. Skirrow (Eds.) Academic Press, New York.
- Guillard, R.R.L., and P. Kilham. 1977. The ecology and marine plankton diatoms ch. 2. The Biology of Diatoms Botanical Monographs vol. 13. University of California Press, Berkeley. 372 - 469.

- Gulland, J.A. 1970. The fish resources of the ocean. FAO Fish. Tech. Pap. 97: 435 pp.
- Halim, Y. 1969. Plankton of the Red Sea. In: Oceanography and Marine Biology. H. Barnes (Ed.) pp. 231 - 276. Hafner Pub. Co. New York.
- Halim, Y. 1976. Marine biological studies in Egyptian Mediterranean waters: A Review. Acta Adriatica 18: 31 - 38.
- Halim, Y., Samaan and F.A. Zaghloul. 1976. Estuarine plankton of the Nile and the effect of freshwater. Phytoplankton Proc. Symposium on the influence of freshwater outflow on biological processes in fjords and coastal waters. The Association of Norwegian Oceanographers, Oslo: 153 - 164.
- Hansen, W. and J. Joseph (Eds.) 1968. Allgemeines physik und chemie des Meeres. "Meteor" Orschungsergebnisse. No. 4. 100 pp.
- Hart, T.J. 1934. On the phytoplankton of the southwest Atlantic and the Bellingshausen Sea, 1929-1931. Discovery Repts. 8: 1 - 268.
- Harrison, W.G. 1980. Nutrient regeneration and primary production in the sea. pp. 433 - 460. In: Primary productivity in the sea. P.G. Falkowski (Ed.) Plenum Press, N.Y.
- Harvey, H.W. 1955. Chemistry and fertility of sea water. Cambridge University Press. 222 pp.
- Harvey, H.W., L.H.N. Cooper, M.V. Lebour, and F.S. Russell. 1935. Plankton production and its control. J. Mar. Biol. Ass. U.K. 20: 407 - 441.
- Hasle, G.R. 1976. The biogeography of some marine planktonic diatoms. Deep-Sea Res. 23: 319 - 338.
- Hassan, E.S.M. 1963. Proc. Egypt Acad Sci. 17: 48 - 59.

- Hendy, N.I. 1951. Littoral diatoms of Chichester Harbour with special reference to fouling. J. Roy Mic. Soc. 71: 1 - 86.
- Henry, J.L., and S.A. Mostert. 1977. Phytoplankton production in Langebaan Lagoon and Saldanha Bay. Trans. Roy. Soc. Afr. 42: parts 3 and 4.
- Hobson, L.A. 1966. Some influences of the Columbia River effluent on Marine phytoplankton during January 1961. Limnol. Oceanogr. 11: 223 - 234.
- Humphrey, G.F. 1972. The biology of the Indian Ocean. Brunn Memorial Lectures. Intergovernmental Oceanographic Commission Technical Series. UNESCO, Paris: 10 7 - 22.
- Humphrey, G.F. 1978. The recalculation of marine chlorophyll concentrations with special reference to Australian waters. Aust. J. Mar. Freshw. Res. 29: 409 - 416.
- Jayaraman, R. 1951. Observations on the chemistry of waters on the Bay of Bengal off Madras City during 1948-1949. Proc. Ind. Acad. Sci. B.33: 92 - 97.
- Kasturirangan, L.R. 1957. A study of the seasonal changes in the dissolved oxygen of the surface waters of the sea on the Malabar Coast, Ind. J. Fish. 4: 134 - 149.
- Khemeleva, N.N. 1970. On the primary production of the Red Sea and the Gulf of Aden. Biology of the Sea 21: 107 - 133.
- Kimor, B., and B. Golanosky. 1977. Microplankton of the Gulf of Elat: aspects of seasonal and bathymetric distribution. Mar. Biol. 42: 55 - 67.
- Klinker, J., Z. Reiss, C. Kropach, I. Levanon, H. Harpaz, and Y. Shapiro. 1978. Nutrients and biomass distribution in the Gulf of Aqaba (Elat), Red Sea. Mar. Biol. 45: 53 - 64.
- Koblentz-Mishke, O.J., and M.A. Semenova. 1977. Phytoplankton pigments in the mesotrophic and eutrophic regions of the tropical Pacific Ocean. Pol-Arch. Hydrobiol. 24: 173 - 183.
- Kobubo, S. 1932. Quantitative studies on microplankton in Amori Bay during 1929-1930. Rec. Oceanogr. Wks. Jap. 4: 171 - 244.
- Kow, T.Ah. 1953. A preliminary study of the physical, chemical and biological characteristics of Singapore Straits. Colonial Fish. Repts. 1: 1 - 65.
- Kuzmenko, L.V. 1973. Primary production of the Northern Arabian Sea. Oceanology 13: 251 - 256.

- Kuzmenko, L.V. 1977. Distribution of phytoplankton in the Arabian Sea. *Oceanology* 17: 70 - 74.
- Lebour, M.V. 1917. The microplankton of Plymouth Sound from the region beyond the breakwater. *J. Mar. Biol. Ass. U.K.* 11: 133 - 182.
- Levanon-Spanier, J.E., E. Padan, and Z. Reiss. 1979. Primary production in a desert-enclosed sea - the Gulf of Elat (Aqaba), Red Sea. *Deep-Sea Res.* 26: 673 - 685.
- Lillick, L.C. 1937. Seasonal studies of the phytoplankton off Woods Hole, Massachusetts. *Biol. Bull., Woods Hole* 73: 488 - 503.
- Loftus, M.E., D.V. Subba Rao, and H.H. Selinger. 1972. Growth and dissipation of phytoplankton in Chesapeake Bay I. Response to a large pulse of rainfall. *Chesapeake Science* 13: 282 - 299.
- Loya, Y. 1972. Community structure and species diversity of hermatypic corals at Eilat, Red SEa. *Mar. Biol.* 13: 100 - 123.
- Maksimova, M.P. 1972. Calculation of nitrogen and phosphorous regeneration rates in the India Ocean waters. *Oceanology* 12: 835 - 840.
- Malone, R.C. 1971. The relative importance of nannoplankton and netplankton as primary producers in tropical oceanic and neritic phytoplankton communities. *Limnol. Oceanogr.* 16: 633 - 639.
- Malone, T.C. 1980. Size-fractionated primary productivity of marine phytoplankton. pp 301 - 319. In: Primary productivity in the sea. P.G. Falkowski (Ed.) Plenum Press, N.Y.
- Margalef, R. 1957. Fitoplancton de las costas de Puerto Rico. *Invest. Pesquera*, 6: 39 - 52.
- Margalef, R. 1968. Perspective in ecological theory. The University of Chicago Press. Chicago. 111 pp.
- Martin, J.H. 1965. Phytoplankton-zooplankton relationships in Narragansett Bay. *Limnol. Oceanogr.* 10: 185 - 191.
- Matthews, D.J. 1932. Tables for the determination of the density of seawater under normal pressure, et. Cons. Perm. Int. Explor. Mer. Andr. Fred. Høst & Fils, Copenhagen. 56 pp.
- McGill, D.A., and T.J. Lawson Jr. 1966. The distribution of chlorophyll in the western Indian Ocean during the northeast monsoon period. Ref. No. 66-12 Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. (Unpublished manuscript).

- Menzel, D.W., and J.H. Ryther. 1960. The annual cycle of primary production in the Sargasso Sea off Bermuda. *Deep-Sea Res.* 6: 351 - 367.
- Michanek, G. 1975. Seaweed resources of the ocean. Food and Agricultural Organisation, Rome (1975).
- Morcos, S.A. 1970. Physical and chemical oceanography of the Red Sea. *Oceanogr. Mar. Biol. Ann. Rev.* 8: 73 - 202.
- Muscantine, L. 1980. Productivity of zooxanthellae. pp 381 - 402. In: Primary productivity in the sea, P.G. Falkowski (Ed.) Plenum Press N.Y.
- Nash, C.B. 1947. Environmental characteristics of a river estuary. *J. Mar. Res.* 6: 147 - 174.
- Neumann, J. 1952. Evaporation from the Red Sea. *Israel Exploration Journal.* 2: 152 - 162.
- Neumann, A.C., and D.A. McGill. 1962. Circulation of the Red Sea in early summer. *Deep-Sea Res.* 8: 223 - 235.
- Neyman, A.A., and A.V. Kondritskiy. 1974. Quantitative distribution of benthos in the Persian Gulf and in the shallow coastal waters of the southern part of the Red Sea. *Oceanology* 14: 291 - 293.
- Nielsen, E.S. 1964. On the determination of the activity in C^{14} ampoules. ICES CM 1964 Plankton Committee Doc. (105), 2 pp.
- Oxner, M. 1962. The determination of chlorinity by the Knudsen method. Reprinted: Jan. 1962 By. G.M. Manufacturing Company, New York. 63 pp.
- Parsons, T., and M. Takahashi. 1973. Biological oceanographic processes. Pergamon Press, Oxford. 186 pp.
- Pingree, R.D., P.R. Pugh, P.M. Holligan, and G.R. Foster. 1975. Summer phytoplankton blooms and red tides along tidal fronts in the approaches to the English Channel. *Nature* 258: 672 - 677.
- Platt, T., and D.V. Subba Rao. 1970. Primary production measurements on a natural plankton bloom. *J. Fish. Res. Bd. Canada* 27: 887 - 899.
- Platt, T., and D.V. Subba Rao. 1973. Some current problems in marine phytoplankton productivity. Fisheries and Marine Service Technical Report. no. 370.
- Pomeroy, L.R., H.H. Haskin, and R.A. Ragotzkie. 1956. Observations on dinoflagellate blooms. *Limnol. Oceanogr.* 1: 54 - 60.

- Ponomareva, L.A. 1968. Euphausiids of the Red Sea collected in summer 1966 by R.V. Academician S. Vavilov. Mar. Biol. 1: 263 - 265.
- Pratt, D.M. 1965. The winter-spring diatom flowering in Narragansett Bay. Limnol. Oceanogr. 10: 173 - 184.
- Qasim, S.Z. 1977. Biological productivity of the Indian Ocean. Ind. J. Mar. Sci. 6: 122 - 137.
- Qasim, S.Z., S. Wellershaus, P.M.A. Bhattathiri, and S.A.H. Abidi. 1969. Organic production in a tropical estuary. Proc. Indian Academy of Sciences vol. LXIX section B no. 2: 51 - 94.
- Qasim, S.Z., M.V.M. Wafar, S. Vijayaraghavan, J.P. Royan and L. Krishna Kumari. 1978. Indian Jour. Mar. Sci. 7: 84 - 93.
- Radhakrishna, K. 1969. Primary productivity studies in the shelf waters off Alleppey, south-west India, during the post-monsoon season. Mar. Biol. 4: 174 - 181.
- Radhakrishna, K., V.P. Devassy, P.M.A. Bhattathiri, and R.M.S. Bhargava. 1978. Primary productivity in the north-eastern Arabian Sea. Ind. J. Mar. Sci. 7: 94 - 98.
- Raymont, J.E.G. 1963. Plankton and productivity in the oceans. Pergamon Press, Oxford. 660 pp.
- Redfield, A.C. 1934. On proportions of organic derivatives in sea water and their relation to the composition of plankton. pp 176 - 192. In: James Johnstone Memorial Volume, Lancashire Sea Fisheries, Liverpool. 348 pp.
- Richards, F.A. 1958. Dissolved silicate and related properties of some Western North Atlantic and Caribbean Waters. J. Mar. Res. 17: 449 - 465.
- Richards, F.A., and T.G. Thompson. 1952. The estimation and characterisation of plankton populations by pigment analyses II. J. Mar. Res. 11: 156 - 172.
- Richards, F.A., and R.F. Vaccaro. 1956. The Cariacs Trench, an aerobic basin in the Caribbean Sea. Deep-Sea Res. 3: 214 - 228.
- Riley, G.A. 1941. Plankton studies. V Regional summary. J. Mar. Res. 4: 162 - 171.
- Riley, G.A. 1952. Hydrographic and biological studies of Block Island Sound, phytoplankton of Block Island Sound, 1949. Bull. Bingham Oceanogr. coll. 13:40 - 64.

- Ryther, J.M. 1963. Geographic variations in productivity. In: The Sea, Vol. 2. pp. 347 - 380. M.N. Hill (Ed.) Wiley-Interscience Publishers, New York.
- Ryther, J.H. 1969. Photosynthesis and food production in the sea. Science 166: 72 - 76.
- Ryther, J.H., and D.W. Menzel. 1965. On the production, composition and distribution of organic matter in the Western Arabian Sea. Deep-Sea Res. 12: 199 - 209.
- Ryther, J.H., J.R. Hall, A.K. Peake, A. Bakun, and M.M. Jones, 1966. Primary organic production in relation to the chemistry and hydrography of the Western Indian Ocean. Limnol. Oceanogr. 11: 371 - 380.
- Saijo, T., and K. Takesue. 1965. Further studies on the size and distribution of photosynthesizing phytoplankton in the Indian Ocean. Jour. Oceanogr. Soc. Japan. 20: 10 - 17.
- Samman, A.A. 1974. Primary production of Lake Edku. Bull. Inst. Ocean & Fish. A.R.E., 4: 261 - 317.
- Savich, M.S. 1969. Seasonal dynamics of phytoplankton in the Gulf of Aden in 1963. Oceanology 9: 848 - 854.
- Savich, M.S. 1971. Some patterns of vertical phytoplankton distribution in the Gulf of Aden as related to oceanographic conditions. Oceanology 11: 396 - 398.
- Schumacher, H. 1973. Die lichtabhängige besiedlung von Hafenstwtzpfieilern durch sessile Tiere und Algen aus dem Korallenriff bei Eilet (Rotes Meer). Helgolander wiss. Meeresunters. 24: 307 - 326.
- Selinger, H.H., J.H. Carpenter, M. Loftus, and W.D. McElroy. 1970. Mechanisms for the accumulation of high concentration of dinoflagellates in a bioluminescent bay. Limnol. Oceanogr. 15: 234 - 245.
- Selinger, H.H., J.H. Carpenter, M. Loftus, W.H. Biggley, and W.D. McElroy. 1971. Bioluminescence and phytoplankton successions in Bahia Fosforescents, Puerto Rico. Limnol. Oceanogr. 16: 608 - 622.
- Selinger, H.H., M.E. Loftus, and D.V. Subba Rao. 1975. Dinoflagellate accumualtions in Chesapeake Bay. Proc. First International Conference on Toxic dinoflagellate blooms. The Massachusetts Science and Technology Foundation, Massachusetts: pp. 181 - 206.

- Smayda, T.J. 1957. Phytoplankton studies in lower Narragansett Bay. *Limnol. Oceanogr.* 2: 342 - 359.
- Smayda, R.J. 1958. Biogeographical studies of marine phytoplankton. *Oikos.* 9: 158 - 191.
- Smayda, T.J. 1965. A quantitative analysis of the phytoplankton of the Gulf of Panama. II. On the relationship between C^{14} assimilation and the diatom standing crop. *Bull. inter-Am. trop. Tuna Commn.* 9: 467 - 531.
- Smayda, T.J. 1973. Phytoplankton in "Coastal and Offshore environmental inventory Cape Hatteras to Nantucket shoals". Marine Publication series no. 2 University of Rhode Island, Kingston, Rhode Island. pp. 1 - 100.
- Sokal, R.R., and F.J. Rohlf. 1973. Introduction to biostatistics. W.H. Freeman and Company, San Francisco. 368 pp.
- Sorokin, Yu. I. 1973. Productivity of coastal tropical waters of the Western Pacific. *Oceanology* 13: 551 - 558.
- Sorokin, Yw.I., I.N. Swkhanova, G.V. Konovalova, and E.B. Pavekteva. 1977. Primary production and the phytoplankton of the equatorial region in the eastern Pacific Ocean. *Pol. Arch. Hydrobiol.* 24 (suppl) : 145 - 162.
- Sournia, A. 1977. Notes on primary productivity of coastal waters in the Gulf of Elat. *Int. Rev. ges. Hydrobiologie* 62: 813 - 819.
- Steele, J.H., and Baird. 1961. Relations between primary production, chlorophyll and particulate carbon. *Limnol. Oceanogr.* 6: 68 - 78.
- Steeman, Nielsen, E. 1952. The use of radioactive carbon (C^{14}) for measuring organic production in the sea. *J. du Conseil, Cons. Perm. Int. Explor. Mer.* 18: 117 - 140.
- Steeman-Nielsen, E. 1963. Productivity, definition and measurement. In: *The Sea*, Vol. 2. pp 129 - 164. M.N. Hill (Ed.) Wiley-Interscience Publishers, New York.
- Steeman Nielsen, E., and A. Jensen. 1957. Primary Oceanic production. *Galathea Repts.* 1: 49 - 136.
- Steidinger, K.A., and J. Williams. 1970. Dinoflagellates. *Memoirs of the Hourglass Cruises vol. II.* Florida Dept. of Natural Resources 2: 1 - 251.

- Steinitz, H. 1973. Fish ecology of the Red Sea and Persian Gulf. pp. 465 - 466, In: The biology of the Indian Ocean. Zeitzschel, B. (Ed.). Springer-verlag, Berlin. 549 pp.
- Strickland, J.D., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bulletin, Fisheries Research Board of Canada 167. 311 pp. (2nd Edition).
- Subba Rao, D.V. 1965. The measurement of total carbon dioxide in dilute tropical waters. Aust. J. Mar. Freshw. Res. 16: 273 - 280.
- Subba Rao, D.V. 1974. Monsoonal influences on production in the Bay of Bengal. 11^e Colloque International sur l'Exploitation des Oceans. vol. 4.
- Subrahmanyam, R. 1959a. Studies on the phytoplankton of the West Coast of India. I. Proc. Indian Acad. Sci. B50: 113 - 187.
- Subrahmanyam, R. 1959b. Studies on the phytoplankton of the West Coast of India. II. Proc. Indian Acad. Sci. B50: 189 - 252.
- Sukhanova, I.N. 1969. Some data on the phytoplankton of the Red Sea and the Western Gulf of Aden. Oceanology 9: 243 - 47.
- Suschenya, L.M., and Z.Z. Finenko. 1965. Primary production in the tropical part of the Atlantic. Okeanologica 5: 60 - 70.
- Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1942. The Oceans. Prentice Hall, New York. 1987 pp.
- Sverdrup, M.V. 1953. On conditions for the vernal blooming of phytoplankton. J. du Conseil. Cons. Perm. Int. Explor. Mer. 18: 287 - 295.
- Thorrington-Smith, M. 1971. West Indian Ocean phytoplankton: A numerical investigation of phytohydrographic regions and their characteristic phytoplankton associations. Mar. Biol. 9: 115 - 147.
- Tyler, M.A., and H.H. Selinger. 1978. Annual subsurface transport of red tide dinoflagellate to its bloom area: Water circulation pattern and organism distributions in Chesapeake Bay. Limnol. Oceanogr. 23: 237 - 246.
- Unesco. 1976. Marine Science programme for the Red Sea. Unesco technical papers in marine science. 25. 21 pp.
- Utermöhl, H. 1958. Zur Vervollkommen der quantitativen phytoplankton. Methodik, Mitt. Int. Ver. Limnol. 9: 1 - 38.

- Vacarro, R.F., and J.H. Ryther. 1960. Marine phytoplankton and the distribution of nitrite in the sea. *J. du Conseil, Cons. Perm. Int. Explor. Mer.* 25: 260 - 271.
- Vinogradov, A.P. 1953. The elementary chemical composition of marine organisms. *Mem. Sears Found. Mar. Res.* 2. 647 pp.
- Volkovinskiyi, V.V. 1974. Degree of consumption of biogenic elements by phytoplankton in the photic layer of the central and South Atlantic. *Oceanology* 14: 70 - 72.
- Weiss, R.F. 1970. The solubility of nitrogen, oxygen and argon in water and seawater. *Deep-Sea Res.* 17: 721 - 735.
- Williams, R.B., and M.B. Murdoch. 1966. Phytoplankton production and chlorophyll concentration in the Beaufort Channel, N.C. *Limnol. Oceanogr.* 11: 73 - 82.
- Winter, D.F., K. Banse, and G.C. Anderson. 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. *Mar. Biol.* 29: 139 - 176.
- Wood, E.J.F. 1963a. Checklist of diatoms recorded from the Indian Ocean. *Rep. Div. Fish. Oceanogr. C.S.I.R.O. Aust.* 36: 1 - 304.
- Wood, E.J.F. 1963b. Checklist of dinoflagellates recorded from the Indian Ocean, Commonwealth Scientific and Oceanographic Report 28. Marine Biological Laboratory Cronulla, Sydney.
- Yentsch, C.S. 1965. Distribution of chlorophyll and phaeophytin in the open ocean. *Deep-Sea Res.* 12: 653 - 666.
- Yentsch, C.S., and L. Wood. 1960. Primary production measurements during IGY 1957-1958. *Publ. Woods Hole Oceanogr. Instn. Ref. no.* 61 - 66. Appendix B. 6 pp.

Table 1: Climatic data at Jiddah† based on observations for the period 1966-1976

	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Direction	N	N	N	N	N	NNW	NNW	NW	N	N	N	N
Wind Mean Speed (Knots)	08	08	09	08	08	08	07	08	07	06	06	07
Extreme High	38	48	46	45	36	30	39	30	30	27	32	40
Air Temp. °C												
Mean Daily Max	28.5	29.0	30.7	33.2	35.1	36.1	37.5	36.8	35.6	34.9	32.4	29.8
Mean Daily Min	19.1	18.7	20.4	22.1	24.4	25.1	26.7	27.0	25.9	23.4	22.3	19.9
Precipitation Mean mm	22.2	9.0	0.4	2.3	2.1	T	T	T	T	0.4	18.3	8.3
*Radiant Energy g cal cm ⁻²	5500	7100	10000	12050	13200	13250	13150	12700	11350	8800	5950	5300

† Meteorological department (climatic section) Kingdom of Saudi Arabia

T Traces

* Neumann (1952)

Table 2: Maxima and minima of physico-chemical variables at the Sharm and offshore stations

	Sharm station				Offshore station							
	<u>Maximum</u>		<u>Minimum</u>		<u>Maximum</u>		<u>Minimum</u>					
	Date	Depth (m)	Value	Date	Depth (m)	Value	Date	Depth (m)	Value			
T°C	29/8/78	0	32.20	11/4/78	20	25.10	10/8/78	0	31.50	25/10/78	200	22.10
S°/°o	2/11/77	15	39.98	30/4/77	0	38.40	31/1/78	200	40.54	10/7/78	25	38.80
σt	25/1/78	30	26.678	29/8/78	0	24.214	31/1/78	200	28.397	10/7/78	0	24.441
Secchi	26/6/78	-	25.0	14/2/78	-	10.0	27/6/78	-	32.0	10/7/78	-	22.0
O ₂	15/8/77	15	4.72	28/5/78	30	2.10	25/10/78	0	4.80	22/2/78	200	1.85
O ₂ Sat	15/8/77	15	110.2	28/5/78	30	46.6	25/10/78	0	114.0	22/2/78	200	38.5
PO ₄	14/3/78	15	0.76	11/7/77	15	0	11/4/78	75	1.46	25/10/78	0	0.01
SiO ₂	15/8/77	30	7.40	25/1/78	0	1.09	31/1/78	200	4.69	23/9/78	0	0.98
NO ₂	18/7/78	0	0.65	+	+	0	11/4/78	200	3.25	28/5/78	0	0.01
NH ₄	11/4/78	0	3.54	+	+	0	21/4/78	200	3.90	28/5/78	0	0.01

† On several occasions similar values were obtained

Table 3: Seasonal phytoplankton abundances (cells L^{-1}) and percentage composition of major groups at the Sharm station

Date	Depth (m)	Number of Cells L^{-1}				Percentage		
		Dinoflagellates	Diatoms	Blue-greens	Total	Dino	Dia	B-g
3/11/77	0	190	620	20	830	22.9%	74.7%	2.4%
	5	130	420	-	550	23.6	76.4	-
	10	110	530	-	640	17.2	82.8	-
	15	70	470	-	540	13.0	87.0	-
	20	60	370	-	430	14.0	86.0	-
	30	70	180	-	250	28.0	72.0	-
	Average	105	432	3	540	19.4	79.9	0.6
17/11/77	0	200	730	-	930	21.5	78.5	-
	5	160	580	-	740	21.6	78.4	-
	10	130	340	-	470	27.7	72.3	-
	15	100	180	-	280	35.7	64.3	-
	20	60	300	-	360	16.7	83.3	-
	30	30	190	-	220	13.6	86.4	-
	Average	113	387	-	500	22.7	77.3	-
Average % Composition For November Samples						21.1	78.6	0.3
27/12/77	0	770	18170	-	18940	4.1	95.9	-
	5	400	11630	-	12030	3.3	96.7	-
	10	190	5390	-	5580	3.4	96.6	-
	15	90	3590	-	3680	2.4	97.6	-
	20	40	1780	-	1820	2.2	97.8	-
	30	30	1340	-	1370	2.2	97.8	-
	Average	217	6983	-	7237	3.5	96.5	-
25/1/78	0	1320	68435	silico-flagellates	69755	1.9	98.1	silico-flagellates
	5	660	42360	10	43030	1.6	98.4	-
	10	665	42440	-	43105	1.5	98.5	-
	15	-	-	-	-	-	-	-
	20	590	21800	10	22400	2.7	97.3	-
	30	230	8200	-	8430	2.7	97.3	-
	Average	578	30539	3	31120	1.9	98.1	0.0
14/2/78	0	420	1700	-	2120	19.8	80.2	-
	5	870	2390	-	3260	26.7	73.3	-
	10	460	2040	-	2500	18.4	81.6	-
	20	210	1560	-	1770	11.9	88.1	-
	30	130	680	-	810	16.0	84.0	-
	Average	348	1395	-	1743	20.0	80.0	-
14/3/78	0	530	840	-	1370	38.7	61.3	-
	5	595	930	-	1525	39.0	61.0	-
	10	430	870	-	1300	33.1	66.9	-
	15	370	750	-	1120	33.0	67.0	-
	20	170	710	-	880	19.3	80.7	-
	30	110	540	-	650	16.9	83.1	-
	Average	368	773	-	1141	32.2	67.8	-

Table 3 continued

Date	Depth (m)	Dinoflagellates	Diatoms	Blue-greens	Total	Dino	Dia	B-g
11/4/78	0	625	1330	-	1955	32.0%	68.0%	-
	5	395	780	-	1175	33.6	66.4	-
	10	420	910	-	1330	31.6	68.4	-
	15	260	790	-	1050	24.8	75.2	-
	20	345	1750	-	2095	16.5	83.5	-
	30	400	1415	-	1815	22.0	78.0	-
	Average	408	1163	-	1570	26.0	74.0	-
21/4/78	0	245	640	-	885	27.7	72.3	-
	5	295	815	-	1110	26.6	73.4	-
	10	135	575	-	710	19.0	81.0	-
	20	205	1080	-	1285	16.0	84.0	-
	30	120	510	-	630	19.0	81.0	-
	Average	167	603	-	770	21.6	78.4	-
Average % Composition for April Samples						24.2	75.8	-
10/5/78	0	330	240	2000	2570	12.8	9.3	77.8
	5	635	360	1700	2695	23.6	13.4	63.0
	10	630	500	1500	2630	24.0	19.0	57.0
	20	500	470	1200	2170	23.0	21.7	55.3
	30	230	310	50	590	39.0	52.5	8.5
	Average	388	313	1075	1776	21.8	17.6	60.5
28/5/78	0	1295	5640	4500	11435	11.3	49.3	39.4
	5	1690	8030	3200	12920	13.1	62.2	24.8
	10	1245	7300	2100	10645	11.7	68.6	19.7
	20	865	5690	380	6935	12.5	82.0	5.5
	30	460	2190	50	2700	17.0	81.1	1.9
	Average	926	4808	1705	7439	12.5	64.6	22.9
Average % Composition For May Samples						17.5	41.2	84.2
20/6/78	0	260	830	5800	6890	3.8	12.0	84.2
	5	390	925	2000	3315	11.8	27.9	60.3
	10	260	1160	500	1920	13.5	60.4	26.0
	20	325	820	200	1345	24.2	61.0	14.9
	30	160	650	-	810	19.8	80.2	-
	Average	233	731	1417	2380	9.8	30.7	59.5

Table 3 continued

Date	Depth (m)	Dinoflagellates	Diatoms	Blue-greens	Total	Dino	Dia	B-g
18/7/78	0	1040	2110	1600	4750	21.9%	44.4%	33.7%
	5	1170	3160	900	5230	22.4	60.4	17.2
	10	620	3590	600	4810	12.9	74.6	12.5
	20	360	2300	150	2810	12.8	81.9	5.3
	30	240	4060	80	4380	5.5	92.7	1.8
	Average	572	2537	555	3663	15.6	69.2	15.2
25/7/78	0	500	220	500	1220	41.0	18.0	41.0
	5	420	210	220	850	49.4	24.7	25.9
	10	250	310	180	740	33.8	41.9	24.3
	20	100	170	150	420	23.8	40.5	35.7
	30	120	110	100	330	36.4	33.3	30.3
	Average	232	170	192	593	39.0	28.7	32.3
Average % Composition For July Samples						27.2	49.2	23.6
20/8/78	0	390	6760	-	7150	5.5	94.5	-
	5	340	8230	-	8570	4.0	96.0	-
	10	200	4670	-	4870	4.1	95.0	-
	20	100	3470	-	3570	2.8	97.2	-
	30	50	1810	-	1860	2.7	97.3	-
	40	-	10	-	10	-	100.0	-
	Average	180	4158	-	4338	4.1	95.9	-
19/9/78	0	160	920	-	1080	14.8	85.2	-
	5	60	640	-	700	8.6	91.4	-
	10	100	410	-	510	19.6	80.4	-
	15	60	270	-	330	18.1	81.8	-
	20	160	360	-	520	30.8	69.2	-
	30	40	150	-	190	21.1	78.9	-
	Average	97	458	-	555	17.4	82.6	-
25/10/78	0	40	10	-	50	80.0	20.0	-
	5	20	20	-	40	50.0	50.0	-
	10	100	-	-	100	100.0	-	-
	20	30	-	-	30	100.0	-	-
	30	20	10	-	30	66.7	33.3	-
	Average	95	7	-	42	84.0	16.0	-

Table 4: Seasonal phytoplankton abundances (cells μ^{-1}) and percentage composition of major groups at the offshore station

Date	Depth (m)	Number of Cells μ^{-1}			Percentage			
		Dinoflagellates	Diatoms	Blue-greens	Total	Dino	Dia	B-g
3/11/77	0	370	3480	-	3850	9.6%	90.4%	-
	25	590	6010	-	6600	8.9	91.1	-
	50	200	3805	-	4005	5.0	95.0	-
	75	230	2060	-	2290	10.0	90.0	-
	100	100	1410	-	1510	6.6	93.4	-
	150	-	580	-	580	-	100.0	-
	200	-	280	-	280	-	100.0	-
	Average	213	2518	-	2731	7.8	92.2	-
7/11/77	0	80	160	50	290	27.6	55.2	17.2
	25	80	240	-	320	25.0	75.0	-
	50	10	130	-	140	7.14	92.86	-
	75	10	60	-	70	14.3	85.7	-
	100	-	20	-	20	-	100.0	-
	150	-	20	-	20	-	100.0	-
	200	-	-	-	-	-	-	-
	Average	26	90	7	123	20.9	73.3	5.8
Average % Composition For November Samples					14.4	82.8	2.8	
27/12/77	0	610	24250	-	24860	2.5	97.5	-
	25	280	17450	-	17730	1.6	98.4	-
	50	60	11760	-	11820	0.5	99.5	-
	75	60	6870	-	6930	0.9	99.1	-
	100	30	2850	-	2880	1.0	99.0	-
	150	-	1750	-	1750	-	100.0	-
	200	-	1030	-	1030	-	100.0	-
	Average	149	9423	-	9571	1.6	98.4	-
29/1/78	0	450	15520	-	15970	2.8	97.2	-
	25	640	22780	-	23420	2.7	97.3	-
	50	290	8020	-	8310	3.5	96.5	-
	75	150	11730	-	11880	1.3	98.7	-
	100	100	13185	-	13285	0.8	99.2	-
	150	150	4680	-	4830	3.1	96.9	-
	200	-	820	-	820	-	100.0	-
	Average	254	10962	-	11216	2.3	97.7	-
22/2/78	0	810	4510	-	5320	15.2	84.8	-
	25	760	4810	-	5570	13.6	86.4	-
	50	300	1910	-	2210	13.6	86.4	-
	75	80	600	-	680	11.8	88.2	-
	100	30	230	-	260	11.5	88.5	-
	150	-	60	-	60	-	100.0	-
	200	-	-	-	-	-	-	-
	Average	283	1731	-	2014	14.0	86.0	-

Table 4 continued

Date	Depth (m)	Dinoflagellates	Diatoms	Blue-green	Total	Dino	Dia	B-g
18/3/78	0	790	2600	500	3890	20.3%	66.8%	12.9
	25	780	1670	-	2450	31.8	68.2	-
	50	670	1460	-	2130	31.5	68.5	-
	75	330	1220	-	1550	21.3	78.7	-
	100	210	780	-	990	21.2	78.8	-
	150	90	510	-	600	15.0	85.0	-
	200	50	450	-	500	10.0	90.0	-
	Average	417	1241	71	1730	24.2	71.7	4.1
11/4/78	0	160	1270	230	1660	9.6	76.5	13.9
	25	430	5220	180	5830	7.4	89.5	3.1
	50	210	4280	-	4490	4.7	95.3	-
	75	20	2160	-	2180	0.9	99.1	-
	100	-	2500	-	2500	-	100.0	-
	150	-	660	-	660	-	100.0	-
	200	-	200	-	200	-	100.0	-
	Average	117	2327	59	2503	4.7	93.0	2.3
21/4/78	0	455	2220	100	2775	16.4	80.0	3.6
	25	330	2475	25	2830	11.7	87.5	0.8
	50	305	4610	-	4915	6.2	93.8	-
	75	195	735	-	930	21.0	79.0	-
	100	-	145	-	145	-	100.0	-
	150	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-
	Average	184	1455	18	1656	11.1	87.8	1.1
Average % Composition for April Samples						7.9	90.4	1.7
28/5/78	0	580	1750	5800	8130	7.1	21.5	71.3
	25	530	2890	2100	5520	9.6	52.4	38.0
	50	530	3415	1800	5745	9.2	59.4	31.3
	75	610	3080	1500	5190	11.8	59.3	28.9
	100	10	950	50	1010	1.0	94.1	5.0
	150	-	240	-	240	-	100.0	-
	200	-	180	-	180	-	100.0	-
	Average	323	1786	1607	3716	8.7	48.1	43.2
27/6/78	0	340	1930	8500	10770	3.2	17.9	78.9
	25	690	3390	2500	6580	10.5	51.5	38.0
	50	385	2500	500	3385	11.4	73.9	14.8
	75	80	1005	-	1085	7.4	92.6	-
	100	40	540	-	580	6.9	93.1	-
	150	-	190	-	190	-	100.0	-
	200	-	-	-	-	-	-	-
	Average	219	1365	1643	3227	6.8	42.3	50.9

Table 4 continued

Date	Depth (m)	Dinoflagellates	Diatoms	Blue-greens	Total	Dino	Dia	B-g
10/7/78	0	3320	2950	9650	15920	20.9%	18.5%	60.6%
	25	2220	7180	2500	11900	18.7	60.3	21.0
	50	1400	4245	950	6595	21.2	64.4	14.4
	75	1520	2550	670	4740	32.1	53.8	14.1
	100	650	1190	250	2090	31.1	56.9	12.0
	150	390	450	100	940	41.5	47.9	10.6
	200	300	180	50	530	56.6	34.0	9.4
	Average	1400	2678	2024	6102	22.9	43.9	33.2
20/8/78	0	650	8980	6200	15830	4.1	56.7	39.2
	25	740	10000	3800	14540	5.1	68.8	25.1
	50	390	6540	1500	8430	4.6	77.6	17.8
	75	100	3620	200	3920	2.6	92.3	5.1
	100	20	1810	50	1880	1.1	96.3	2.6
	150	30	870	-	900	3.3	96.7	-
	200	-	300	-	300	-	100.0	-
	Average	276	4589	1679	6543	4.2	70.1	25.7
23/9/78	0	470	2900	80	3450	13.6	84.1	2.3
	25	290	2140	50	2480	11.7	86.3	2.0
	50	290	1290	-	1580	18.4	81.6	-
	75	200	1030	-	1230	16.3	83.7	-
	100	160	970	-	1130	14.2	85.8	-
	150	-	320	-	320	-	100.0	-
	200	50	150	-	200	25.0	75.0	-
	Average	209	1257	19	10390	14.1	84.7	1.3
25/10/78	0	80	-	-	80	100.0	-	-
	25	60	-	-	60	100.0	-	-
	50	90	-	-	90	100.0	-	-
	75	60	-	-	60	100.0	-	-
	100	60	-	-	60	100.0	-	-
	150	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-
	Average	50	-	-	50	71.4	-	-

Table 5: Maximum and minimum values of biological variables and parameters at the Sharm and offshore stations

Sharm station						
	Maximum			Minimum		
	Date	Depth (m)	Value	Date	Depth (m)	Value
Cell nos. λ^{-1}	25/1/78	30	69,755.00	20/8/78	40	10.00
Div. Ind.	11/4/78	0	4.56	25/10/78	20	0.92
Chl $\underline{a}$ (mg m $^{-3}$)	25/1/78	0	1.83	18/7/78	0	0.07
Chl $\underline{b}$ (mg m $^{-3}$)	25/1/78	0	1.42	2/11/77	30	0.03
C 14 (mgC m $^{-3}$ hr $^{-1}$)	21/4/78	0	6.34	29/8/78	20	0.31
Ratio C 14 /Chl $\underline{a}$	14/2/78	5	14.57 $\dagger$	14/2/78	30	1.21
C 14 (mgC m $^{-2}$ hr $^{-1}$)	27/12/77	-	199.84	29/8/78	-	29.16
Offshore station						
	Maximum			Minimum		
	Date	Depth (m)	Value	Date	Depth (m)	Value
Cell nos. λ^{-1}	12/12/78	0	24,860.00	*	75	0*
Div Ind.	12/7/78	100	4.62	25/10/78	100	0.65
Chl $\underline{a}$ (mg m $^{-3}$)	29/12/77	75	2.25	*	*	0*
Chl $\underline{b}$ (mg m $^{-3}$)	29/12/77	75	1.86	*	*	0*
C 14 (mgC m $^{-3}$ hr $^{-1}$)	10/7/78	0	9.40	*	*	0*
Ratio C 14 /Chl $\underline{a}$	25/10/78	-	17.70	31/1/78	75	0.11
C 14 (mgC m $^{-2}$ hr $^{-1}$)	10/8/78	-	206.13	28/5/78	-	25.45

* On several occasions, similar values were obtained
[†] Suspect high values in July and October omitted

[illegible]

C14

Table 8: Comparison of inorganic phosphate values ($\mu\text{g-at } \ell^{-1}$) from some selected regions

Region	Minimum	Maximum	Reference
Sharm inshore station	0	0.62	Present study
Offshore station	0.01	1.46	Present study
Gulf of Aqaba (Elat)	0.03	0.99 (>2.5) *	<u>Klinker et al (1978)</u>
Red Sea	0.20	2.83	<u>Hansen et al (1968)</u>
Straits of Bab el Mandeb	0.20	2.50	<u>Grasshoff (1969)</u>
Gulf of Elat	~0.05	~0.40	<u>Levanon-Spanier et al (1979)</u>
Gulf of Elat	0.03	0.25	<u>Sournia (1977)</u>
Western Indian Ocean	~0.20	~2.20	<u>Ryther et al (1966)</u>
N.E. Arabian Sea	0.11	1.42	<u>Radhakrishna et al (1978)</u>
Baltic Sea	0	9.0	<u>Grasshoff (1975)</u> **
Oslo Fjord	0.2	0.8	<u>Grasshoff (1975)</u> **
Black Sea	~0.5	~8.0	<u>Grasshoff (1975)</u> **

* episodic high values due to air-transported particulate phosphate from fertilizer loading facilities

** citation

Table 9: Comparison of silicate values ($\mu\text{g at l}^{-1}$) from some selected regions

Region	Minimum	Maximum	Reference
Sharm inshore station	0.09	7.40	Present study
Offshore station	0.98	4.69	Present study
Gulf of Aqaba (Elat)	0.03	6.46	<u>Klinker et al (1978)</u>
Red Sea	0.01	1.30	<u>Hansen et al (1968)</u>
Straits of Bab el Mandeb	0	29.00	<u>Grasshoff (1969)</u>
Gulf of Elat	1.17	2.55	<u>Sournia (1977)</u>
Bay of Bengal	2.00	22.00	<u>Jayaraman (1951)</u>
Baltic		~50.00	<u>Grasshoff (1975)</u> **
Black Sea	~10.00	~100.00	<u>Grasshoff (1975)</u> **

** Citation

Table 10: Comparison of nitrite values (μg at L^{-1}) from some selected regions

Region	Minimum	Maximum	Reference
Sharm inshore station	0	0.58	Present study
Offshore station	0.01	3.25	Present study
Arabian Sea		3.91	<u>Deuser et al (1978)</u>
Red Sea	0.02	0.79	<u>Hansen et al (1968)</u>
Straits of Bab el Mandeb	<1.0	>0.5	<u>Grasshoff (1969)</u>
Gotland Deep		<0.5	<u>Grasshoff (1975)</u> **
N. E. Arabian Sea	0	6.01	<u>Radhakrishna et al (1978)</u>

** Citation

Table 11: Comparison of ammonia values ($\mu\text{g at } \lambda^{-1}$) from some selected regions

Region	Minimum	Maximum	Reference
Sharm inshore station	0.10	3.27	Present study
Offshore station	0.01	3.90	Present study
Red Sea	~2.00	~4.00	<u>Grasshoff (1969)</u>
Gotland Deep		<1.00	<u>Grasshoff (1975)</u> **
Oslo Fjord		~1.00	<u>Grasshoff (1975)</u> **
Black Sea		~85.00	<u>Grasshoff (1975)</u> **

136

** Citation

Table 12: Composition of phytoplankton blooms in the Red Sea

Region	Bloom Season		Reference
	Summer	Winter	
Sharm station	Diatoms, Dinoflagellates and Cyanophyta	Diatoms (Dinoflagellates in October)	Present study
Offshore station	Diatoms, Dinoflagellates and Cyanophyta	Diatoms (Dinoflagellates in October)	Present study
Edkw	Cyanophyta, Diatoms	Diatoms	<u>Samman (1974)</u>
Marint	Cyanophyta	Chlorophyta	<u>Samman (1974)</u>
Red Sea	Dinoflagellates	Diatoms	<u>Halim (1969)</u>
Gulf of Elat	Diatoms, Dinoflagellates and Cyanophyta	Diatoms	<u>Levanon-Spanier et al (1979)</u>
Gulf of Elat	Cyanophyta	Diatoms	<u>Kimor and Golandsky (1977)</u>
Egyptian Mediterranean delta	succession noticed Diatoms most dominant	-----	<u>Aleem and Dowidar (1967)</u>

Table 13: Comparison of abundance of phytoplankton cell numbers from selected regions
(cell nos. $\times 10^6$)

Region	Minimum	Maximum	Reference
Sharm station	30	69,755	Present study
Offshore station		24,860	Present study
Singapore		2,500	<u>Kow (1953)</u>
Calicut		238,000	<u>Subrahmanyam (1959)</u>
Gulf of Aden		3,000	<u>Sukhanova (1969)</u>
Gulf of Aden	6.3×10^6	427×10^6	<u>Savich (1969)</u>
Egyptian Mediterranean Delta	2×10^6	9.362×10^6	<u>Aleem and Dowidar (1967)</u>
Arabian Sea	2×10^6	700×10^6	<u>Kuzmenko (1977)</u>
Suez Canal	6,870	68,810	<u>Dowidar (1976)</u>
Egyptian Mediterranean		20×10^6	<u>Halim et al (1976a)</u>
Rosetta Estuary-Suez	0.22×10^6	2×10^6	<u>Halim et al (1976b)</u>
Aomori Bay	560	87,600	<u>Kokubo (1932)</u>
Woods Hole	1,200	305,000	<u>Lillick (1937)</u>
Georges Bank		65,000	<u>Riley (1941)</u>

Table 13 continued

Block Island Sound	26,000	<u>Riley (1952)</u>
Long Island Sound	194,000	<u>Riley (1952)</u>
Narragansett Bay	6.7 x 10 ⁶	<u>Smayda (1973)</u>
Continental Shelf off Cape Cod	164,000	<u>Smayda (1973)</u>
Continental Shelf off Bermuda	51,000	<u>Smayda (1973)</u>

Table 14: Comparison of Chlorophyll a ($\mu\text{g l}^{-1}$) from selected regions

Region	Minimum	Maximum	Reference
Sharm station	0.07	1.83	<u>Present study</u>
Offshore station	0	1.20	<u>Present study</u>
Red Sea stations	0.01	0.80	<u>McGill and Lawson (1966)</u>
Gulf of Elat	0.23	0.31	<u>Sournia (1977)</u>
Gulf of Elat	0.05	0.40	<u>Levanon-Spanier et al (1979)</u>
N.E. Arabian Sea	0.02	1.50	<u>Radhaksishna et al (1978)</u>
Saldhanha Bay	4.90	32.90	<u>Henry et al (1977)</u>
West Coast of India	0.75	18.80	<u>Dehadri and Bhargava (1972)</u>
Goa Estuary	0.56	6.05	<u>Bhargava and Dwivedi (1976)</u>
North Occidental Mediterranean	0.01	0.50	<u>Cahet et al (1972)</u>
Off Columbia River	0.20	2.80	<u>Hobson (1966)</u>
Peruvian Mesotrophic Waters	19.00	21.00	<u>Koblentz-Mishke and Semenova (1977)</u>
Peruvian Eutrophic Waters	42.00	356.00	<u>Koblentz-Mishke and Semenova (1977)</u>
Southern North Sea	1.10	19.50	<u>Gieskes and Kraay (1977)</u>
St. Margaret's Bay	0.38	33.83	<u>Platt and Subha Rao (1970)</u>
Chesapeake Bay	13.30	147.00	<u>Loftus et al (1972)</u>

Table 15: Comparison of primary production (C_{14} method) from selected regions

Region	$\text{mg C m}^{-3} \text{ hr}^{-1} *$		$\text{mg C m}^{-2} \text{ hr}^{-1} *$		Reference
	Min	Max	Min	Max	
Sharm station	0.70	6.34	29.16	199.84	Present study
Offshore station	0.01	9.40	25.45	206.13	Present study
Red Sea			10.10	34.00	<u>Yentsch and Wood (1960)</u>
Gulf of Elat	0.70	2.50	-	-	<u>Sournia (1977)</u>
Gulf of Elat	0.05	3.38	16.42	93.50	<u>Levanon-Spanier et al (1979)</u>
N. Arabian Sea	0.03	5.00	0.20	224.20	<u>Kuzmenko (1973)</u>
East African Coast	0.92	2.08	25.00	141.70	<u>Suschenya and Finenko (1965)</u>
West Equatorial Area	0.14	0.68	13.30	55.83	<u>Suschenya and Finenko (1965)</u>
Subtropical Sargasso			10.80	166.67	<u>Menzel and Ryther (1960)</u>
Barbados			15.80	51.67	<u>Beers et al (1968)</u>
Beaufort Channel			10.00	60.00	<u>Williams and Murdoch (1966)</u>
Chesapeake Bay			16.70	83.00	<u>Flemer (1970)</u>
Goa Estuary			5.00	45.00	<u>Bhattathiri et al (1976)</u>
N.E. Arabian Sea	0.24	8.25	7.50	128.50	<u>Radhakrishna et al (1978)</u>
Cochin backwaters			57.50	126.67	<u>Qasim et al (1969)</u>

Table 15 continued

Saldanha Bay	28.00	125.70	83.70	317.40	<u>Henry et al (1977)</u>
South African Estuary	5.00	13.10	0.92	15.0	<u>Robarts (1976)</u>
North Occidental Mediterranean	0.34	3.00			<u>Cahet et al (1972)</u>
Southern North Sea			1.20	318.90	<u>Gieskes and Kraay (1977)</u>
Equatorial Eastern Pacific	1.34	2.08	33.30	75.00	<u>Sorokin et al (1977)</u>

* Daily production is divided by 12 for hourly production calculations.

Table 16: Comparison of carbon assimilation ratios ($\text{mg C mg Chl a}^{-1} \text{ hr}^{-1}$) from selected regions.

Region	Minimum	Maximum	Reference
Sharm station	1.21	12.03	Present study
Offshore station	0.11	17.70	Present study
Gulf of Elat	0	5.50	<u>Levanon-Spanier et al (1979)</u>
Red Sea		<1.50	<u>Yentsch and Wood (1960)</u>
Red Sea	3.91	7.01	<u>Khemelova (1970)</u>
Cochin	1.20	10.70	<u>Qasim et al (1969)</u>
Arabian Sea Inshore	2.70	4.60	<u>Radhakrishna (1969)</u>
Indian Ocean	2.30	7.40	<u>Saijo and Takesue (1965)</u>
Gulf of Thailand	0.60	5.60	<u>Subha Rao (1965)</u>
Carribean	2.30	10.80	<u>Malone (1971)</u>
Fladen Ground	0	19.90	<u>Steele and Baird (1961)</u>
Gulf of Panama	0.18	5.70	<u>Smayda (1965)</u>
Tropical Atlantic	2.15	17.00	<u>Suschenya and Finenko (1965)</u>
Woods Hole	1.70	25.00	<u>Yentsch (1954a)</u>
Tokyo Bay	1.24	9.10	<u>Saijo and Takesue (1965)</u>

Table 16 continued

North Occidental Mediterranean	3.40	11.80	<u>Cahet et al (1972)</u>
Off Columbia River	2.60	6.70	<u>Hobson (1966)</u>
Chesapeake Bay	4.00	10.00	<u>Seliger et al (1975)</u>

Table 17: Comparison of duration, range and amplitude of primary production during major phytoplankton blooms in selected regions.

Region	Duration	Range (mgC m ⁻² day ⁻¹)	Amplitude (mgC m ⁻² day ⁻¹)	Annual Pro- ductign (gC m ⁻² yr ⁻¹)	Reference
Sharm station	8 weeks	912-2400	2.60	361	Present study
Offshore station		480-2280	4.80	422	Present study
Gulf of Elat	8 weeks	197-1118	5.70	85*	Levanon-Spanier et al (1979)
Lake Maruit		3400-7700	2		Aleem and Dowidar (1967)
Lake Maruit Stn I	-	3596-10572	3	2667	Aleem and Samaan (1969)
III	-	2005-9685	5	1967	Aleem and Samaan (1969)
Lake Edku	I	408-1395	3	118	Samman (1974)
III	-	195-824	4	288	Samman (1974)
IV	-	180-1634	9	283	Samman (1974)
Cochin	8 weeks	690-1520	3	272	Qasim et al (1969)
West Coast of India		380-1110	3		Radhakrishna (1969)
Saldanha Bay	12 weeks	1426-3301	2.30	638	Henry et al (1977)
Bay of Bengal	-	120-600	5	-	Steemann, Nielsen and Jensen (1957)
Indian and Indonesian	>12 weeks	230-1300	6	-	Cushing (1971)

Table 17 continued

Peruvian upwelling area	830-1790	2	<u>Beers et al (1971)</u>
Coastal tropical Pacific	160-2460		<u>Sorokin (1973)</u>
Gulf of Panama	1500-4160	2.50	<u>Smayda (1965)</u>

* Based on 8 months' observations.

Table 18: Period of occurrence of phytoplankton blooms in the Red Sea area

Region	I	II	III	Reference
Sharm station	December	October	April	Present study
Offshore station	January-February	July-August	April	Present study
Station H Gulf of Elat	January	August	November	<u>Klinker et al (1978)</u>
Station A-G Gulf of Elat	March	June	November	<u>Klinker et al (1978)</u>
Gulf of Elat	January	July		<u>Levanon-Spanier et al (1979)</u>
Gulf of Elat	February	June		<u>Kimor and Golandsky (1977)</u>
Lake Edk	March	August		<u>Samman (1974)</u>
Lake Mariut I, II (Polluted)	June			<u>Aleem and Samaan (1969)</u>
(Unpolluted)	June			
Rosetta Estuary (Nile)	March-April	August		<u>Halim et al (1976b)</u>

Figure 1. The Red Sea, showing major geographic features.

Figure 2. Study area showing location of inshore (Sharm)
and offshore stations.

Figure 3. Showing the major coastal features of the City of Jiddah.

Figure 4. Lithography and sediment types around Sharm-Obhor.

Figure 5. Monthly mean wind velocities (nautical miles per 24 hrs.) for the Red Sea area. Compass vectors indicate frequency of direction, and sum to 100%.

VELOCITY NAUTICAL MILES / 24 HRS

Figure 6. Seasonal temperature distribution at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10).

Figure 7. Seasonal temperature distribution at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11).

Figure 8. Seasonal salinity ‰ distribution at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10).

Figure 9. Seasonal salinity distribution at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11).

Figure 10. Seasonal density (σ_t) distribution at the Sharm station.

SHARM STATION - σ_t

Figure 11. Seasonal density (σ_t) distribution at the offshore station.

Figure 12. Seasonal changes in Secchi disc visibility at the Sharm and offshore stations.

Figure 13. Seasonal distribution of dissolved oxygen at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10).

Figure 14. Seasonal distribution of percent(°/°) oxygen
saturation at the Sharm station. (TRANSPARENCY
IN REAR POCKET - TO OVERLAY Figure 10).

Figure 15. Seasonal distribution of dissolved oxygen at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11).

Figure 16. Seasonal distribution of percent (°/°) oxygen saturation at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11.)

Figure 17. Seasonal distribution of soluble reactive
phosphorus ($\text{PO}_4\text{-P}$) at the Sharm station.
(TRANSPARENCY IN REAR POCKET - TO OVERLAY
Figure 10).

Figure 18. Seasonal distribution of soluble reactive
phosphorus ($\text{PO}_4\text{-P}$) at the offshore station.
(TRANSPARENCY IN REAR POCKET - TO OVERLAY
Figure 11).

Figure 19. Seasonal distribution of reactive silicate
(SiO_2) at the Sharm station. (TRANSPARENCY
IN REAR POCKET - TO OVERLAY Figure 10).

Figure 20. Seasonal distribution of reactive silicate
(SiO_2) at the offshore station. (TRANSPARENCY
IN REAR POCKET - TO OVERLAY Figure 11).

Figure 21. Seasonal distribution of nitrite (NO_2) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10).

Figure 22. Seasonal distribution of nitrite (NO_2) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11).

Figure 23. Seasonal distribution of ammonia (NH_4) at the Sharm station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 10).

Figure 24. Seasonal distribution of ammonia (NH_4) at the offshore station. (TRANSPARENCY IN REAR POCKET - TO OVERLAY Figure 11).

Figure 25. Salinity (‰) - reactive silicate (Si)
relationships and water masses in the study
area.

Figure 26. Seasonal distribution of reactive silicate:
soluble reactive phosphorus ratios at the
Sharm station.

SILICATE-PHOSPHATE RATIOS SHARM STATION

Figure 27. Seasonal distribution of reactive silicate:
soluble reactive phosphorus ratios at the
offshore station.

SILICATE-PHOSPHATE RATIOS OFFSHORE STATION

Figure 28. Seasonal composition of the phytoplankton by major groups at the Sharm station.

Sharm Station – Phytoplankton Composition

Figure 29. Seasonal variation in diversity indices of the phytoplankton community at the Sharm station, for surface (0) and 30 m depths, and total water column.

Sharm Station – Phytoplankton Diversity

Figure 30. Seasonal composition of the phytoplankton by major groups at the offshore station.

Offshore Station – Phytoplankton Composition

Figure 31. Seasonal variation in diversity indices of the phytoplankton community at the offshore station, for surface (0), 100 m and 200 m depths, and total water column

Offshore Station – Phytoplankton Diversity

Figure 32. Seasonal abundances of phytoplankton cells by major groups at the Sharm station.

Figure 33. Examples of vertical distributions of the major
phytoplankton groups at the Sharm stations.

N.B. Cells/ 1×10^2 should read:
Cells $\times 10^2$ /l

VERTICAL DISTRIBUTION OF PHYTOPLANKTON GROUPS SHARM STATION

DECEMBER 4, 1977

MAY 10, 1978

JULY 18, 1978

AUGUST 20, 1978

Figure 34. Seasonal abundances of phytoplankton cells by major groups at the offshore station.

Figure 35. Examples of vertical distributions of the major phytoplankton groups at the offshore station.

N.B. Cells/ 1×10^2 should read:
Cells $\times 10^2$ /1

VERTICAL DISTRIBUTION OF PHYTOPLANKTON GROUPS OFFSHORE STATION

DECEMBER 27, 1977

AUGUST 20, 1978

APRIL 11, 1978

JULY 10, 1978

Figure 36. Seasonal profiles of chlorophyll a concentration
at the Sharm station.

Figure 37. Seasonal profiles of chlorophyll b concentration
at the Sharm station.

Figure 38. Seasonal profiles of chlorophyll a concentration
at the offshore station.

Figure 39. Seasonal profiles of chlorophyll b concentration
at the offshore station.

Figure 40. Seasonal variations in vertical profiles of carbon fixation (primary production rate) at the Sharm Station.

Sharm Station
- C-14 Uptake

Figure 41. Seasonal variations in vertical profiles of carbon fixation (primary production rate) at the offshore station.

Figure 42. Integral primary production rates at the Sharm
and offshore stations.

Figure 43. Carbon assimilation ratios ($\text{mgC mg Chl } \underline{a}^{-1} \text{ hr}^{-1}$)
at the Sharm station.

CARBON ASSIMILATION RATIOS AT SHARM STATION

Figure 44. Carbon assimilation ratios ($\text{mgC mg Chl } \underline{a}^{-1} \text{ hr}^{-1}$)
at the offshore station.

CARBON ASSIMILATION RATIOS AT OFFSHORE STATION

PHYTOPLANKTON ECOLOGY AND PRODUCTION OF THE RED SEA
OFF JIDDAH, SAUDI ARABIA

VOLUME 2

by

ESSAM ABID SHAIKH B.A., M.Sc.

College of Oceanography

King Abdulaziz University, Jiddah, Saudi Arabia

A Thesis

Presented to

The Faculty of Science

of

The Open University

(In Two Volumes)

In partial fulfilment of requirements

for the degree of

Doctor of Philosophy

October, 1981

© Essam Abid Shaikh, 1981.

APPENDIX 1A: PHYSICAL, CHEMICAL AND BIOLOGICAL DATA - Sharm Station

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	a	b	total	
March 28/77	0	26.9	38.60	4.35	0.14	1.6	0.0	0.12	0.22	0.916	0.416	-
	10	-	-	-	-	-	-	-	-	-	-	-
	15	26.8	38.62	4.20	0.16	1.8	0.0	1.26	0.19	0.28	0.47	-
	20	-	-	-	-	-	-	-	-	-	-	-
	30	26.4	38.8	4.15	0.15	2.0	0.0	0.14	0.20	0.18	0.38	-
April 30/77	0	26.4	38.4	4.29	0.09	1.9	0.0	0.0	0.64	0.52	1.16	-
	10	-	-	-	-	-	-	-	-	-	-	-
	15	26.2	38.59	4.12	0.08	2.0	0.0	0.0	0.50	0.47	0.97	-
	20	-	-	-	-	-	-	-	-	-	-	-
	30	25.8	38.64	4.05	0.10	2.2	0.0	0.0	0.45	0.41	0.86	-
May 15/77	0	29.5	38.85	4.33	0.05	2.1	0.01	0.0	0.2	0.18	0.38	-
	10	27.2	38.90	4.20	0.02	2.0	0.0	0.01	0.26	0.21	0.47	-
	15	-	-	-	-	-	-	-	-	-	-	-
	20	26.6	38.98	3.90	0.08	1.8	0.01	0.08	0.2	0.24	0.44	-
	30	26.2	39.1	3.91	0.13	1.9	0.03	0.12	0.12	0.13	0.25	-

APPENDIX 1A continued.

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (μg-at l ⁻¹)				Chlorophyll (mg m ⁻³) C ₁₄ -uptake			
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	a	b	total	(mgCm ⁻³ hr ⁻¹)
June 4/77	0	30.0	38.69	4.16	0.0	2.1	0.0	0.12	-	-	-	-
	15	27.6	38.80	3.82	0.003	2.3	0.0	0.09	-	-	-	-
	30	27.3	38.84	3.71	0.02	3.3	0.0	0.24	-	-	-	-
July 11/77	0	29.2	38.95	4.19	0.38	1.8	0.0	3.27	-0.39	0.34	0.73	-
	15	29.1	39.02	3.71	0.0	1.6	0.0	0.44	-	-	-	-
	30	27.5	39.07	3.62	0.17	2.1	0.04	0.50	-0.89	0.88	1.77	-
August 15/77	0	32.0	39.36	4.35	0.04	5.3	0.0	0.97	0.68	0.61	1.29	-
	15	29.5	39.36	4.72	0.06	5.8	0.0	0.43	-	-	-	-
	30	27.7	39.36	4.32	0.07	7.4	0.0	1.55	0.62	0.56	1.18	-
November 2/77	0	28.6	38.86	3.33	0.19	2.98	0.17	1.0	0.25	0.065	0.0	0.91
	5	28.5	38.87	-	0.29	2.82	0.24	1.3	0.20	0.22	0.0	2.7
	10	28.3	39.91	3.94	0.62	2.62	0.20	0.4	0.55	0.58	0.0	2.3
	15	28.1	39.98	3.99	-	-	-	-	-	-	-	3.37
	20	27.7	39.01	4.01	0.39	3.17	0.22	0.31	0.24	0.34	0.0	1.53
	25	-	-	-	-	-	-	-	-	-	-	2.03
	30	27.2	39.20	3.38	0.45	3.5	0.24	1.0	0.17	0.03	-	1.15

APPENDIX 1A continued.

Date	Depth(m)	T°C	S _p /‰	O ₂ (ml l ⁻¹)	Nutrients (μg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
December 27/77	0	26.8	38.92	4.05	0.23	2.82	0.0	1.5	1.33	1.2	2.53	4.36
	10	26.4	38.92	3.95	0.23	2.25	0.08	0.3	1.24	1.25	2.49	5.54
	20	26.0	39.01	4.1	0.23	2.06	0.12	1.38	0.71	0.54	1.25	5.63
	30	25.2	39.20	3.92	0.38	3.26	0.11	1.59	0.35	0.42	0.77	4.45
January 25/78	0	26.8	39.07	4.15	0.29	1.09	0.12	0.58	1.83	1.42	3.25	3.87
	5	26.1	39.20	4.15	0.29	1.9	0.12	0.52	1.42	1.4	2.82	-
	10	26.0	39.42	3.94	0.48	1.98	0.24	0.67	0.8	0.27	1.07	3.99
	15	25.8	39.20	4.01	0.42	4.23	0.28	0.21	0.52	0.68	1.20	2.33
	20	25.9	39.31	4.01	0.17	3.26	0.27	0.33	0.24	0.26	0.50	-
	30	25.2	39.46	3.99	0.17	2.82	0.23	0.41	0.2	0.12	0.32	0.86
February 14/78	0	26.7	39.13	4.15	0.20	1.98	0.22	0.57	0.38	0.29	0.67	4.57
	5	26.1	39.20	4.22	0.17	2.17	0.28	0.10	0.21	0.42	0.63	3.06
	10	26.1	39.27	4.22	0.18	1.2	0.29	0.33	0.3	0.15	0.45	3.98
	15	26.0	39.42	4.01	0.25	2.5	0.21	0.33	0.32	0.26	0.58	-
	20	25.9	39.07	4.22	0.11	2.39	0.34	0.53	0.24	0.25	0.49	2.33
	30	25.5	39.07	4.22	0.20	2.06	0.31	0.51	0.1	0.05	0.15	1.06

APPENDIX 1A continued.

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
March 14/78	0	26.6	38.55	4.16	0.48	1.33	0.13	1.62	0.09	0.11	0.20	1.75
	5	26.4	38.55	4.10	0.38	1.98	0.23	1.76	-	-	-	2.47
	10	26.2	38.59	4.13	0.16	2.85	0.18	1.98	0.12	0.04	0.16	1.28
	15	26.1	38.59	4.15	0.76	2.85	0.25	2.34	-	-	-	1.74
	20	26.0	38.61	4.30	0.19	1.90	0.15	2.46	-	-	-	-
	30	25.3	38.87	4.10	0.29	2.13	0.23	2.58	0.3	0.4	0.7	1.575
April 11/78	0	26.5	38.62	4.55	0.25	1.06	0.38	3.54	0.32	0.28	0.60	0.45
	5	26.2	38.69	4.06	0.10	1.95	0.28	3.18	0.35	0.34	0.69	3.09
	10	25.9	39.21	4.125	0.157	2.01	0.4	3.06	0.37	0.36	0.73	1.3
	15	-	-	-	-	-	-	-	-	-	-	-
	20	25.1	39.12	4.125	0.08	1.84	0.10	3.18	0.59	0.69	1.28	2.4
	30	25.1	39.26	3.99	0.25	3.87	0.13	2.28	0.356	0.47	0.826	1.85
April 21/78	0	28.8	38.78	4.45	0.11	1.6	0.18	2.65	0.71	0.48	1.19	6.34
	5	27.4	38.90	4.51	0.28	2.4	0.12	2.50	0.78	0.44	1.22	4.94
	10	27.0	39.13	4.38	0.15	2.2	0.19	2.8	0.68	0.59	1.27	3.29
	15	-	-	-	-	-	-	-	-	-	-	-
	20	26.2	39.28	4.62	0.13	3.69	0.27	2.3	0.97	0.66	1.63	2.21
	30	26.1	39.32	4.55	0.29	3.76	0.12	3.2	0.32	0.52	0.84	0.65

APPENDIX 1A continued.

Date	Depth(m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
May 10/78	0	29.4	38.74	4.38	0.10	2.5	0.58	1.3	0.38	0.29	0.67	2.91
	5	28.5	38.84	4.36	0.15	1.8	0.50	1.5	0.37	0.58	0.95	2.28
	10	26.8	38.87	4.15	0.25	1.8	0.4	2.2	0.71	0.4	1.11	2.335
	20	26.3	38.87	3.2	0.43	2.01	0.35	2.3	0.76	1.0	1.76	2.07
	30	26.1	38.89	2.9	0.48	2.6	0.33	2.9	0.64	0.54	1.18	0.885
May 28/78	0	28.6	38.98	4.5	0.06	2.4	0.5	1.0	0.60	0.48	1.08	0.94
	5	26.8	39.00	3.9	0.025	2.57	0.4	1.2	0.36	0.47	0.83	0.67
	10	26.5	39.11	2.7	0.01	2.36	0.55	2.1	0.70	0.84	1.54	0.765
	20	26.4	39.23	2.2	0.15	2.38	0.30	2.4	0.70	0.86	1.56	1.28
	30	26.4	39.23	2.1	0.476	2.8	0.35	2.5	0.09	0.35	0.44	0.88
June 20/78	0	31.0	39.31	4.3	0.22	2.92	0.3	0.5	0.61	0.58	1.19	4.145
	5	29.3	39.13	4.4	0.26	2.5	0.2	1.28	0.49	0.46	0.95	5.045
	10	28.2	39.02	4.3	0.62	3.9	0.3	2.25	0.48	0.35	0.83	1.71
	20	27.8	39.24	4.1	0.32	4.2	0.2	2.85	0.35	0.37	0.72	1.055
	30	27.5	39.21	4.05	0.32	4.5	0.2	1.5	0.35	0.37	0.72	0.525

APPENDIX 1A' continued.

Date	Depth(m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	a	b	total	
July 18/78	0	32.0	39.49	4.23	0.18	2.8	0.65	1.1	0.072	0.11	0.182	2.13
	5	30.6	39.23	4.05	0.15	2.2	0.45	1.20	0.33	0.32	0.65	2.145
	10	30.5	39.23	4.1	0.13	2.15	0.32	1.46	0.38	0.32	0.70	2.06
	20	30.1	39.30	4.1	0.21	3.10	0.38	1.50	0.45	0.63	1.08	1.36
	30	30.0	39.36	3.85	0.35	3.14	0.25	1.59	0.81	1.2	2.01	0.98
August 29/78	0	32.2	39.31	4.23	0.03	2.3	0.18	0.13	0.38	0.32	0.70	2.5
	5	30.5	39.07	4.035	0.01	1.9	0.21	0.0	0.25	0.21	0.46	1.575
	10	30.5	39.21	4.16	0.08	1.9	0.15	0.0	0.21	0.24	0.45	0.175
	20	30.2	39.30	4.1	0.09	2.14	0.08	1.2	0.26	0.22	0.48	0.31
	30	30.1	39.40	4.16	0.20	3.2	0.15	1.5	0.10	0.11	0.21	0.41
September 19/78	0	29.5	39.49	4.52	0.01	1.2	0.18	1.22	0.45	0.66	1.11	2.23
	5	29.1	39.46	4.61	0.15	1.1	0.08	1.22	0.41	0.42	0.83	-
	10	29.0	39.56	4.65	0.37	1.9	0.06	1.44	0.38	0.26	0.64	3.07
	20	28.1	39.60	4.1	0.12	1.9	0.43	1.43	0.58	0.83	1.41	2.275
	30	27.3	39.50	4.15	0.28	3.4	0.45	2.5	0.45	0.59	1.04	1.27

APPENDIX 1A continued.

Date	Depth(m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
October 25/78	0	30.4	39.51	4.35	0.09	1.6	0.05	1.13	0.15	0.09	0.24	1.48
	5	30.3	39.52	4.29	0.11	1.8	0.02	1.22	0.19	0.1	0.29	2.10
	10	29.5	39.73	4.15	0.13	1.8	0.03	1.05	0.11	0.05	0.16	3.8
	15	29.4	39.61	4.15	0.16	1.1	0.02	1.15	-	-	-	-
	20	28.6	39.54	4.18	0.18	1.9	0.3	2.7	0.13	0.10	0.23	3.04
	30	28.1	39.69	3.8	0.25	3.9	0.2	2.9	0.09	0.08	0.17	1.7

APPENDIX 1B: PHYSICAL, CHEMICAL AND BIOLOGICAL DATA - offshore station

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
November 2/77	0	28.5	38.95	4.082	0.01	2.93	0.31	1.2	0.313	0.227	0.540	0.65
	25	28.7	39.12	4.013	0.065	2.17	0.35	1.0	0.22	0.19	0.41	0.44
	50	28.3	28.3	4.013	0.12	2.28	0.22	1.15	0.075	0.089	0.164	0.12
	75	27.9	39.26	4.41	0.21	2.81	0.20	1.58	0.132	0.11	0.242	0.09
	100	27.7	39.45	3.88	0.15	2.17	0.1	2.3	0.08	0.12	0.21	0.05
	150	24.4	39.82	3.8	0.29	2.25	0.11	2.4	0.05	0.02	0.07	-
	200	22.7	39.98	2.2	0.39	2.40	0.08	2.5	-	-	-	-
December 21/77	0	26.3	39.21	4.10	0.14	2.21	0.20	1.9	0.25	0.21	0.46	0.5
	25	26.0	39.25	4.21	0.14	1.80	0.24	1.4	0.36	0.28	0.64	0.6
	50	25.9	39.42	4.0	0.265	1.74	0.18	1.2	0.61	0.44	1.05	1.1
	75	25.8	39.58	3.9	0.23	2.5	0.15	1.5	2.25	1.86	4.11	1.8
	100	25.5	39.62	3.7	0.265	1.63	0.16	2.05	0.78	0.62	1.40	0.6
	150	22.8	39.74	3.62	0.35	3.58	0.10	2.5	0.19	0.12	0.31	-
	200	22.7	40.25	2.35	0.43	2.93	0.10	2.6	0.05	0.03	0.08	-

APPENDIX 1B continued.

Date	Depth(m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	
January 31/78	0	25.9	39.69	4.22	0.14	2.09	0.26	1.39	0.39	0.52	0.91	2.25
	25	25.6	39.74	4.15	0.29	2.43	0.29	1.54	0.42	0.40	0.82	2.83
	50	25.3	39.81	4.15	0.29	2.36	0.36	1.59	0.50	0.222	0.722	1.02
	75	24.9	39.81	4.01	0.29	2.21	0.54	1.50	0.18	0.15	0.33	0.02
	100	24.6	39.93	3.87	0.29	2.40	0.29	2.1	0.025	0.01	0.035	0.01
	150	24.5	39.97	3.87	0.53	3.43	0.3	2.32	0.01	0.026	0.036	-
	200	22.2	40.54	2.4	0.56	4.69	0.23	2.27	0.0	0.0	0.0	-
February 22/78	0	25.9	38.77	4.01	0.13	1.52	0.32	1.36	1.0	0.4	1.4	2.8
	25	25.5	38.86	3.64	0.12	1.63	0.25	1.67	1.2	0.8	2.0	2.95
	50	25.2	38.95	4.29	0.18	1.98	0.54	1.39	1.0	0.2	1.2	2.41
	75	25.3	39.62	3.87	0.21	1.85	0.28	1.5	0.65	0.34	0.99	0.85
	100	24.2	39.69	3.45	0.16	1.85	0.18	2.2	0.11	0.2	0.31	0.05
	150	23.0	39.98	2.93	0.42	3.02	0.20	3.54	0.0	0.0	0.0	0.0
	200	22.3	40.17	1.85	0.33	3.89	0.17	3.54	0.0	0.0	0.0	0.0

APPENDIX 1B continued.

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (μg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	a	b	total	
April 11/78	25	26.5	39.42	4.10	0.09	1.8	0.48	2.98	0.35	0.41	0.76	0.45
	50	26.2	39.65	4.30	0.15	1.85	0.32	2.46	0.56	0.49	1.05	0.32
	75	25.9	39.78	4.10	0.21	1.85	0.18	1.52	0.25	0.18	0.43	0.1
	100	25.8	39.85	3.09	0.51	2.22	0.21	1.24	0.05	0.12	0.17	0.0
	150	22.6	40.02	3.2	0.45	3.81	0.20	2.34	-	-	-	-
	200	22.4	40.01	2.4	0.62	3.95	0.18	1.6	-	-	-	-
	0	28.1	39.0	4.32	0.05	1.84	0.15	1.6	0.644	0.833	1.477	1.26
	25	27.0	39.35	4.32	0.63	1.06	0.13	2.2	0.188	0.873	1.061	0.41
	50	25.0	39.51	4.64	0.55	1.98	0.15	2.68	0.392	0.655	1.047	0.10
	75	23.9	39.92	4.38	1.46	1.28	0.15	2.22	0.228	0.468	0.696	1.15
	100	23.6	39.94	4.12	1.09	1.88	0.15	1.62	0.32	0.52	0.84	0.07
	150	23.2	40.21	3.99	1.10	2.85	0.33	2.28	0.26	0.282	0.542	-
	200	22.5	40.28	2.13	1.17	3.96	3.25	2.1	0.15	0.27	0.42	-

APPENDIX 1B continued.

Date	Depth(m)	T°C	S _i /‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³) C ₁₄ -uptake			
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	(mgCm ⁻³ hr ⁻¹)
April 21/78	0	28.3	38.98	4.58	0.22	1.85	0.05	0.18	0.28	0.32	0.6	1.5
	25	27.2	38.98	4.52	0.25	2.310	0.10	2.96	0.46	0.27	0.73	0.55
	50	25.2	39.20	4.44	0.34	2.6	0.34	1.8	0.64	0.766	1.406	0.35
	75	24.4	39.42	4.11	0.32	2.5	1.01	1.18	0.48	0.36	0.84	0.69
	100	23.4	39.65	4.05	0.39	2.7	0.6	1.32	0.301	0.23	0.531	0.3
	150	23.1	40.16	3.78	0.47	3.4	0.08	2.4	0.312	0.159	0.471	0.0
	200	22.6	40.42	2.1	0.81	4.2	0.04	3.9	0.0	0.0	0.0	0.0
May 28/78	0	27.5	39.05	4.02	0.05	1.5	0.01	0.01	0.604	0.583	1.187	0.64
	25	26.8	39.11	4.4	0.10	1.4	0.03	0.05	0.168	0.104	0.272	0.205
	50	25.1	39.23	2.6	0.10	1.7	0.02	0.05	0.212	0.159	0.371	0.12
	75	24.2	39.26	3.2	0.164	1.76	0.03	0.2	0.534	0.130	0.664	0.36
	100	23.5	39.94	2.3	0.15	1.6	0.03	0.5	0.05	0.02	0.07	0.0
	150	23.3	40.38	2.07	0.33	2.58	0.15	1.0	0.0	0.0	0.0	0.12
	200	22.7	40.46	2.07	0.63	2.76	0.21	1.2	0.0	0.0	0.0	0.045

APPENDIX 1B continued.

Date	Depth (m)	T°C	S‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³) C ₁₄ -uptake			
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	(mgCm ⁻³ hr ⁻¹)
June 27/78	0	29.4	39.05	4.20	0.08	1.8	0.28	0.39	0.86	0.79	1.65	3.84
	25	28.7	38.95	4.02	0.09	1.8	0.25	0.39	0.63	0.43	1.06	0.895
	50	26.4	39.22	3.9	0.11	1.5	0.15	0.44	0.46	0.33	0.79	0.275
	75	24.2	40.16	3.6	0.19	2.28	0.10	0.50	0.08	0.05	0.13	0.20
	100	23.5	40.22	3.2	0.18	2.59	0.05	0.20	0.23	0.37	0.60	0.145
	150	22.9	40.34	2.6	0.28	2.95	0.05	0.18	0.23	0.215	0.445	0.0
	200	22.5	40.40	2.5	0.65	3.65	0.09	0.10	0.21	0.07	0.28	0.0
July 10/78	0	30.8	38.95	4.35	0.14	1.79	0.30	0.21	0.85	0.68	1.53	9.4
	25	28.7	38.80	4.28	0.15	1.68	0.25	0.20	0.48	0.28	0.76	0.77
	50	27.9	38.90	4.15	0.16	1.68	0.18	0.26	0.56	0.29	0.85	0.565
	75	27.3	38.89	4.15	0.16	1.7	0.15	0.26	0.66	0.28	0.94	1.535
	100	23.7	39.97	3.4	0.18	2.12	0.04	0.25	0.40	0.14	0.54	0.075
	150	22.9	40.28	2.6	0.19	2.12	0.01	0.21	0.15	0.02	0.17	0.055
	200	22.6	40.35	2.5	0.28	3.15	0.0	0.2	0.25	0.07	0.31	0.01

APPENDIX 1B continued.

Date	Depth(m)	T°C	S°/‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³)			C ₁₄ -uptake (mgCm ⁻³ hr ⁻¹)
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	a	b	total	
August 10/78	0	31.5	39.45	4.21	0.05	2.1	0.12	0.16	0.41	0.35	0.76	6.21
	25	29.4	39.50	4.17	0.07	2.15	0.10	0.28	0.40	0.30	0.70	2.85
	50	27.6	39.61	4.14	0.07	2.26	0.26	0.32	0.21	0.25	0.46	1.125
	75	27.2	39.76	4.1	0.04	2.35	0.25	0.38	0.18	0.20	0.38	0.875
	100	23.8	40.12	3.9	0.02	3.11	0.20	0.35	0.15	0.10	0.25	0.175
	150	23.0	40.30	3.7	0.21	3.5	0.18	0.38	-	-	-	0.01
	200	22.6	40.51	2.9	0.35	3.6	0.35	0.48	-	-	-	-
September 23/78	0	30.1	39.87	4.45	0.035	0.98	0.08	0.1	0.328	0.623	0.951	0.795
	25	28.9	39.51	4.61	0.03	1.8	0.15	0.3	0.28	0.75	1.03	0.94
	50	27.1	39.22	4.15	0.02	1.3	0.20	0.13	0.65	0.64	1.29	0.35
	75	26.2	39.67	4.01	0.024	1.14	0.03	0.5	1.06	0.81	1.87	0.17
	100	25.1	39.69	3.90	0.15	2.17	0.02	0.5	0.94	0.34	1.28	0.1
	150	22.8	40.41	2.25	0.24	2.5	0.35	0.5	0.272	0.425	0.697	-
	200	22.4	40.39	2.1	0.38	3.52	0.55	1.2	0.29	0.42	0.71	-

APPENDIX 1B continued.

Date	Depth(m)	T°C	S _t /‰	O ₂ (ml l ⁻¹)	Nutrients (µg-at l ⁻¹)				Chlorophyll (mg m ⁻³) C ₁₄ -uptake			
					PO ₄ -P	SiO ₂ -Si	NO ₂ -N	NH ₄ -N	<u>a</u>	<u>b</u>	total	(mgCm ⁻³ hr ⁻¹)
October 25/78	0	30.5	39.67	4.80	0.01	1.1	0.3	0.65	0.1	0.11	0.21	1.77
	25	29.1	39.78	4.56	0.02	0.98	0.2	0.65	0.15	0.16	0.31	2.095
	50	27.2	39.98	4.23	0.05	1.2	0.5	1.5	0.08	0.05	0.13	0.63
	75	25.4	40.39	4.02	0.05	1.4	0.4	1.0	0.11	0.08	0.19	0.755
	100	23.9	40.39	4.02	0.13	1.6	1.3	1.44	0.02	0.01	0.03	0.205
	150	22.5	40.40	3.2	0.23	2.6	2.4	2.90	0.0	0.0	0.0	0.0
	200	22.1	40.40	2.68	0.35	2.8	2.1	2.98	0.0	0.0	0.0	-

APPENDIX 2: PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH,
Sharm station - Abundance in cells/l (Van Dorn bottle collections)

		NOVEMBER 3, 1977					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
15	Chaetoceros coarctatum	30	50		20		
	Cocconeis spp.	30	10			30	
	Leptocylindrus danicus	150	100	180	250	150	30
	Licmophora abbreviata	30		50		50	
	Nitzschia closterium	50	20	30	30	10	30
	N. delicatissima	50	20	30	10		
	N. seriata	250	200	220	150	80	100
	Pennate diatoms	30	20	20	10	50	20
	TOTAL DIATOMS	620	420	530	470	370	180
Dinophyceae							
	Ceratium declinatum	20		10		10	10
	C. furca	30	20		10		10
	C. trichoceros	10					
	Diplopsalis lenticula	10			10		
	Exuviaella compressa	30	30	50	10	20	10
	Goniodoma sphaericum		10				
	Gonyaulax polygramma			20			
	Gymnodinium spp.	30	20	10		20	10
	Prorocentrum micans	20	30	10	20		20

APPENDIX 2 continued

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Pyrocystis elegans	10					
Unidentified	30	20	10	20	10	10
TOTAL DINOFLAGELLATES	190	130	110	70	60	70
Cyanophyta						
Trichodesmium spp.	20					
TOTAL PHYTOPLANKTON	830	550	640	540	430	250

APPENDIX 2 continued.

Species	NOVEMBER 17, 1977 Abundance in cells/ μ Depth in meters					
	0	5	10	15	20	30
Bacillariophyceae						
Leptocylindrus danicus	120	150	80	50	70	30
Licmophora flabellata	50	30	20	20	10	20
Nitzschia closterium	80	120	100	50	80	30
N. delicatissima	30					
N. seriata	400	250	120	50	120	80
Pennate diatoms	50	30	20	10	20	30
TOTAL DIATOMS	730	580	340	180	300	190
Dinophyceae						
Ceratium declinatum	20	20	10	20		10
C. furca	10	20	10		10	
C. teres	10		10			
Exuviaella spp.	20	40	30	20	20	
Goniodoma spp.		10				
Gonyaulax spp.	30	20	20	10	10	
Naked dinoflagellates	30	20	20	10		10
Peridinium spp.	30	10	20	10		
Prorocentrum micans	50	20	10	30	20	10
TOTAL DINOFLAGELLATES	200	160	130	100	60	30
TOTAL PHYTOPLANKTON	930	740	470	280	360	220

APPENDIX 2 continued.

Species	DECEMBER 27, 1977 Abundances in cells/ Depth in meters					
	0	5	10	15	20	30
Bacillariophyceae						
<i>Bacteriastrium delicatulum</i>	450	350	80	30	25	
<i>B. hyalinum</i>	650	350	120	80	50	
<i>Chaetoceros affinis</i>	1100	700	500	750	350	100
<i>C. coarctatum</i>	120		50			
<i>C. compressus</i>	2100	1200	700	100		50
<i>C. concaviformis</i>	250	180	150	120		
<i>C. convolutus</i>	80	50				
<i>C. curvisetum</i>	4500	3800	1200	1500	800	950
<i>C. dadayi</i>	500	70	50			
<i>C. decipiens</i>	80	170	120	150	200	50
<i>C. didymum</i>	120	80		50		
<i>C. messanensis</i>	50					
<i>C. peruvianum</i>	950	450	200	50	80	50
<i>C. tetrastichon</i>	500	120	70	50		
<i>Coscinodiscus excentrica</i>	30	20				
<i>Dactyliosolen mediterraneus</i>	250	150	80	30		
<i>Guinardia blavyana</i>	120					
<i>G. flaccida</i>	350	150	70	50	25	
<i>Hemiaulus membranaceus</i>	650	500	150	50	50	
<i>H. sinensis</i>				10		

APPENDIX 2 continued.

	Species	Abundance in cells/l Depth in meters					
		0	5	10	15	20	30
19	<i>Leptocylindrus danicus</i>	950	700	500	100		
	<i>Nitzschia seriata</i>	120	80	100	70	20	50
	<i>Planktoniella sol</i>	50					
	<i>Rhizosolenia alata</i>	350	300	150	50		
	<i>R. bergonii</i>	850	350	70			
	<i>R. calcar-avis</i>	120		20			
	<i>R. hebetata</i>	950	700	300	150	50	50
	<i>R. Shrubsolei</i>	1500	850	500	100	50	
	<i>Thalassiosira decipiens</i>	30	50	20		10	
	<i>T. subtilis</i>	80	50	30		10	
	<i>Thalassiothrix delicatula</i> spp.	80	50	20	10		
	<i>T. fraunfeldii</i>	120	80	70	50	30	30
	<i>T. spp. "A"</i>	120	80	70	40	30	10
	TOTAL DIATOMS	18170	11630	5390	3590	1780	1340
Dinophyceae							
	<i>Amphidinium</i> spp.	20	10	10			
	<i>Ceratium candelabrum</i>		10				
	<i>C. declinatum</i>	150	80	50	20	10	
	<i>C. furca</i>	70	50	30			
	<i>C. fusus</i>	10	20				

APPENDIX 2 continued.

Species	Abundance in cells/ℓ					
	Depth in meters					
	0	5	10	15	20	30
Ceratium pentagonum		10				
C. tenue	30		10			
C. teres	150	120	70	30		10
Ceratocorys horrida	20					
Dinophysis caudata	20					
Exuviaella compressa	30					
Goniodoma polyedricum	10					
G. shaericum	10					
Gonyaulax polygramma	20					
Naked dinoflagellates	30	50	10	40	30	20
Peridinium cerasus	20					
P. steinii	10					
Phalacroma circumsutum	10					
P. doryphorium	10					
P. parvulum	10					
Podalampas bipes	30	20				
P. spinifera	10					
Prorocentrum micans	20	20	10			
Protoceratium reticulatum	20					
Pyrocystis elegans	20					

APPENDIX 2 continued.

Species	Abundance in cells/ℓ Depth in meters					
	0	5	10	15	20	30
Pyrocystis fusiformis	30	10				
P. pseudonociluca	10					
TOTAL DINOFLAGELLATES	770	400	190	90	40	30
TOTAL PHYTOPLANKTON	18940	12030	5580	3680	1820	1370

APPENDIX 2 continued.

		JANUARY 25, 1978					
		Abundance in cells/l					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
Asterionella japonica		120	150	70		50	
A. notata		50	200	120		50	
Bacteriastrium delicatulum		120	80				
B. hyalinum		650		300			
Chaetoceros affinis		2600	1200	1100		600	200
C. atlanticus		2800	1100	1500		400	200
C. brevis		150	650	800			
C. coarctatum		3300	1800	1500		650	100
C. compressus		7100	5200	4500		1500	500
C. concaviformis		2100	1200	800		100	250
C. convolutus		50					
C. curvisetum		16120	9500	12200		6200	2100
C. dadayi			50			80	
C. danicus		250		50			
C. decipiens		3120	1600	1800		500	200
C. dicheata		1500	1200	900		1000	800
C. didymum		280	1200	1500		800	500
C. eibonii		950	620	180		150	
C. laciniosus		2700	800	1100		500	
C. pendulum			20				

APPENDIX 2 continued.

	Species	Abundance in cells/l Depth in meters					
		0	5	10	15	20	30
	Chaetoceros peruvianum	250	50			80	
	C. teres	50					
	C. tetrastichon	100	50				
	C. tortissimum	4100	2500	3100		1500	250
	Climacodium fraunfeldianum	950	1100	500		100	
	Coscinodiscus excentricus	20		20			
23	Dactyliosolen mediterraneus	500	280	100			
	Fragilaria oceanica	50		20			
	Guinardia flaccida	250	80	120		50	
	Hemiaulus hauckii	50	80	30			
	Lauderia borealis	50					
	Navicula membranacea	120	80			30	
	Nitzschia closterium	1170	800	600		950	300
	N. longissima		10				
	N. seriata	6500	3100	2100		650	500
	Pennate Diatoms	200	280	50		70	40
	Planktonella sol			10			
	Rhizosolenia alata	400	800	1200		500	
	R. alata v. spp. "A"	400		150			
	R. bergonii	50					
	R. calcar-avis	25					

APPENDIX 2 continued

	Species	Abundance in cells/l Depth in meters					
		0	5	10	15	20	30
	Rhizosolenia delicatula	50	75	30			
	R. fragilissima	1200	800	850		300	400
	R. hebetata	260	150	180			
	R. imbricata	150					
	R. Shrubsolei	1500	650	700		800	500
	R. Stolterfothii	800	1100	1500		1800	500
	Streptotheca thamesis	30	25	20		50	10
24	Thalassionema nitzschioides	2500	2000	1200		250	400
	Thalassiosira subtilis	30	50	40			
	Thalassiothrix delicatula	120	80	50		40	
	T. fraunfeldii	1550	950	800		1200	300
	T. pacifica	1050	700	650		850	150
	TOTAL DIATOMS	68435	42360	42440		21800	8200
Dinophyceae							
	Ceratium furca	20		30			10
	C. fusus			30		20	
	C. Kofoidii	150	80	80		50	20
	C. tenue			30			
	C. teres		20	50			
	C. trichoceros					20	

APPENDIX 2 continued.

		Abundance in cells/l Depth in meters					
Species		0	5	10	15	20	30
	Ceratium tripos			20		20	30
	Exuviaella spp.	120	80	60		50	20
	Gonyaulax turbynei		80			50	
	Peridinium abei			10			
	P. cerasus	120		50			
	P. trochoideum	250	200	180		120	50
	Prorocentrum micans	60	80	65		80	50
	Unidentified	600	120	60		180	50
25	TOTAL DINOFLAGELLATES	1320	660	665		590	230
Chrysophyta							
	Dictyocha fibule		10			10	
	TOTAL PHYTOPLANKTON	69755	43030	43105		22400	8430

APPENDIX 2 continued.

		FEBRUARY 14, 1978					
		Abundance in cells/ℓ					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
	Asterionella notata		80	120		50	
	Benthic Diatoms	40	50	80		50	30
	Chaetoceros affinis	300	550	600		800	250
	C. coarctatum		50			50	
	C. decipiens	50	80	50		50	
	Dactyliosolen mediterraneus	50	80	60			
26	Guinardia flaccida	50					
	Nitzschia closterium	140	160	150		180	150
	N. seriata	90	160	120		50	50
	Rhizosolenia alata	50	200	150		50	50
	R. bergonii		30	80			
	R. Shrubsolei	50	250	220		80	50
	R. Stolterfothii	80	50	30		50	40
	Skeletonema costatum	800	600	350		150	50
	Thalassiothrix spp. "A"		50	30			10
	TOTAL DIATOMS	1700	2390	2040		1560	680
Dinophyceae							
	Ceratium contortum			10			
	C. declinatum		30	60		40	20
	C. furca	80	120	60		20	20

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Ceratium fusus	60	80	30			
C. macroceros		50	30		20	
C. teres	40	80	50		20	20
C. trichoceros		10	20			
Diplopsalis lenticula		30				
Goniodoma sphaericum	40	40	50		30	20
Naked dinoflagellates	200	400	150		80	50
Pyrophacus horologium		30				
TOTAL DINOFLAGELLATES	420	870	460		210	130
TOTAL PHYTOPLANKTON	2120	3260	2500		1770	810

APPENDIX 2 continued.

		MARCH 14, 1978					
		Abundance in cells/l					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
Achnanthes brevipes		10					
Bacillaria paradoxa		30	80	50	20		
Chaetoceros affinis		80	150	120	50	20	
C. dadayi			30	50			
C. spp.		50	80	120	200	150	180
Climacodium fraunfeldianum		120	50	80	10	30	50
Leptocylindrus danicus		150	80	100	80	60	50
Nitzschia closterium		30	50	20	30	50	
N. delicatissima		50	80	50	30	150	80
Rhizosolenia alata		150	200	120	150	100	80
R. Shrubsolei		80	50	80	50	20	20
Schroderella delicatula		50					
Thalassiosira decipiens		20	10	50	80	120	80
T. rotula		20	50	30	20	10	
Thalassiothrix spp. "A"			20		30		
TOTAL DIATOMS		840	930	870	750	710	540
Dinophyceae							
Ceratium declinatum				50			
C. extensum			10				
C. furca		50	30	10	30	20	

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Ceratium fusus	20	50	40	50	20	
C. Kofoidii	30	50	50			
C. tenue	10	20				
C. teres	20	50				
C. trichoceros	20	60	30	30		
C. tripos	20	15	20	30	20	10
Diplopsalis lenticula		10	50		30	
Goniodoma polyedricum	10	20		20		
Gonyaulax turbynei	50	30	20	60		20
Peridinium conicum		10			10	
P. steinii		20		10		20
P. trochoideum	150	120	80	60	20	
Small dinoflagellates	150	100	80	80	50	60
TOTAL DINOFLAGELLATES	530	595	430	370	170	110
TOTAL PHYTOPLANKTON	1370	1525	1300	1120	880	650

APPENDIX 2 continued.

		APRIL 11, 1978					
		Abundance in cells/l					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
	Amphiprora spp.	60	50	30	10	100	80
	Bacillaria paradoxa	120	80		100	80	150
	Bellerrochea malleus						30
	Benthic Diatoms	120	300	180	200	320	100
	Biddulphia aurita	30		50		40	20
	Chaetoceros decipiens	100	50	300	50	120	210
30	Climacodium fraunfeldianum	20	10	10	20	80	80
	Cocconeis spp.	120	40	10	50	80	50
	Coscinodiscus excentricus	20	10	20	30	60	10
	Diploneis crabro	60	20	10	20	80	20
	Isthmia enervis	10			10		10
	Licmophora abbreviata	60	30	50		20	10
	L. flabellata	30	20			80	30
	Nitzschia closterium	80	20	50	80	120	200
	N. longissima v. reversa	80	10			60	15
	N. seriata	60	20	40	30	100	150
	Pleurosigma rectum	30	10		20		20
	P. rigidum	30		50		40	20
	P. spp.	120	50	60	80	150	80
	Rhizosolenia alata	20	20		10	40	10
	R. bergonii			10		10	40

APPENDIX 2 continued.

Species	Abundance in cells/ℓ Depth in meters					
	0	5	10	15	20	30
<i>Thalassionema nitzschioides</i>	140	30	40	80	120	80
<i>Thalassiothrix mediterranea</i>	20	10			50	
TOTAL DIATOMS	1330	780	910	790	1750	1415
<i>Dinophyceae</i>						
<i>Ceratium bohmi</i>	10		30	20	10	20
<i>C. breve</i>	30			10	20	15
<i>C. candelabrum</i>		10		10		
<i>C. declinatum</i>	10	10		10	10	25
<i>C. furca</i>	20	10	10	20	10	30
<i>C. fusus</i>	120	10	20	50	10	10
<i>C. massiliense</i>						10
<i>C. trichoceros</i>					10	
<i>C. tripos</i>			10		20	30
<i>Ceratocorys armata</i>	60	10	50		15	20
<i>C. horrida</i>	10	30	40		10	10
<i>Cladopyxis brachiolata</i>	20	50			15	
<i>Dinophysis caudata</i>	10	40	10	30	20	20
<i>Diplopsalis lenticula</i>	20		30		10	10
<i>Exuviaella compressa</i>	20		10		10	10
<i>E. oblonga</i>	30				10	
<i>Goniodoma polyedricum</i>	20	10		20	30	10

APPENDIX 2 continued.

Species	Abundance in cells/% Depth in meters					
	0	5	10	15	20	30
Goniodoma sphaericum	10		10			15
Gonyaulax polygramma	10		10	40	10	10
G. turbynei	20		30			
Ornithocercus magnificus		10	20		10	
Peridinium abei	10	10				
P. cerasus	10				10	10
P. conicum	10	15	10			30
P. crassipes	10	20	10	20	10	10
P. depressum	10	10	30	10	15	10
P. divergens	10	20	10		10	
P. granii	20	10	20			
P. oblongum	10	20		10		10
P. steinii			20			
Peridiniopsis asymmetrica		20			15	
P. trochoideum	20					10
Phalacroma porodictyum	10	20	10		15	25
Podalampas bipes	5	10			10	10
P. palmipes			10			20
Prorocentrum gracile	20			10		
P. micans	30	50	10		20	10
Triposolenia bicornis	30		10		10	10

APPENDIX 2 continued

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
TOTAL DINOFLAGELLATES	625	395	420	260	345	400
TOTAL PHYTOPLANKTON	1955	1175	1330	1050	2095	1815

APPENDIX 2 continued.

APRIL 21, 1978
Abundance in cells/l
Depth in meters

Species	Depth in meters					
	0	5	10	15	20	30
Bacillariophyceae						
Benthic diatoms	60	50	40		90	70
Biddulphia obtusa		10			50	20
Chaetoceros decipiens	150	180	80		250	90
C. socialis	320	450	340		500	180
Coscinodiscus excentricus	10				20	30
Leptocylindrus danicus	30	25	20			20
Rhizosolenia alata	30	20				10
R. calcar-avis	10	30	15		20	10
Thalassiothrix spp.	30	50	80		150	80
TOTAL DIATOMS	640	815	575		1080	510
Dinophyceae						
Ceratium bohmi						10
C. breve	10	30	10		30	10
C. declinatum	60	80	10		50	10
C. furca	30	120	50		40	20
C. furca v. spp. "A"						10
C. fusus	80	30	10		20	10
C. massiliense		10			15	
C. trichoceros		10				10
C. tripos	20	15	20		30	20

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Peridinium depressum	10		20			10
P. divergens	15				20	
P. granii	20		15			10
TOTAL DINOFLAGELLATES	245	295	135		205	120
TOTAL PHYTOPLANKTON	885	1110	710		1285	630

APPENDIX 2 continued.

		MAY 10, 1978				
		Abundance in cells/l				
		Depth in meters				
Species	0	5	10	15	20	30
Bacillariophyceae						
Amphiprora spp.		10	20			
Asterionella notata	10	20	50		80	20
Benthic diatoms	20	30	50		120	150
Leptocylindrus minimus	30	50	50		60	30
Licmophora abbreviata	20	20	30		10	
Nitzschia closterium	80				60	
N. delicatissima	60	150	220		80	80
N. longissima		50	30			
Thalassiothrix longissima	20	30	50		60	30
TOTAL DIATOMS	240	360	500		470	310
Dinophyceae						
Ceratium breve		10				
C. furca	60	75	50		40	20
C. fusus	80	60	120		40	
C. Kofoidii	10	30	50		30	
C. tripos		20				
Exuviaella spp.	10	30	40		60	10
Ornithocercus spp.	30	10	20			
Peridinium granii	20	50	30		30	20
P. trochoideum	50	120	50		80	30

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Prorocentrum micans	20	50	60		40	
Small dinoflagellates	50	180	210		180	150
TOTAL DINOFLAGELLATES	330	635	630		500	230
Cyanophyta						
Trichodesmium spp.	2000	1700	1500		1200	50
TOTAL PHYTOPLANKTON	2570	2695	2630		2170	590

APPENDIX 2 continued.

		MAY 28, 1978					
		Abundance in cells/l					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
Amphiprora alata				30			
Asterionella notata		30	50	80		20	20
Chaetoceros affinis v. Willei		30	90	80		150	120
C. compressus		60	230	300		50	50
C. curvisetum		150	350	400		320	200
C. danicus			100	150		80	
C. peruvianum			10	50			
C. pseudocurvisetum		20	50	120		150	50
C. socialis		250	400	500		450	
Cocconeis spp.			20				
Guinardia flaccida				30			
Hemiaulus hauckii				30		40	
Leptocylindrus danicus		750	920	420		350	150
L. minimus			50	30		50	50
Licmophora spp.		10	20	30		80	
Nitzschia closterium		50	80	160		150	180
N. delicatissima		3500	4520	3500		2500	180
N. longissima			10				
N. seriata		80	150	120		200	200
Pennate diatoms		50	80	120		300	350

APPENDIX 2 continued.

	Species	Abundance in cells/l Depth in meters					
		0	5	10	15	20	30
63	Pleurosigma spp.	10	30	50		10	20
	Rhizosolenia acuminata	20					
	R. alata	250	300	380		350	250
	R. bergonii		10				
	R. calcar-avis		10				
	R. delicatula	350	450	600		350	300
	R. Shrubsolei		30	20			10
	R. Stolterfothii	10	20	30		20	30
	Thalassiothrix longissima	10	30	50		60	30
	T. spp. "A"	10	20	20		10	
	TOTAL DIATOMS	5640	8030	7300		5690	2190
Dinophyceae							
	Ceratium declinatum	10	25	20		25	20
	C. furca	80	80	50		20	20
	C. fusus	20	20	25		40	
	C. Kofoidii	125	150	80		60	50
	C. teres	50	45				
	Dinophysis caudata	90					
	Exuviaella spp.	30	80	50		60	50
	Goniodoma polyedricum	20	40	40		10	

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Gonyaulax polygramma	20	20	10		20	
Peridinium brochii	50	110	80		20	
P. cerasus	50	180	140		80	40
P. divergens	100	50	80		20	50
P. granii	160	140	150		80	50
P. steinii	50	80	20			
P. trochoideum	120	80	120		130	50
40 Peridiniopsis asymmetrica	30	120	40		50	20
Prorocentrum micans	60	120	50		40	
Small dinoflagellates	150	200	170		180	80
Unidentified	80	150	120		30	30
TOTAL DINOFLAGELLATES	1295	1690	1245		865	460
Cyanophyta						
Trichodesmium spp.	4500	3200	2100		380	50
TOTAL PHYTOPLANKTON	11435	12920	10645		6935	2700

APPENDIX 2 continued.

JUNE 20, 1978
Abundance in cells/l
Depth in meters

Species	0	5	10	15	20	30
Bacillariophyceae						
Amphiprora spp.	10					
Asterionella notata		50	40		60	
Benthic diatoms	40	70	60		80	80
Chaetoceros danicus		20	20			
C. peruvianum		10	20			
Diploneis crabro			10			
Hemiaulus hauckii		20	30			
Nitzschia closterium	60	80	200		150	120
N. delicatissima	100	120	150		220	180
N. longissima		10				
N. paradoxa		30	50			
N. seriata	50	20	60			
Pleurosigma spp.	10	5	10			
Rhizosolenia alata	200	310	350		250	220
R. delicatula	350	150	120		50	50
R. Stolterfothii		10				
Thalassiothrix longissima			20			
T. spp. "A"	10	20	20		10	
TOTAL DIATOMS	830	925	1160		820	650

APPENDIX 2 continued.

		Abundance in cells/l Depth in meters					
Species		0	5	10	15	20	30
Dinophyceae							
	Ceratium breve		10	10			
	C. declinatum	20					
	C. furca v. spp. "A"	30					
	C. fusus		10				
	C. Kofoidii	50	60				
42	C. tripos	10				10	
	Dinophysis caudata	10	20	10		10	
	Diplopsalis lenticula	10	10	10		20	10
	Goniodoma polyedricum	20	20	50		40	20
	Peridinium cerasus	20	50	20		40	30
	Peridiniopsis asymmetrica	20	80	80		60	20
	Prorocentrum micans	10	20	20		25	10
	Pyrophacus horologium		10				
	Small dinoflagellates	60	100	60		120	70
	TOTAL DINOFLAGELLATES	260	390	260		325	160
Cyanophyta							
	Trichodesmium spp.	5800	2000	500		200	
	TOTAL PHYTOPLANKTON	6890	3315	1920		1345	810

APPENDIX 2 continued.

JULY 18, 1978
Abundance in cells/l
Depth in meters

Species	Depth in meters					
	0	5	10	15	20	30
Bacillariophyceae						
Chaetoceros curvisetum	80	350	380		120	130
C. dadayi	80	120	90		50	
C. laciniosus	80	350	400		200	120
C. peruvianum	10	30				
C. Weissflogii	800	1250	1700		1240	3200
Nitzschia closterium	30	50	30		50	30
N. delicatissima	50	80	180		150	300
N. longissima		20			30	
Pennate, unidentified	560	350	420		120	80
Rhizosolenia alata	90	120	30		40	50
R. delicatula	270	350	250		120	80
R. hebetata	30	30	50		40	20
R. Stolterfothii	20	50	30		120	50
Thalassiothrix spp. "A"	10	10	30		20	
TOTAL DIATOMS	2110	3160	3590		2300	4060
Dinophyceae						
Ceratium breve			20			
C. candelabrum	60					
C. declinatum	30	80	50		10	20

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Ceratium furca	30	150	60		30	20
C. trichoceros	20	20	50		30	10
Goniodoma polyedricum	10	50	30		20	20
Gonyaulax polygramma	20	30	30		50	20
Peridinium cerasus	10	50	20			
P. steinii	50	30				
Prorocentrum micans	30	50	30		20	10
44 Pyrophacus horologium		10				
Small dinoflagellates	720	650	250		180	120
Unidentified	60	50	80		20	20
TOTAL DINOFLAGELLATES	1040	1170	620		360	240
Cyanophyta						
Trichodesmium spp.	1600	900	600		150	80
TOTAL PHYTOPLANKTON	4750	5230	4810		2810	4380

APPENDIX 2 continued.

JULY 25, 1978
Abundance in cells/l
Depth in meters

Species	0	5	10	15	20	30
Bacillariophyceae						
Amphiprora alata	10	20			10	
Benthic diatoms	90	50	120		60	50
Licmophora flabellata	20	20	30		20	10
L. obtusa	30	10	20		10	
Nitzschia closterium	30	20	50		30	10
N. longissima		10				
N. seriata	20	30	40		20	10
Pleurosigma fasciola			10			
P. naviculaceum						10
P. spencerii		10				
Rhizosolenia alata	10	30	20		10	
R. Shrubsolei	10	10	20			10
Surirella fastuosa						10
S. spp. "A"					10	
TOTAL DIATOMS	220	210	310		170	110
Dinophyceae						
Ceratium breve	60	40	20			
C. furca	270	220	150		50	30
Gonaulax turbynei	20	30				

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Naked dinoflagellates	90	40	20		20	50
Peridinium trochoideum	30	50	30		10	20
Unidentified	30	40	30		20	20
TOTAL DINOFLAGELLATES	500	420	250		100	120
Cyanophyta						
Trichodesmium spp.	500	220	180		150	100
TOTAL PHYTOPLANKTON	1220	850	740		420	330

APPENDIX 2 continued.

		AUGUST 20, 1978					
		Abundance in cells/l					
		Depth in meters					
Species		0	5	10	15	20	30
Bacillariophyceae							
Chaetoceros affinis		200	250	150	50	80	
C. coarctatum		200	250	80	50	50	
C. compressus		1200	1500	600	200	200	
C. curvisetum		2500	3500	1800	2000	800	
C. decipiens		200	300	350	200	120	
47 C. tortissimum		500	400	220	150		
Climacosphenia moniligera			20	10			
Dactyliosolen mediterraneus		120	80	50	30		
Guinardia flaccida		150	80	50	20	50	
Hemiaulus sinensis			50	30			
Leptocylindrus danicus		120	80	50	30		
Licmophora flabellata		20	80	50	30	30	
Navicula membranacea			20				
Nitzschia seriata		80	120	150	100	80	
Pleurosigma spp.		20	20	30	10		10
Rhizosolenia alata		150	250	200	50	80	
R. bergonii		200	100	50	50		
R. calcar-avis		30	50				
R. fragilissima		250	300	200	180	120	
R. hebetata		300	350	300	120	50	

APPENDIX 2 continued.

Species	Abundance in cells/l Depth in meters					
	0	5	10	15	20	30
Rhizosolenia Shrubsolei	250	100	50	80	50	
R. Stolterfothii	250	300	250	120	100	
Thalassiothrix spp. "A"	20	30				
TOTAL DIATOMS	6760	8230	4670	3470	1810	10
Dinophyceae						
Ceratium declinatum	50		30		10	
C. furca	70	50	30	10		
C. fusus	50					
C. tripos	10					
Ceratocorys horrida			10	10		
Dinophysis caudata		10				
Peridinium divergens		10				
P. spp.	90	120	50	30		
Unidentified	120	150	80	50	40	
TOTAL DINOFLAGELLATES	390	340	200	100	50	
TOTAL PHYTOPLANKTON	7150	8570	4870	3570	1860	10

APPENDIX 3: PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF JIDDAH,
Offshore station - Abundance in cells/l (Van Dorn bottle collections)

Species	NOVEMBER 3, 1977 Depth in meters						
	0	25	50	75	100	150	200
Bacillariophyceae							
Asterionella japonica	80	100	50	80	30	30	
Bacteriastrium hyalinum	150	80	120	80	50	50	
Chaetoceros affinis	50	120	80		30		
C. brevis		50	280		50		
C. coarctatum	80	50	30				
49 C. compressus	250	280	50	100			
C. curvisetum	800	3590	500	300	250	150	150
C. decipiens	70	50	150		50		
C. pendulum		50					
Coscinodiscus asteromphalus				10			
C. concinnus			10	50	20		
C. excentricus				30			
C. gigas				100			
C. nobilis				60			
C. oculus-iridis				90			
C. perforatus				20			
C. radiatus				40			
Guinardia flaccida	120	80	100	50			
Leptocylindrus spp.	250	200	300	150		50	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Nitzschia seriata	350	300	400	250	220	100	
Rhizosolenia alata	100	90	220	60			
R. calcar-avis		25	50		10		
R. delicata		50	60				
R. fragilissima	500	250	700	250	300	50	50
R. hebetata		35	25				
R. imbricata	50	120	50				
R. Shrubsolei	80	30	80	40	50		30
R. Stolterfothii	500	300	450	300	350	150	50
Thalassiothrix delicatula	30	20					
T. fraunfeldii		50	100				
T. spp. "A"	20	30					
Unidentified diatoms		60					
TOTAL DIATOMS	3480	6010	3805	2060	1410	580	280
Dinophyceae							
Ceratium furca	50	120		30			
C. trichoceros					20		
Exuviaella spp.	80	90	50				
Oxytoxum tesselatum		20					
Naked Dinoflagellates	80	150	50	80			
Peridinium pellucidum	20	30					

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Peridinium pyriforme	20	30					
Prorocentrum spp.	80	150	100	120	80		
Pyrocystis elegans	20						
P. fusiformis	20						
TOTAL DINOFLAGELLATES	370	590	200	230	100		
TOTAL PHYTOPLANKTON ABUNDANCE	3850	6600	4005	2290	1510	580	280

APPENDIX 3 continued.

NOVEMBER 7, 1977
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Chaetoceros concaviformis	50	20	25	10			
Nitzschia closterium	25	50	20				
N. longissima	10	10	15		10		
N. seriata	25	80	20	30		20	
Rhizosolenia alata	50	80	50	20	10		
TOTAL DIATOMS	160	240	130	60	20	20	
Dinophyceae							
Ceratium breve		10					
C. contortum	10						
C. declinatum	20	10	10				
C. furca	10	20					
C. teres		10					
Other Dinoflagellates	10	20		10			
Peridinium spp.	20	10					
Pyrocystis elegans	10						
TOTAL DINOFLAGELLATES	80	80	10	10			
Cyanophyta							
Trichodesmium	50						
TOTAL PHYTOPLANKTON	290	320	140	70	20	20	

APPENDIX 3 continued.

DECEMBER 27, 1977
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Bacillaria paradoxa	450	100					
Bacteriastrium hyalinum	300	200	250	250	150	120	
Benthic diatoms	250	300	80	50	70	50	30
Chaetoceros affinis	2200	1500	700	150	50		
C. coarctatum	600	500	300	200	50	50	
C. compressum	1500	1200	900	500	100	150	100
C. concaviformis	3500	2800	2000	1500	500	100	100
C. convolutus	1100	850	700	500	200	150	100
C. curvisetum	6500	5000	4000	2200	1100	850	500
C. dadayi	300	100	50				
C. decipiens	300	250	450	300	250	100	100
C. didymum	150	100					
C. peruvianum	800	650	450	100	50		50
Coscinodiscus spp.	300	100		50			
Grammatophora marina	300	100					
Guinardia blavyana	50						
G. flaccida	450	300	100	50			
Hemiaulus membranaceus	450	350	100	50			
Leptocylindrus danicus	450	450	300	150			
Nitzschia seriata	800	600	200	150	50	80	50

APPENDIX 3 continued.

Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Planktoniella sol	50			20			
Rhizosolenia alata	450		300				
R. bergonii	450	350	100	30			
R. calcar-avis	300		100				
R. hebetata	1100	750	300	200	150	50	
R. Shrubsolei	900	750	300	350	100	50	
Thalassiothrix delicatula	250	150	80	70	30		
TOTAL DIATOMS	24250	17450	11760	6870	2850	1750	1030

Dinophyceae

C. contortum	10						
C. declinatum v. normale	20						
C. furca	150	120	50	10			
C. Kofoidii	30	10		20	20		
C. macroceros	10						
C. tenue	20						
C. teres	30	20					
C. trichoceros	10						
Goniodoma polyedricum	30	20					
Gonyaulax polygramma	30	20					
Peridinium cerasus	30	10					
P. granii	10						

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Peridinium steinii	30	10					
P. trochoideum	50	20					
Podalampas spinifera	10						
Prorocentrum micans	120	50	10	30	10		
Pyrocystis fusiformis	10						
P. lunula	10						
TOTAL DINOFLAGELLATES	610	280	60	60	30		
TOTAL PHYTOPLANKTON	24860	17730	11820	6930	2880	1750	1030

APPENDIX 3 continued.

JANUARY 29, 1978
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Bacteriastrum biconicum	1200	800	500	600	500	400	120
B. delicatulum	400	200	300	150			
B. hyalinum	200	450	300	580	800	350	
Benthic Diatoms	200	220	50	180	300	200	120
Cerataulina pelagica			50	220	120	50	
Chaetoceros affinis	500	800	200	550	800	550	50
C. atlanticum	500	800	250	350	500		
C. coarctatum	800	1500	500	800	1100	220	50
C. compressus	1600	1100	400	800	650	150	50
C. concaviformis	600	1500	350	400	800	100	
C. convolutus	800	1800	350	650	1100	300	50
C. curvisetum	3000	3800	1500	800	1800	850	50
C. decipiens	900	1200	350	850	500	200	80
C. dictyota	150	250	50	80	100		
C. didymum	250	350	50	120	200	80	
C. laciniosus	50	150	180	250	500		
C. lauderi			50				
C. peruvianum	80	200	80	250	100	80	20
C. teres		50					

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Chaetoceros tetrastichon		50					
C. tortissimum	300	500	200	800	500	200	50
Climacodium fraunfeldianum	300	450	100	200	80		
Guinardia flaccida	130	250	100	150	80		
Leptocylindrus danicus	300	500	250	100	80		
Licmophora flabella				400			
Nitzschia closterium	300	150	100	300	50		
N. longissima	100	120	80	120	50		
N. seriata	400	300	80	250	400		
Planktoniella sol	20		10		25		
Rhizosolenia alata	200	350	250	180	500	350	50
R. alata v. indica		50					
R. bergonii	50	80	40				
R. calcar-avis	80	120					
R. delicatula	150		50				
R. fragilissima	280	2500	300	450	500		50
R. hebetata	300	250	100	50			
R. imbricata	80					80	
R. Shrubsolei	250	450	100	250	50	120	80
R. Stolterfothii	400	850	250	300	500	400	
Stephanopyxis turris		30					

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
<i>Streptotheca thamesis</i>				150			
<i>Thalassiosira subtilis</i>	300	180	100	50			
<i>Thalassiothrix longissima</i>	100	80	100	150	200		
<i>T. spp. "A"</i>	250	350	300	200	300		
TOTAL DIATOMS	15520	22780	8020	11730	13185	4680	820
Dinophyceae							
<i>Ceratium declinatum</i>	100	50	30				
<i>C. fusus</i>	20	30					
<i>C. kofoidii</i>			20			50	
<i>C. trichoceros</i>						20	
<i>Diplopsalis lenticula</i>						50	
<i>Exuviaella spp.</i>	20	120		50		30	
<i>Goniodoma shaericum</i>	30	50	40				
<i>Peridinium divergens</i>		20					
<i>Peridinium steinii</i>		20					
<i>P. trochoideum</i>	100						
<i>P. spp.</i>	50	150	120	50	100		
<i>Prorocentrum micans</i>	100	180	60	50			
<i>Pyrocystis pseudonoctiluca</i>	30	20	20				
TOTAL DINOFLAGELLATES	450	640	290	150	100	150	
TOTAL PHYTOPLANKTON	15970	23420	8310	11880	13285	4830	820

APPENDIX 3 continued.

FEBRUARY 22, 1978
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Asterionella japonica	80	120	50				
A. notata	100	80	120	40	50		
Bacteriastrium hyalinum	200	250					
Benthic Diatoms	120	100	110	80	50	40	
Chaetoceros affinis	1200	1500	900	200	80		
C. coarctatum	50	80					
C. compressus	200	180					
C. curvisetum	1550	1350	350	150			
C. decipiens	150	200	80	50			
C. laciniosus	50	40					
C. peruvianum	30	50					
Guinardia flaccida	20						
Planktoniella sol		10					
Rhizosolenia alata	50	80		30		20	
R. hebetata	120	80					
R. Shrubsolei	120	80	50		20		
R. Stolterfothii	200	150	50		30		
Skeletonema costatum	220	380	150	50			
Thalassiothrix spp. "A"	50	80	50				
TOTAL DIATOMS	4510	4810	1910	600	230	60	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Dinophyceae							
Ceratium bohmi	120	80	50	10	30		
C. breve		20					
C. furca	80	50	60	20			
C. fusus	40	50					
C. trichoceros		10					
Ceratocorys horrida	20	50	60	10			
Cladopyxis brachiolata			20				
Diplopsalis lenticula		30					
Exuviaella compressa	110	80	30				
Goniodoma shaericum				20			
Gonyaulax polygramma		20					
Naked dinoflagellates	150	120					
Peridinium cerasus	30	20					
P. pellucidum	30	50					
P. steinii	50	20					
P. trochoideum	100	80					
Phalacroma porodictyum		30	20				
Prorocentrum micans	80	50	60	20			
TOTAL DINOFLAGELLATES	810	760	300	80	30		
TOTAL PHYTOPLANKTON	5320	5570	2210	680	260	60	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
<i>Thalassionema nitzschioides</i>	80	30	20		10		
<i>Thalassiosira rotula</i>	50	20	50	30	20	80	40
TOTAL DIATOMS	2600	1670	1460	1220	780	510	450
Dinophyceae							
<i>Ceratium breve</i>	20	10					
<i>C. candelabrum</i>		10					
<i>C. declinatum</i>	50	30		10			
<i>C. dens</i>		10					
<i>C. extensum</i>	10	10	20		10		
<i>C. furca</i>	80	60	130	50	40		20
<i>C. fusus</i>	60	40	30	20	30	20	
<i>C. Kofoidii</i>	20	30	40				
<i>C. massiliense</i>		10		10			
<i>C. tenue</i>	10	20		10		30	10
<i>C. teres</i>	20	20					
<i>C. trichoceros</i>	40	30			10		
<i>C. tripos</i>	30	10					
<i>Ceratocorys horrida</i>	10						
<i>Cladopyxis brachiolata</i>	10						
<i>Diplopsalis lenticula</i>	10	30	20				

APPENDIX 3 continued.

MARCH 18, 1878
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Asterionella japonica	20	50	30				
Bacillaria paradoxa	10	30					
Chaetoceros affinis	950	640	500	420	250	120	100
C. dadayi	20	30	50				
C. decipiens	50	50	80	120	50	80	60
C. peruvianum	20	10	30	40	50	20	20
C. Wighami	20	40	30	50	20		
C. spp.	850	320	250	300	210	150	150
Climacodium fraunfeldianum	120	80	120	60	40		10
Guinardia flaccida	10						
Hemidiscus cuneiformis		10					
Leptocylindrus danicus	80	60	90	70	30	10	
Nitzschia closterium	40	20	20	30	10		
N. delicatissima	30	50	20	10			
N. seriata	30	20	20				
Planktoniella sol		10					
Pleurosigma spp.	20	10	10		10		
Rhizosolenia acuminata		10					
R. alata	80	120	60	50	50	30	20
R. Shrubsolei	120	60	80	40	30	20	50

APPENDIX 3 continued.

	Species	Abundance in cells/l Depth in meters						
		0	25	50	75	100	150	200
	Exuviaella spp.	80	60	50	40	20	10	
	Naked dinoflagellates	20	50	80	10	10		
	Ornithocercus spp.		10			10		
	Peridinium cerasus	50	60	80	30			
	P. conicum		10					
	P. crassipes	20						
	P. granii	10	20					
63	P. oblongum	10		10				
	P. steinii	50	40	50	20	30		
	P. trochoideum	50	80	50	40			
	Peridiniopsis assymetrica	50	40	30	20			
	Podalampas spinifera		10					
	Prorocentrum spp.	50	60	50	30	40	20	20
	Small dinoflagellates	20	20	30	40	10	10	
	Triposolenia bicornis	10						
	TOTAL DINOFLAGELLATES	790	780	670	330	210	90	50
	Cyanophyta							
	Trichodesmium spp.	500						
	TOTAL PHYTOPLANKTON	3890	2450	2130	1550	990	600	500

APPENDIX 3 continued.

APRIL 11, 1978

Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Amphiprora spp.		50	30	40			
Asterionella japonica		50	80				
Bacillaria paradoxa	50	80	20				
Bacteriastrium delicatulum	100	820	650	420	500	120	50
B. hyalinum	50	150	180	50	50	20	
Benthic diatoms	60	60	80	50	120	80	30
Chaetoceros affinis	30	100	300	120	80	50	
C. compressus		20	30	50			
C. decipiens	200	1500	800	690	1200	280	120
C. peruvianum	250	630	820	150	50	20	
C. socialis		400	150	100	300	50	
Climacodium fraunfeldianum	20	120	150	50	20		
Coscinodiscus excentrica		10					
Guinardia flaccida	20	80	10	10			
Leptocylindrus danicus		30	50	40	50		
Nitzschia closterium	60	100	50				
N. seriata	80	380	120	50			
Planktoniella sol			20				
Pleurosigma balticum	30	80	50	20			
Pleurosigma spp.	80	20	20	10			

APPENDIX 3 continued.

	Species	Abundance in cells/l Depth in meters						
		0	25	50	75	100	150	200
	Rhizosolenia alata			20				
	R. bergonii		50	120	80	50	20	
	R. calcar-avis	20	50	80	20	10		
	R. hebetata	20	50	80				
	R. Shrubsolei	60	250	180	50	20		
	R. styliiformis			20	30			
	Thalassionema nitzschioides	20	50	120	50	20		
65	Thalassiothrix mediterranea	120	90	50	80	30	20	
	TOTAL DIATOMS	1270	5220	4280	2160	2500	660	200
	Dinophyceae							
	Ceratium bohmi		20					
	C. breve	20						
	C. candelabrum		10	30	10			
	C. declinatum declinatum		40					
	C. declinatum v. normale		20					
	C. furca	30						
	C. tripos		30	50	10			
	Dinophysis caudata	20						
	Diplopsalis lenticula		30					
	Goniodoma polyedricum		30	20				

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Ornithocercus magnificus		10	20				
Phalacroma porodictyum		10	20				
Podalampas spinifera		120	50				
Prorocentrum spp.	40	30					
Triposelenia bicornis	50	80	20				
TOTAL DINOFLAGELLATES	160	430	210	20			
Cyanophyta							
Trichodesmium spp.	230	180					
TOTAL PHYTOPLANKTON	1660	5830	4490	2180	2500	660	200

APPENDIX 3 continued.

		APRIL 21, 1978						
		Abundance in cells/l						
		Depth in meters						
Species		0	25	50	75	100	150	200
Bacillariophyceae								
Asterionella japonica		50	40	80				
Bacteriastrium delicatulum		150	125	450	120			
B. hyalinum		50	40	100				
Chaetoceros compressum		250	100	100				
C. decipiens		500	1200	1750	120			
C. indicum		20			10			
C. messanensis		50	80	160	25			
C. sociale		250	150	500	120	50		
Climacodium fraunfeldianum		120	250	350	25			
Corethron hystrix				40	10			
Guinardia flaccida		120						
Leptocylindrus danicus		80						
Nitzschia closterium		120	50					
N. longissima			25					
N. seriata		120	100	250	120	50		
Planktoniella sol			10	40	10			
Rhizosolenia alata		80	50		10			
R. bergonii		30		80				
R. calcar-avis		30	25	80	10			
R. hebetata		80	50	140	25			

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
<i>R. imbricata</i>		25		10			
<i>Thalassionema</i> spp.	20		80	25	10		
<i>Thalassiosira decipiens</i>	50	50	80	20	10		
<i>T. spp.</i>		30	80				
Unidentified Diatoms	50	75	250	75	25		
TOTAL DIATOMS	2220	2475	4610	735	145		
Dinophyceae							
<i>Ceratium bohmi</i>		10					
<i>C. breve</i>	50		20				
<i>C. declinatum</i>	30		20				
<i>C. furca</i>	30		10				
<i>C. fusus</i>	20		10				
<i>C. inflatum</i>		10	20				
<i>C. trichoceros</i>	20						
<i>C. tripos</i>	25			10			
<i>Ceratocorys armata</i>	25		20	10			
<i>Exuviaella compressa</i>			25				
<i>Goniodoma polyedricum</i>	25	50					
<i>Gonyaulax pacifica</i>			10				
<i>G. polygramma</i>	25						
Naked dinoflagellates	25	150	50	120			

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters					
	0	25	50	75	100	150 200
Ornithocercus magnificus	80	10	50	10		
Peridinium crassipes			10			
P. oblongum	25					
Peridiniopsis asymmetrica	25					
Phalacroma argus		25		10		
P. parvulum		25	10	10		
P. porodictyum		25				
Podalampas spinifera		25	50	25		
Prorocentrum micans	25					
Triposolenia bicornis	25					
TOTAL DINOFLAGELLATES	455	330	305	195		
Cyanophyta						
Trichodesmium spp.	100	25				
TOTAL PHYTOPLANKTON	2775	2830	4915	930	145	

APPENDIX 3 continued.

MAY 28, 1978
Abundance in cells/l
Depth in meters

	Species	0	25	50	75	100	150	200
70	Bacillariophyceae							
	Chaetoceros compressus		200	300	450	200	80	50
	C. sociale	200	400	500	600	200		
	Coscinosira spp.		25		50	30	20	
	Dactyliosolen spp.		50	200	100	50		
	Leptocylindrus minimus	200	350	600	800	100	50	
	Nitzschia closterium	250	250	300	350	50	20	30
	N. delicatissima	200	350	250	220	100	20	50
	N. seriata	50	75	250	50			
	N. sigma	50	30					
	Pleurosigma spp.	50	120	150	200	50	30	50
	Rhizosolenia alata v. gracillima	350	500	250	80	30		
	R. calcar-avis	20				10		
	R. delicatula	100	250	180	80	50	20	
	R. styliiformis	20	30	50	20			
	R. Shrubsolei	20	30	50	30			
	Schroderella delicatula			25				
	Thalassiosira decipiens			20		30		
	T. subtilis	30						
	Thalassiothrix fraunfeldii	200	180	250	50	30		

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
<i>Thalassiothrix longissima</i>	10	50	20				
<i>T. pacifica</i>			20		20		
TOTAL DIATOMS	1750	2890	3415	3080	950	240	180
Dinophyceae							
<i>Ceratium declinatum</i>	50	20	30				
<i>C. furca</i>	10	50	20				
<i>C. fusus</i>	30						
<i>C. kofoidii</i>	50	50	30	50			
<i>C. teres</i>	10						
<i>C. trichoceros</i>		20					
<i>C. tripos</i>	10		10		10		
<i>Dinophysis caudata</i>			30				
<i>Exuviaella</i> spp.	50	150	100	100			
<i>Goniodoma polyedricum</i>	20	50					
<i>Gonyaulax monacantha</i>	50	10	10	30			
<i>G. polygramma</i>	10	20	30	50			
<i>G. turbynei</i>	30	10					
<i>Oxytoxum scolopax</i>			20	50			
<i>Peridinium cerasus</i>	50	20	20	10			
<i>P. granii</i>	100	20	50	50			
<i>P. steinii</i>	10						

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Peridinium trochoideum	30	10					
Peridiniopsis asymmetrica	50	10	30	20			
Pyrophacus horologium		10					
Triposolenia bicornis		30					
Unidentified	20	50	150	250			
TOTAL DINOFLAGELLATES	580	530	530	610	10		
Cyanophyta							
Trichodesmium spp.	5800	2100	1800	1500	50		
TOTAL PHYTOPLANKTON	8130	5520	5745	5190	1010	240	180

APPENDIX 3 continued.

JUNE 27, 1978
Abundance in cells/l
Depth in meters

	Species	0	25	50	75	100	150	200
	Bacillariophyceae							
	Amphiprora gigantea	60	30	50	20	10		
	Chaetoceros affinis v. Willei	300	350	220	80	70	50	
	C. compressus		50	120	40			
	C. curvisetum	300	400	380	250	150		
	C. peruvianum			10				
73	C. pseudocurvisetum	240	200	180	80	60	50	
	C. sociale	300	350	40				
	Climacodium biconcavum		50		10			
	Coscinodiscus spp.			10				
	Coscinosira spp.			30				
	Hemiaulus hauckii		50	30	25			
	Leptocyldrus danicus	50	120	150	50	50	20	
	L. minimus	120	400	320	50	40		
	Licmophora abbreviata	20	80					
	Nitzschia closterium	80	80	120	30	20		
	N. delicatissima	50	80	120	10	30	10	
	Rhizosolenia alata	120	450	250	180	50		
	R. bergonii			10				
	R. calcar-avis			20				
	R. hebetata	30	40	80	20	10		

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters					
	0	25	50	75	100	150 200
Rhizosolenia Stolterfothii		200		50		10
Schroderella delicatula		20	50			
Thalassionema nitzschioides	250	400	300	100	50	50
Thalassiothrix spp. "A"	10	40	10	10		
TOTAL DIATOMS	1930	3390	2500	1005	540	190

Dinophyceae

74

Ceratium candelabrum		40				
C. declinatum	10	30	10			
C. furca	50	150	10			
C. fusus	50	30	50	10		
C. Kofoidii	10	30	50		10	
C. teres		50		10		
C. tripos				10		
Goniodoma polyedricum	10					
Gonyaulax dicantha		10				
G. turbynei	60	50				
Peridinium brochii		10				
P. cerasus	60	50	25	20	10	
P. steinii		20	20			
Peridiniopsis asymmetrica		10				

APPENDIX 3 continued.

		Abundance in cells/l Depth in meters						
Species		0	25	50	75	100	150	200
	Phalacroma doryphorium		10	10				
	Podalampas spinifera		50					
	Prorocentrum micans	20	50	80	10			
	Protoceratium spp. "A"	20						
	Spiraulax jolliffei			10				
	Triposolenia bicornis		20					
	Unidentified	50	80	120	20	20		
75	TOTAL DINOFLAGELLATES	340	690	385	80	40		
	Cyanophyta							
	Trichodesmium	8500	2500	500				
	TOTAL PHYTOPLANKTON	10770	6580	3385	1085	580	190	

APPENDIX 3 continued.

JULY 10, 1978
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Amphiprora gigantea	10			30	50	20	
Chaetoceros affinis	50	80	250	120	80	80	50
C. castracanei	50	80	120	150	50		
C. compressus	150	1200	500	400	30	120	80
C. curvisetum	50	120	350	200	120	80	50
C. Wighami	20	50	80	200	120	50	
C. spp.	800	500	350	120	80		
Dactyliosolen mediterraneus		20					
Guinardia flaccida		20					
Hemiaulus hauckii			25	50			
H. membranaceus		10					
Leptocylindrus danicus	430	980	250	120	50		
L. minimus	320	340	80	80	20		
Nitzschia closterium		180	60	50	50		
N. delicatissima		1600	950	250	180	50	
Pennate diatoms	50	60	80	50	120		
Rhizosolenia alata v. gracillima	300	550	120	50	80		
R. bergonii		10					
R. calcar-avis		60					
R. delicatula	100	720	400	150	20		

APPENDIX 3 continued.

Species	Abundance in cells/% Depth in meters						
	0	25	50	75	100	150	200
<i>Dinophysis sphaerica</i>		10		10	10		
<i>Diplopsalis lenticula</i>	20	50	10				
<i>Exuviaella</i> spp.	80	120	30	50			
<i>Gonyaulax polygramma</i>	10	30	50	30	10	10	
<i>G. turbynei</i>	50	20	30	50			
Naked dinoflagellates	1600	120	240	200	120	50	50
<i>Oxytoxum scolopax</i>				20			
<i>Peridinium cerasus</i>	200	250	180	150	100	80	80
<i>P. conicum</i>		10					
<i>P. granii</i>	40	50	80	100	50		
<i>P. pallidum</i>	10						
<i>P. pellucidum</i>	20	10	30	50	10		
<i>P. steinii</i>	40	20	30	50	10		
<i>P. trochoideum</i>	580	120	60	250	50	50	
<i>Peridiniopsis asymmetrica</i>	40	60					
<i>Phalacroma porodictyum</i>	10		20	10	20	10	10
<i>Prorocentrum micans</i>	200	120	80	150	80	50	50
<i>Pyrophacus horolocium</i>	20	10					
Small dinoflagellates	200	800	250	120	80	20	50
TOTAL DINOFLAGELLATES	3320	2220	1400	1520	650	390	300

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Rhizosolenia hebetata	20	50	80	50	10		
R. Shrubsolei	50	80	220	200	50	50	
R. Stolterfothii	50	60	30	80	10		
R. styliiformis		10					
Schroderella delicatula	400	250	250	80	20		
Thalassiosira decipiens	20	80	50	100	50		
Thalassiothrix longissima	80	20					
87 T. spp. "A"		50		20			
TOTAL DIATOMS	2950	7180	4245	2550	1190	450	180
Dinophyceae							
Ceratium breve	10						
C. declinatum	20	50	30	10		50	10
C. furca	40	80	80	100	60	50	40
C. furca v. "A"	40	40	20				
C. fusus	20	50	20	10		10	
C. Kofoidii	40	60	90	100	50		10
C. pentagonum		10					
C. teres	20	30	50	10			
C. trichoceros		60		50			
C. tripos		20	10				
Dinophysis ovum	10	20	10			10	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Cyanophyta							
Trichodesmium spp.	9650	2500	950	670	250	100	50
TOTAL PHYTOPLANKTON	15920	11900	6595	4740	2090	940	530

APPENDIX 3 continued.

		AUGUST 20, 1978						
		Abundance in cells/l						
		Depth in meters						
Species		0	25	50	75	100	150	200
Bacillariophyceae								
80	Chaetoceros affinis	350	450	300	200	80	120	50
	C. breve	120	80	100			50	
	C. coarctatum	450	350	150	50			
	C. compressus	800	1500	1100	650	150	50	
	C. curvisetum	2000	1800	1500	800	600	150	50
	C. decipiens	350	250	100	80	50		
	C. dichæta	150	300	180	50		50	
	C. Lauderi	50						
	C. peruvianum	120		80		50		
	C. tortissimum	150	180	50				
	Corethron spp. "A"	120	180	100	80			
	Dactyliosolen mediterraneus	900	700	600	150	50		
	Guinardia flaccida	1100	2000	850	600	250	150	100
	Leptocylindrus danicus	500	400	150	50	50		
	Nitzschia seriata	100	80	20	50	30		
	Rhizosolenia alata	50	80	150	120	30	50	
	R. bergonii	300	250	150	100	50		
	R. calcar-avis	350	150	200	120	80	50	
	R. fragilissima	300	400	250	120	80	50	50
	R. hebetata	300	250	150	120	50	50	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Rhizosolenia Shrubsolei	250	400	300	180	120	50	50
R. Stolterfothii	100	150	50	100	80	50	
Thalassiothrix delicatula	20	10					
T. spp. "A"	50	40	10		10		
TOTAL DIATOMS	8980	10000	6540	3620	1810	870	300
Dinophyceae							
Amphisolenia bidentata	10	20					
Ceratium declinatum	50	30	20	10			
C. extensum		20					
C. furca	120	80	50		10		
C. fusus	50	10	30	10			
C. massiliense	10						
C. tenue	10	30	20	10			
C. trichoceros	80	120	50	30			
C. tripos			20				
Cladopyxis brachiolata	10						
Dinophysis caudata	20	20	50				
Exuviaella spp.	50	80	30	20		10	
Gonyaulax polygramma	20	20	50		10		
Peridinium conicum	20	10					
Peridinium steinii	30	50					

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
Peridinium trochoideum	30	50	20				
Prorocentrum micans	120	180	50	20		20	
Pyrocystis elegans	20	10					
P. fusiformis		10					
TOTAL DINOFLAGELLATES	650	740	390	100	20	30	
Cyanophyta							
Trichodesmium spp.	6200	3800	1500	200	50		
TOTAL PHYTOPLANKTON	15830	14540	8430	3920	1880	900	300

APPENDIX 3 continued.

SEPTEMBER 23, 1978
Abundance in cells/l
Depth in meters

Species	0	25	50	75	100	150	200
Bacillariophyceae							
Asterionella japonica		10					
A. notata			360	300	400	100	
Chaetoceros coarctatum		10					
C. compressus	120	80	100	70	50		
C. curvisetum	200	150	180	140	50		
C. tortissimum	120	80	50	70	20		
Ditylium Brightwellii					20		
Guinardia flaccida	50						
Leptocylindrus danicus	120	80	50	80			
Licmophora flabellata							50
Navicula membranacea	10	30					
Nitzschia closterium	10		30	50	80	70	
N. seriata	1800	1300					
Pennate diatoms	120	80	70	120	50	20	50
Rhizosolenia alata	50	130	80	40	60	30	
R. bergonii		10					
R. calcar-avis		30	20				
R. hebetata	50		50			20	
R. Shrubsolei	50	20	40	30	10		
R. Stolterfothii	150	80	120	50	40	30	

APPENDIX 3 continued.

Species	Abundance in cells/l Depth in meters						
	0	25	50	75	100	150	200
<i>Thalassionema nitzschioides</i>	50	50	120	80	140	50	50
<i>Thalassiosira decipiens</i>			20		50		
TOTAL DIATOMS	2900	2140	1290	1030	970	320	150
Dinophyceae							
<i>Ceratium Kofoidii</i>	30	20	30	10	10		
<i>C. teres</i>	10	10	20				
<i>Exuviaella compressa</i>	50	20	10				
Naked dinoflagellates	150	160	100	150	120		
<i>Oxytoxum scolopax</i>		20					
<i>Peridinium</i> spp.	80	30	50		10		
<i>Prorocentrum micans</i>	150	30	80	40	20		50
TOTAL DINOFLAGELLATES	470	290	290	200	160		50
Cyanophyta							
<i>Trichodesmium</i> spp.	80	50					
TOTAL PHYTOPLANKTON	3450	2480	1580	1230	1130	320	200

APPENDIX 3 continued.

OCTOBER 25, 1978
Abundance in cells/l
Depth in meters

Species	Depth in meters						
	0	25	50	75	100	150	200
Dinophyceae							
Ceratium bohmi		10					
C. contrarium	10						
C. declinatum	10	10		10			
C. furca	30	10	10	20	10		
C. trichoceros	10		40	20	50		
Exuviaella compressa		20					
Podalampas spinifera			10				
Prorocentrum micans	10		10				
Unidentified spp.	10	10	20	10			
TOTAL DINOFLAGELLATES	80	60	90	60	60		
TOTAL PHYTOPLANKTON	80	60	90	60	60		

APPENDIX 4: PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF
JIDDAH - Sharm Station; Net hauls and bottle casts

NOVEMBER 3, 1977

Bacillariophyceae

Biddulphia vesiculosa
B. spp.
Campylodiscus spp.
Chaetoceros coarctatum
C. convolutus
Cocconeis spp.
Gossleriella tropica
Leptocylindrus danicus
Licmophora abbreviata
Nitzschia closterium
N. delicatissima
N. seriata
Pennate diatoms

Dinophyceae con't

Pyrocystis elegans
P. fusiformis
Unidentified

Cyanophyta

Trichodesmium spp.

Dinophyceae

Ceratium carriense
C. contortum
C. declinatum
C. furca
C. macroceros
C. trichoceros
Diplopsalis lenticula
Exuviaella compressa
E. spp.
Goniodoma sphaericum
Gonyaulax polygramma
Gymnodinium spp.
Prorocentrum micans

APPENDIX 4 continued.

NOVEMBER 17, 1977

Bacillariophyceae

Campylodiscus spp.
Chaetoceros affinis
C. coarctatum
C. decipiens
Gossleriella tropica
Leptocylindrus danicus
Licmophora flabellata
Nitzschia closterium
N. delicatissima
N. seriata
Pennate diatoms
Planktoniella sol

Dinophyceae con't

Pyrocystis pseudonociluca

Cyanophyta

Dinophyceae

Ceratium carriense
C. contortum
C. declinatum
C. furca
C. teres
C. trichoceros
Exuviaella spp.
Goniodoma spp.
Gonyaulax spp.
Gymnodinium spp.
Naked dinoflagellates
Peridinium spp.
Prorocentrum micans
Pyrocystis elegans
P. fusiformis

DECEMBER 27, 1977

Bacillariophyceae

Bacteriastrum delicatulum
 B. hyalinum
 Biddulphia spp.
 Campylodiscus spp.
 Chaetoceros affinis
 C. coarctatum
 C. compressus
 C. concaviformis
 C. convolutus
 C. curvisetum
 C. dadayi
 C. decipiens
 C. didymum
 C. messanensis
 C. peruvianum
 C. tetrastichon
 Coscinodiscus concinnus
 C. excentricus
 C. spp.
 Dactyliosolen mediterraneus
 Ditylium Brightwelli
 Guinardia blavyana
 G. flaccida
 Hemiaulus membranaceus
 H. sinensis
 Leptocylindrus danicus
 Nitzschia seriata
 Planktoniella sol

Bacillariophyceae con't

Rhizosolenia alata
 R. bergonii
 R. calcar-avis
 R. hebetata
 R. Shrubsolei
 Striatella delicatula
 S. unipunctata
 Thalassiosira decipiens
 T. subtilis
 Thalassiothrix delicatula spp.
 T. fraunfeldii
 T. spp. "A"
 Tropidoneis lepidoptera

Dinophyceae

Amphidinium spp.
 Amphisolenia bidentata
 Ceratium candelabrum
 C. contortum
 C. contrarium
 C. declinatum
 C. extensum
 C. furca
 C. fusus
 C. macroceros
 C. massiliense
 C. pentagonum
 C. platycorne

APPENDIX 4 continued.

Dinophyceae con't

Ceratium reflexum
C. tenue
C. teres
C. trichoceros
C. vultur
Ceratocorys armata
C. horrida
Dinophysis caudata
Exuviaella compressa
Goniodoma polyedricum
G. spaericum
Gonyaulax monacantha
G. polygramma
Histioneis spp.
Naked dinoflagellates
Noctiluca miliaris
Peridinium brochii
P. cerasus
P. divergens
P. steinii
P. truncatum
P. spp.
Phalacroma circumsutum
P. doryphorium
P. parvulum
Podalampas bipes
P. spinifera
Prorocentrum micans
Protoceratum reticulatum

Dinophyceae con't

Pyrocystis elegans
P. fusiformis
P. pseudonociluca
Pyrophacus horologium
Triposolenia bicornis

JANUARY 25, 1978

Bacillariophyceae

Asterionella japonica
 A. notata
 Bacteriastrum delicatulum
 B. hyalinum
 Cerataulina bergonii
 Chaetoceros affinis
 C. atlanticus
 C. brevis
 C. coarctatum
 C. compressus
 C. concaviformis
 C. convolutus
 C. curvisetum
 C. dadayi
 C. danicus
 C. decipiens
 C. dictyota
 C. didymum
 C. diversus
 C. eibonii
 C. laciniosus
 C. Lauderer
 C. pendulum
 C. peruvianum
 C. teres
 C. tetrastichon
 C. tortissimum
 Climacodium fraunfeldianum
 Coscinodiscus excentricus
 C. spp.

Bacillariophyceae con't

Coscinosira spp.
 Dactyliosolen mediterraneus
 Fragilaria oceanica
 Guinardia blavyana
 G. flaccida
 Hemiaulus hauckii
 Hemidiscus cuneiformis
 Lauderia borealis
 Navicula membranacea
 Nitzschia closterium
 N. longissima
 N. seriata
 Other pennates
 Planktoniella sol
 Rhizosolenia alata
 R. alata v. spp. "A"
 R. bergonii
 R. calcar-avis
 R. castracanei
 R. delicatula
 R. fragilissima
 R. hebetata
 R. imbricata
 R. Shrubsolei
 R. Stolterfothii
 R. styliiformis
 R. spp.
 Streptotheca thamesis
 Striatella unipunctata

APPENDIX 4 continued.

Bacillariophyceae con't

Thalassionema nitzschioides
Thalassiosira decipiens
T. subtilis
Thalassiothrix delicatula
T. fraunfeldii
T. spp. "A"

Dinophyceae

Amphisolenia bidentata
Ceratium arietinum
C. carriense
C. contrarium
C. declinatum
C. furca
C. fusus
C. inflatum
C. Kofoidii
C. macroceros
C. massiliense
C. reflexum
C. tenue
C. teres
C. trichoceros
C. tripos
C. vultur
Dinophysis caudata
D. spp.
Diplopsalis lenticula

Dinophyceae con't

Exuviaella spp.
Goniodoma polyedricum
G. sphaericum
Gonyaulax polygramma
G. turbynei
Peridinium abei
P. brochii
P. cerasus
P. conicum
P. crassipes
P. depressum
P. diabolus
P. divergens
P. granii
P. oblongum
P. oceanicum
P. pallidum
P. trochoideum
P. truncatum
Peridiniopsis asymmetrica
Prorocentrum micans
Pyrophacus horologium
Spiraulax jolliffei
Unidentified

Chrysophyta

Dictyocha fibule

APPENDIX 4 continued.

FEBRUARY 14, 1978

Bacillariophyceae

Asterionella notata
Benthic diatoms
Chaetoceros affinis
C. coarctatum
C. decipiens
C. tetrastichon
Dactyliosolen mediterraneas
Fragilaria oceanica
Guinardia flaccida
Nitzschia closterium
N. seriata
Planktoniella sol
Rhizosolenia alata
R. bergonii
R. Shrubsolei
R. Stolterfothii
Skeletonema costatum
Thalassiothrix spp. "A"

Dinophyceae

Ceratium arietinum
C. breve
C. carriense
C. candelabrum
C. contortum
C. declinatum
C. dens
C. furca

Dinophyceae con't

Ceratium fusus
C. Karstenii
C. longirostrum
C. macroceros
C. massiliense
C. pavillardii
C. teres
C. trichoceros
C. vultur
Diplopsalis lenticula
Goniodoma polyedricum
G. sphaericum
Naked dinoflagellates
Peridinium depressum
P. diabolus
P. globulus
P. pyriforme
Pyrocystis elegans
P. pseudonoctiluca
Pyrophacus horologium

APPENDIX 4 continued.

MARCH 14, 1978

Bacillariophyceae

Achnanthes brevipes
Bacillaria paradoxa
Chaetoceros affinis
C. dađayi
C. Wighami
C. spp.
Campylodiscus echensis
Climacodium fraunfeldianum
Dactyliosolen spp.
Hemidiscus cuneiformis
Leptocylindrus danicus
Nitzschia closterium
N. delicatissima
Planktoniella sol
Rhizosolenia acuminata
R. alata
R. Shrubsolei
Schroderella delicatula
Striatella delicatula
S. unipunctata
Thalassiosira decipiens
T. rotula
Thalassiothrix spp. "A"

Dinophyceae

Ceratium breve
C. contortum
C. declinatum
C. dens

Dinophyceae con't

Ceratium extensum
C. furca
C. fusus
C. incisum
C. Kofoidii
C. massiliense
C. pentagonum
C. tenue
C. teres
C. trichoceros
C. tripos
Ceratocorys armata
C. horrida
Diplopsalis lenticula
Goniodoma polyedricum
Gonyaulax turbynei
Ornithocercus spp.
Peridinium conicum
P. crassipes
P. diabolus
P. oceanicum
P. steinii
P. trochoideum
Small dinoflagellates
Triposolenia bicornis

APPENDIX 4 continued.

APRIL 11, 1978

Bacillariophyceae

Amphiprora spp.
Bacillaria paradoxa
Bellerochea malleus
Biddulphia aurita
Chaetoceros decipiens
Climacodium fraunfeldianum
Cocconeis spp.
Coscinodiscus excentricus
Isthmia enervis
Licmophora abbreviata
L. flabellata
Nitzschia closterium
N. longissima v. reversa
N. seriata
Other benthic diatoms
Pleurosigma rectum
P. rigidum
P. spp.
Rhizosolenia alata
R. bergonii
R. calcar-avis
Thalassionema nitzschioides
Thalassiothrix mediterranea

Dinophyceae

Ceratium bohmi
C. breve
C. candelabrum

Dinophyceae con't

Ceratium declinatum
C. egyptiacum
C. furca
C. fusus
C. massiliense
C. trichoceros
C. tripos
Ceratocorys armata
C. horrida
Cladopyxis brachiolata
Dinophysis caudata
Diplopsalis lenticula
Exuviaella compressa
E. oblonga
Goniodoma polyedricum
G. sphaericum
Gonyaulax polygramma
G. turbynei
Ornithocercus magnificus
Peridinium abei
P. cerasus
P. conicum
P. crassipes
P. depressum
P. divergens
P. granii
P. oblongum
P. steinii
Peridiniopsis asymmetrica

APPENDIX 4 continued.

Dinophyceae con't

Peridiniopsis trochoideum

Phalacroma porodictyum

Podalampas bipes

P. palmipes

Prorocentrum gracile

P. micans

Triposolenia bicornis

APPENDIX 4 continued.

APRIL 21, 1978

Bacillariophyceae

Benthic diatoms
Biddulphia obtusa
Chaetoceros decipiens
C. socialis
Coscinodiscus excentricus
Leptocylindrus danicus
Rhizosolenia alata
R. calcar-avis
Thalassiothrix spp.

Dinophyceae

Ceratium bohmi
C. breve
C. contrarium
C. declinatum
C. egyptiacum
C. furca
C. furca v. spp. "A"
C. fusus
C. massiliense
C. trichoceros
C. tripos
Exuviaella compressa
Peridinium depressum
P. divergens
P. granii
P. steinii
P. trochoideum

APPENDIX 4 continued.

MAY 10, 1978

Bacillariophyceae

Amphiprora spp.
Asterionella notata
Benthic diatoms
Leptocylindrus minimus
Licmophora abbreviata
Nitzschia closterium
N. delicatissima
N. longissima
Rhizosolenia acuminata
R. alata
Striatella unipunctata
Thalassiothrix longissima

Dinophyceae con't

Prorocentrum micans
Pyrophacus horologium
Small dinoflagellates

Cyanophyta

Trichodesmium spp.

Dinophyceae

Ceratium breve
C. contrarium
C. furca
C. fusus
C. Kofoidii
C. massiliense
C. trichoceros
C. tripos
Ceratocorys armata
Exuviaella compressa
Ornithocercus spp.
Peridinium brochii
P. granii
P. trochoideum

MAY 28, 1978

Bacillariophyceae

Amphiprora alata
 Asterionella notata
 Cerataulina bergonii
 Chaetoceros affinis v. Willei
 C. compressus
 C. curvisetum
 C. danicus
 C. peruvianum
 C. pseudoperuvianum
 C. socialis
 Climacosphenia spp.
 Cocconeis spp.
 Ethmodiscus gazellae
 Guinardia flaccida
 Hemiaulus hauckii
 Hemidiscus cuneiformis
 Leptocylindrus danicus
 L. minimus
 Licmophora spp.
 Nitzschia closterium
 N. delicatissima
 N. longissima
 N. seriata
 Pennate diatoms
 Pleurosigma fasciola
 P. spp.
 Rhizosolenia acuminata
 R. alata
 R. bergonii
 R. calcar-avis

Bacillariophyceae con't

Rhizosolenia delicatula
 R. Shrubsolei
 R. Stolterfothii
 Thalassiothrix longissima
 T. spp. "A"
 Unidentified

Dinophyceae

Ceratium breve
 C. candelabrum
 C. contrarium
 C. declinatum
 C. extensum
 C. furca
 C. fusus
 C. Kofoidii
 C. massiliense
 C. pentagonum
 C. tenue
 C. teres
 C. trichoceros
 Dinophysis caudata
 Exuviaella spp.
 Goniiodoma polyedricum
 Gonyaulax polygramma
 Ornithocercus spp.
 Peridinium brochii
 P. cerasus
 P. divergens
 P. globulus

APPENDIX 4 continued.

Dinophyceae con't

Peridinium granii

P. oceanicum

P. steinii

P. trochoideum

Peridiniopsis asymmetrica

Prorocentrum micans

Small dinoflagellates

Cyanophyta

Trichodesmium spp.

JUNE 20, 1978

Bacillariophyceae

Amphiprora spp.
Asterionella notata
Benthic diatoms
Biddulphia pelagica
Chaetoceros danicus
C. peruvianum
Climacospheia moniligera
Diploneis crabro
Hemiaulus hauckii
Licmophora abbreviata
Nitzschia closterium
N. delicatissima
N. longissima
N. longissima v. reversa
N. paradoxa
N. seriata
Pleurosigma spp.
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. delicatula
R. imbricata
R. Stolterfothii
Thalassiothrix longissima
T. spp. "A"

Dinophyceae

Ceratium breve
C. candelabrum
C. contrarium

Dinophyceae con't

Ceratium declinatum
C. extensum
C. furca v. spp. "A"
C. fusus
C. Kofoidii
C. massiliense
C. strictum
C. trichoceros
C. tripos
Cladopyxis brachiolata
Dinophysis caudata
D. tripos
Diplopsalis lenticula
Goniodoma polyedricum
Gonyaulax polygramma
Ornithocercus spp.
Peridinium cerasus
P. steinii
Peridiniopsis asymmetrica
Prorocentrum micans
Pyrophacus horologium
Small dinoflagellates

Cyanophyta

Trichodesmium spp.

JULY 18, 1978

Bacillariophyceae

Chaetoceros compressus
C. curvisetum
C. dadayi
C. hispidus
C. peruvianum
C. pseudoperuvianum
C. Weissflogii
Hemiaulus membranaceus
Nitzschia closterium
N. delicatissima
N. longissima
Pennate, unidentified
Rhizosolenia alata
R. delicatula
R. hebetata
R. Stolterfothii
Thalassiothrix longissima
T. spp. "A"

Dinophyceae

Ceratium breve
C. candelabrum
C. declinatum
C. furca
C. trichoceros
C. tripos
Ceratocorys horrida
Dinophysis caudata

Dinophyceae con't

Goniodoma polyedricum
Gonyaulax polygramma
Naked Gymnodinium & Amphidinium
Ornithocercus spp.
Peridinium brochii
P. cerasus
P. crassipes
P. depressum
P. divergens
P. steinii
Prorocentrum micans
Pyrophacus horologium
Unidentified small dinoflagellates

Cyanophyta

Trichodesmium spp.

APPENDIX 4 continued.

JULY 25, 1978

Bacillariophyceae

Amphiprora alata
Bellerocha malleus
Benthic diatoms
Biddulphia pelagica
B. spp.
Climacosphenia moniligera
Fragilaria spp.
Licmophora flabellata
L. spp.
Mastogloia spp.
Nitzschia closterium
N. longissima
N. seriata
Pleurosigma fasciola
P. naviculaceum
P. spencerii
Rhizosolenia alata
R. Shrubsolei
Surirella fastuosa
S. spp. "A"
S. spp.
Tropidoneis lepidoptera

Dinophyceae

Ceratium breve
C. furca
C. fusus
C. massiliense

Dinophyceae con't

Ceratium trichoceros
C. tripos
Ceratocorys armata
C. gourettii
C. horrida
Dinophysis caudata
Diplopsalis lenticula
Gonyaulax polygramma
G. turbynei
Naked dinoflagellates
Peridinium cerasus
P. conicum
P. depressum
P. pallidum
P. steinii
P. trochoideum
Peridiniopsis asymmetrica
Unidentified

Cyanophyta

Trichodesmium spp.

APPENDIX 4 continued.

AUGUST 20, 1978

Bacillariophyceae

Chaetoceros affinis
C. coarctatum
C. compressus
C. curvisetum
C. decipiens
C. tortissimum
Climacosphenia moniligera
Dactyliosolen mediterraneus
Guinardia blavyana
G. flaccida
Hemiaulus sinensis
Leptocylindrus danicus
Licmophora flabellata
Navicula membranacea
Nitzschia seriata
Pleurosigma spp.
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. fragilissima
R. hebetata
R. Shrubsolei
R. Stolterfothii
R. styliiformis
R. temperei
Thalassiothrix delicatula
T. spp. "A"

Dinophyceae

Ceratium breve
C. contrarium
C. declinatum
C. egyptiacum
C. furca
C. fusus
C. macroceros
C. massiliense
C. trichoceros
C. tripos
Ceratocorys horrida
Dinophysis caudata
Peridinium divergens
P. pyriforme
P. spp.
Unidentified

APPENDIX 4 continued.

SEPTEMBER, 1978

Bacillariophyceae

Chaetoceros affinis
C. decipiens
Climacospheia moniligera
Guinardia flaccida
Leptocylindrus danicus
Licmophora spp.
Nitzschia closterium
N. seriata
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. hebetata
R. Shrubsolei
R. Stolterfothii

Dinophyceae con't

Oxytoxum scolopax
Peridinium brochii
P. divergens
P. pyriforme
P. steinii
Peridiniopsis asymmetrica
Prorocentrum micans
Pyrocystis elegans
P. fusiformis
P. pseudonociluca
Pyrophacus horologium
P. spp. "A"
Unidentified

Dinophyceae

Ceratium breve
C. egyptiacum
C. furca
C. fusus
C. Kofoidii
C. massiliense
C. trichoceros
Dinophysis caudata
Diplopsalis lenticula
Exuviaella spp.
Goniodoma shaericum
Gonyaulax monacantha
G. polygramma
G. turbynei

APPENDIX 4 continued.

OCTOBER, 1978

Bacillariophyceae

Diatom centric

Diatom pennate

Dinophyceae

Ceratium furca

C. furca v. spp. "A"

Exuviaella compressa

Peridinium pallidum

Prorocentrum micans

Unidentified dinoflagellates

APPENDIX 5: PHYTOPLANKTON SPECIES RECORDED IN THE REGION OF
JIDDAH - Offshore Station; Net hauls and bottle casts

NOVEMBER 3, 1977

Bacillariophyceae

Asterionella japonica
Bacteriastrum hyalinum
Chaetoceros affinis
C. brevis
C. coarctatum
C. compressus
C. concaviformis
C. curvisetum
C. decipiens
C. didymum
C. pendulum
C. peruvianum
Coscinodiscus asteromphalus
C. concinnus
C. excentricus
C. gigas
C. nobilis
C. oculus-iridis
C. perforatus
C. radiatus
Guinardia flaccida
Leptocylindrus spp.
Nitzschia bilobata
N. seriata
Rhizosolenia alata
R. calcar-avis
R. delicatula
R. fragilissima

Bacillariophyceae con't

Rhizosolenia hebetata
R. imbricata
R. Shrubsolei
R. Stolterfothii
Streptotheca thamesis
Thalassiothrix delicatula
T. fraunfeldii
T. spp. "A"

Dinophyceae

Amphisolenia bidentata
Ceratium breve
C. dens
C. furca
C. massiliense
C. trichoceros
Exuviaella spp.
Oxytoxum tessellatum
Naked dinoflagellates
Peridinium pellucidum
P. pyriforme
Prorocentrum spp.
Pyrocystis elegans
P. fusiformis

Cyanophyta

Trichodesmium spp.

NOVEMBER 7, 1977

Bacillariophyceae

Chaetoceros concaviformis

Nitzschia closterium

N. longissima

N. seriata

Rhizosolenia alata

Dinophyceae

Amphisolenia bidentata

Ceratium breve

C. contortum

C. declinatum

C. dens

C. furca

C. macroceros

C. teres

Peridinium spp.

Pyrocystis elegans

P. fusiformis

Other dinoflagellates

Cyanophyta

Trichodesmium spp.

DECEMBER 27, 1977

Bacillariophyceae

Bacillaria paradoxa
 Bacteriastrum hyalinum
 Benthic diatoms
 Chaetoceros affinis
 C. coarctatum
 C. compressus
 C. concaviformis
 C. convolutus
 C. curvisetum
 C. dadayi
 C. decipiens
 C. didymum
 C. peruvianum
 C. tetrastichon
 Coscinodiscus spp.
 Grammatophora marina
 Guinardia blavyana
 G. flaccida
 Hemiaulus membranaceus
 Leptocylindrus danicus
 Nitzschia seriata
 Planktoniella sol
 Rhizosolenia acuminata
 R. alata
 R. bergonii
 R. calcar-avis
 R. castracanei
 R. hebetata
 R. Shrubsolei

Bacillariophyceae con't

Thalassiothrix delicatula

Dinophyceae

Amphisolenia bidentata
 Ceratium bohmi
 C. carriense
 C. contortum
 C. contrarium
 C. declinatum
 C. declinatum v. normale
 C. extensum
 C. furca
 C. fusus
 C. hexacanthum
 C. Kofoidii
 C. lunula
 C. macroceros
 C. massiliense
 C. tenue
 C. teres
 C. trichoceros
 Ceratocorys armata
 C. horrida
 Dinophysis caudata
 D. spp.
 Goniiodoma polyedricum
 Gonyaulax monacantha
 G. polygramma
 Histioneis spp.

APPENDIX 5 continued.

Dinophyceae con't

Ornithocercus magnificus

O. steinii

Parahistioneis spp.

Peridinium abei

P. cerasus

P. divergens

P. granii

P. steinii

P. trochoideum

P. truncatum

Phalacroma doryphorium

Podalampas bipes

P. spinifera

Prorocentrum micans

Pyrocystis elegans

P. fusiformis

P. lunula

P. pseudonoctiluca

Pyrophacus horologium

Triposolenia bicornis

JANUARY 29, 1978

Bacillariophyceae

Bacteriastrium biconicum
B. delicatulum
B. hyalinum
Benthic diatoms
Biddulphia spp.
Cerataulina bergonii
Chaetoceros affinis
C. atlanticus
C. coarctatum
C. compressus
C. concaviformis
C. convolutus
C. curvisetum
C. decipiens
C. dictyota
C. didymum
C. laciniatus
C. lauderi
C. peruvianum
C. teres
C. tetrastrum
C. tortuosum
Climacodium fraunfeldianum
Guinardia blavyana
G. flaccida
Leptocylindrus danicus
Licmophora flabellata
Navicula membranacea
Nitzschia closterium

Bacillariophyceae con't

Nitzschia longissima
N. seriata
Planktoniella sol
Rhizosolenia alata
R. alata indica
R. bergonii
R. calcar-avis
R. delicatula
R. fragilissima
R. hebetata
R. imbricata
R. Shrubsolei
R. Stolterfothii
R. styliiformis
Stephanopyxis turris
Streptotheca thamesis
Striatella unipunctata
Thalassiosira subtilis
Thalassiothrix longissima
T. spp. "A"

Dinophyceae

Amphisolenia bidentata
Ceratum arietinum
C. breve
C. carriense
C. contrarium
C. declinatum
C. furca

APPENDIX 5 continued.

Dinophyceae con't

Ceratium fusus

C. Kofoidii

C. macroceros

C. massiliense

C. teres

C. trichoceros

C. tripos

Diplopsalis lenticula

Exuviaella spp.

Goniodoma polyedricum

G. sphaericum

Gonyaulax polygramma

Peridinium divergens

P. oceanicum

P. pyriforme

P. sphaericum

P. spp.

P. steinii

P. trochoideum

P. truncatum

Prorocentrum micans

Pyrocystis lunula

P. pseudonociluca

Pyrophacus horologium

FEBRUARY 22, 1978

Bacillariophyceae

Asterionella japonica
 A. notata
 Bacteriastrum hyalinum
 Benthic diatoms
 Chaetoceros affinis
 C. coarctatum
 C. compressus
 C. concaviformis
 C. curvisetum
 C. decipiens
 C. laciniosus
 C. peruvianum
 Guinardia flaccida
 Hemidiscus cuneiformis
 Planktoniella sol
 Rhizosolenia alata
 R. bergonii
 R. hebetata
 R. Shrubsolei
 R. Stolterfothii
 Skeletonema costatum
 Thalassiothrix spp. "A"

Dinophyceae con't

Ceratium fusus
 C. spp.
 C. trichoceros
 C. tripos
 Ceratocorys horrida
 Cladopyxis brachiolata
 Diplopsalis lenticula
 Exuviaella compressa
 Goniiodoma sphaericum
 Gonyaulax polygramma
 Naked dinoflagellates
 Peridinium cerasus
 P. pellucidum
 P. steinii
 P. trochoideum
 Phalacroma parvulum
 Prorocentrum micans

Dinophyceae

Ceratium arietinum
 C. bohmi
 C. breve
 C. furca

MARCH 3, 1978

Bacillariophyceae

Asterionella japonica
Bacillaria paradoxa
Chaetoceros affinis
C. dadayi
C. decipiens
C. peruvianum
C. Wighami
Climacodium fraunfeldianum
Guinardia flaccida
Hemidiscus cuneiformis
Leptocylindrus danicus
Nitzschia closterium
N. delicatissima
N. seriata
Planktoniella sol
Pleurosigma spp.
Rhizosolenia acuminata
R. alata
R. Shrubsolei
Striatella unipunctata
Thalassionema nitzschioides
Thalassiosira rotula

Dinophyceae

Ceratium breve
C. candelabrum
C. contrarium
C. declinatum

Dinophyceae con't

Ceratium dens
C. extensum
C. furca
C. fusus
C. incisum
C. Kofoidii
C. massiliense
C. pentagonum
C. schmidtii
C. tenue
C. teres
C. trichoceros
C. tripos
C. vultur
Ceratocorys armata
C. horrida
Cladopyxis brachiolata
Diplopsalis lenticula
Exuviaella spp.
Naked dinoflagellates
Ornithocercus spp.
Peridinium cerasus
P. conicum
P. crassipes
P. depressum
P. diabolus
P. granii
P. oblongum

APPENDIX 5 continued.

Dinophyceae con't

Peridinium oceanicum

P. pallidum

P. steinii

P. trochoideum

Peridiniopsis asymmetrica

Podalampas spinifera

Prorocentrum spp.

Small dinoflagellates

Triposolenia bicornis

APPENDIX 5 continued.

APRIL 11, 1978

Bacillariophyceae

Amphiprora spp.
Asterionella japonica
Bacillaria paradoxa
Bacteriastrium delicatulum
B. hyalinum
Benthic diatoms
Chaetoceros affinis
C. compressus
C. decipiens
C. peruvianum
C. socialis
Climacodium fraunfeldianum
Coscinodiscus excentricus
Guinardia flaccida
Hemidiscus cuneiformis
Isthmia enervis
Leptocylindrus danicus
Nitzschia closterium
N. seriata
Planktoniella sol
Pleurosigma balticum
P. spp.
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. hebetata
R. Shrubsolei
R. styliiformis

Bacillariophyceae con't

Thalassionema nitzschioides
Thalassiothrix mediterranea

Dinophyceae

Ceratium bohmi
C. breve
C. candelabrum
C. contrarium
C. declinatum declinatum
C. declinatum v. normale
C. dens
C. egyptiacum
C. furca
C. fusus
C. horridum
C. massiliense
C. schmidtii
C. trichoceros
C. tripos
C. vultur
C. spp.
Ceratocorys armata
C. horrida
Cladopyxis brachiolata
Dinophysis caudata
Diplopsalis lenticula
Exuviaella spp.
Goniodoma polyedricum

APPENDIX 5 continued.

Dinophyceae con't

Goniodoma sphaericum
Gonyaulax dicantha
G. monacantha
G. turbynei
Ornithocercus magnificus
O. quadratus
Peridinium brochii
P. cerasus
P. conicum
P. crassipes
P. depressum
P. diabolus
P. divergens
P. granii
P. oblongum
P. pellucidum
P. steinii
Peridiniopsis asymmetrica
Phalacroma argus
P. porodictyum
Podalampas spinifera
Prorocentrum spp.
Triposolenia bicornis

Cyanophyta

Trichodesmium spp.

APRIL 21, 1978

Bacillariophyceae

Asterionella japonica
Bacteriastrium delicatulum
B. hyalinum
Campylodiscus echensis
Chaetoceros compressus
C. decipiens
C. indicum
C. messanensis
C. socialis
Climacodium fraunfeldianum
Corethron hystrix
Guinardia flaccida
Leptocylindrus danicus
Nitzschia closterium
N. longissima
N. seriata
Planktoniella sol
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. hebetata
R. imbricata
Surirella spp. "A"
Synedra crystallina
Thalassionema spp.
Thalassiosira decipiens
T. spp.
Unidentified diatoms

Dinophyceae

Ceratium bohmi
C. breve
C. candelabrum
C. contrarium
C. declinatum
C. egyptiacum
C. furca
C. furca v. hircus
C. fusus
C. inflatum
C. longirostrum
C. pentagonum
C. schmidtii
C. trichoceros
C. tripos
Ceratocorys armata
C. horrida
Cladopyxis brachiolata
Diplopsalis lenticula
Exuviaella compressa
Goniodoma polyedricum
Gonyaulax pacifica
G. polygramma
Naked dinoflagellates
Ornithocercus magnificus
Peridinium crassipes
P. depressum
P. divergens
P. oblongum
P. spp.

APPENDIX 5 continued.

Dinophyceae con't

Peridiniopsis asymmetrica

Phalacroma argus

P. parvulum

P. porodictyum

Podalampas palmipes

P. spinifera

Prorocentrum micans

Triposolenia bicornis

Cyanophyta

Trichodesmium spp.

MAY 28, 1978

Bacillariophyceae

Chaetoceros compressus
C. socialis
Coscinosira spp.
Dactyliosolen spp.
Leptocylindrus minimus
Nitzachia closterium
N. delicatissima
N. seriata
N. sigma
Pleurosigma spp.
Rhizosolenia alata v. gracillima
R. calcar-avis
R. delicatula
R. imbricata
R. Shrubsolei
R. styliiformis
Schroderella delicatula
Thalassiosira decipiens
T. subtilis
Thalassiothrix fraunfeldii
T. longissima
T. spp. "A"

Dinophyceae

Ceratium breve
C. candelabrum
C. contortum
C. declinatum

Dinophyceae con't

Ceratium extensum
C. furca
C. fusus
C. Kofoidii
C. macroceros
C. massiliense
C. pentagonum
C. tenue
C. teres
C. trichoceros
C. tripos
Ceratocorys horrida
Dinoflagellates unidentified
Dinophysis caudata
Diplopsalis lenticula
Exuviaella compressa
Goniodoma polyedricum
Gonyaulax monacantha
G. polygramma
G. turbynei
Ornithocercus spp.
Oxytoxum scolopax
Peridinium cerasus
P. crassipes
P. granii
P. oceanicum
P. pallidum
P. pellucidum

APPENDIX 5 continued.

Dinophyceae con't

Peridinium steinii

P. trochoideum

Peridiniopsis asymmetrica

Pyrophacus horologium

Triposolenia bicornis

Cyanophyta

Trichodesmium spp.

JUNE 27, 1978

Bacillariophyceae

Amphiprora gigantea
 Asterionella japonica
 A. notata
 Biddulphia pelagica
 B. schroderiana
 Chaetoceros affinis v. Willei
 C. compressus
 C. curvisetum
 C. peruvianum
 C. pseudoperuvianum
 C. socialis
 Climacodium biconcavum
 Coscinodiscus spp.
 Coscinosira spp.
 Hemiaulus hauckii
 Hemidiscus cuneiformis
 H. membranaceus
 Leptocylindrus danicus
 L. minimus
 Licmophora abbreviata
 Nitzschia closterium
 N. delicatissima
 Rhizosolenia alata
 R. alata v. gracillima
 R. bergonii
 R. calcar-avis
 R. clevei
 R. hebetata

Bacillariophyceae con't

Rhizosolenia imbricata
 R. Stolterfothii
 Schroderella delicatula
 Thalassionema nitzschioides
 Thalassiothrix spp. "A"

Dinophyceae

Ceratium breve
 C. candelabrum
 C. contortum
 C. declinatum
 C. furca
 C. fusus
 C. Kofoidii
 C. longirostrum
 C. tenue
 C. teres
 C. trichoceros
 C. tripos
 C. vultur
 Ceratocorys armata
 C. horrida
 Cladopyxis brachiolata
 Diplopsalis lenticula
 Goniodoma polyedricum
 Gonyaulax diacantha
 G. polygramma
 G. turbynei

JUNE 27, 1978

Dinophyceae con't

Ornithocercus magnificus

O. spp.

Peridinium brochii

P. cerasus

P. divergens

P. steinii

Peridiniopsis asymmetrica

Phalacroma doryphorium

Podalampas spinifera

Prorocentrum micans

Protoceratium spp. "A"

Spiraulax jolliffei

Triposolenia bicornis

Unidentified

Cyanophyta

Trichodesmium spp.

JULY 10, 1978

Bacillariophyceae

Amphiprora gigantea
 Biddulphia pelagica
 Chaetoceros affinis
 C. castracanei
 C. compressus
 C. curvisetum
 C. Wighami
 C. spp.
 Dactyliosolen mediterraneus
 Guinardia flaccida
 Hemiaulus hauckii
 H. membranaceus
 Leptocylindrus danicus
 L. minimus
 Nitzschia closterium
 N. delicatissima
 Pennate diatoms
 Rhizosolenia alata v. gracillima
 R. bergonii
 R. calcar-avis
 R. curviseta
 R. delicatula
 R. hebetata
 R. Shrubsolei
 R. Stolterfothii
 R. styliiformis
 Schroderella delicatula
 Striatella unipunctata

Bacillariophyceae con't

Thalassiosira decipiens
 Thalassiothrix longissima
 T. spp. "A"

Dinophyceae

Amphidinium spp.
 Ceratium breve
 C. candelabrum
 C. contrarium
 C. declinatum
 C. dens
 C. egyptiacum
 C. furca
 C. furca v. spp. "A"
 C. fusus
 C. Kofoidii
 C. massiliense
 C. pentagonum
 C. teres
 C. trichoceros
 C. tripos
 Dinophysis caudata
 D. ovum
 D. sphaerica
 Diplopsalis lenticula
 Exuviaella spp.
 Goniiodoma polyedricum
 Gonyaulax polygramma

APPENDIX 5 continued.

Dinophyceae con't

Gonyaulax turbynei
Gymnodinium spp.
Naked dinoflagellates
Ornithocercus spp.
Oxytoxum scolopax
Peridinium brochii
P. cerasus
P. conicum
P. crassipes
P. divergens
P. granii
P. leonis
P. pallidum
P. pellucidum
P. steinii
P. trochoideum
Peridiniopsis asymmetrica
Phalacroma porodictyum
Prorocentrum micans
Pyrophacus horologium
Small dinoflagellates
Spiraulax jolliffei
Triposolenia bicornis

Cyanophyta

Trichodesmium spp.

AUGUST 20, 1978

Bacillariophyceae

Chaetoceros affinis
 C. brevis
 C. coarctatum
 C. compressus
 C. curvisetum
 C. decipiens
 C. dictyota
 C. lauderi
 C. peruvianum
 C. teres
 C. tortissimum
 Corethron spp.
 Corethron spp. "A"
 Dactyliosolen mediterraneus
 Gosslerella tropica
 Guinardia flaccida
 Leptocylindrus danicus
 Nitzschia seriata
 Planktoniella sol
 Rhizosolenia acuminata
 R. alata
 R. bergonii
 R. calcar-avis
 R. fragilissima
 R. hebetata
 R. Shrubsolei
 R. Stalteri
 R. styliformis
 R. temperei

Bacillariophyceae con't

Schroederella delicatula
 Thalassiothrix delicatula
 Thalassiothrix spp. "A"

Dinophyceae

Amphisolenia bidentata
 Ceratium breve
 C. carriense
 C. contortum
 C. declinatum
 C. egyptiacum
 C. extensum
 C. furca
 C. fusus
 C. massiliense
 C. teres
 C. trichoceros
 C. tripos
 Cladopyxis brachiolata
 Dinophysis caudata
 D. spp.
 Exuviaella spp.
 Gonyaulax polygramma
 Peridinium conicum
 P. depressum
 P. pyriforme
 P. steinii
 P. trochoideum

APPENDIX 5 continued.

Dinophyceae con't

Peridinium truncatum

Pyrocystis elegans

P. fusiformis

Triposolenia bicornis

Cyanophyta

Trichodesmium spp.

SEPTEMBER 23, 1978

Bacillariophyceae

Asterionella japonica
A. notata
Chaetoceros coarctatum
C. compressus
C. curvisetum
C. dadayi
C. teres
C. tetrastichon
C. tortissimum
Climacosphenia moniligera
Ditylium Brightwellii
Guinardia blavyana
G. flaccida
Leptocylindrus danicus
Licmophora flabellata
Navicula membranacea
Nitzschia closterium
N. seriata
Pennate diatoms
Rhizosolenia alata
R. bergonii
R. calcar-avis
R. hebetata
R. Shrubsolei
R. Stolterfothii
Thalassionema nitzschioides
Thalassiosira decipiens
Triceratium punctatum

Dinophyceae

Ceratium egyptiacum
C. furca
C. Kofoidii
C. massiliense
C. teres
Diplopsalis lenticula
Exuviaella compressa
Goniodoma sphaericum
Naked dinoflagellates
Oxytoxum scolopax
Peridinium breve
P. divergens
P. spp.
Porella spp.
Prorocentrum micans
Pyrophacus horologium

Cyanophyta

Trichodesmium spp.

OCTOBER 25, 1978

Bacillariophyceae

Pennate diatoms

Dinophyceae

Ceratium bohmi

C. breve

C. contrarium

C. declinatum

C. furca

C. trichoceros

Exuviaella compressa

Podalampas spinifera

Prorocentrum micans

Pyrophacus horologium

Unidentified

Cyanophyta

APPENDIX 6: TAXA LIST OF ALL GENERA AND SPECIES IDENTIFIED
FROM THE RED SEA, 1977-1978.

BACILLARIOPHYTA	Authority
CENTRALES	
Bacteriastrum	Shadbolt
B. biconicum	Pavillard
B. delicatulum	Cleve
B. hyalinum	Lauder
B. spp.	
Bellerrochea	van Heurck
B. malleus	van Heurck
Biddulphia	Gray
B. aurita	(Lyngb.) Brébisson
B. obtusa	(Kütz.) Ralfs
B. pelagica	Schröder
B. schroderiana	Schussnig
B. vesiculosa	(Agardh) Boyer
B. spp.	
Campylodiscus	Ehrenberg
C. echensis	Ehrenberg
C. spp.	
Cerataulina	Peragallo
C. bergonii	Peragallo
C. pelagica	(Cleve) Hendey
Chaetoceros	Ehrenberg
C. affinis	Lauder
C. affinis v. Willei	(Gran) Hustedt
C. atlanticus	Cleve
C. brevis	Schütt
C. castracanei	Peragallo
C. coarctatum	Lauder
C. compressus	Lauder
C. concaviformis	Mangin
C. convolutus	Castracane
C. curvisetum	Cleve
C. dadayi	Pavillard
C. danicus	Cleve
C. decipiens	Cleve
C. dictyota	Ehrenberg
C. didymum	Ehrenberg
C. diversus	Cleve
C. eibenii	Grunow in van Heurck
C. hispidus	(Ehrenberg) Brightwell
C. indicum	Subrahmanyam
C. laciniosus	Schütt
C. lauderi	Ralfs
C. messanensis	Castracane
C. pendulum	Karsten

Chaetoceros peruvianum	Brightwell
C. pseudoperuvianum	Mangin
C. socialis	Lauder
C. teres	Cleve
C. tetrastichon	Cleve
C. tortissimum	Gran.
C. Weissflogii	Schütt
C. Wighami	Brightwell
C. spp.	
Climacodium	Grunow
C. biconcavum	Cleve
C. fraunfeldianum	Grunow
Climacosphenia	Ehrenberg
C. moniligera	Ehrenberg
C. spp.	
Corethron	Castracane
C. hystrix	Hensen
C. spp. "A"	
C. spp.	
Coscinodiscus	Ehrenberg
C. asteromphalus	Ehrenberg
C. concinnus	W. Smith
C. excentricus	(Ehrenberg) Cleve
C. gigas	Ehrenberg
C. nobilis	Grunow
C. oculus-iridis	Ehrenberg
C. perforatus	Ehrenberg
C. radiatus	Ehrenberg
C. spp.	
Coscinosira	Gran.
C. spp.	
Dactyliosolen	Castracane
D. mediterraneus	Peragallo
D. spp.	
Ditylium	Bailey
D. Brightwellii	(West.) Grunow
Ethmodiscus	Castracane
E. gazellae	(Janisch) Hustedt
Gossleriella	Schütt
G. tropica	Schütt
Guinardia	Peragallo
G. blavyana	Peragallo
G. flaccida	(Castracane) Peragallo

Hemiaulus	Ehrenberg
H. hauckii	Grunow
H. membranaceus	Cleve
H. sinensis	Greville
Hemidiscus	Wallachi
H. cuneiformis	Wallachi
Isthmia	Agardh
I. enervis	Ehrenberg
Lauderia	Cleve
L. borealis	Gran.
Leptocylinthus	Cleve
L. danicus	Cleve
L. minimus	Gran.
L. spp.	
Planktoniella	Schütt
P. sol	(Wallichi) Schütt
Rhizosolenia	(Ehrenberg) Kützing
R. acuminata	(Peragallo) Gran.
R. alata	Brightwell
R. alata v. "A"	
R. alata v. gracillima	Cleve
R. alata v. indica	(Peragallo) Ostenfeld
R. arafurensis	Castracane
R. bergonii	Peragallo
R. calcar-avis	Schultze
R. castracanei	Peragallo
R. clevei	Ostenfeld
R. curviseta	Hustedt
R. delicatula	Cleve
R. fragilissima	Bergon
R. hebetata	(Bailey) Gran.
R. imbricata	Brightwell
R. Shrubsolei	Cleve
R. Stolterfothii	Peragallo
R. styliiformis	Brightwell
R. temperei	Peragallo
Schroderella	Pavillard
S. delicatula	(Peragallo) Pavillard
Skeletonema	Greville
S. costatum	(Greville) Cleve
Stephanopyxis	Ehrenberg
S. turris	(Grev. & A.) Ralfs

Thalassiosira	Cleve
T. decipiens	(Grunow) Jorgensen
T. rotula	Meunier
T. subtilis	(Ostenfeld) Gran.
T. spp.	
Triceratium	Ehrenberg
T. punctatum	Brightwell
PENNALES	
Achnanthes	Bory
A. brevipes	Agardh
Amphiprora	Ehrenberg
A. alata	Kützing
A. gigantea	Grunow
A. spp.	
Asterionella	Hassall
A. japonica	Cleve
A. notata	Grunow
Bacillaria	Gmelin
B. paradoxa	Gmelin
Cocconeis	Ehrenberg
C. spp.	
Diploneis	Ehrenberg
D. crabro	Ehrenberg
D. spp.	
Fragilaria	Lyngbye
F. oceanica	Cleve
F. spp.	
Grammatophora	Ehrenberg
G. marina	(Lyngbye) Kützing
Licmophora	Agardh
L. abbreviata	Agardh
L. flabellata	(Greville) Agardh
L. spp.	
Mastogloia	Thwaites
M. spp.	
Navicula	Bory
N. membranacea	Cleve

Nitzschia	Hassall
N. bilobata	W. Smith var. minor Grunow
N. closterium	Ehrenberg
N. delicatissima	Cleve
N. longissima	(Brébisson) Ralfs
N. longissima v. reversa	W. Smith
N. paradoxa	(Gmelin) Grunow
N. seriata	Cleve
N. sigma	(Kützinger) W. Smith
Pleurosigma	W. Smith
P. balticum	(Ehrenberg) W. Smith
P. fasciola	(Ehrenberg) W. Smith
P. naviculaceum	Brébisson
P. rectum	Donk.
P. rigidum	W. Smith
P. spencerii	W. Smith
P. spp.	
Streptotheca	Cleve
S. thamesis	Shrubsole
Striatella	Agardh
S. delicatula	(Kützinger) Grunow
S. unipunctata	(Lyngbye) Agardh
Surirella	Turpin
S. fastuosa	Ehrenberg
S. spp. "A"	
S. spp.	
Synedra	(Ehrenberg) Kützinger
S. crystallina	(Agardh)
Thalassionema	Grunow
T. nitzschoides	Grunow
T. spp.	
Thalassiothrix	Cleve and Grunow
T. delicatula	Cupp
T. delicatula v. "A"	
T. fraunfeldii	(Grunow) Cleve & Grunow
T. longissima	Cleve & Grunow
T. mediterranea	Pavillard
T. spp. "A"	
T. spp.	
Tropidoneis	Cleve
T. lepidoptera	(Greg.) Cleve

DINOPHYTA

Amphidinium	Claparedo & Lachmann
A. spp.	
Amphisolenia	Stein
A. bidentata	Schroder
Ceratium	Schank
C. arietinum	Cleve
C. bohmi	Graham & Bronikovsky
C. breve	(Ost. & Sch.) Schröder
C. candelabrum	(Ehrenberg) Stein
C. carriense	Gourret
C. contortum	(Gourret) Cleve
C. contrarium	(Gourret) Pavillard
C. declinatum	Karsten
C. declinatum declinatum	Jorgensen
C. declinatum v. normale	Jorgensen
C. dens	Ost. & Sch.
C. egyptiacum	Halim
C. extensum	(Gourret) Cleve
C. furca	(Ehrenberg) Clap. & Lachm.
C. furca v. hircus	(Schröder)
C. furca v. spp. "A"	
C. fusus	(Ehrenberg) Dujardin
C. hexacanthum	Gourret
C. horridum	Gran.
C. incisum	(Karsten) Jorgensen
C. inflatum	(Kofoid) Jorgensen
C. Karstenii	Pavillard
C. Kofoidii	Jorgensen
C. longirostrum	Gourret
C. lunula	(Schimper) Jorgensen
C. macroceros	(Ehrenberg) Vanh.
C. massiliense	(Gourret) Jorgensen
C. pavillardii	Jorgensen
C. pentagonum	Gourret
C. platycorne	Daday
C. reflexum	Cleve
C. schmidtii	Jorgensen
C. strictum	(Okam. & Nish.) Kofoid
C. tenue	Jorgensen
C. teres	Kofoid
C. trichoceros	(Ehrenberg) Kofoid
C. tripos	(O.F. Muller) Nitz.
C. vultur	Cleve
C. spp. "A"	
Ceratocorys	Stein
C. armata	(Schütt) Kofoid
C. gourettii	Paulsen
C. horrida	Stein

Cladopyxis	Stein
C. brachiolata	Stein
Dinophysis	Ehrenberg
D. caudata	Saville-Kent
D. ovum	Schütt
D. sphaerica	Stein
D. tripos	Gourret
D. spp. "A"	
D. spp.	
Diplopsalis	Bergh.
D. lenticula	Bergh.
Exuviaella	Cienkowski
E. compressa	(Bailey) Ost.
E. oblonga	Schiller
E. spp.	
Goniodoma	Stein
G. polyedricum	(Pauch.) Jorgensen
G. sphaericum	Murray & Whitting
G. spp.	
Gonyaulax	Diesing
G. dicantha	Meunier
G. monacantha	Pavillard
G. pacifica	Kofoed
G. polygramma	Stein
G. turbynei	Murray & Whitting
G. spp.	
Gymnodinium	Stein
G. spp.	
Histioneis	Stein
H. longicollis	Kofoed
H. spp.	
Noctiluca	Suriray ex Lamarck
N. miliaris	Suriray
Ornithocercus	Stein
O. magnificus	Stein
O. quadratus	Schütt
O. steinii	Schütt
O. spp.	
Oxytoxum	Stein
O. scolopax	Stein
O. tessellatum	Schütt

Parahistioneis	Kofoid v. Skogsberg
P. spp.	
Peridinium	Ehrenberg
P. abei	Paulsen
P. breve	Paulsen
P. brochii	Kofoid & Swezy
P. cerasus	Paulsen
P. conicum	(Gran)Ost. & Schm.
P. crassipes	Kofoid
P. depressum	Bailey
P. diabolus	Cleve
P. divergens	Ehrenberg
P. globulus	Stein
P. granii	(Ost.)Paulsen
P. leoni	Pavillard
P. oblongum	Aurivillius
P. oceanicum	Vanhoffen
P. pallidum	Ostenfeld
P. pellucidum	(Bergh.)Schütt
P. pyriforme	Paulsen
P. sphaericum	Murray & Whitting
P. steinii	Jorgensen
P. trochoideum	(Stein)Lemmermann
P. truncatum	Graham
P. spp. "A"	
P. spp.	
Peridiniopsis	Lemmermann
P. asymmetrica	Mangin
P. trochoideum	(Stein)Lemmermann
Phalacroma	Stein
P. argus	Stein
P. circumsutum	Karsten
P. doryphorium	Stein
P. parvulum	(Schütt)Jorgensen
P. porodictyum	Stein
Podalampas	Stein
P. bipes	Stein
P. palmipes	Stein
P. spinifera	Okamura
Porella	Schiller
P. spp.	
Prorocentrum	Ehrenberg
P. gracile	Schütt
P. micans	Ehrenberg
P. spp.	

APPENDIX 6 continued.

Protoceratium	Bergh.
P. reticulatum	(Clap. & Lachm.) Bütschli
P. spp. "A"	
Pyrocystis	Murray & Schutt
P. elegans	Pavillard
P. fusiformis	Thompson & Murray
P. lunula	(Schütt) Schütt
P. pseudonoctiluca	Thompson & Murray
Pyrophacus	Stein
P. horologium	Stein
P. spp. "A"	
Spiraulax	Kofoid
S. jolliffei	(Murray & Whitting) Kofoid
S. Kofoidii	Graham
Triposolenia	Kofoid
T. bicornis	Kofoid
CHRYSOPHYTA	
Dictyocha	Ehrenberg
D. fibule	Ehrenberg
CYANOPHYTA	
Trichodesmium	Ehrenberg

APPENDIX 7: ADDITIONS TO THE PHYTOPLANKTON TAXONOMIC LIST FOR
THE RED SEA FROM THE PRESENT STUDY IN 1977-1978

BACILLARIOPHYTA
CENTRALES

Bacteriastrum	Shadbolt
B. biconicum	Pavillard
Biddulphia	Gray
B. schroderiana	Schussnig
B. vesiculosa	(Agardh) Boyer
Cerataulina	Peragallo
C. pelagica	(Cleve) Hendey
Chaetoceros	Ehrenberg
C. affinis v. Willei	(Gran) Hustedt
C. atlanticus	Cleve
C. castracanei	Peragallo
C. convolutus	Castracane
C. dadayi	Pavillard
C. dictyota	Ehrenberg
C. eibonii	Grunow in van Heurck
C. hispidus	(Ehrenberg) Brightwell
C. indicum	Subrahmanyam
C. pendulum	Karsten
C. pseudoperuvianum	Mangin
C. teres	Cleve
C. weissflogii	Schütt
C. Wighami	Brightwell
Climacosphenia	Ehrenberg
C. moniligera	Ehrenberg
Corethron	Castracane
C. hystrix	Hensen
Coscinodiscus	Ehrenberg
C. asteromphalus	Ehrenberg
C. concinnus	W. Smith
Coscinosira	Gran.
C. spp.	
Dactyliosolen	Castracane
D. spp.	
Ethmodiscus	Castracane
E. gazellae	(Janisch) Hustedt
Gosslerella	Schütt

APPENDIX 7 continued.

Isthmia	Agardh
I. enervis	Ehrenberg
Leptocylindrus	Cleve
L. spp.	
Rhizosolenia	(Ehrenberg) Kützing
R. acuminata	(Peragallo) Gran.
R. alata v. "A"	
R. arafurensis	Castracane
R. bergonii	Peragallo
R. castracanei	Peragallo
R. clevei	Ostenfeld
R. curviseta	Hustedt
R. temperei	Peragallo
Stephanopyxis	Ehrenberg
S. turris	(Grev. & A.) Ralfs
Thalassiosira	Cleve
T. spp.	
Triceratium	Ehrenberg
T. punctatum	Brightwell
PENNALES	
Achnanthes	Bory
Amphiprora	Ehrenberg
A. alata	Kützing
A. gigantea	Grunow
Asterionella	Hassall
A. notata	Grunow
Bacillaria	Gmelin
B. paradoxa	Gmelin
Campylodiscus	Ehrenberg
C. echensis	Ehrenberg
Cocconeis	Ehrenberg
C. spp.	
Diploneis	Ehrenberg
D. crabro	Ehrenberg

APPENDIX 7 continued.

Fragillaria F. spp.	Lyngbye
Licmophora L. spp	Agardh
Mastogloia M. spp	Thwaites
Nitzschia N. longissima v. reversa	Hassall W. Smith
Pleurosigma P. balticum P. fasciola P. rigidum P. spencerii	W. Smith (Ehrenberg) W. Smith (Ehrenberg) W. Smith W. Smith W. Smith
Surirella S. fastuosa	Turpin Ehrenberg
Thalassionema T. spp	Grunow
Thalassiothrix T. delicatula v. "A"	Cleve and Grunow
DINOPHYTA	
Amphidinium A. spp	Claparedo & Lachmann
Ceratium C. bohmi C. furca v. spp. "A" C. platycorne C. vultur	Schank Graham & Bronikovsky Daday Cleve
Dinophysis D. ovum	Ehrenberg Schutt
Exuviaella E. spp	Cienkowski
Goniodoma G. spp	Stein

APPENDIX 7 continued.

Gonyaulax	Diesing
G. monacantha	Pavillard
G. pacifica	Kofoid
Gymnodinium	Stein
G. spp	
Histioneis	Stein
H. longicollis	Kofoid
Ornithocercus	Stein
O. steinii	Schütt
Parahistioneis	Kofoid v. Skogsberg
P. spp.	
Peridinium	Ehrenberg
P. oblongum	Aurivillius
P. pallidum	Ostenfeld
P. pellucidum	(bergh.) Schütt
P. pyriforme	Paulsen
P. truncatum	Graham
Peridiniopsis	Lemmermann
P. trochoideum	(Stein) Lemmermann
Phalacroma	Stein
P. circumsutum	Karsten
P. parvulum	(Schütt) Jorgensen
Podalampas	Stein
P. spinifera	Okamura
Porella	Schiller
P. spp	
Prorocentrum	Ehrenberg
P. spp	
Protoceratium	Bergh.
P. spp "A"	
Pyrocystis	Murray & Schütt
P. elegans	Pavillard
Pyrophacus	Stein
P. spp "A"	

APPENDIX 7 continued.

Spiraulax	Kofoid
S. Kofoidii	Graham

Triposolenia	Kofoid
T. bicornis	Kofoid

CHRY SOPHYTA

Dictyocha	Ehrenberg
D. fibule	Ehrenberg

APPENDIX 8 : REFERENCES USED IN COMPILING THE PHYTOPLANKTON
SPECIES LIST IN THE REGION OF JIDDAH 1977-78.

- Astrid-Cleve Euler, 1951. Die Diatomeen Van Schweden Und Finland, Bibliotheca Phycologica Band 5, Reprint 1968, 3301 Lehr, Verlag Von J. Cramer, N.Y. Stockholm, 1951.
- Cholnoky, B.J. 1968. Die Okologie Der Diatomeen In Binnengewässern Verlag Von J. Cramer, Germany 1968.
- Cleve, P.T. 1900. Plankton From The Red Sea. Svenska Vetenskapakademien, Ofversigt at Kongl. Vetenskaps - Akadem. Forhandlingar 1900. Vol. 57: 1025-1038.
- Cleve, P.T. 1903. Report on Plankton collected by Mr. Thorild Wulff during a voyage to and from Bombay.
- Dowidar, N.M. 1976. The phytoplankton of the Suez Canal. Acta Adriatica, Institut Za Oceanography I, Vol. XVIII, No. 14: 241-255.
- Dowidar, N.M., S.A. Raheem, El-Din and A.A. Aleem 1976. Phytoplankton Populations in the Region of Obhur (Jeddah, Saudi Arabia). Oceanography Depart., Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia, Unpublished manuscript.
- Geither, Lothar 1932. Cyanophyceae - L. Rabenhorst (ed.) Kryptogamen-Flora Volume XIV, Johnson Reprint Corporation, New York.
- Gemeinhardt, K. 1930. Silicoflagellatae in L. Rabenhorst (ed.) Kryptogamen-Flora Volume X, Section II, Johnson Reprint Corporation, New York.
- Gerloff, J. and B.J. Cholnoky 1970. Diatomaceae II, Nova Hedwigia Heft 31. Verlag Von J. Cramer, 1970.
- Halim, Y. 1969. Plankton of the Red Sea. IN Oceanography and Marine Biology, Ed. H. Barnes, Hafner Publishing Company, New York, 231-276.
- Hasle, G.R. (1959). A quantitative study of phytoplankton from the equatorial Pacific. Deep-Sea Research 6: 38-59.
- Heimdal, B.R., J.P. Taasen, and M. Elbrachter, 1977. Net Phytoplankton of the Great Bitter Lake in the Suez Canal. Sarsia, 63(2): 75-84.
- Hendey, N. Ingram 1961. An Introductory Account of the Smaller Algae of British Coastal Waters. V. Bacillariophyceae (Diatoms) HMSO, London 318 pp.

- Heurck, H.V. 1962. A Treatise on the Diatomaceae. Wheldon & Wesley, Ltd. & Verlag J. Cramer.
- Kimor, B. 1972. The Suez Canal as a Link and a Barrier in the Migration of Planktonic Organisms, *Isr. J. Zool.* 21:391-403.
- Kuz'menko, L.V. 1971. Phytoplankton in the Arabian Sea during the summer. *Hydrobiol. J. (Eng. Tranl. Gibrobio. Zlt)* 7(5):16-21.
- Matzena, Ver. L. 1933. Die Dinoflagellaten Des Indischen Ozeans, *Botanisches Archiv Zeitschrift Fur Die Gesamte Botanik* Vol. 35: 437-510.
- Schiller, Josef 1877- Dinoflagellatae (Peridineae) in Monographischer Behandlung. L. Rabenhorst (Ed.) Kryptogamen-Flora Volume X, Section III, Part I, Johnson Reprint Corporation, New York.
- Schroder, B. 1906. Beitrage zur kenntnis des Phytoplanktons warmer Meere, *Vjschr. naturf. Ges. Zurich*, 51:319-377.
- Simonsen, Reimer 1973. Second Symposium on Recent and Fossil Marine Diatoms, London Sept. 4-9, 1972 Proceedings, Nova Hedwigia Heft 45, Verlag Von J. Cramer.
- Simonsen, Reimer 1974. The Diatom Plankton of the Indian Ocean expedition of R/V "Meteor" 1964-1965. "Meteor" Forsch. Ergebn. D19: 1-107.
- Sournia, A. 1970. A checklist of planktonic diatoms and dinoflagellates from the Mozambique Channel. *Bull. mar. science*, Vol. 20, No. 3: 678-696.
- Steidinger, K.A. and J. Williams 1979. Dinoflagellates - Memoirs of the Hourglass Cruises, Volume II, (Florida Dept. of Natural Resources) 2: 1-251.
- Tailer, F.J.R. 1975. Dinoflagellates from the International Indian Ocean Expedition - A Report on material collected by the R.V. "Anton Bruun" 1963-64. *Bibliotheca Botanica* Heft. 132, Stuttgart 1976.
- Venrick, E.L. 1971. Recurrent groups of diatom species in the North Pacific, *Ecology* 52: 614-625.
- Werner, Dietrich 1977. The Biology of Diatoms, Botanical Monographs, Volume 13, Blackwell Scientific Publications, Oxford 1977.

Wood, E.J.F. 1958. Studies of phytoplankton ecology in tropical and subtropical environments of the Atlantic Ocean. Part 3, Phytoplankton communities in the Providence Channels and the Tongue of the Ocean, Bull. Mar. Science 18: 481-543.

Wood, E.J.F. 1963. Checklist of Dinoflagellates recorded from the Indian Ocean, Commonwealth Scientific and Oceanographic Report 28, Marine Biological Laboratory Cronulla, Sydney, 1963.

Wood, E.J.F. 1963. Checklist of diatoms recorded from the Indian Ocean. Rep. Div. Fish. Oceanogr. C.S.I.R.O. Aust. 36: 1-304.

APPENDIX 9: DIVERSITY INDICES FOR DIATOMS AND DINOFLAGELLATES IN THE REGION OF JIDDAH (SHARM STATION) DURING THE PERIOD NOVEMBER 1977 TO OCTOBER 1978.

Date	Phytoplankton Group	0m	5m	10m	15m	20m	30m
3/11/77	Diatoms	2.463	2.130	2.030	1.699	2.227	1.690
	Dinoflagellates	3.045	2.515	2.229	2.243	1.924	2.529
17/11/77	Diatoms	1.350	1.946	2.028	2.264	1.957	2.135
	Dinoflagellates	2.837	2.884	2.882	2.454	1.924	1.590
27/12/77	Diatoms	3.942	3.659	3.866	3.055	2.651	1.697
	Dinoflagellates	3.985	2.925	2.359	1.535	0.814	0.921
25/01/78	Diatoms	3.915	4.237	4.016	-	3.953	3.778
	Dinoflagellates	2.258	2.679	3.252	-	2.867	2.636
14/02/78	Diatoms	2.565	3.199	3.172	-	2.519	2.656
	Dinoflagellates	2.019	2.370	2.829	-	2.363	2.199
14/03/78	Diatoms	3.348	3.385	3.425	3.111	2.929	2.572
	Dinoflagellates	2.846	3.502	3.120	2.978	2.662	1.691
11/04/78	Diatoms	4.054	3.301	3.144	3.398	4.019	3.883
	Dinoflagellates	4.458	4.062	4.295	3.466	4.625	4.570
21/04/78	Diatoms	2.125	1.993	1.819	-	2.122	2.622
	Dinoflagellates	2.617	2.220	2.541	-	2.707	3.261

APPENDIX 9 continued.

Date	Phytoplankton Group	0m	5m	10m	15m	20m	30m
10/05/78	Diatoms	2.426	2.641	2.669	-	2.636	1.924
	Dinoflagellates	2.817	3.004	2.805	-	2.690	1.600
28/05/78	Diatoms	2.104	2.555	3.017	-	3.106	3.604
	Dinoflagellates	1.652	2.291	2.361	-	3.394	3.479
20/06/78	Diatoms	2.354	3.052	3.152	-	2.414	2.155
	Dinoflagellates	3.058	2.978	2.588	-	2.546	2.231
18/07/78	Diatoms	2.596	2.826	2.510	-	2.525	1.331
	Dinoflagellates	1.849	2.308	2.536	-	2.527	2.601
25/07/78	Diatoms	2.556	3.110	2.595	-	2.668	2.411
	Dinoflagellates	1.971	2.102	1.765	-	1.766	1.894
20/08/78	Diatoms	3.224	3.055	3.226	-	2.564	2.897
	Dinoflagellates	2.359	1.762	2.072	-	1.691	0.724
-/09/78	Diatoms	2.949	2.587	2.918	2.404	2.866	2.474
	Dinoflagellates	2.265	1.924	2.378	1.924	2.758	1.003
-/10/78	Diatoms	0	0	-	-	-	0
	Dinoflagellates	2.006	1.003	1.691	-	0.921	1.003

APPENDIX 10: DIVERSITY INDICES FOR DIATOMS AND DINOFLAGELLATES IN THE REGION OF JIDDAH
(OFFSHORE STATION) DURING THE PERIOD NOVEMBER 1977 TO OCTOBER 1978.

Date	Phytoplankton Group	0m	25m	50m	75m	100m	150m	200m
3/11/77	Diatoms	3.458	2.615	3.738	3.158	2.833	2.590	1.720
	Dinoflagellates	2.742	2.496	1.504	1.407	0.724	-	-
7/11/77	Diatoms	2.142	2.024	2.401	3.133	1.504	2.801	-
	Dinoflagellates	2.507	2.507	0	-	-	-	-
27/12/77	Diatoms	3.929	3.613	3.774	3.546	2.952	2.678	2.392
	Dinoflagellates	3.552	2.578	0.652	1.463	0.921	-	-
29/01/78	Diatoms	4.443	4.416	4.569	4.752	4.381	3.816	3.619
	Dinoflagellates	2.727	2.732	2.269	1.590	0	1.914	-
22/02/78	Diatoms	3.034	3.066	2.486	2.497	2.183	0.921	-
	Dinoflagellates	3.238	3.751	2.685	2.257	0	-	-
18/02/78	Diatoms	2.732	3.171	3.235	2.836	2.901	2.575	2.680
	Dinoflagellates	4.318	4.392	3.557	3.506	3.092	2.204	1.526
11/04/78	Diatoms	3.724	3.564	3.766	3.515	2.443	2.524	1.357
	Dinoflagellates	2.234	3.156	2.687	1.003	-	-	-
21/04/78	Diatoms	3.803	2.978	3.243	3.405	2.035	-	-
	Dinoflagellates	3.786	2.524	3.428	1.915	-	-	-

APPENDIX 10 continued.

Date	Phytoplankton Group	0m	25m	50m	75m	100m	150m	200m
28/05/78	Diatoms	3.346	3.502	3.601	3.129	3.351	2.577	1.977
	Dinoflagellates	3.318	3.478	3.224	2.619	0	-	-
27/06/78	Diatoms	3.337	3.725	3.693	3.435	3.110	2.316	-
	Dinoflagellates	3.042	3.647	2.793	2.507	1.504	-	-
10/07/78	Diatoms	3.418	3.621	3.695	4.067	3.910	2.423	1.551
	Dinoflagellates	2.762	3.587	3.782	3.791	3.316	3.140	2.687
20/08/78	Diatoms	3.876	3.678	3.640	3.525	3.381	3.410	2.258
	Dinoflagellates	3.535	3.425	3.358	2.454	1.003	0.921	-
23/09/78	Diatoms	2.243	2.315	3.334	3.135	2.854	2.570	1.590
	Dinoflagellates	2.209	2.123	2.258	0.995	1.190	-	0
25/10/78	Diatoms	-	-	-	-	-	-	-
	Dinoflagellates	2.413	2.258	2.065	1.924	0.652	-	-

Figure 10. (Repeated). Seasonal density (σ_t) distribution
at the Sharm station.

Figure 11. (Repeated). Seasonal density (σ_t) distribution
at the offshore station.

Figure 7. TO OVERLAY Figure 11.

Figure 9. TO OVERLAY Figure 11.

SHARM STATION - σ_t

Figure 13. TO OVERLAY Figure 10.

Figure 15. TO OVERLAY Figure 11.

Figure 16. TO OVERLAY Figure 11.

Figure 17. TO OVERLAY Figure 10.

Fig. 10. (repeated)

Figure 18. TO OVERLAY Figure 11.

Figure 21. TO OVERLAY Figure 10.

Figure 22. TO OVERLAY Figure 11.

SHARM STATION - σ_t
 $\text{NH}_4\text{-N}$ ($\mu\text{g-at l}^{-1}$)

Figure 23. TO OVERLAY Figure 10.

OFFSHORE STATION - σ_t
 $\text{NH}_4\text{-N}$ ($\mu\text{g-at l}^{-1}$)

Figure 24. TO OVERLAY Figure 11.