PN-ACF-300
101714
M15-062

Cooperative Marine Technology Program for the Middle East (Phase IV)

Final Report

Compiled and Edited by
Dr. Sayed Z. El-Sayed
Principle Investigator and Chief Scientist

Submitted to U.S. Agency for International Development
(Contract No. HNE-0158-G-00-2062-00)

1 June 1998

RECEIVED
JUN 28 1999
BY .....

PN-ACF-300

Cooperative Marine Technology Program for the Middle East (Phase IV)

FINAL REPORT

PART I

TABLE OF CONTENTS

Cooperative Marine Technology Program for

the Middle East - Phase IV

FINAL REPORT

		Page
Part I		
	Table of Contents	i
I	Foreword	ii
II	Executive Summary	iii
III	Program Management	1
IV	Trophodynamics of the Southeastern Mediterranean with Special Reference to Commercially Important Fishes	
	IV-I Israel	12
	IV-II U S A	39
	IV-III Egypt	64
V	Investigations of Lake Ecosystems in Israel and Egypt with Implications for Fisheries and Water Quality Management	
	V-I Lake Kinneret (Israel)	67
	V-II Lake Qarun (Egypt)	93
Part II		
Seafood Safety and Fish Decontamination-Technical and Health Implications		
Volume I		
	Project Goals & Research Appproach, Surveys of Fish Contaminants, Chemical Depuration Models, Risk Health Assessment	1-268
Volume II		
	Depuration of Bacterial and Viral Contaminants, Disinfection using Hydrogen Peroxide and Silver, Survival of Hepatitus A Virus and Seafood Safety, Survey of Heavy Metals and Microbial Pathogens in Fresh fish in Israel	1-120
Volume III		
	Toxic Metal in Fish from Egypt Coastal Waters, Uptake and Depuration of Metals from Fish, Metal Bioassay Investigations	1-175
Volume IV		
	Fish Parasites in Egypt, Fish Viral and Bacterial Contaminants in Egypt	1-324

Cooperative Marine Technology Program for the Middle East
(Phase IV)
Contract No HNE-0158-G-00-2062-00

FINAL REPORT

I FOREWORD

The Cooperative Marine Technology Program for the Middle East is a component of the Middle East Regional Cooperative (MERC) Program The Marine Technology Program, Phase IV the focus of this report, is the extension of 13 years of prior effort (Phases I to III, 1980-1993) The overall objective of Phase IV Program is to increase cooperative effort among Egyptian and Israeli scientific institutions by addressing critical and much needed research in the fields of marine and freshwater fisheries, seafood safety and related public health problems Phase IV began (per effective grant date) on September 29, 1992, and although it was originally scheduled to terminate on September 28, 1995 a series of extensions resulted in actual termination date on December 31, 1997

The research activities of the three projects undertaken during Phase IV are reported herein, these projects are

1 Trophodynamics of the Southeastern Mediterranean with Special Reference to Commercially Important Fishes
2 Investigations of Lake Ecosystems in Egypt and Israel with Implications for Fisheries and Water Quality Management
3 Seafood Safety and Fish Decontamination - Technical and Health Implications

Also included in this Final Report is a section on Program Management

As the Program Principal Investigator and Chief Scientist, I wish to express on behalf of the Program Manager, the Program National Coordinators and the Projects' Principal Investigators and their associates my sincere thanks and deep appreciation to the U S Agency for International Development for the financial support of the Program

June 1998

Sayed Z El-Sayed
Principal Investigator & Chief Scientist

FINAL REPORT
II EXECUTIVE SUMMARY

Project I **Trophodynamics of the Southern Mediterranean with Special Reference to Commercially Important Fishes**

The investigations carried out during Phases I & II (1980-1986), were to evaluate the levels of primary production in the nearshore and pelagic regions of the Southeastern Mediterranean Sea adjacent to the Egyptian and Israeli coasts in order to assess the fishery potential of the regions The results of these investigations gave us, for the first time, quantification of primary production of the regions and provided details of the composition of the phytoplankton and zooplankton populations and their spatial and temporal distribution The study showed that the phytoplankton biomass and primary productivity of the SE Mediterranean pelagic region are among the lowest recorded for any marine region These findings imply that fish production in the SE Mediterranean must be very low compared to other regions On the other hand, higher levels of phytoplankton productivity and potentially high benthic algal production in the coastal shelf may permit enhanced levels of fish stocks along the coastal region

During Phase IV (1992-1997), hydroacoustic investigations carried out on the coastal shelf have shown that in general pelagic fish are present only in very low densities along the coast of Israel, with high concentration present in a few localized areas Demersal fish distribution has been correlated with water temperature, so it should be possible to predict locations of fish schools from temperature measurements For instance, it was found that in the Israeli waters red mullet prefer the areas of warm water

The expertise in the use of the hydroacoustic method developed during this project together with the equipment acquired, can be usefully applied in the future to make baseline studies environmental impact investigations, and studies of the effects of coastal structures on fish behavior

It should be pointed out that the scientific efforts in this project were aimed not only at carrying out acoustic surveys of the fisheries zone, but also at the optimization of the design survey themselves

Acoustic surveys of the pelagic fish and concurrent measurements of environmental parameters were conducted onboard Israeli and Egyptian research vessels At the stations occupied the physical and chemical parameters were studied, together with the study of the phytoplankton and zooplankton populations Off the Israeli coasts, trawling surveys of the demersal fish stocks were carried out on commercial trawlers by experts from the Fisheries Department of the Ministry of Agriculture, simultaneously with the fish acoustic surveys

Demersal fish density was calculated on the basis of commercial catches of fishing vessels by taking into account the size of the mouth of the trawls used and the distance trawled

The investigations carried out during Phase IV showed that the highest productive regions were those nearest to the Israeli coast (average of 0 40 gC m^{2} day^{1}, bottom depth ~ 15m), and the lowest production was found in the deeper "oceanic' regions (average of 0 15 gC m^{2} day^{1} bottom depth > 50 m) A significant part of the primary production was contributed by the picoplankton (cell size <2 μm) and the nanoplankton (cell size between 2 and 20 μm) The highest biomass and productivity rates were found in late winter/early spring Also it was found that in the SE Mediterranean, phosphorus appears to be the principal limiting nutrient for phytoplankton growth, in contrast with most other seas

Although emphasis in this project centered around fish stock assessment, studies of inorganic nutrients, phytoplankton and zooplankton populations were also undertaken These studies revealed positive correlation between the distribution of chlorophyll, silicic acid, and phosphate concentrations A positive correlation was also found between the distribution of zooplankton and phytoplankton and fish populations Further, the Ecopath model has provided a summary of the food web with an emphasis on commercial fish The model could be improved with better information on the abundance of the zooplankton, and the biomass and distribution of the benthic organisms

Using our estimate of primary production and applying different levels of trophic efficiency, we were able to calculate the potential yield (in terms of fish production) Comparing the calculated potential yield with the 'actual' fish catch showed that the ecosystem of the Israeli continental shelf can easily sustain a greater fishing pressure

Finally, the results of this project clearly indicated that efforts to enhance fish production and to obtain sustainable yields should be directed at coastal shelf regions only, and that the prospects of expansion of pelagic fisheries may not be too rewarding

Project II Investigations on Lake Ecosystems in Egypt and Israel with Implications for Fisheries and Water Quality Management

1 Lake Kinneret (Israel)

Lake Kinneret is the only natural freshwater lake in Israel, it feeds the vital national Water Carrier System and provides water for irrigation, drinking, commercial fisheries and recreation Therefore maintaining adequate quality in the lake is of great national and

international concern The lake has been studied intensively for over 3 decades, and a wealth of information exists on its physics, chemistry and biology

Results of studies on fish and zooplankton made during the AID project allowed improved management of the lake with regards to water quality During AID-Phase 1 (1980-82) investigation of the diets of two species of fish stocked in the lake led to recommending the cessation of stocking of Jordan Saint Peter's fish *Oreochromis aureus* and increased stocking of the native *Sarotherodon galilaeus* It was also proposed to protect the spawning grounds of *S galilaeus* The changes in stocking policy were implemented In Phase II (1984-86), pressure on zooplankton from fish was further documented The findings provided a scientific basis for recommending the elimination of the exotic silver carp from the lake Stocking was stopped It was also documented that Lake Kinneret sardine, the most common fish in the lake is almost exclusively zooplanktivorous, and it was recommended to reduce its stock However, this was not implemented because of its very low commercial value Fishing restrictions designed to protect spawning *S galilaeus* in the Beteicha lagoons were passed into law During AID-Phase III (1992-present) interactions between sardines and *S galilaeus* were studied Intensive field investigations of the behavior of sardines in relation to their zooplankton food have strengthened the arguments in favor of reducing the stock of sardines Detailed acoustic studies have revealed changes in the size of the sardine stock, which for the first time have been directly related to the size of the zooplankton stocks Changes in the sardine biomass and size composition have led us to recommend a subsidy program for reducing the biomass of sardines in the lake, in an attempt to protect the water quality of the lake The program was implemented, and monitoring showed that it was a success In summary we feel that the AID program has made a significant contribution to protecting the drinking water supply from the only freshwater lake in Israel

2 Lake Qarun (Egypt)

Investigation of Lake Qarun ecosystem, which was carried out over 48 successive months (January 1993-December 1996) was aimed at providing detailed information on the physical chemical and biological conditions of the lake and to determine the factors responsible for the severe decline in fish production It was found that the primary and secondary productions are sufficiently high to account for the essential requirements of the higher trophic levels Further, the chemical data revealed high levels of all major nutrient

salts as well as the essential trace elements The investigation also provided information on the natural food, grazing pressure and feeding behavior of mullet fry in the lake

Pollution studies conducted during this investigation provided no evidence for external source of heavy metal pollution in the lake Raw sewage, on the other hand, was found to be the main source of pollution in the lake and was responsible for the increase in bacterial diseases and parasites among the indigenous and transplanted fish species These diseases have direct effects on the survival of fish and are the cause of mass mortality of *Solea aegyptiaca* in addition to their adverse effect on the growth rate and reproduction of the infected fish Further, the discovery that the transplanted mullet fry from near Damietta (in northern Delta) were highly infected with trematodes was called to the attention of the General Authority for Fish Resources Development, who approved our recommendation to collect mullet fry from near Port Said (on the Mediterranean Sea) where the fry are less infected It was further recommended that a hatchery for mullet fry production be constructed near Lake Qarun The hatchery will also feed the nearby Wadi El-Rayan Lakes (18,000 hectares)

The Lake Qarun investigation underscored that all the fish stocks in the lake (both indigenous and transplanted) are overexploited, and that efforts should be made to reduce their exploitation in order to achieve the maximum yield per recruit Thus among the major findings of the Lake Qarun investigation is that the severe decline of the fish population is due to the lack of a proper management plan for the fishery rather than to ecological factors *per se*

Project III Seafood Safety and Fish Decontamination - Technical and Health Implications

The overall goal of this project is to promote seafood safety practices in Egypt and Israel The basic framework of this study was based on engaging a number of highly qualified scientists and engineers from Egypt and Israel to investigate seafood safety issues Specialized training was offered to project scientists by the collaborating institutions, this included methods for health risk assessment and the application of advanced computer techniques for data processing and modeling purposes

Tackling the Project objectives was carried out along several prongs, listed below

Review of Literature and Data Bank

A comprehensive review of the literature on "Seafood Safety was conducted This included natural and anthropogenic contaminants in seafood, public health implications of fish preparation, marketing and depuration and decontamination practices

Microbial Contaminants in Fish

This study addressed microbial agents in fish, including bacteria and parasites An extensive survey of fish harvested at different sites in Egypt showed that the degree of contamination increased from south to north and was highest in the Delta region, northern lakes, and coastal waters Levels of chemical contaminants, such as pesticides and toxic metals were highest in samples collected from polluted sites in Lake Manzala In-depth study was conducted on food borne parasites transmitted to humans from eating fish It was shown that fishermen communities and villages in the northern Delta exhibited high rate of infection

Impact of Water Quality on Fish Production

Studies were conducted in Egypt and Israel on *Tilapia* fish species These studies focused on the quality of fish production from those reared in fish ponds supplied with wastewater vs fish ponds without wastewater The results indicated that the production of fish was greater in fish ponds supplied with wastewater Microbial assay indicated that there was no difference between wastewater-enriched and non-wastewater agricultures for *E Coli* and *Aeromonas* (an opportunistic pathogen)

Active Decontamination and Detection of Microbes and Heavy Metals Marketed in Israel

This study was conducted to (a) examine the efficiency of changing the water (in the holding tanks) to reduce the level of microorganisms in fish tissues, and (b) to test for the presence of microbes and heavy metals in marketed fish

The results showed that although both microbial and heavy metal concentrations were within the acceptable Israeli ranges, however, it was recommended that measures should be taken in processing the fish to prevent cross-contamination of edible tissue by the digestive tract and skin

Chemical Contaminants in Fish Decontamination

Chemical residues were analyzed from fish taken from Lake Manzala, which receives agricultural drainage and untreated sewage effluents, and from the Suez Experimental Station, where fish is grown in treated sewage effluents Results indicated that there was a higher concentration of organochlorine pesticides and heavy metals (lead, copper, zinc cadmium) present in Lake Manzala than in fish from the Suez Station

Further studies of fish in Egypt indicated that in certain locations, the organic chemicals chlordane, endrin and PCB exceed the most conservative international standards

Science Policy Linkages and Regulatory Approaches

The relevant authorities in Egypt were provided with the research results of this project Among these results is that the reuse of treated domestic wastewater is highly preferred over the reuse of agricultural drainage water in fish farming The research also pointed to the pressing need for public education programs to advise consumers on how to minimize the health risks from eating contaminated seafood This includes (a) advisories on eating salted raw fish or improperly prepared fish, (b) guidelines for purchasing, storing and cooking and (c) information on the nutritional values of seafood

Program Management

The Cooperative Marine Technology Program for the Middle East is coordinated by a Steering Committee composed of Dr R B Abel, Program General Manager, Dr S Z El-Sayed, Principal Investigator and Chief Scientist, and the two lead country coordinators, Dr Y Cohen, Director, Israeli Institute for Oceanographic and Limnological Research (IOLR), and Dr H K Badawi, Director, National Institute of Oceanography and Fisheries (NIOF) and Mr A I El-Ibiary, General Counselor, Egyptian Academy of Science and Technology

During Phase IV, the Steering Committee held eight meetings, the venue of these meetings alternated between Egypt, Israel and U S A Most of these meetings were held in conjunction with the Program Workshops

Among the prominent accomplishments of the Marine Technology Program during Phase IV was the dramatic expansion in the number of scientists participating in this phase compared to earlier phases Further several universities and institutions in Egypt and Israel, previously unaffiliated with the Program, were recruited to the Program

At the suggestion of members of the Steering Committee, Dr R B Abel authored a book on "The Effect of Technical Cooperation on Reducing Tensions in the Middle East", which included chapters dealing with the history and accomplishments of the Marine Technology Program and its contributions to technical cooperation between the Middle East countries

III PROGRAM MANAGEMENT

I The Steering Committee and Chronology of its Meetings

Phase IV of the Cooperative Marine Technology Program for the Middle East began (per effective grant date) on September 29, 1992 Although it was originally scheduled to terminate on September 28, 1995, a series of extensions resulted in actual termination on December 31, 1997

As has been mentioned in earlier reports, the Marine Technology Program established managerial custom for the Program, by forming in 1981 a Steering Committee during Phase I This Committee has played a dominant role in governing the Program It consists of Dr R B Abel Program General Manager, Dr S Z El-Sayed, Principal Investigator and Chief Scientist, and the two lead country coordinators, Dr Yuval Cohen Director Israeli Institute for Oceanographic and Limnological Research (IOLR) and Dr H K Badawi Director National Institute of Oceanography and Fisheries (NIOF) As customary the Egyptian Academy of Science & Technology General Counselor Mr A I El-Ibiary, participated in all sessions

During Phase IV, the Committee was co-chaired by Dr A A Latif, President of the Egyptian Academy of Scientific Research and Technology (until his death in 1994), and by Dr R B Abel, Stevens Institute of Technology, New Jersey

Dr El-Sayed became Principal Investigator for the project when authority was ceded to Texas A&M University by the New Jersey Marine Sciences Consortium He continued in his capacity of Chief Scientist as well Dr El-Sayed thus bore responsibility for all of the scientific components of the program, including compiling and editing the technical semi-annual and annual reports He also presided at the workshops

Dr Abel maintained interaction and cooperation among the Steering Committee members project Principal Investigators and officials concerned, and/or interested in the program He and Dr El-Sayed shared responsibility for planning all the meetings

Additional persons were invited to the Steering Committee meetings on an *ad hoc* basis according to the subject matter and their expertise For instance, Drs Mohammed Wahbeh Dureid Mehasneh and Mohammed Abu Hilal represented Jordan at all of the meetings Also Dr K H Mancy, of the University of Michigan and Principal Investigator of the Seafood Safety Project, usually joined the group

A preliminary agenda for the meetings was normally drafted by Dr Abel and circulated to the members for review and amendment prior to issuing a final agenda

During Phase IV the Steering Committee meetings were usually held in conjunction with the Program Workshops, the meetings dates and places are the following

July 20, 1991 at Taba, Egypt The proposal for the Phase IV had been formulated in a draft form prior to that date, it was put through a refinement process at this time

The US embassies in Tel Aviv, Cairo, and Riyadh (Saudi Arabia) seconded, respectively, Drs Charles Lawson, Robert Nemeth, and Jerry Gaines as observers to this meeting

October 20, 1993 in Washington, D C This meeting was significant for several reasons

1 AID hosted part of the meeting, enabling the committee members to meet Mr Francis Weedon, Deputy Assistant Administrator of AID as well as the Science/Technology staff of the Bureau
2 The Egyptians were accompanied by Ambassador Mustafa, Director of the Office of Israeli Affairs of the Egyptian Foreign Office, and the Israelis were accompanied by Ambassador Zvi, Director of Egyptian Affairs of the Israeli Foreign Ministry The group's cohesion and strength did not escape the attention of our hosts
3 The entire group met with Senator Claiborne Pell, Chairman of the US Senate Committee on Foreign Relations and with Representative James Scheuer of the House, who had been among the early and strong supporters of the MERC Program
4 AID permitted, indeed welcomed, discussion of the Aqaba Program Plan, in which they expressed deep interest

December 15, 1993 at Haifa, Israel The Steering Committee met in Haifa for two days The Committee members then joined all of the Phase IV project participants in Sharm El-Sheikh, Egypt, for the Phase's First Annual Workshop i e , review and critique of the first year's activities

The final report of Phase III-Amended had been submitted to USAID during the previous September Also by the time of the meeting, the Phase IV first annual report was about ready for transmittal to AID It reflected considerable imbalance in start-up timing, principally owing to equipment failures in the Trophodynamics Project (This will becovered in more detail in the following Section III)

The meeting was also the first occasion in which the performance of the Texas A&M Research Foundation could be evaluated In general, the Egyptians and especially the Israelis were highly satisfied with the Foundation's efficiency

As an adjunct to the regular Mediterranean work, the Steering Committee members had -- for the previous five years -- been developing plans for a program in the Gulf of Aqaba

It was at this meeting that Dr Abel invited everyone's attention to the program evaluations which implicitly suggested the desirability of periodic personnel turnover He announced his intention to phase out of the program at the end of Phase IV salary-wise, remaining available to any project where his services might be needed

May 25, 1994 in Washington, D C This was the program's last meeting in Washington, it having been decided that the expense of travel to the USA and need to site the meetings where the action was taking place, overrode the advantage of meeting with AID and other government officials The Steering Committee members were joined by Dr Mohammed Wahbeh of the University of Jordan This gave the Committee the opportunitv to have an in-depth discussion on the proposed Gulf of Aqaba proposed project

The group met with Dr Dan Kurtzer Deputy Assistant Secretary of State for Middle Easter Affairs While the meeting was essentially dedicated to progress monitoring of Phase IV this particular session was dominated by discussion of the Aqaba Program Plan

There then ensued a meeting with AID officials directly responsible for the MERC Program Dr John Daley and Mssrs Kenneth Prussner and Edward Lijewski The meeting highlighted

I Reduced AID financial power vs increasing proposal development

II AID's current priorities

- A Health and Population
- B Environment
- C Economic Growth
- D "Building Democracy"

The rest of the meetings were devoted to priorities for present and future action

September 20, 1994 in Haifa and Cairo In order to spread the action, the Steering Committee decided to hold its management meeting in Haifa and the technical workshop in Cairo

The Committee was mainly concerned with accelerating the Trophodynamics project, whose progress was plagued by logistics problems, relating to equipment and ship acquisition

April 4, 1995 in Aqaba, Jordan An historic "first" occurred when the Israeli, Egyptian, and Jordanian teams met at the Marine Science Station, in Aqaba An additional (to Phase IV assessment) objective was furtherance of the Aqaba proposal Aspects needing additional work included capacity building, education and training, and recruitment of additional institutions With the Governor of the Aqaba District presiding, the officials offered their aspirations for increased collaboration The meeting was followed by an in depth Phase IV project-progress workshop, offering the Jordanian scientists a close examination of trans-national cooperation in marine science

July 14, 1996 in Taba Egypt The Phase IV project workshop which followed the Steering Committee meeting was extensive and extremely detailed

March 26, 1997 at Texas A&M University Rather than a conventional Steering Committee meeting, this session was preparatory to Phase IV evaluation, and included only the American participants and the U S AID Evaluation Team The meeting dealt primarily with a review of all aspects of the Program's Phase IV from the American perspective

II Management Accomplishments

Clearly, the most prominent accomplishment of the Marine Technology Program's Phase IV was the dramatic expansion of the "*dramatis personae*" Nearly twice the number of scientists participated in this phase, than in earlier phases

Another accomplishment was the recruitment of institutions previously unaffiliated with the Program In Egypt this relates to several universities, e g , Ain Shams Cairo Suez Canal In Israel, introduction of the United Universities for the Aqaba planning, brought the Hebrew University of Jerusalem and the University of Tel Aviv

Scores of graduate students participated in this phase, many of them used the data collected in the various projects to write their theses and dissertations Further numerous Israeli scientists visited their Egyptian counterparts and, likewise, the Egyptian investigators reciprocated the visits

While not specifically pertinent to Phase IV, the logistics of the meetings permitted the Steering Committee to discuss other subjects In almost all of our meetings during this period included Jordanian participation

III Some Thoughts On The Program's Management

A In retrospect the Steering Committee members believe that much credit is due Dr El-Sayed for his intensive efforts on behalf of Phase IV The Lakes Management and Seafood Safety projects, lived up to all requirements of the AID/MERC Program They promoted cooperation did good science, and offered clear paths to economic growth

B Several obstacles were encountered in the Trophodynamics Project The acoustic equipment purchased for the project was inadequate, and the oft breakdowns haunted the project throughout its duration The Egyptians also experienced difficulties in arranging shipboard operations Finally, communications were less effective than anticipated

C Failure of the hydroacoustic equipment in the Trophodynamics Project with consequent considerable damage to the project marked the second instance in the Program's history, in which strict adherence to, and strict observance of, government regulations has severely undermined the project The project scientists unanimously demanded a Norwegian product whose reliability and effectiveness had been demonstrated many times over They were forced instead to accept an American product which was not only prohibitively more expensive, but operationally of a lesser quality The equipment failed repeatedly, was shipped back and forth between Seattle and Haifa/Cairo several times, and eventually caused great damage to the project (Ironically, the American company salesman who had played the law' so vigorously, has transferred to the Norwegian firm a month after the sale was consummated!)

IV Related Events

A As previously mentioned, during the September 1992 meeting in Cairo, the Egyptian delegation suggested that the Steering Committee design a protocol of working relationships among the countries, committees, projects, and related officials It would not only serve as a useful guide for our own intra-program conduct, it might also prove useful to other prospective entrants to the MERC Program Consensus was arrived at with surprising ease, owing to long standing interrelationships

B On December 12, 1995, Dr Abel reconvened (for the third time) a meeting of the MERC projects' Principal Investigators The meeting was hosted by Dr Eileen Herrera of the Department of Agriculture and chaired by Abel It offered an excellent opportunity, not only for the P I 's to compare notes, but for the first major interaction between the (then) new AID MERC Program Manager and his grantees A summary of the proceedings is given in Annex 1

C In 1990 Mr A I El-Ibiary suggested that a book be prepared, as a sort of analytical chronology of the program, including reminiscences of officials who had opportunity to judge it from the outside The book "The Effect of Technical Cooperation on Reducing Tensions in the Middle Ease", authored by Dr R B Abel, was published by University Press International, Inc The book did not fulfill its planners' expectations, but did serve to penetrate the peace talk environment, where technical cooperation is often ignored as an instrumentality of international diplomacy

V Effects of the Marine Program on the Middle East Peace Process

Comprehensive analysis of this topic is far beyond the scope of this report The fundamental issue is treated most cogently by Dr Milton J Esman, Emeritus Professor, Cornell University, in his comprehensive assessment "Can Foreign Aid Moderate Ethnic Conflict?[1]

> "Since World War II, a ccomplex network has emerged of bilateral and multilateral agencies that manage economic assistance to low income countries in the form of investment projects, policy advice and technical assistance Although each of these agencies has its distinctive personality, most of them have avoided facing up to the post-Cold War reality of burgeoning ethnic conflict This reluctance to deal with the violent consequences of ethnic pluralism is often self-defeating, for such violence can destabilize the environment within which the agencies operate and thus undermine their efforts The same reluctance can also blind agencies to the damage that the ill-considered provision of foreign aid can inflict on ethnic relations within aid-receiving nations Some interventions may have neutral or even positive sum outcomes Too many spurred by the logic of "developmentalism" that ranks economic growth and modernization above values such as democracy and interethnic fairness, have distributional effects that generate or aggravate ethnic conflict, as one community is perceived by its rivals to be benefiting at their expense Host governments-the critical intermediaries between assistance organizations and the local communities targeted to receive assistance often ensure ethnically destabilizing outcomes by deliberately skewing the benefits of development aid in favor of a particular ethnic community "

First to establish proper perspective it must be recognized that MERC funding represents approximately one tenth of one percent of total USA funds spent in the Middle East It is understood however that a recent AID policy-level review has identified agriculture as the dominant feature of the MERC program in terms of effect on the peace initiative It is proposed in the strongest possible terms, that mariculture must be subsumed under this rubric In fact, if anything in utilitarian Middle East context, mariculture might well

[1] Peaceworks No 13, Published by the United States Institute of Peace in March 1977

be considered the most important component of agriculture, owing to its independence from fresh water! Yet, mariculture was dropped in the AID priority ladder about a half-decade ago The question has been asked, "Would mariculture command Israeli-Arab cooperation, were American funding to be removed?" In fact, the process has survived demonstrably -- perhaps more so than from any other discontinued AID/MERC project Of much more significance, everyone else's recognition of the importance of mariculture has resulted in continuance of the work in Egypt and Israel, separately The reason relates to large scale funding by the European Union, the Japanese, etc Unfortunately, these funds are granted to the Middle East countries individually, hardly encouraging technical cooperation or the MERC ethic, generally

Annex 1

MIDDLE EAST REGIONAL COOPERATION
MEETING OF MERC PROJECT DIRECTORS
DECEMBER 12, 1995

SUMMARY OF PROCEEDINGS

The third meeting of Directors of the MERC projects was convened by the Chairman Dr Robert B Abel, on December 12, 1996

Dr Eileen Herrera, as host, offered a welcome to the U S Department of Agriculture

Dr Abel as Chairman gave a brief overview of the MERC Program's history, goals, and development He then relinquished the gavel to the MERC project officer, Mr Edward Lijewski who described the Program's new (under the reorganization) goals and objectives He distributed an excellent catalog of the Program's projects, and outlined AID's aspirations for the Program (Rapporteur's note Since that time, AID has been still further reorganized Lijewski has been assigned to the "Womens' Opportunities Division" and the entire MERC Program has been transferred to the Agriculture Division) At that point each participant introduced him/herself and at Dr Abel's request each P I described his/her program in terms of goals, activities, and future plans

In summary

1 AID in contrast to earlier years, now receives proposals aggregating approximately 700% of their budget This cannot help but improve the program
2 AID project officers are overwhelmed by these proposals and are backlogged
3 Emphasis is now clearly on "environmental protection" vis-a-vis the traditional challenges of food and water
4 Nearly all recent grants have been made to U S Government agencies, in contrast to earlier grants directed to NGO's and their overseas colleagues

The MERC Program has emerged as one of the most valuable (defined in political, economic or cultural terms) of all the AID programs

IV-1 TROPHODYNAMICS OF THE SOUTHEASTERN MEDITERRANEAN, WITH SPECIAL REFERENCE TO COMMERCIALY IMPORTANT FISHES

Principal Investigators *Yigal Kalıkhman and Paul Wallıne*

Collaborating Investigators *Ilıa Ostrovsky, Yosef Yacobı, Nurıt Kress, and MosheTom*

FINAL REPORT, September 1992 - September 1996

Israel Oceanographıc & Lımnologıcal Research

Previous Page Blank

Table of Contents

I	**Abstract**	13
II	**Introduction**	14
III	**Mathematical Model Design**	15
IV	**Mathematical Experiments**	16
	Isotropic Field	16
	Anisotropic Field	17
	General Case	17
V	**Application of the Acoustic Method**	18
VI	**Multidisciplinary Surveys**	19
	Survey of 5-9 December 1993	19
	Survey of 27 February - 2 March 1994	19
	Survey of 14-18 August 1994	19
	Survey of 14-18 May 1995	20
	Survey of 17-20 September 1995	20
VII	**Method of Identification of Correlation Zones**	20
	Survey of 27 February-2 March 1994	21
	Survey of 14-18 August 1994	21
	Survey of 14-18 May 1995	22
	Survey of 17-20 September 1995	22
	Distributions on the Transects	24
VIII	**Ecopath 3 0 Model**	24
IX	**Conclusions**	28
X	**References**	30
XI	**International Cooperation**	32
XII	**Publications and Presentations**	33
XIII	**Participants**	33
XIV	**Legends to Figures**	34
XV	**Acknowledgements**	37

IV TROPHODYNAMICS OF THE SOUTHEASTERN MEDITERRANEAN, WITH SPECIAL REFERENCE TO COMMERCIALY IMPORTANT FISHES

I Abstract

In the early stages of the Cooperative Marine Technology Program for the Middle East (Phases I and II), studies of the plankton distribution and abundance off the Egypt and Israeli coasts showed that the large blooms of phytoplankton previously extant in the Fall have disappeared, and as a result the sardine population have become more dispersed and more scarce The study also showed that phytoplankton biomass and primary productivity in the S E Mediterranean pelagic region are among the lowest recorded for any marine region Further, it has been shown that in the Eastern Mediterranean, phosphorus appears to be the principal limiting nutrient, in contrast with most other seas These findings imply that fish production in the S E Mediterranean must be very low compared to the other regions

Hydroacoustic investigations on the coastal shelf of Israel during the current phase of the project (i e Phase IV) have shown that, in general, pelagic fish are present only in very low densities, with high concentrations present only in a few localized areas Demersal fish (e g red mullet) distribution has been found to correlate with temperature distribution, so it should be possible to predict locations of fish schools from temperature measurements Investigators have shown that while the Kishon River provides the main supply of nutrients, the river is also the main source of water contamination in the Israeli fisheries zones It should be pointed out that the scientific efforts in the project were aimed not only at carrying out acoustic surveys of the Israeli fisheries zone, but also at optimization of the design of the surveys themselves The expertise in the hydroacoustic method developed during this project together with the hydroacoustic equipment acquired, can be usefully applied in the future to make baseline studies, environmental impact studies, and studies of the effect of coastal structures on fish behavior

Higher levels of phytoplankton productivity and potentially high benthic algal production along the relatively narrow coastal shelf area may permit enhanced levels of fish stocks along the coastal region The results of this project clearly indicated that efforts to enhance fisheries and to obtain sustainable yields should be directed at coastal shelf regions **only**

Although emphasis in this project centered around fish stock assessment (using hydroacoustic techniques), studies of the inorganic nutrients, phytoplankton and zooplankton populations were also undertaken These studies revealed positive correlation between the distribution of chlorophyll and the silicic acid, and phosphate concentrations Positive correlation was also found between the distribution of the zooplankton and phytoplankton and fish populations Finally, the Ecopath model has provided a summary of the food web with an emphasis on commercial fish The model could be improved with better information

on the abundance and fate of zooplankton, and the biomass and distribution of benthic animals

II Introduction

The principal aim of this project (during its early phases i e 1980-1986) was to evaluate the levels of primary production in the near shore and pelagic regions of the Southeastern Mediterranean adjacent to the Israeli and Egyptian coasts in order to assess the fishery potential of this region The result of this investigation permitted for the first time quantification of primary production and revealed details of the population composition of phytoplankton and their spatial and temporal distribution The study showed that phytoplankton biomass and productivity in the Southeastern Mediterranean pelagic region are among the lowest recorded for any marine region Most (80 to >90%) of the primary production was attributed to very small (1-2 μm) organisms (picocyanobacteria and prochlorophytes) which also made up the bulk of the phytoplankton biomass In the Eastern Mediterranean phosphorus appears to be the principal limiting nutrient, in contrast with most other seas These findings imply that fish production in the SE Mediterranean must be very low compared to other regions Higher levels of phytoplankton productivity and potentially high benthic algal production along the relatively narrow coastal shelf area may permit enhanced levels of fish stocks along the coastal region The results of this project clearly indicated that efforts to enhance fisheries and to obtain sustainable yields should be directed at coastal shelf regions <u>only</u> and that expansion of pelagic fisheries should not be encouraged

Hydroacoustic investigations on the coastal shelf during the current phase of the project (1992-present) have shown that, in general, pelagic fish are present only in very low densities along the coast of Israel, with high concentrations present only in a few localized areas Demersal fish distribution has been correlated with temperature distribution, so it should be possible to predict locations of fish schools from temperature measurements Expertise in the hydroacoustic method developed during the project, together with the equipment acquired, can be usefully applied in the future to make baseline studies, environmental impact studies, and studies of the effect of coastal structures on fish behavior

In this project, our scientific efforts were aimed not only at carrying out acoustic surveys of the Israeli fisheries zone, but also at optimization of the design of surveys themselves A major goal of acoustic surveys of fish concentrations is to reconstruct the distribution field studied Survey design is considered optimal if it ensures conformity of a reconstructed field to the actual one with a specified precision and minimal expenditures Since the distribution of fish and other ecosystem components is usually patchy (Steele, 1976), the survey path should be chosen on the basis of statistical characteristics of a patchy

distribution field

Yudanov *et al* (1984) recommended spacing transects of an acoustic survey at a distance close to the autocorrelation radius for the field However, no procedures for determination of the accuracy of a survey were established Since the real fish distributions under natural conditions are never known, we applied a computerized mathematical simulation technique to reveal these relationships The relative error of a fish abundance estimate (the bias of the survey) was used as a measure of the survey quality (Kalikhman *et al*, 1986, Kalikhman, 1989)

Within the framework of ecological research, it is often necessary to estimate the spatial structure and organization of populations For example, analysis of distribution fields for different ecosystem components allowed elucidation of some interrelationships between fish and environmental parameters (Kalikhman *et al*, 1992, 1995) Among the aims of the present study was to determine survey design parameters allowing the unbiased reconstruction of a patchy distribution field The latter were compared with the original, simulated patchy fields by correlation analysis

III Mathematical Model Design

The mathematical model is based on the approach described by Kizner *et al* (1983) and Zaripov *et al* (1983) The surveyed area is a rectangular array of numbers, each of which represents the value of the field in an elementary area (node) The distance between the nodes is equal to one To simulate a distribution field, patches are generated The sizes of the patches are adjusted to fit the surveyed area Outside the patches the field variable is zero (or a constant background) Inside a patch the variable increases from the outer border towards the center according to a law obtained by analyzing data from real acoustic surveys (Williamson, 1980) Patches may be circular (isotropic) or elliptical (anisotropic) with different sizes and spatial orientation, separate or overlapping (partially or fully), forming larger patches with more complicated shapes Random fluctuations can be superimposed on the simulated patchy field

The resulting (constructed) patchy distribution field is then sampled by simulation of an acoustic survey We choose a survey path and the general direction of the survey The transects are constructed perpendicular to the general direction of the survey Thus, the survey track consists of parallel transects and connecting sections perpendicular to the transects The distance between parallel transects is constant and equal to D (length of tracks) The values of a field along the survey path are considered to be measured with no error These sampled values are used to reconstruct the field To evaluate the conformity of the reconstructed field to that originally generated, pairs of values (original and estimated) are

taken at the full set of nodes of the array representing the surveyed area Conformity is evaluated by the coefficient of determination representing the square of the standard Pearson correlation coefficient (r)

As is mentioned in the Introduction, the autocorrelation radius (R) is used as a characteristic of a field in choosing distance between acoustic survey transects When the autocorrelation axes are located horizontally (or vertically), the autocorrelation radius is determined in a plot of the autocorrelation function as the distance from the coordinate center to the point where the lag is zero The autocorrelation radius for a field in an arbitrary direction is defined as a half-length of the projection of the autocorrelation ellipse on the axis in this direction

IV Mathematical Experiments

The surveyed area was represented by an array of 2500 numbers making up a square matrix of 50 lines and 50 columns The total number of mathematical experiments conducted was 235 The gridding methods employed use weighted interpolating algorithms The kriging method widely used in reconstruction of distribution fields was tested This algorithm assumes an underlying variogram (Matheron, 1963, Cressie, 1991) The method of gridding was chosen so that the correlation between the reconstructed field and that originally generated is maximized Preliminary experiments indicated that in most cases the maximal correlations were attained when using kriging with the linear variogram model In order to exclude the effect of gridding method on relationships of interest, in all our experiments distribution fields were reconstructed by kriging with the linear variogram model The search option controlled which data points are considered by the gridding operations when interpolating grid nodes

Isotropic (non-directional) and anisotropic (directional) distributions were simulated and studied Results of experiments with anisotropic fields indicated that the correlation between the reconstructed field and its original depends upon the orientation of the ellipse for the data weighting and search The maximal correlation is attained if in reconstructing the field the major axis of this ellipse is adjusted to the direction of patch elongation In carrying out mathematical experiments, it was assumed that *a priori* information was available either on the field isotropy, or on the anisotropic patch orientation (in surveying fields on shelves it is often observed that patches are extended along the coast and not in any other direction) On the basis of this information, in reconstructing the fields the major axis of the ellipse for the data weighting and search was adjusted to the direction of patch elongation

Isotropic Field For each simulated isotropic field (examples are given in Fig 1), the autocorrelation radii in different directions were similar (0 14-0 17, left, 0 08-0 10, right)

Thus, the radius for the entire field could be determined as an average of the radii in different directions In the case of isotropic fields, the mathematical experiments indicated that the conformity of a reconstructed field to that originally generated is independent of the direction of the survey For example, for the isotropic field of R=0 15 (Fig 1, left), surveys carried out with D=0 2 in two perpendicular directions gave similar results of r^2=0 81 and r^2=0 85, for the field of R=0 09 (Fig 1, right), surveys carried out with D=0 2 in perpendicular directions also gave similar results of r^2=0 20 and r^2=0 28 Increase in the distance between transects and decrease in the autocorrelation radius both lead to lower correlation between the reconstructed field and that originally generated (Fig 1) Thus, the conformity of a reconstructed field to its original depends upon the D/R ratio

Anisotropic Field This kind of field was modeled as a set of anisotropic patches with similar spatial orientation Anisotropic fields were derived from isotropic patches which were stretched in the direction of one axis and compressed in the perpendicular direction to simulate anisotropic ones (Fig 2) For each simulated anisotropic field, the axis of the autocorrelation ellipse in the direction of patch stretching or compressing was determined as an average of the autocorrelation radii along the transects taken in this direction (Fig 2) As expected, the simulations conducted indicated that surveys in the direction of patch elongation permit us to reconstruct the original field more precisely than those made in a perpendicular direction For example, in the case of the anisotropic field of R_X=0 27 and R_Y=0 13 (Fig 2, left), a survey carried out with D=0 2 in the direction of patch elongation gave better results in terms of the original field conformity (r^2 =0 94) than a survey carried out in a perpendicular direction (r^2=0 66) Similarly, for the anisotropic field of R_X=0 06 and R_Y=0 23 (Fig 2, right), a survey with D=0 2 in the direction of patch elongation permitted us to reconstruct the original field much better (r^2 = 0 94) than a survey with D=0 2 in a perpendicular direction (r^2 = 0 16)

The distribution fields were rotated to a certain angle (an example of rotation for 30° is given in Fig 3) to examine the efficiency of surveys which, for some reason, cannot be conducted in the optimal direction The results of the experiments indicate that an increase in the angle between the survey direction and that of patch elongation leads to lower coefficient of determination between the reconstructed field and that originally generated (Fig 3) This is explained by the fact that the D/R ratio in the direction of patch elongation is smaller than that in any other direction

General Case Surveys of isotropic and anisotropic fields gave similar results (Fig 4) The existence of a distinct relationship fitting the generalized data set (r^2 versus D/R ratio) confirms the possibility of using the autocorrelation radius as a parameter of a field in choosing the distance between acoustic survey transects From Fig 4 it can be seen that with

the D/R ratio increasing to 1 0-1 5, the coefficient of determination changes only slightly and remains comparatively high, while with further increase, this coefficient falls considerably For this reason, we suggest choosing the distance between transects to be less than 1 0-1 5R Thus, when designing a survey, if *a priori* information is available on the autocorrelation radius for a field in any direction, the distance between the transects of a survey in this direction can be chosen, ensuring the required match between the reconstructed field and the actual field

V Application of the Acoustic Method

For each acoustic survey, the fish distributions along the longitudinal transect TR were mapped (Fig 5) and the associated autocorrelation functions calculated (Fig 6) The autocorrelation radius of the field along this transect was estimated as 13 4 km (February 1994), 16 8 km (August 1994), 22 4 km (May 1995) and 14 9 km (September 1995) In every case it was larger than 10 km As the extent of the Israeli fisheries zone is about 180 km, 19 acoustical transects are required to cover this area The grid chosen contains 19 acoustical transects (Fig 7, left) Thus, we concluded that this grid of transects ensures adequate reconstruction of the patchy fish distribution fields which characterize the Israeli continental shelf Since on shelves patches are generally extended along the coast and not in any other direction, acoustical transects should be spaced perpendicular to the shore, while the general direction of surveying should be parallel to the shore This was the survey design employed in our study

Acoustic surveys of pelagic fish stock and concurrent measurements of environmental parameters were conducted on the Research Vessel *Shikmona* by the Israeli scientific team with participation of Prof Sayed Z El-Sayed and Gert van Dijken (Texas A&M University, USA), Abdel Rahman El-Shazli and Mohammed Abdallah Ali (National Institute of Oceanography and Fisheries, Egypt) [1] At sampling stations, concentrations of zooplankton, chlorophyll, and nutrients were measured, as well as the temperature of the water The survey grid contained 29 sampling stations Trawling surveys of the demersal fish stocks were carried out on commercial trawlers by experts from the Fisheries Department of the Ministry of Agriculture of Israel simultaneously with the acoustic survey (Fig 7, right) Demersal fish density was calculated on the basis of commercial catches of fishing vessels by taking into account the mouth size of the trawls used and the distance trawled

[1] Prof Sayed El-Sayed took part only in the survey carried out in August 1994, Gert van Dijken was present on all cruises made during the project Mohammed Abdallah Ali participated in only the survey conducted in December 1993, Abdel Rahman El-Shazli - in December 1993, February and August 1994, and May 1995

VI Multidisciplinary Surveys

Due to the multiple failures of the BioSonics ES-1000 Dual-Beam Echo Sounder, and then a reconditioned Model 102 Dual-Beam Echo Sounder, the number of acoustic surveys was considerably reduced as compared to initial plans Within the framework of the project, five multidisciplinary surveys were undertaken on the following dates on the 5-9 December 1993 (not completed due to the failure of the echo sounder), 27 February - 2 March 1994, 14-18 August 1994, 14-18 May 1995 and 17-20 September 1995

Survey of 5-9 December 1993 The surface water temperature in the study region ranged from 20 51 to 21 78, and the temperature at the bottom from 15 23 to 21 63 From trawling data, the distribution and biomass of two demersal species could be estimated for the northern and central parts of the fisheries zone The greatest abundance of the most commercially important species, red mullet (*Mullus barbatus* and *Mullus surmuletus*), coincided with the areas of the highest water temperature at the bottom (Fig 8) The biomass of red mullet was estimated as 180 tons The general distribution pattern for another commercial species, pandora (*Pagellus erythrinus*), was similar to that for red mullet (Fig 9) The biomass of pandora was 80 tons The location of the peak of pelagic fish density (Fig 10) coincided with the area where maximal catches were obtained by the purse seiners in the past (Pisanty, 1969) The biomass of pelagic fish in the central part of the zone was estimated as only 1070 tons

Survey of 27 February - 2 March 1994 The water temperature in the study region was very uniform the surface temperature ranged from 17 01 to 17 71, and the temperature at the bottom from 16 86 to 17 47 The heaviest catches of red mullet were obtained as a result of trawlings conducted between the 200 and 400 m isobaths (Fig 11) The biomass of red mullet was estimated to be 320 tons The heaviest catches of pandora were obtained near Atlit at the outer border of the fisheries zone (Fig 11) The biomass of pandora was estimated as 400 tons The highest concentrations of nutrients were observed in Haifa Bay (Fig 12 and 13), of chlorophyll in Haifa Bay and in the area between Caesarea and Hadera (Fig 13), of zooplankton near Akko[2] The highest pelagic fish density was found near Atlit (Fig 14) The biomass of pelagic fish was low, only 570 tons

Survey of 14-18 August 1994 The surface water temperature ranged from 27 70 to 29 87, and the temperature at the bottom from 15 07 to 29 75 The heaviest catches of red mullet were obtained in the northern region in areas with high water temperature at the bottom (Fig 15) The biomass of red mullet was evaluated as 470 tons The highest concentrations of silicic acid were observed to the south of Atlit and between Tel-Aviv and Palmahim (Fig

---

No significant relationships of concentrations of nutrients chlorophyll or zooplankton with depth were observed Therefore, concentrations were averaged over depth

16) Nitrate and nitrite and phosphate were highest in Haifa Bay (Fig 16 and 17) The same pattern of distribution was found for chlorophyll (Fig 17) and zooplankton (Fig 18) Pelagic fish densities were comparatively high and no relationship to water temperature was found Dense concentrations were observed in the north and in the area near Haifa (Fig 18) The total biomass of pelagic fish was estimated to be 6080 tons

Survey of 14-18 May 1995 The surface water temperature ranged from 20 21 to 22 90, and the water temperature at the bottom from 15 51 to 22 80 During the survey the number of trawlings was too low to determine the distribution and the stock of demersal fish The highest concentration of silicic acid was observed in Haifa Bay and to the south of Atlit Nitrate and nitrite were comparatively uniform (Fig 19) The peaks of the phosphate and chlorophyll concentrations were situated in Haifa Bay (Fig 20) The maximum of zooplankton distribution was located between Haifa and Hadera near-shore Pelagic fish targets could not be separated from sound scattering layers, which were common on this survey Highest densities were observed in the northern area and in the region from Herzliya to Tel-Aviv (Fig 21) The biomass of pelagic fish and that of the scattering layers together was estimated at 12500 tons

Survey of 17-20 September 1995 The surface water temperature ranged from 27 54 to 28 99, and the temperature at the bottom from 15 89 to 29 00 The number of trawlings was too low to determine the distribution and the stock of demersal fish The maximum of the silicic acid concentration was observed to the north of Herzliya off-shore Nitrate and nitrite (Fig 22) and phosphate (Fig 23) concentrations were highest in Haifa Bay Zooplankton was most abundant near Haifa, and the peak of the pelagic fish density was in the north of the study region (Fig 24)[3] The biomass of pelagic fish was evaluated to be 2250 ton

VII Method of Identification of Correlation Zones

The method of identification of correlation zones for two distribution fields can be summarized as follows (Kalikhman *et al*, 1995)

1 Radii of autocorrelation circles (or ellipses) are determined for each distribution field A regular grid of points is chosen with the distance between nodes smaller than the autocorrelation radius of the fields

2 Gradients of the fields are calculated at the nodes of the grid Angles between corresponding gradients are calculated Zones containing neighboring nodes at which gradients are co-phased (or anti-phased) are outlined Zones smaller than the autocorrelation circles (or ellipses) are rejected

[3] When mapping the distribution of chlorophyll, it was found that the point in Haifa Bay, critical for the distribution as a whole, was missing For this reason, we could not map the distribution of chlorophyll

3 The original distribution field is sampled at the nodes of the grid located in each zone outlined Correlations are calculated for the corresponding values of the fields belonging to each zone The correlations obtained are analyzed together with other characteristics of the zones

The required distance between sampling locations was estimated on the basis of the analysis of autocorrelation of the fields (Sokal and Wartenberg, 1981, Legendre and Fortin, 1989, McArdle and Blackwell, 1989, Kalikhman *et al*, 1992) Typical transects for the fields were chosen crossing the areas of high concentrations in the northern part of the study area (Fig 25) The distributions of all the ecosystem components along these transects were plotted and associated autocorrelation functions were calculated (Fig 26) The autocorrelation radius is the distance from the coordinate center to the point at which the value of autocorrelation function is zero (Gandin, 1965) The autocorrelation radii for the distribution fields considered ranged from 5 0 to 29 0 km (Table 1) Thus, the distance between nodes of the sampling grid must be not more than 5 0 km to ensure that all points in the fields would be related statistically to one or more sampling locations A grid with 5 0-km intervals between nodes was selected to fulfil the requirements (Fig 27)

Survey of 27 February - 2 March 1994 A positive correlation zone was identified between the distributions of chlorophyll and silicic acid (with the silicic acid concentration not lower than 0 12-0 14 M) (Fig 28) A positive correlation zone was observed between chlorophyll and phosphate distributions (with the concentration of the latter >0 02-0 04 M) (Fig 29) The same kind of interaction was found between the distributions of zooplankton and chlorophyll (the concentration of chlorophyll >0 20 μg/l) (Fig 30) At the same time a positive correlation zone was identified between the distributions of pelagic fish and zooplankton (>0 20 mg/l), and a negative correlation zone was found (Fig 31) The negative correlation zone was observed at the same place where a negative correlation zone for fish and phosphate (the concentration of phosphate >0 05 M) (Fig 32) This means that zooplankton attracts fish only until the water contamination becomes too high, otherwise the second factor prevails It should be noted, first, that the marine water contamination mostly comes with the water of Kishon river, and second, the maximal fish density was found in the area where the minimal concentration of nutrients was observed [4]

Survey of 14-18 August 1994 A positive correlation zone was identified between the distributions of chlorophyll and phosphate (with the phosphate concentration not lower than 0 05 M) (Fig 33) A positive correlation zone was found between the zooplankton and chlorophyll distributions (when the chlorophyll concentration >0 20 μg/l) (Fig 34) The

[4] In fact negative correlation zones are observed between the distributions of pelagic fish and contaminating substances which decompose in seawater with the formation of nutrients

same kind of interaction pattern was observed between pelagic fish and zooplankton (when the concentration of the latter >0 20 mg/l) (Fig 35) A negative correlation zone was found between the distributions of pelagic fish and nitrate and nitrite (with the nitrate and nitrite concentration >0 40 M) (Fig 36)

Survey of 14-18 May 1995 A positive correlation zone was identified between the distributions of chlorophyll and phosphate (with the concentration of phosphate >0 05 M) (Fig 37) The same interaction pattern was found between zooplankton and chlorophyll (when the chlorophyll concentration >0 20 ug/l) (Fig 38) As mentioned above, the pelagic fish density was inseparable from that contributed by the sound scattering layers For this reason, no correlation zones between the pelagic fish distribution and the distributions of zooplankton and nutrients were observed

Survey of 17-20 September 1995 As indicated before, we had to refuse the mapping of the distribution of chlorophyll, therefore, the correlation zones were identified directly between the concentrations

Table 1 Autocorrelation radii (km) and areas (km^{-2}) of different correlation zones

Date	Field	Transect	Radius, km	Area, km^2	Autocorrelation
27 02-02 03 1994	Silicic Acid	1	23 5		457 5
		2	6 2		—
	Nitrate+Nitrite	1	22 4		436 1
		2	6 2		
	Phosphate	1	11 2		218 0
		2	6 2		
	Chlorophyll	1	23 5		457 5
		2	6 2		
	Zooplankton	1	19 0		298 3
		2	5 0		
	Pelagic Fish	1	13 4		210 4
		2	5 0		
14-18 08 1994	Silicic Acid	1	14 6		238 4
		2	5 2		
	Nitrate+Nitrite	1	9 0		149 8
		2	5 3		
	Phosphate	1	20 5		328 3
		2	5 1		
	Chlorophyll	1	25 0		392 5
		2	5 0		
	Zooplankton	1	28 0		439 6
		2	5 0		
	Pelagic Fish	1	16 8		274 3
		2	5 2		
14-18 05 1995	Silicic Acid	1	28 5		501 4
		2	5 6		
	Nitrate+Nitrite	1	29 0		911 1
		2	10 0		
	Phosphate	1	27 2		427 3
		2	5 0		
	Chlorophyll	1	18 5		360 3
		2	6 2		
	Zooplankton	1	17 0		320 4
		2	6 0		
	Pelagic Fish	1	22 4		351 9
		2	5 0		
17-20 09 1995	Silicic Acid	1	15 0		235 6
		2	5 0		
	Nitrate+Nitrite	1	18 0		294 1
		2	5 2		
	Phosphate	1	13 3		213 1
		2	5 1		
	Zooplankton	1	20 3		440 0
		2	6 9		
	Pelagic Fish	1	14 9		337 0
		2	7 2		

of zooplankton and nutrients A positive correlation zone was found between the zooplankton and phosphate distributions (with the phosphate concentration >0 05 M) (Fig 39) Negative correlation zone was identified between the distributions of pelagic fish and zooplankton (Fig 40), this one being observed at the same place where the negative correlations were found between the distributions of fish and nitrate and nitrite (the concentration >0 30 M) (Fig 41), and fish and phosphate (the concentration >0 05-0 10 M) (Fig 42)

Distributions on the transects On 27 February - 2 March 1994, the maximal concentration of pelagic fish was observed in the area with the minimal concentration of nutrients and zooplankton (Fig 43) On 14-18 August 1994, the maximal nitrate and nitrite and phosphate concentrations corresponded to the minimal pelagic fish density, although the zooplankton concentration in this area was highest (Fig 44) On 14-18 May 1995, the positive correlation zones were identified between the distributions of phosphate and chlorophyll, and chlorophyll and zooplankton (Fig 45) On 17-20 September 1995, the peak concentrations of nitrate and nitrite and phosphate corresponded to the minimal pelagic fish density, although the zooplankton concentration is this area was highest (Fig 46)

VIII Ecopath 3 0

In order to summarize the data collected during this and previous AID projects, we decided to apply the Ecopath model (Christensen and Pauly 1993) Ecopath is a steady-state ecosystem model that has been applied in many systems around the world, making it possible to compare our results with those obtained for the Egyptian shelf and for shelves from other oceans

Software for constructing an Ecopath model is readily available on diskettes (ICLARM, MCPO Box 2631, 0718 Makati, Metro Manila, Philippines), and is very user friendly, especially in its most recent version (3 0) It includes extensive help sections, including several literature-based methods for estimating missing data The inputs necessary for the Ecopath model are 1) the production/biomass ratio (P/B), 2) the diet composition of all the groups included in the model, 3) the fishery catches, 4) the ecotrophic efficiency, which is for each group the fraction of total production consumed by predators (including the fishery), 5) the primary production, 6) detritus biomass, and 7) food consumption per unit biomass (Q/B) Some of these parameters are relatively well-known for components of the SE Mediterranean ecosystem, some were measured during the AID project, and others had to estimated using methods included in the Ecopath software package or from literature values from other oceans Below, we will describe the sources of data used in the model

In the process of constructing the Ecopath model of the Israeli shelf, it was necessary to review all the data collected during the project and to review the literature to find

other sources for ecosystem components not examined during the AID projects The first decision to be made in constructing the model was to decide what are the most important components of the ecosystem Species were lumped on the basis of available information For example, zooplankton were lumped into a single category, as data on the biomass, production, and bioenergetics for individual species do not exist The fish groups were chosen on the basis of available catch data (Snovsky and Shapiro 1997), and it is possible that some of the groups with similar diets should be combined The fishing grounds do not include the entire Israeli shelf (especially in recent years, when the area of Gaza has been closed to Israeli fisherman), but for the purposes of the model, we used the area of the shelf (2850 km^2) The estimates of biomass obtained from the echo sounder surveys were obtained from the entire shelf

Diets of the fish in the model were estimated from data collected over many years by D Golani of Hebrew University, Israel He has classified the fish species of Israel (they are in the 100's) into 5 trophic categories 1) piscivorous, 2) piscivorous and benthic, 3) benthic, 4) planktivorous, and 5) herbivorous This classification was used to divide the food items of each group between the potential food items

Catches in the Israeli fishery are tabulated and summarized on an annual basis For the Ecopath model, we used the average of catches made in 1994 and 1995, and reported by Snovsky and Shapiro (1997) The catch of pelagic fish has been around 1,000 tons for the last 10 years The catch of demersal fish (caught by trawlers) is usually higher, averaging around 1,500 tons, and the inshore catch (caught using trammel nets and longlines) is around 1,372 tons Data on the species composition of the trawl and pelagic catch is available in the 1997 Snovsky and Shapiro report Data on the species composition of the inshore catch was obtained from the Israeli Department of Fisheries

Extensive work was done in the current phase of the AID project to allow estimation of surface chlorophyll from satellite data Unfortunately, the launching of the SeaWifs satellite was delayed (by over 5 years!), so we are not in a position to measure surface chlorophyll from space Satellite images made in the 80's are of poorer quality than those that will be obtained from the newer satellites, and they do not provide better estimates than those made using the chlorophyll data used to calibrate them (Gitelson *et al* 1996) So for now we must rely on the chlorophyll data set collected during the AID projects We used a value of 0 14 mg Chl m^{-3} as an annual average for *neritic* stations Of course, there are plumes with much higher values of chlorophyll near sewage outfalls (Tel-Aviv) and in Haifa Bay The contribution of these high chlorophyll areas to the overall productivity of the Israeli shelf is very difficult to evaluate We hope that eventually this sampling problem can be overcome by means of satellite images

Estimates of primary production were based on an equation relating surface layer chlorophyll concentration to production (Eppley *et al* 1985)

$$\log(\text{primary production, mg C m}^{-2}\text{d}^{-1}) = 3 + \log(\text{surface chlorophyll, mg m}^{-3})$$

For a value of surface chlorophyll concentration of 0 14 mg m^{-3} (see above), primary production is calculated to be 140 mg C m^{-2} d^{-1} or 511 g weight wet m^{-2} year $^{-1}$ The value for daily primary productivity calculated from the equation is similar to the rate measured by C^{14} uptake experiments at neritic stations during the project

Seasonal and geographic variations in the abundance of zooplankton in Israeli coastal waters are poorly known During our work we made vertical net hauls with a ring net, and measured the settling volume to provide a very crude estimate of the abundance of zooplankton Highest concentrations were observed in February, as might be expected, since phytoplankton is most abundant during the winter-spring season The average of all seasons and locations was 0 158 mg l^{-1}, which translates to 15 8 t km^{-2} This value was used as a starting point, but to balance the model it was necessary to reduce it to 4 t km^{-2}

Benthos was not sampled during the project, with the exception of benthic fish sampled by the fishing boats manned by Fishery Department personnel during our acoustic surveys Although there has been quite a bit of taxonomic and descriptive work on the benthos of the Israeli shelf, quantitative studies (measurement of biomass) are rare The only data we were able to find were from a study of Haifa Bay made from 1954-1956 by Eliezer Gotleib as part of his doctoral thesis There have no doubt been significant changes since then, and Haifa Bay is probably enriched in comparison to other areas of the Israeli shelf, but these data were used without adjustment for this initial run of the Ecopath model Although Gotleib provides data by taxonomic groups and substrate types, we combined all into an average for "benthos" as a whole The average obtained from his Table 4 is 16 t km^{-2}, but this is heavily influenced by a single station with 97 t km^{-2} of echinoderms We chose to adjust the value downward, to account for the lower biomasses expected outside Haifa Bay, and because of the doubtful role of echinoderms in the food webs leading to benthic fish We used a value of 10 t km^{-2} for the benthos of the Israeli shelf

The production and consumption rates (P/B and Q/B) of the fish in the model were not measured for any fish in Israeli coastal waters However, there exist empirical models to help fill the gap of missing information, and we used values from Gucu (1995) for many of the fish in our model Gucu (1995) used the empirical model of Palomares and Pauly (1989) to calculate Q/B for the fish in his model, and calculated the P/B ratio from the results of standard analysis of the fish population dynamics Since the species are the same as occur in

Israel (his work was done in the NE Mediterranean in Turkey), we used the values in his Tables 1 and 3 for all species groupings used in common For the remaining groups, we used values from other Ecopath models presented in the volume edited by Christensen and Pauly (1993)

Finally, detritus biomass was estimated using the empirical relationship relating detritus standing stock to primary production and the euphotic depth (Pauly *et al* 1987) The ecological efficiency was in most cases estimated by the program, but in a few cases, a value of 0 95 was entered and the biomass was estimated by the program

The assigning of food items determines the linkages in the food web (Fig 47) Most of the fish are calculated to function at a trophic level of approximately 3 The piscivores have a trophic level of around 4 Shrimps, zooplankton, and benthos comprise the lowest trophic level and constitute the food of fish other than piscivores Three of the groups (groupers, sharks, and scombrids) were considered to have no predators other than man, and as such are the top predators in the system As mentioned above, we will probably combine some of the fish groups with similar diet compositions

In this first run of Ecopath, it is clear that major parts of the food web are not known well enough to allow the creation of a balanced ecosystem model if we use the data available This is especially true for two components zooplankton and benthos The estimates of phytoplankton production and biomass are rather well known, and are insufficient to account for the measured values of zooplankton standing stock We conclude that the actual zooplankton standing stocks and production must be lower than that estimated from the ring net tows On the other hand, even the reduced values we used result in a surplus of zooplankton, which is not consumed by other components in the model as it stands now (Table 2) In short, neither the standing stocks and production nor the fate of zooplankton are known well enough to be modeled, even approximately

The standing stock of benthos used in the model and based on values from Haifa Bay is also probably overestimated, as judged from the low ecological efficiency that results (0 640) The estimate can probably be reduced slightly, and the diets of some of the fish adjusted to consume more benthos The model seems to give a reasonable picture of the relation between fish, their biomasses, and their diets Consultations with the Fishery Department are continuing, and we expect that these aspects of the model can be further refined and improved Eventually, we expect to publish the results, if possible together with the results obtained for the Egyptian shelf by our project partners

IX Conclusions

1 *A priori* information on the patch orientation and autocorrelation radius for the field allows optimization of survey design and the algorithm of data analysis A survey in the direction of patch elongation is optimal Independent of the survey direction, in reconstructing the field the major axis of the ellipse for the data weighting and search should be adjusted to the direction of patch elongation A patchy field can be reconstructed properly (r>0 85) if D=(1 0-1 5)R, where R is the autocorrelation radius in the direction of a survey

2 The number of fish in the Israeli fisheries zone very changes in time It can be supposed that at least part of the fish stock crosses the border of the zone

3 Under certain conditions, red mullet prefer the areas of warm water This gives the possibility of looking for red mullet by measuring the water temperature

4 The main source of water contamination in the Israeli fisheries zone is the Kishon River It also provides the main supply of nutrients

5 The positive correlation zones were identified between the distributions of chlorophyll and the silicic acid (with the concentration of the latter >0 12-0 14 M), and phosphate (with the concentration >0 02-0 05 M) Positive correlation zone was observed between the distributions of zooplankton and phosphate (>0 05 M) This confirms the fact that the nutrients are necessary for the development of phytoplankton and indirectly for that of zooplankton

6 The vast positive correlation zones were found between the distributions of the zooplankton and chlorophyll (with the chlorophyll concentration >0 20 g/l) As chlorophyll characterizes the phytoplankton concentration, the conclusion can be made that the phytoplankton is necessary for the zooplankton to feed

Table 2 Sample output from the Ecopath 3 0 program, listing the ecosystem components considered in the model and giving their estimated annual average biomass, annual production (P/B) and consumption (Q/B), ecological efficiency (EE) and gross efficiency (GE) Units throughout are tons wet weight

7 The positive correlation zones were identified between the distributions of pelagic fish and zooplankton (with the zooplankton concentration >0 20 mg/l) This confirms the conclusion that the zooplankton is necessary for pelagic fish to feed

8 The negative correlation zones were observed between the distributions of pelagic fish and nitrate and nitrite (the concentration >0 30-0 40 M) and phosphate (the concentration >0 05-0 10 M) It should be mentioned that the correlation of pelagic fish and nutrients is indirect and is explained by the fact that the zones are actually formed between the distributions of fish and the contaminating substance(s)

9 In the presence of the water contamination, even when the zooplankton concentration is high, fish avoid the place and thus form the negative correlation zones between the distributions of fish and zooplankton

10 Initial runs of the Ecopath model have provided a summary of the food web, with an emphasis on commercial fish The model could be improved with better information on the abundance and fate of zooplankton, and the biomass and distribution of benthic animals

X References

Christensen, V and D Pauly, editors 1993 Trophic models of aquatic ecosystems ICLARM Conf Proc 26, 390 p

Cressie, N A C 1991 Statistics for Spatial Data John Wiley and Sons, Inc , New York, 900 p

Eppley, R W , E Stewart, M R Abbott and U Heyman 1985 Estimating ocean primary production from satellite chlorophyll Introduction to regional differences and statistics for the Southern California Bight J Plank Res 7 57-70

Gandin, L S 1965 Objective Analysis of Meteorological Fields Translated from Russian Israel Program for Scientific Translations, Jerusalem

Gitelson, A A , Y Z Yacobi, A Karnieli and N Kress 1996 Reflectance spectra of polluted marine waters in Haifa Bay, Southeastern Mediterranean Features and application for remote estimation of chlorophyll concentration Isr J Earth Sci 45 127-136

Gucu, A C 1995 A box model for the basic elements of the Northeastern Mediterranean Sea trawl fisheries Israel J Zool 41 551-567

Kalikhman, I L 1989 Correcting distance between acoustic survey tracks *In* Progress in Fisheries Acoustics, an Underwater Acoustic Group Conference held at MAFF Fisheries Laboratory, Lowestoft, England, 21/22 March 1989 Proceedings of the Institute of Acoustics, Vol 11, Pt 3, 212-215

Kalikhman, I L , Kizner, Z I , Zaripov, B R , and Tesler, W D 1986 Choosing distance between acoustic survey tracks Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers, V/BG/24, 152-164

Kalikhman, I , Walline, P , and Gophen, M 1992 Simultaneous patterns of temperature, oxygen, zooplankton and fish distribution in Lake Kinneret, Israel *Freshwater Biology*, 28 337-347

Kalikhman, I , Ostrovsky I , Walline, P , Gophen, M , and Yacobi, Y Z 1995 Distribution fields for aquatic ecosystem components method of identification of correlation

zones *Freshwater Biology*, 34 317-328
Kizner, Z I , Tesler W D , and Zaripov B R 1983 Methodological recommendations on mathematical simulation of commercial concentrations and treatment of survey data with computers Moscow, VNIRO, 44 p , (in Russian)
Legendre, P , and Fortin, M J 1989 Spatial pattern and ecological analysis *Vegetatio*, 80, 107-138
Matheron, G 1963 Principles of geostatistics *Economic Geology*, 58 1246-1266
McArdle, B H , and Blackwell, R G 1989 Measurement of density variability in the bivalve *Chione stutchburyi* using spatial autocorrelation *Marine Ecology Progress Series*, 52, 245-252
Palomares, M L and D Pauly 1989 A multiple regression model for predicting the food consumption of marine fish populations Aust J Mar Freshwater Res 40 259-284
Pauly, D , M L Soriano-Bartz and M L D Palomares 1993 Improved construction, parametrization and interpretation of steady-state ecosystem models, p 1-13 *In* V Christensen and D Pauly (eds) Trophic models of aquatic ecosystems ICLARM Conf Proc 26, 390 p
Pisanty S Ben-Yami, M , and Oren, O H 1969 Mapping temperature distribution along the fish-spotting flight *Fisheries and Fishbreeding in Israel*, 4(3) 20-22
Snovsky, G and J Shapiro, editors 1997 The fisheries and aquaculture of Israel, 1995, in figures Israel Ministry of Agriculture, Department of Fisheries 45 p (Hebrew and English)
Sokal R R , and Wartenberg, D E 1981 Space and population structure Dynamic Spatial Model (eds D A Griffith and R D Mackinnon), pp 186-213 Alphen aan den Rijn, Sijthoff, Netherlands
Steele, J H 1976 Patchiness *In* Cushing D H and Walsh J J , eds The Ecology of the Seas Blackwell Scientific Publications, London, 98-115
Williamson, N T 1980 Effect of serial correlation on precision of fish abundance estimates derived from quantitative echo sounder survey BIOMASS, Acoustic Krill Estimation Working Party News, Vol 2, 16 p
Yudanov, K I , Kalikhman, I L , and Tesler W D 1984 Manual of Hydroacoustic Surveys Moscow, VNIRO, 124 p , (in Russian)
Zaripov, B R , Kizner, Z I , and Tesler, W D 1983 The analysis of methods used in the treatment of data obtained in echo surveys by means of a mathematical model of moving fish aggregations Fishery Hydroacoustic Problems, Scientific Proceedings of VNIRO, 25-36, (in Russian)

XI International Cooperation

Drs Paul Walline and Yigal Kalikhman met with Dr Ali Beltagi at the first Annual Project meeting in Cairo in December 1992 Scientific background for the project was reviewed and plans made for integrating the results of the project by careful scheduling of the respective cruises It was expected that the echosounders necessary for the work would arrive in a few months, and that the first cruise could be held in the spring

Very soon after the equipment arrived, two Egyptian scientists from Dr A Beltagi's group, Mr El-Shazly and Mr Abdallah, visited IOLR (Kinneret Laboratory) to work with the new system, together with Drs Kalikhman and Walline They worked at KLL for a week, and then participated in the first multidisciplinary survey of the Israeli Mediterranean shelf undertaken 5-9 December 1993 G Van Dijken, from the US side of the project, joined this cruise also (he was present on all cruises made during the project)

Results of this first survey were reported at the second Annual Project meeting, held in Sharm El Sheik in December 1993 Although Mr El Shazly and Mr Abdallah were not able to attend, technical information, including solutions to several problems that arose during tests of the new equipment, were reported by Drs Walline and Kalikhman to Dr Beltagi

A second multidisciplinary survey was made from 27 February to 2 March1994 The Israeli team was again accompanied by Mr El-Shazly from Egypt and Mr G van Dijken from Texas A&M Prof Sayed El-Sayed and Mr El-Shazly participated in the *R/V Shikmona* cruise made from 14-18 August 1994, and Mr El-Shazly also took part in the cruise made from 14-18 May 1995

Dr Paul Walline attended the project wrap-up meeting held at Taba, Egypt in September 1996, and presented findings from the last few multidisciplinary cruises made on the Israeli shelf

Mr Abdallah visited the Kinneret Laboratory in July 1997 to work on acoustic tapes recorded during Egyptian hydroacoustic surveys, and to review results obtained during the project Attempts were made to analyze the tapes using the Dr Walline's equipment, but without success Still, the visit provided an opportunity to discuss the practical aspects of analyzing hydroacoustic data, and lead to some important conclusions concerning the procedures to be used for recording acoustic data in the future work on the Mediterranean Work toward started during Mr Abdallah's visit will be pursued further, either in a meeting at Taba, or possibly through e-mail contacts The aim of this work is to reach agreement concerning results of analysis of acoustic data

XII Publications and Presentations

"Identification of correlation zones for aquatic ecosystem component distributions", I Kalikhman, I Ostrovsky, P Walline, M Gophen and Y Z Yacobi, oral presentation (Kalikhman), ICES International Symposium on Fisheries and Plankton Acoustics, Aberdeen, June 12-16, 1995

"Patchy distribution fields survey design and adequacy of reconstruction", I Kalikhman and I Ostrovsky, Poster Session II Data Analysis and Methodology, ICES International Symposium on Fisheries and Plankton Acoustics, Aberdeen, June 12-16, 1995

Gitelson, A A , Y Z Yacobi, A Karnieli and N Kress 1997 Reflectance spectra of polluted marine waters in Haifa Bay, Southeastern Mediterranean features and application for remote estimation of chlorophyll concentration Isr J Earth Sci 45 127-136

Kalikhman, I , I Ostrovsky, P Walline, M Gophen and Y Z Yacobi 1995 Distribution fields for aquatic ecosystem components method of identification of correlation zones Freshwat Biol 34 317-328

Kalikhman, I and I Ostrovsky 1997 Patchy distribution fields survey design and adequacy of reconstruction ICES Journal of Marine Science (Accepted)

XIII List of Participants

IOLR

Dr Yigal Kalikhman, PI
Dr Paul Walline, PI
Dr Ilia Ostrovsky, Collaborating Investigator (CI)
Dr Y Yacobi, CI, (chlorophyll, optical oceanography)
Dr N Kress, CI, (nutrients)
Dr M Tom, CI, (zooplankton)
Dr Bela Galil, (benthos)
Mr Yaron Gerstner, (technician)
Mr S Kaganovsky, (technician)

Fishery Department

Mr Shmuel Pisanty

Israeli Universities

Dr David Iluz
Dr A Gittleson
Dr A Gurfink

XIV Legends to Figures

Figure 1 First panel - simulated patchy isotropic fields (the straight lines indicate the transects used to estimate the autocorrelation functions) Second panel - autocorrelation circles for the fields Third and fourth panels - paths of the simulated surveys (dotted lines) and the fields as reconstructed (here and below, D and R are given in proportion to the size of the square representing a surveyed area)

Figure 2 First panel - simulated patchy anisotropic fields (the straight lines indicate the transects used to estimate the autocorrelation functions) Second panel - autocorrelation ellipses for the fields Third and fourth panels - paths of the simulated surveys (dotted lines) conducted in the directions of the major or minor axes of autocorrelation ellipses and the distribution fields as reconstructed using *a priori* information on the patch orientation

Figure 3 First panel - simulated patchy anisotropic fields (the straight lines indicate the transects used to estimate the autocorrelation functions) Second panel - autocorrelation ellipses for the fields (the autocorrelation radii in two arbitrarily chosen perpendicular directions are indicated) Third and fourth panels - paths of the simulated surveys (dotted lines) conducted in the directions chosen and the distribution fields as reconstructed using *a priori* information on the patch orientation

Figure 4 Coefficient of determination between the reconstructed field and that originally generated with different D/R ratios Symbols correspond to the results of the simulated surveys of the fields given in Fig 1-3 squares - Fig 1, left, circles - Fig 1, right, triangles - Fig 2, left, asterisks - Fig 2, right, circles with four radial beams - Fig 3, left, circles with eight radial beams - Fig 3, right (filled symbols correspond to surveys in the direction of the abscissa, empty symbols - to surveys in the direction of the ordinate) The solid line represents the non-linear regression ensuring the minimal sum of squared residuals The dotted lines are the borders of the confidence interval with the probability p=0 99

Figure 5 The longitudinal transect TR to estimate the required distance between acoustic survey transects

Figure 6 The autocorrelation functions for the fish distribution fields to estimate the distance between acoustic survey transects (the labels show the month and the year when the acoustic survey was undertaken)

Figure 7 The grid of multidisciplinary survey (the points show the sampling stations) and example of the trawling survey

Figure 8 Distribution of the water temperature at the bottom and red mullet, 5-9 December 1993

Figure 9 Distribution of pandora, 5-9 December 1993

Figure 10 5-9 December 1993 The distribution of pelagic fish

Figure 11 27 February - 2 March 1994 The distributions of pandora and red mullet

Figure 12 27 February - 2 March 1994 The distributions of silicic acid and nitrate and nitrite

Figure 13 27 February - 2 March 1994 The distributions of phosphate and chlorophyll

Figure 14 27 February - 2 March 1994 The distributions of zooplankton and pelagic fish

Figure 15 14-18 August 1994 The distributions of the water temperature at the bottom and red mullet

Figure 16 14-18 August 1994 The distributions of silicic acid and nitrate and nitrite

Figure 17 14-18 August 1994 The distributions of phosphate and chlorophyll

Figure 18 14-18 August 1994 The distributions of zooplankton and pelagic fish

Figure 19 14-18 May 1995 The distributions of silicic acid and nitrate and nitrite

Figure 20 14-18 May 1995 The distributions of phosphate and chlorophyll

Figure 21 14-18 May 1995 The distributions of zooplankton and pelagic fish

Figure 22 17-20 September 1995 The distributions of silicic acid and nitrate and nitrite

Figure 23 17-20 September 1995 The distribution of phosphate

Figure 24 17-20 September 1995 The distributions of zooplankton and pelagic fish

Figure 25 The typical transects for estimating the autocorrelation functions for the fields

Figure 26 The autocorrelation functions for the fields (left upper - 27 February - 2 March 1994, right upper - 14-18 August 1994, left lower - 14-18 May 1995, right lower - 17-20 September 1995) (S - silicic acid, N - nitrate and nitrite, P - phosphate, C - chlorophyll, Z - zooplankton, F - pelagic fish, the number 1 or 2 indicate the transect)

Figure 27 Grid of points for sampling the distribution fields to calculate the correlation zones

Figure 28 27 February - 2 March 1994 The distributions of silicic acid and chlorophyll The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 29 27 February - 2 March 1994 The distributions of phosphate and chlorophyll The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 30 27 February - 2 March 1994 The distributions of chlorophyll and zooplankton The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 31 27 February - 2 March 1994 The distributions of zooplankton and pelagic fish The groups of points for sampling the distribution fields to calculate their correlations and the correlation zones

Figure 32 27 February - 2 March 1994 The distributions of phosphate and pelagic fish The groups of points for sampling the distribution fields to calculate their correlations and the correlation zones

Figure 33 14-18 August 1994 The distributions of phosphate and chlorophyll The group of points for sampling the distribution fields to calculate their correlations and the correlation zone

Figure 34 14-18 August 1994 The distributions of chlorophyll and zooplankton The group of points for sampling the distribution fields to calculate their correlations and the correlation zone

Figure 35 14-18 August 1994 The distributions of zooplankton and pelagic fish The groups of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 36 14-18 August 1994 The distributions of nitrate and nitrite and pelagic fish The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 37 14-18 May 1995 The distributions of phosphate and chlorophyll The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 38 14-18 May 1995 The distributions of chlorophyll and zooplankton The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 39 17-20 September 1995 The distributions of phosphate and zooplankton The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 40 17-20 September 1995 The distributions of zooplankton and pelagic fish The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 41 17-20 September 1995 The distributions of nitrate and nitrite and pelagic fish The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 42 17-20 September 1995 The distributions of phosphate and pelagic fish The group of points for sampling the distribution fields to calculate their correlation and the correlation zone

Figure 43 27 February - 2 Match 1994 The distribution of the ecosystem components along the transects TR1 and TR2

Figure 44 14-18 August 1994 The distribution of ecosystem components along transects TR1 and TR2

Figure 45 14-18 May 1995 The distribution of the ecosystem components along transects TR1 and TR2

Figure 46 17-20 September 1995 The distribution of ecosystem components along transects TR1 and TR2

Figure 47 Food web of the SE Mediterranean as depicted in the Ecopath model For each component, the biomass (B), production (P), and food consumption (Q) is presented near the appropriate box in units of tons km^{-2} The trophic level of each group is given according to the scale at the left of the figure Backflows to the detritus box are not shown Respiration, harvest and export are written near the appropriate symbol, according to the legend

XV Acknowledgements

We wish to express our thanks to the captain and crew members of the *R/V Shikmona* for their excellent help and support during the oceanographic cruises We also wish to extend our thanks to the Fisheries Department of the Israeli Ministry of Agriculture for their cooperation and assistance with our research effort We are indeed grateful to the USAID for the financial support of this project

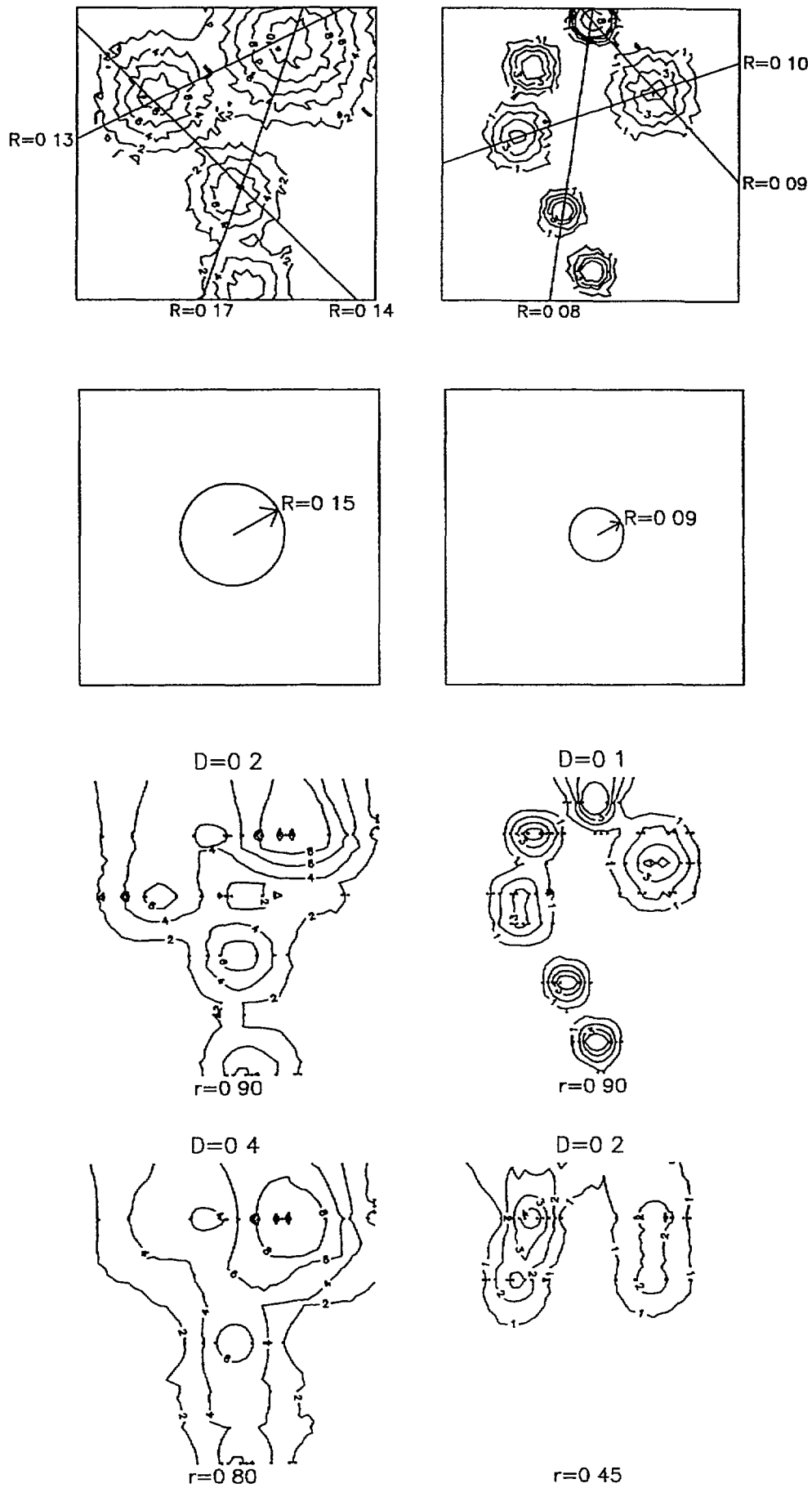

R=0 13
R=0 17
R=0 14
R=0 10
R=0 09
R=0 08
R=0 15
R=0 09
D=0 2
r=0 90
D=0 1
r=0 90
D=0 4
r=0 80
D=0 2
r=0 45

Fig 1

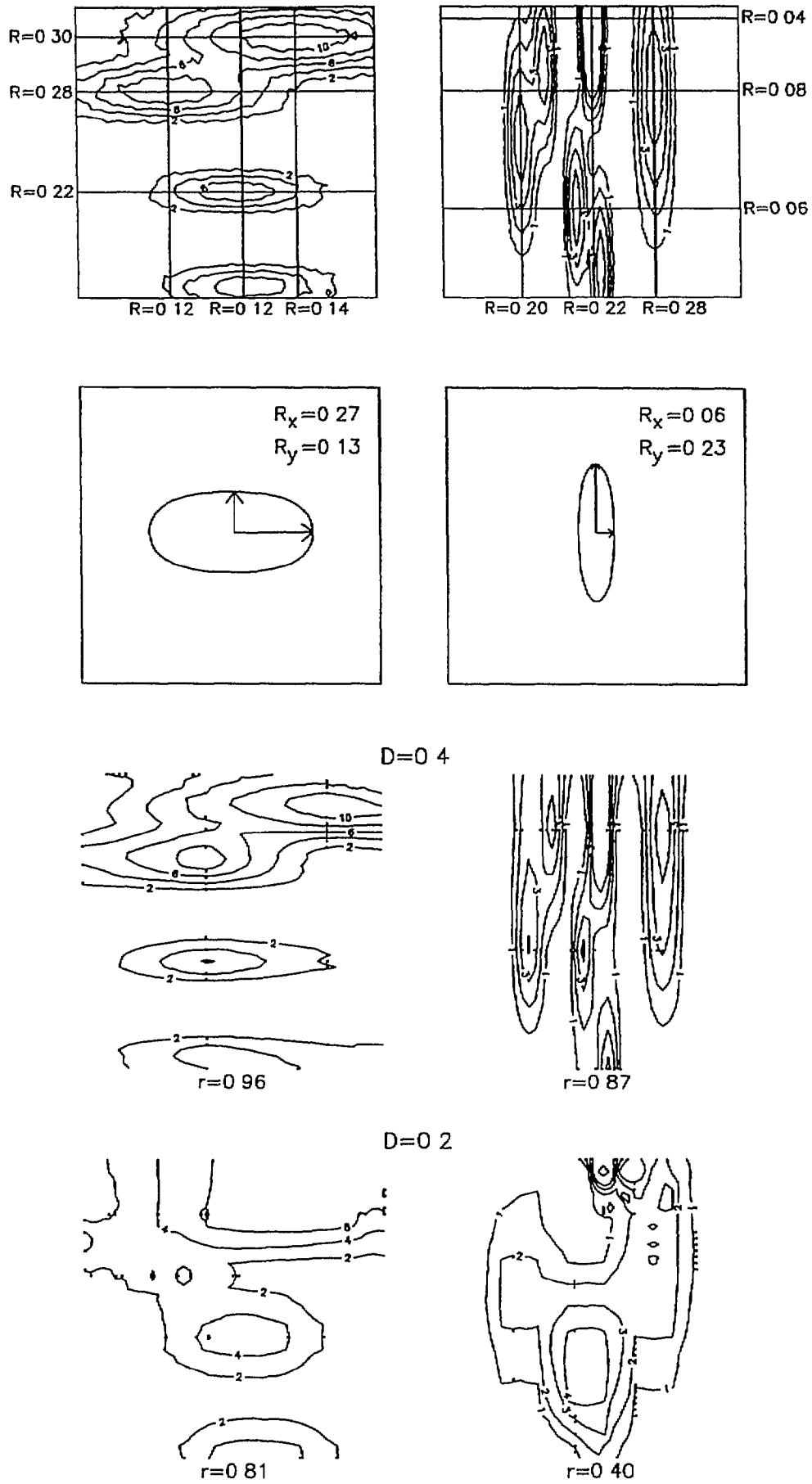

R=0 30
R=0 28
R=0 22
R=0 12 R=0 12 R=0 14
R=0 04
R=0 08
R=0 06
R=0 20 R=0 22 R=0 28
R_x=0 27
R_y=0 13
R_x=0 06
R_y=0 23
D=0 4
r=0 96
r=0 87
D=0 2
r=0 81
r=0 40

Fig 2

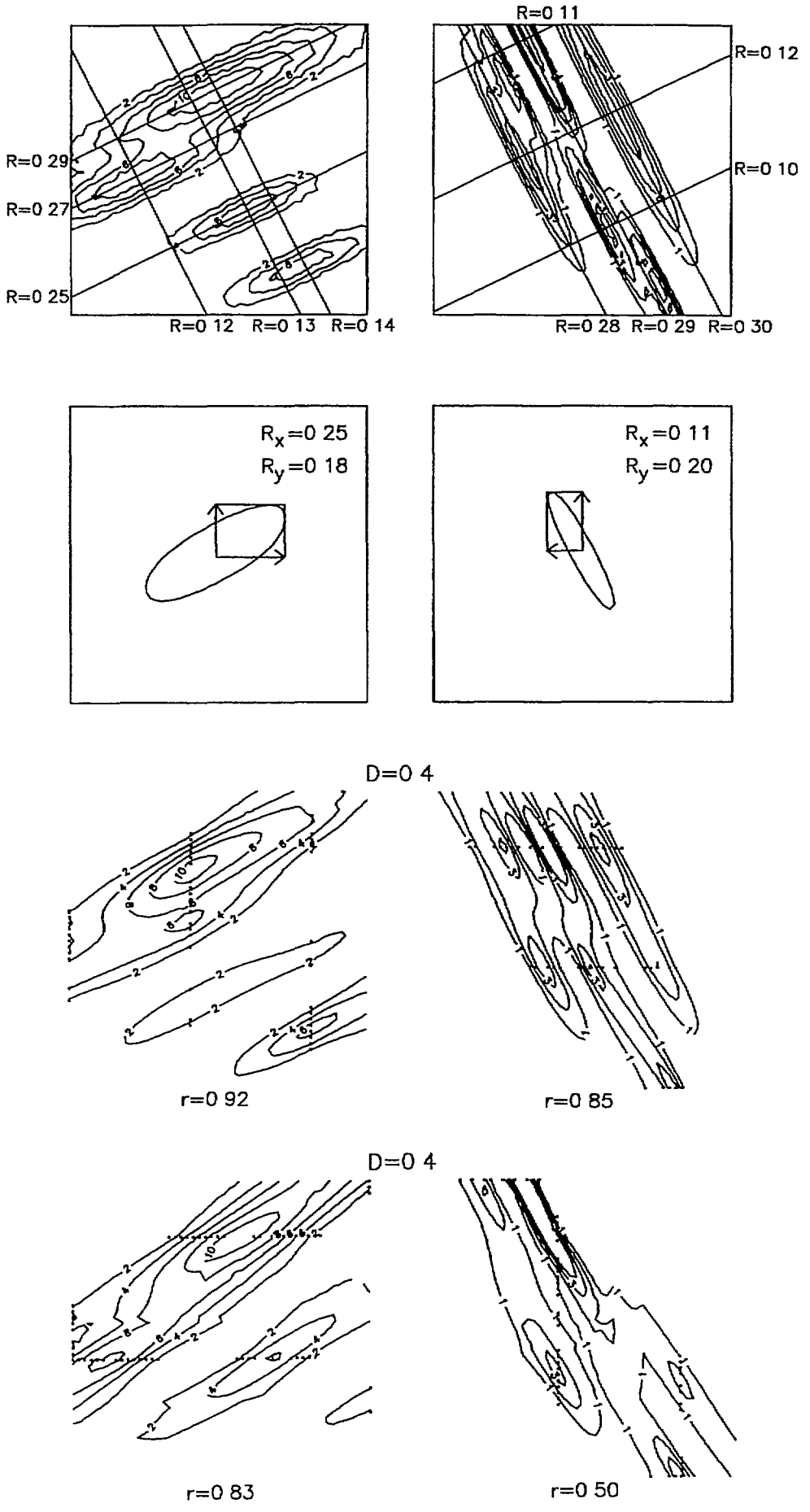

R=0 11
R=0 12
R=0 29
R=0 27
R=0 25
R=0 12 R=0 13 R=0 14
R=0 10
R=0 28 R=0 29 R=0 30
R_x=0 25
R_y=0 18
R_x=0 11
R_y=0 20
D=0 4
r=0 92
r=0 85
D=0 4
r=0 83
r=0 50

Fig 3

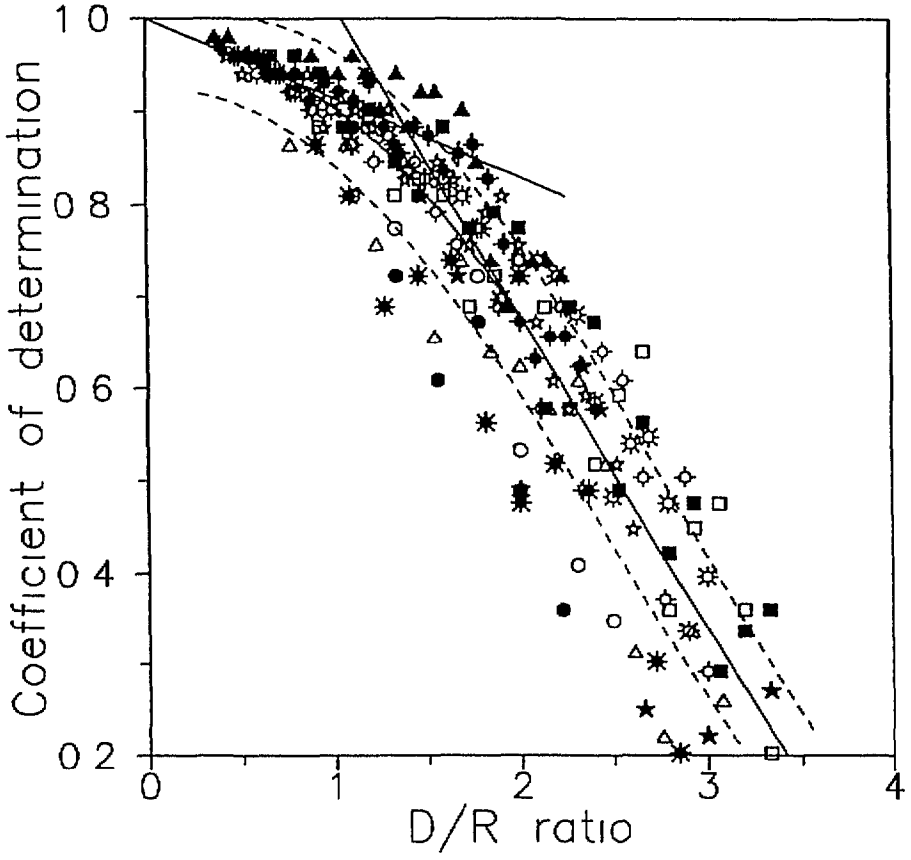


Fig 4

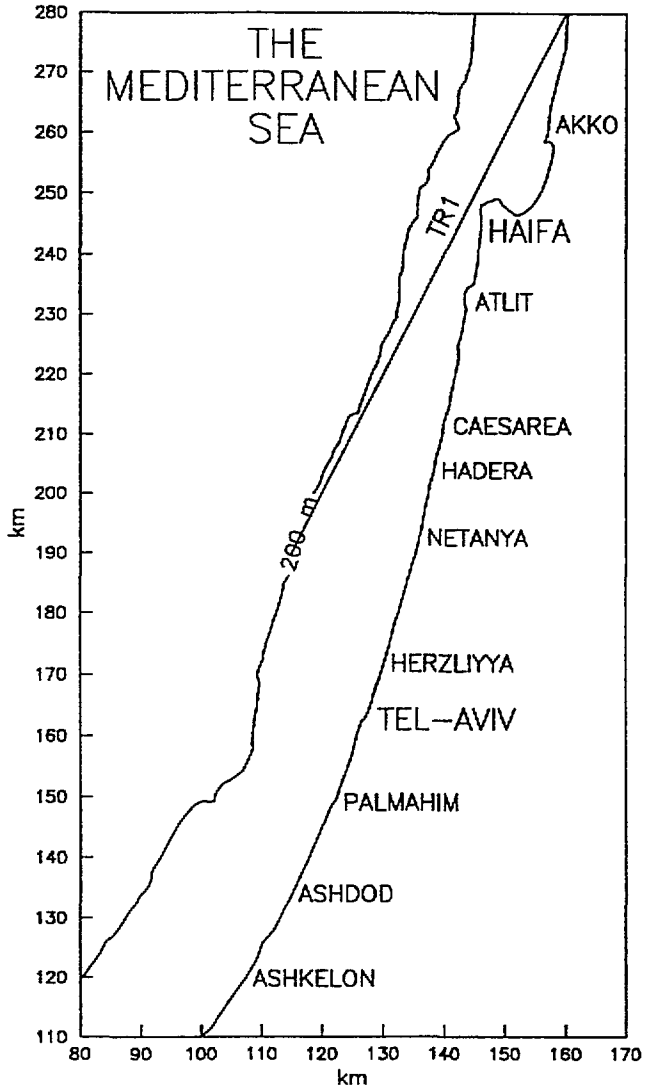

THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL–AVIV
PALMAHIM
ASHDOD
ASHKELON
TR1
200 m
km
km
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
80
90
100
110
120
130
140
150
160
170

Fig 5

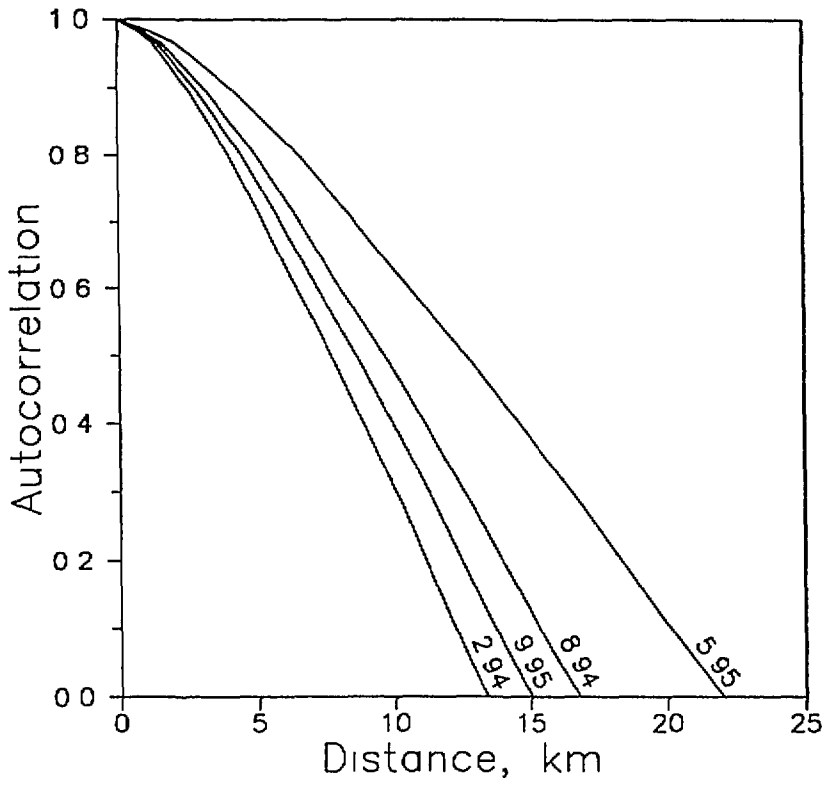

1 0
0 8
0 6
0 4
0 2
0 0
Autocorrelation
0
5
10
15
20
25
Distance, km
2 94
9 95
8 94
5 95

Fig 6

SURVEY GRID

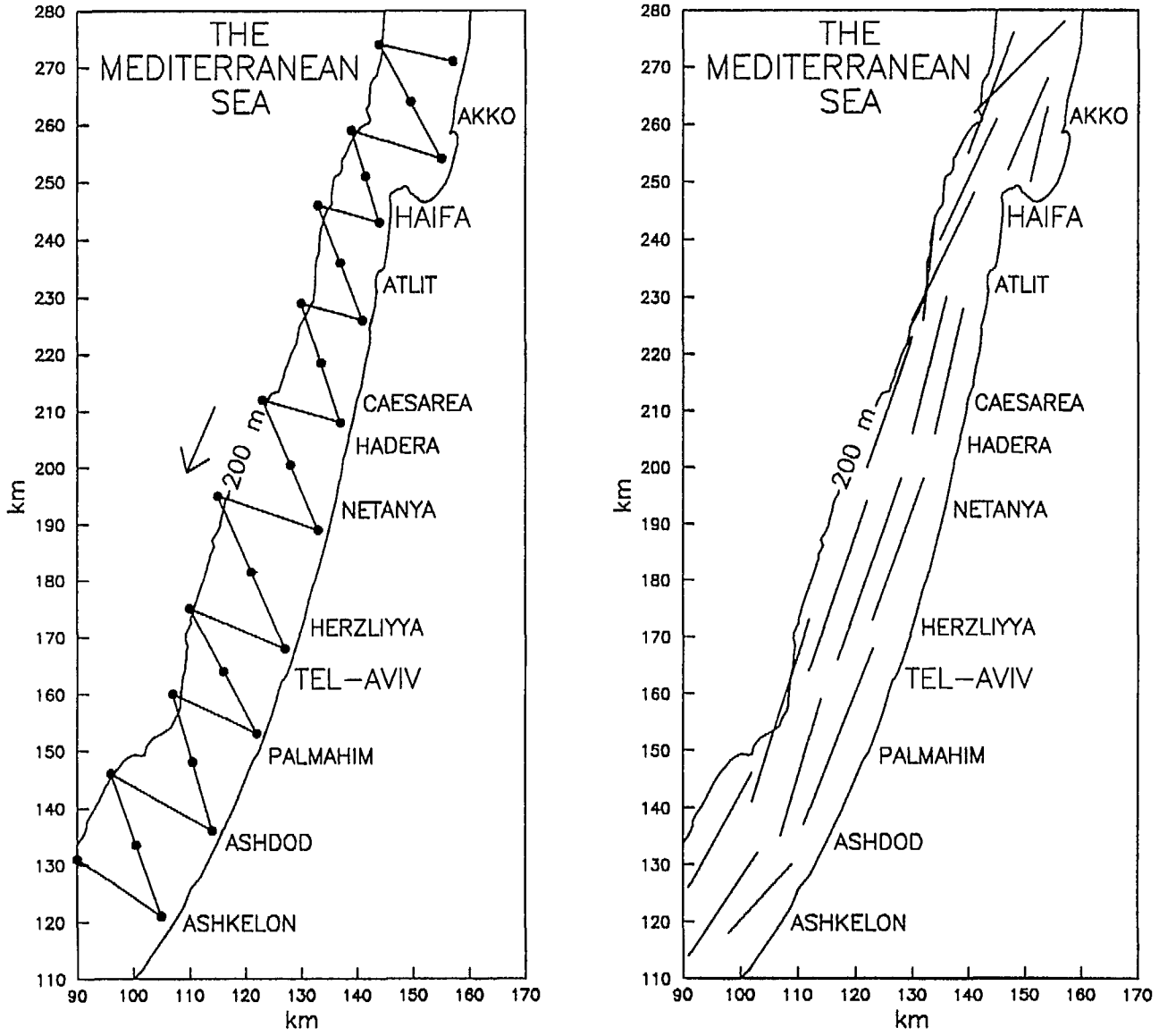
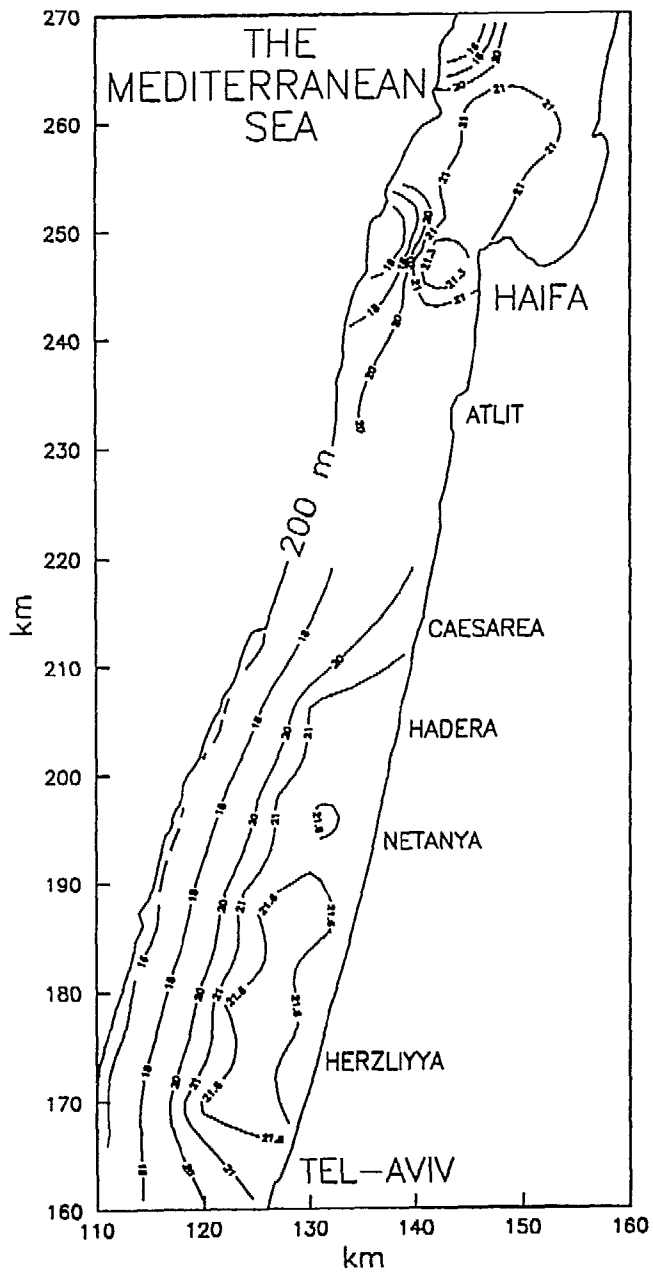
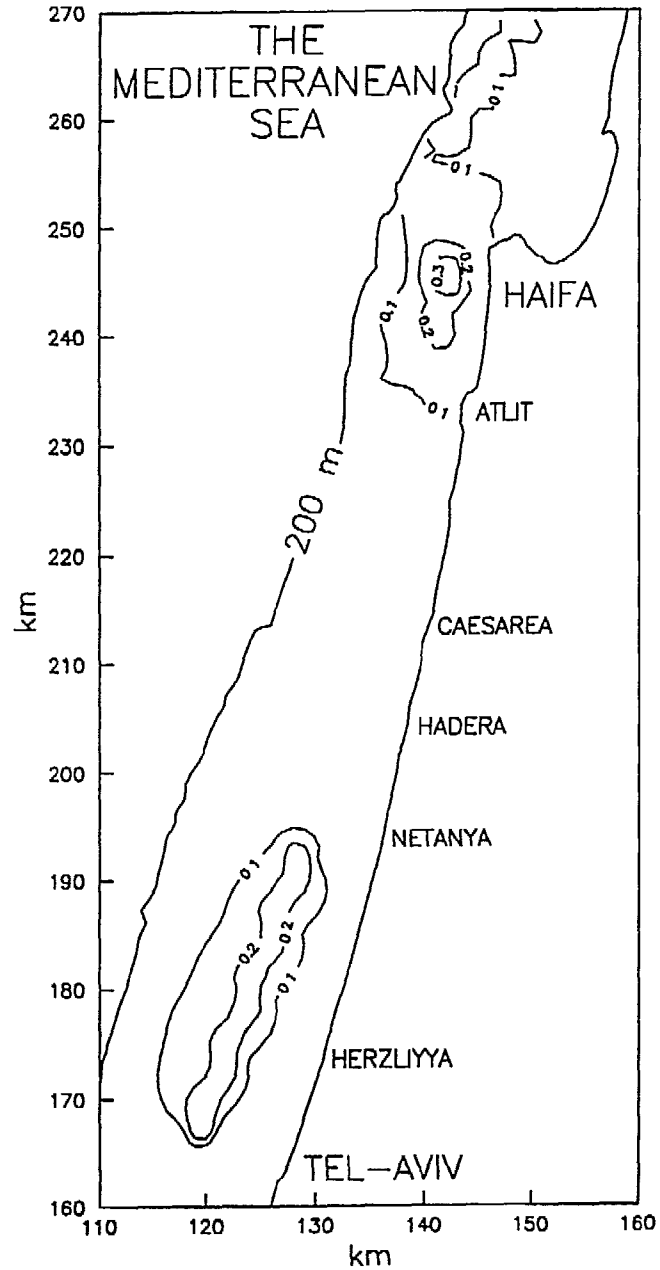


Fig 7

TEMPERATURE AT THE BOTTOM



RED MULLET
(ton per sq km)



R=180 tons

Fig 8

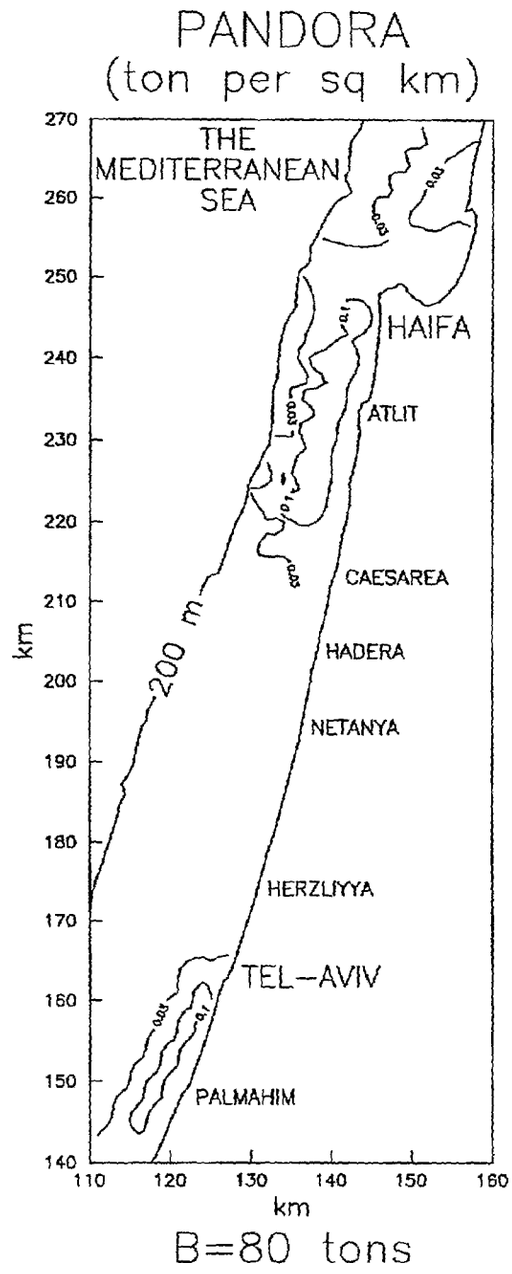

PANDORA
(ton per sq km)
THE
MEDITERRANEAN
SEA
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
200 m
km
km
B=80 tons

Fig 9

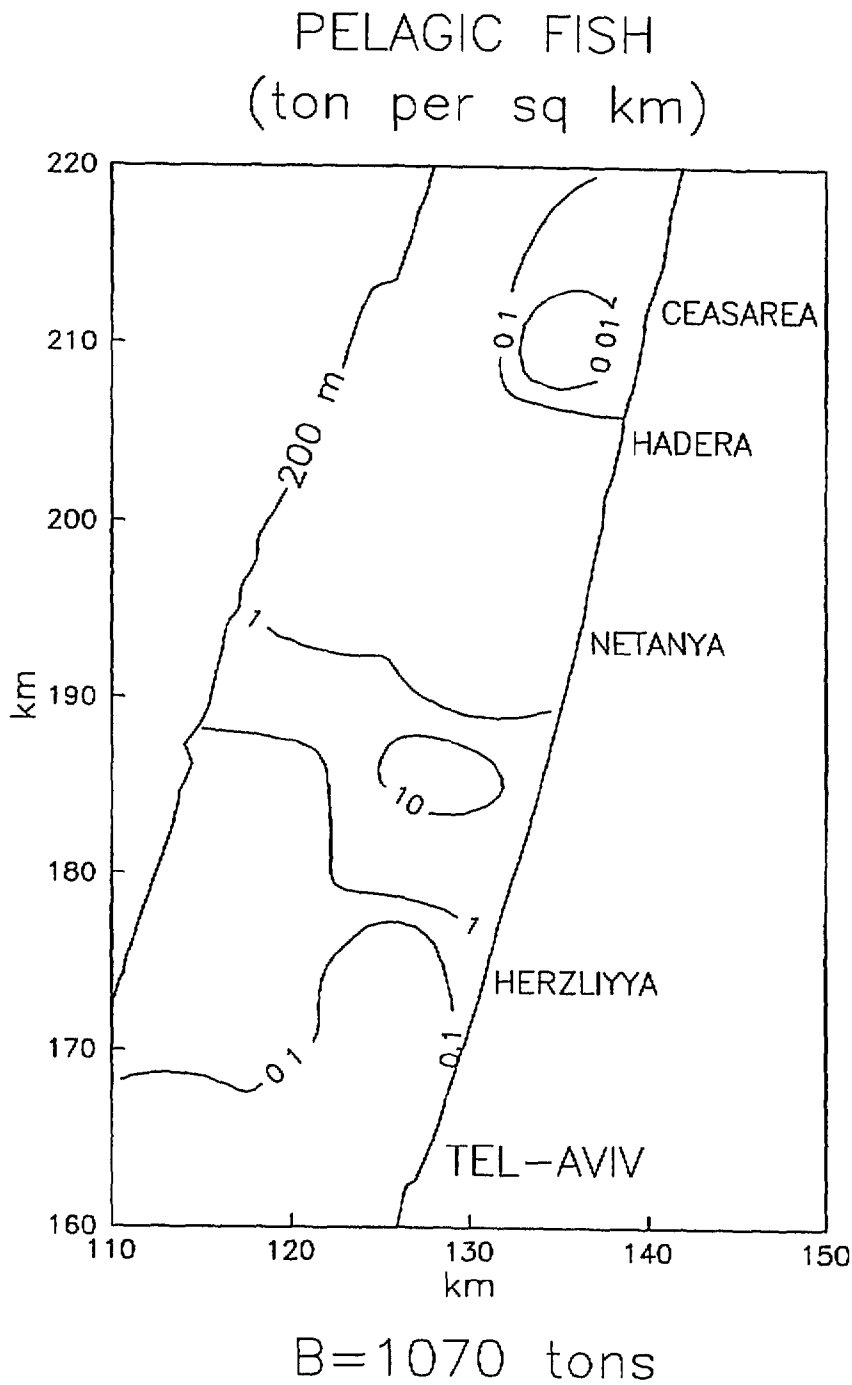

PELAGIC FISH
(ton per sq km)
220
210
200
190
180
170
160
km
110
120
130
140
150
km
200 m
0.1
0.01
CEASAREA
HADERA
1
NETANYA
10
1
HERZLIYYA
0.1
0.1
TEL-AVIV
B=1070 tons

Fig 10

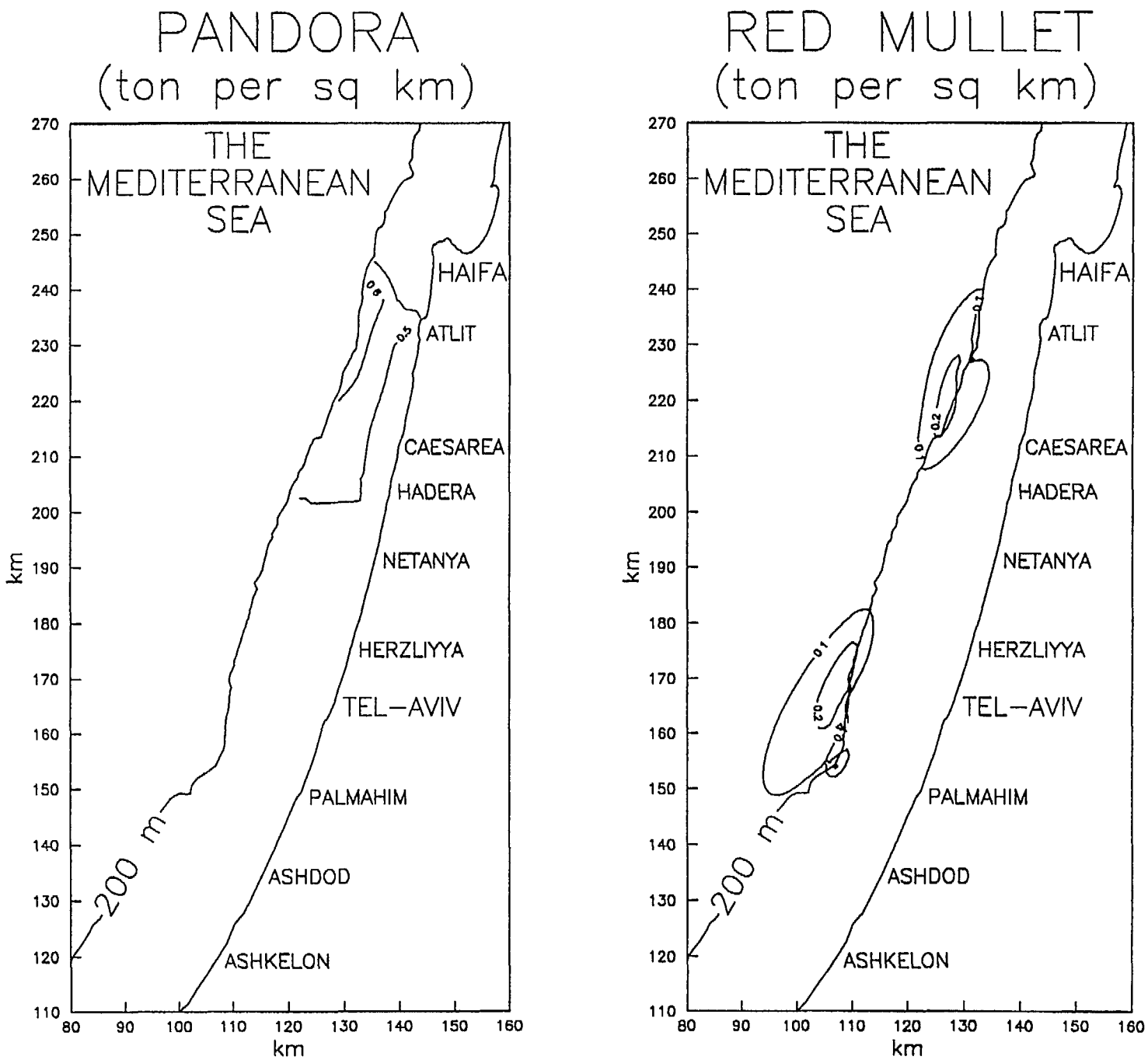

PANDORA
(ton per sq km)
THE MEDITERRANEAN SEA
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
0.5
0.8
km
B=400 tons
RED MULLET
(ton per sq km)
THE MEDITERRANEAN SEA
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
0.1
0.2
1.0
0.8
km
B=320 tons

Fig 11

48

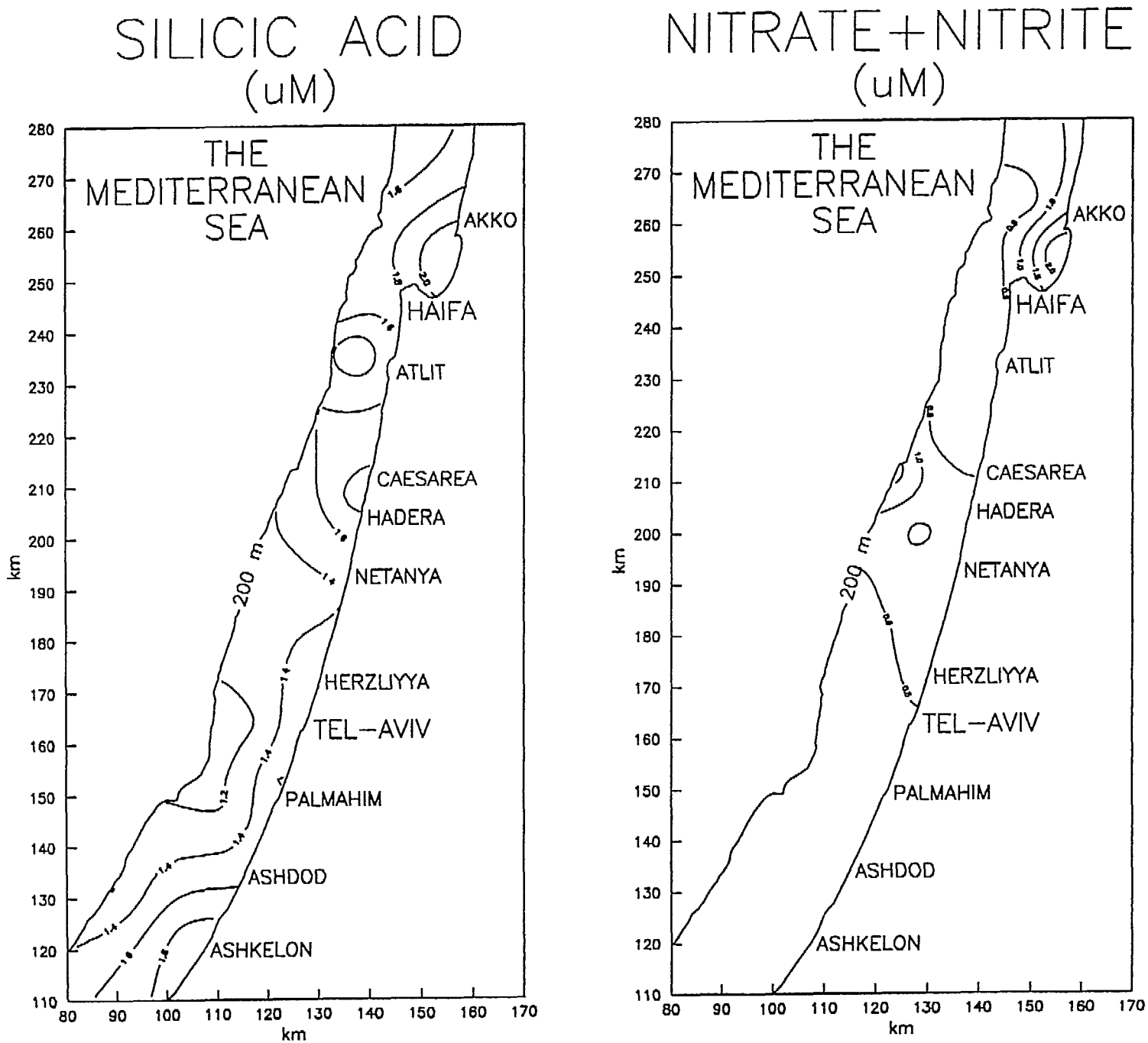

SILICIC ACID
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
NITRATE+NITRITE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km

Fig 12

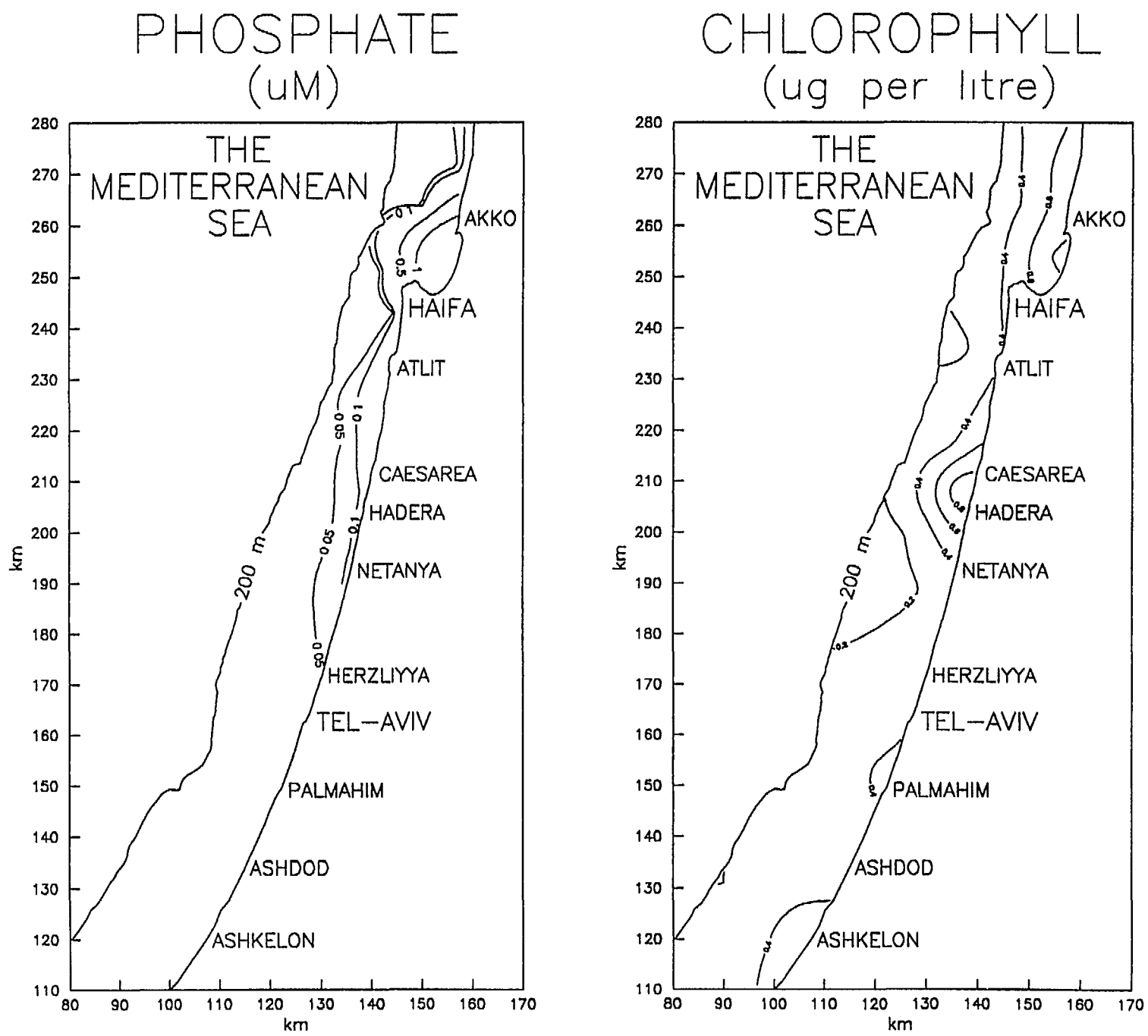

PHOSPHATE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL—AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
CHLOROPHYLL
(ug per litre)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL—AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km

Fig 13

50

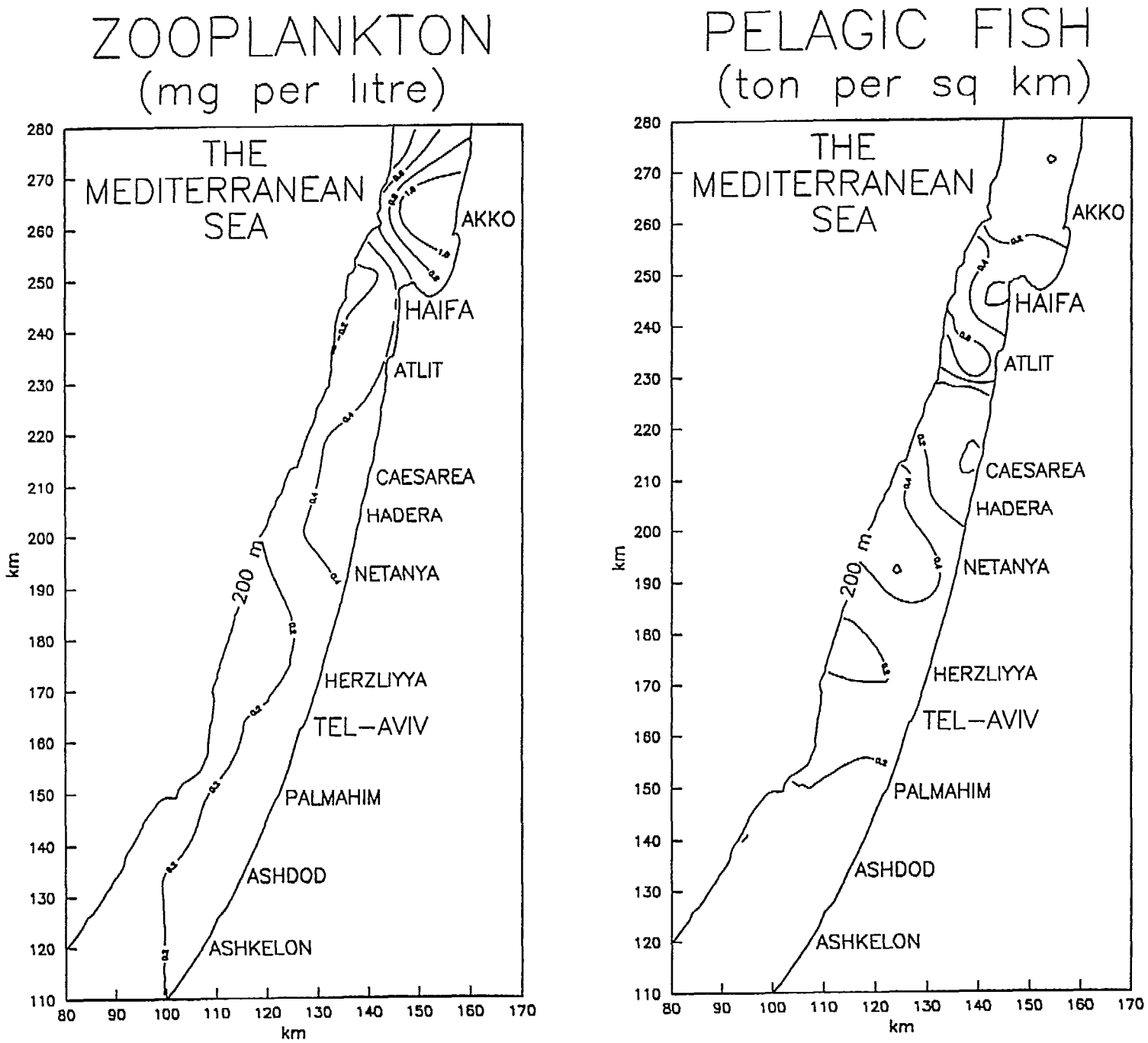

ZOOPLANKTON
(mg per litre)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
PELAGIC FISH
(ton per sq km)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
B=570 tons

Fig 14

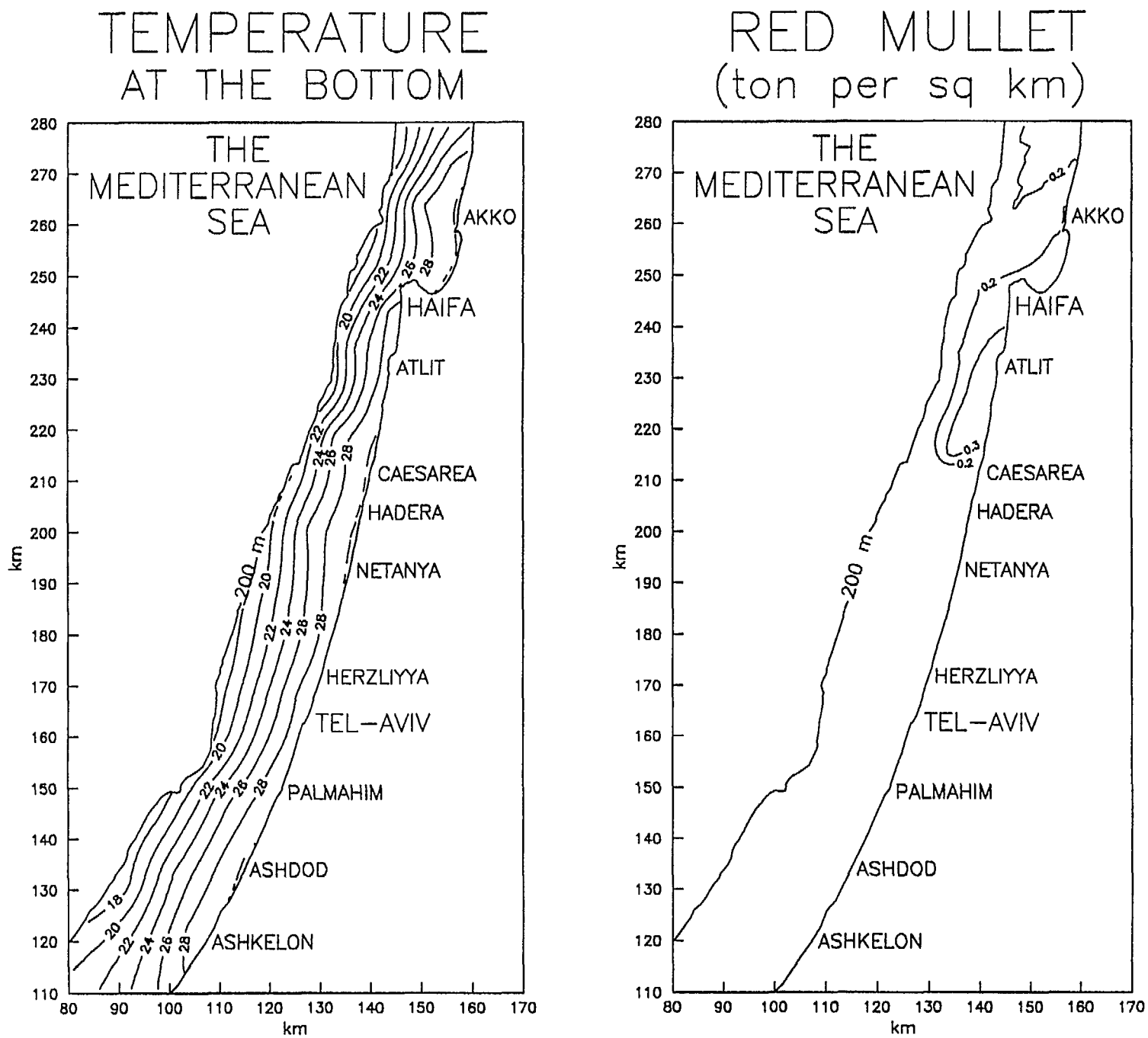


Fig 15

B=470 tons

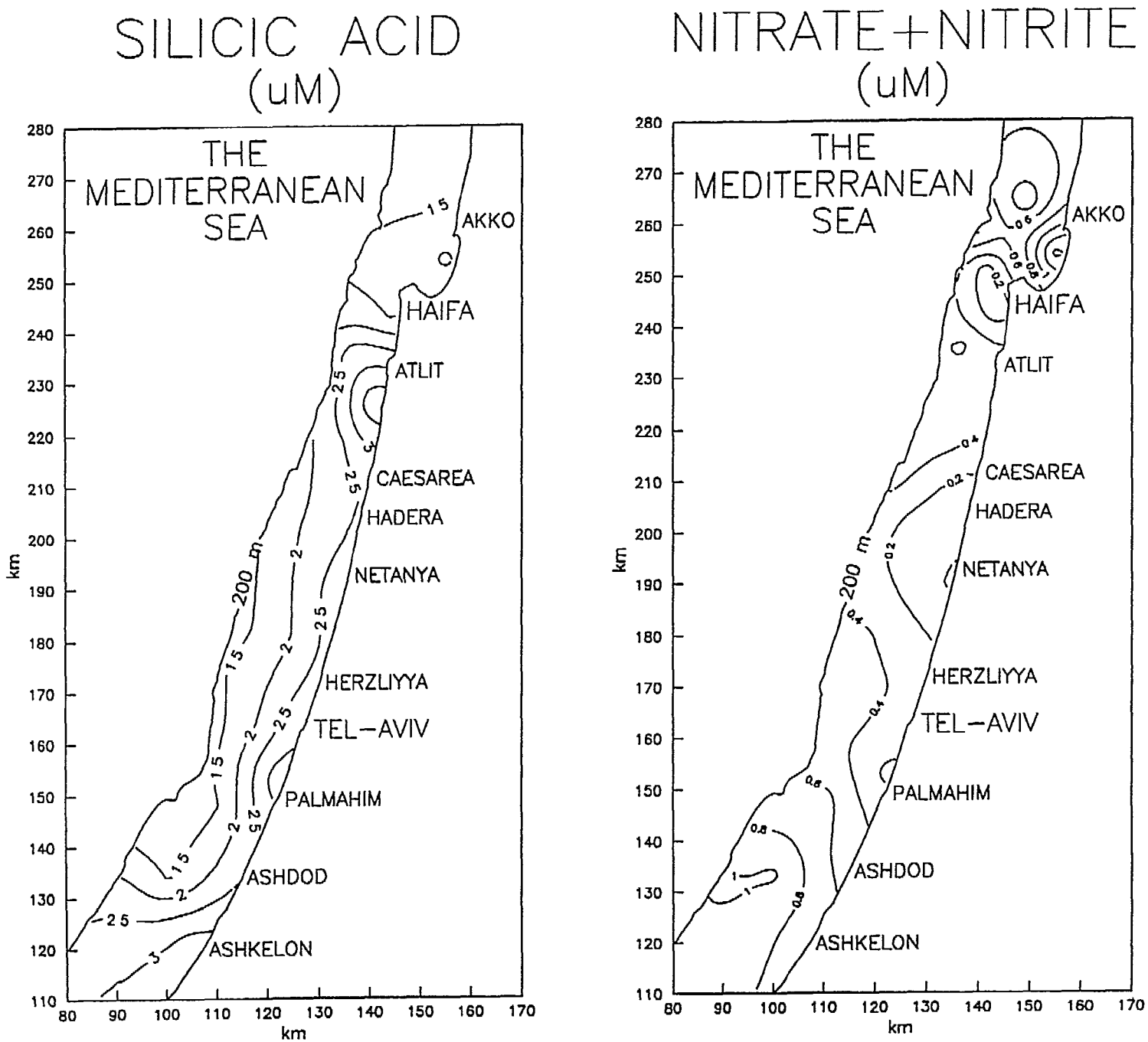

SILICIC ACID
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
NITRATE+NITRITE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km

Fig 16

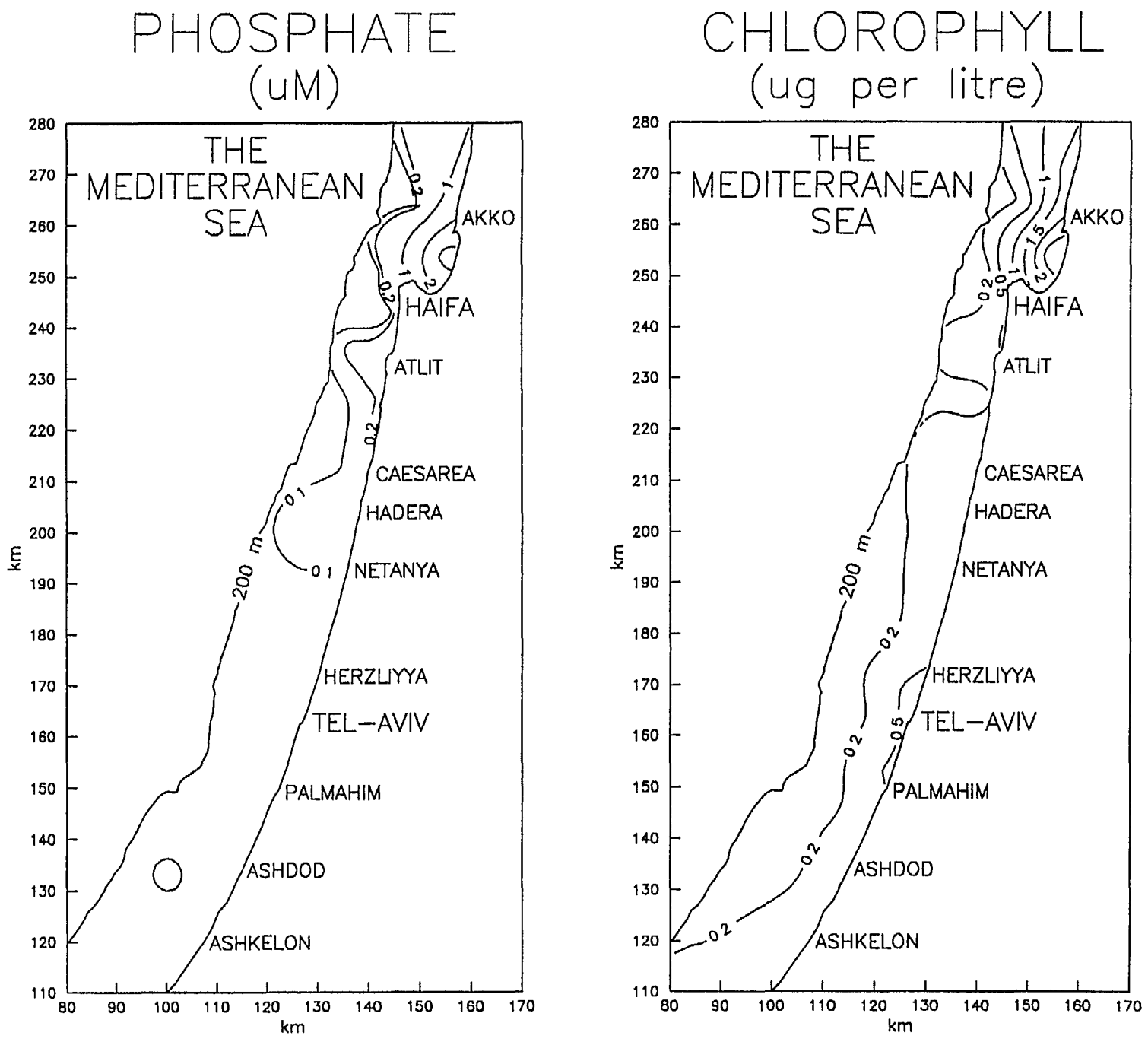

PHOSPHATE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
CHLOROPHYLL
(ug per litre)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km

Fig 17

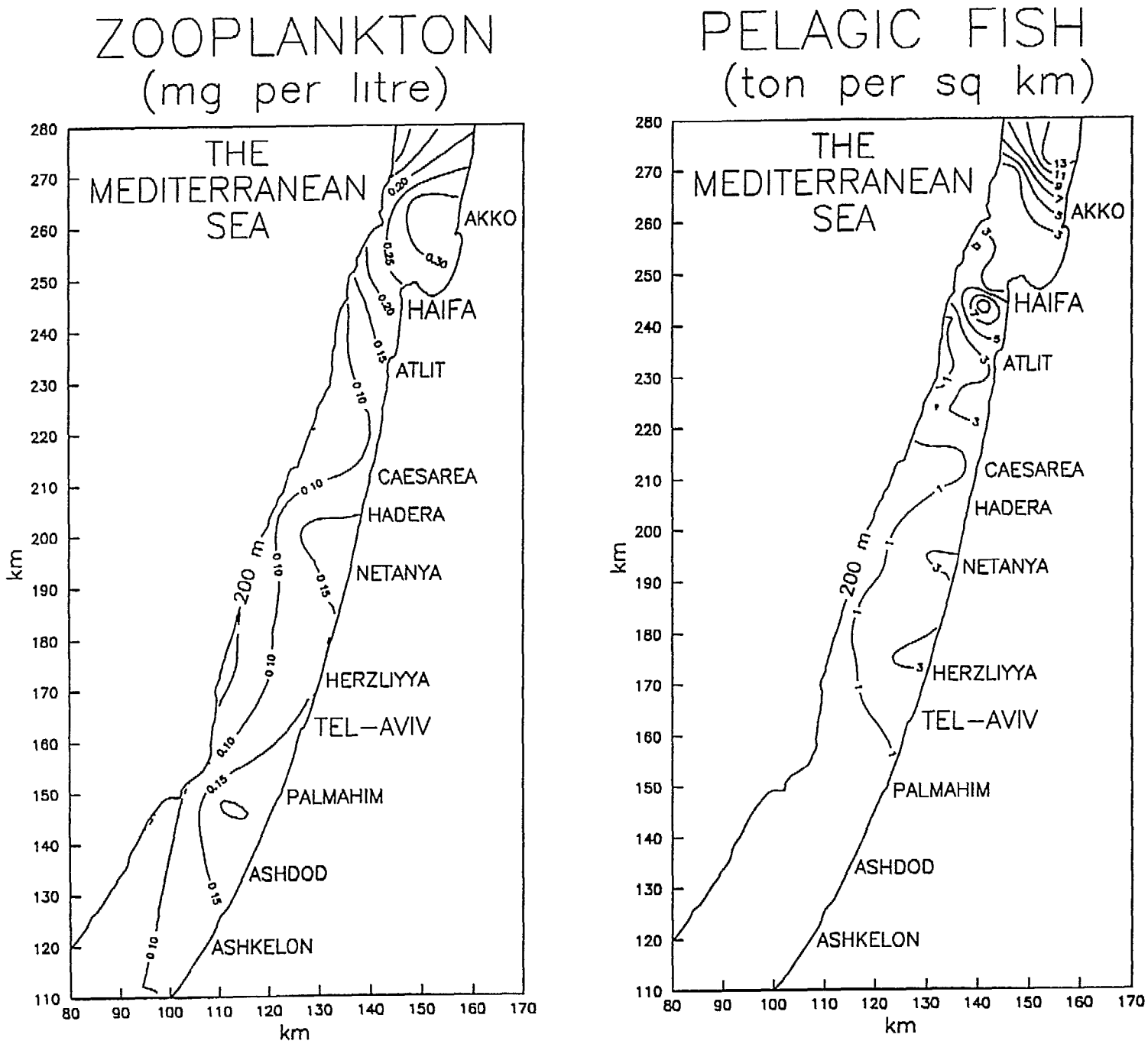

ZOOPLANKTON
(mg per litre)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
PELAGIC FISH
(ton per sq km)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
B=6080 tons

Fig 18

55

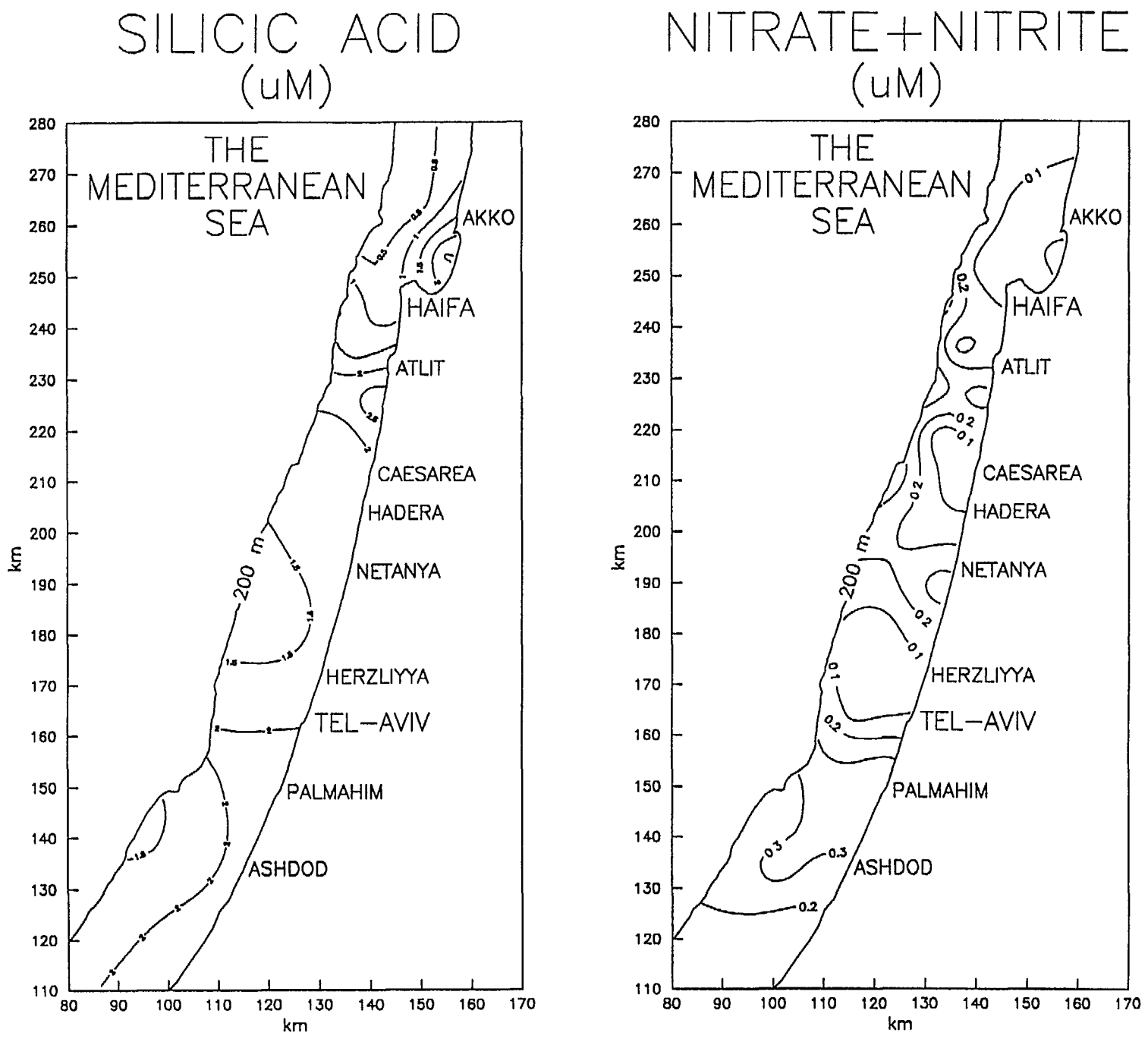

SILICIC ACID
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
200 m
km
NITRATE+NITRITE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
200 m
km

Fig 19

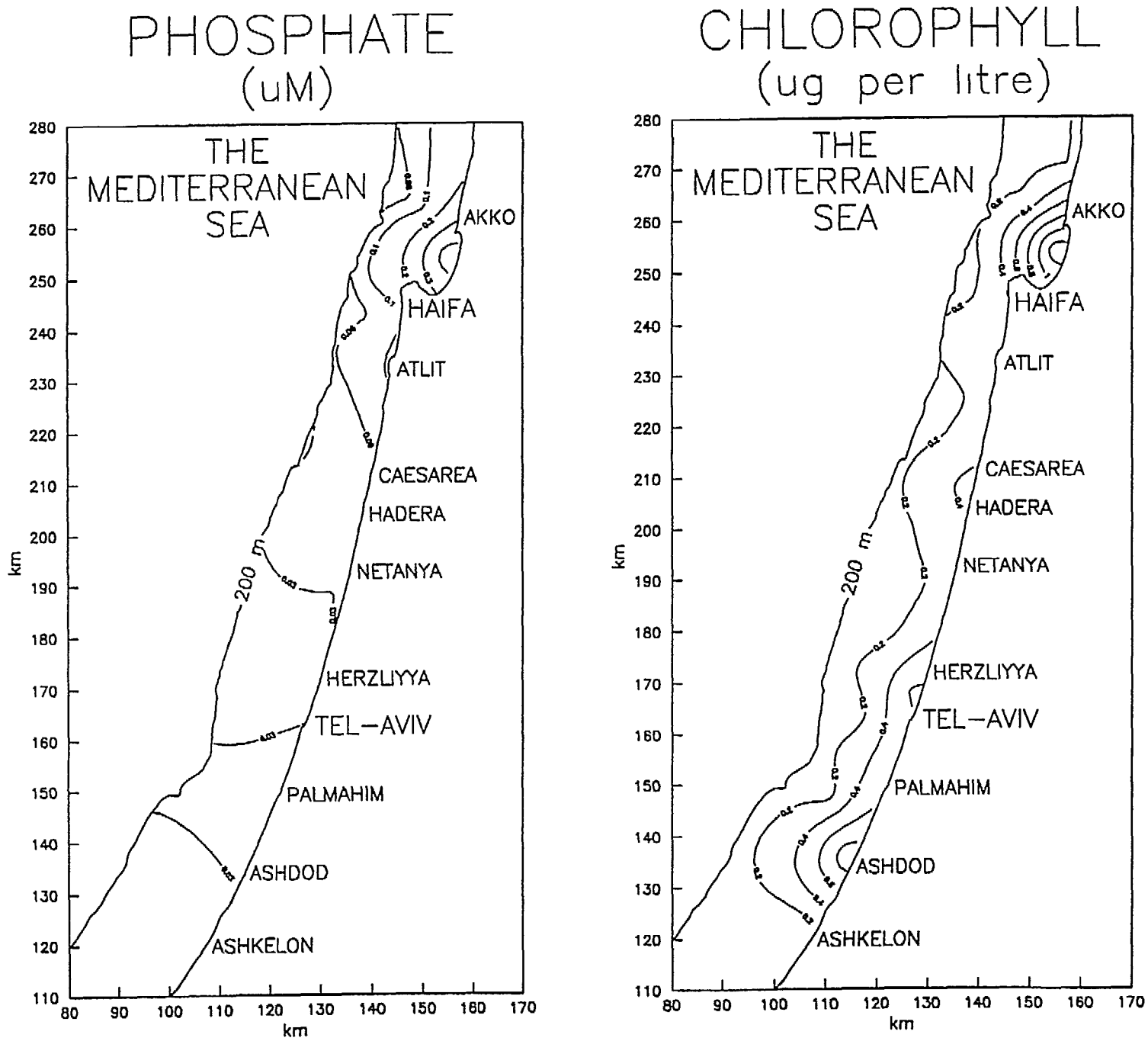

PHOSPHATE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
CHLOROPHYLL
(ug per litre)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km

Fig 20

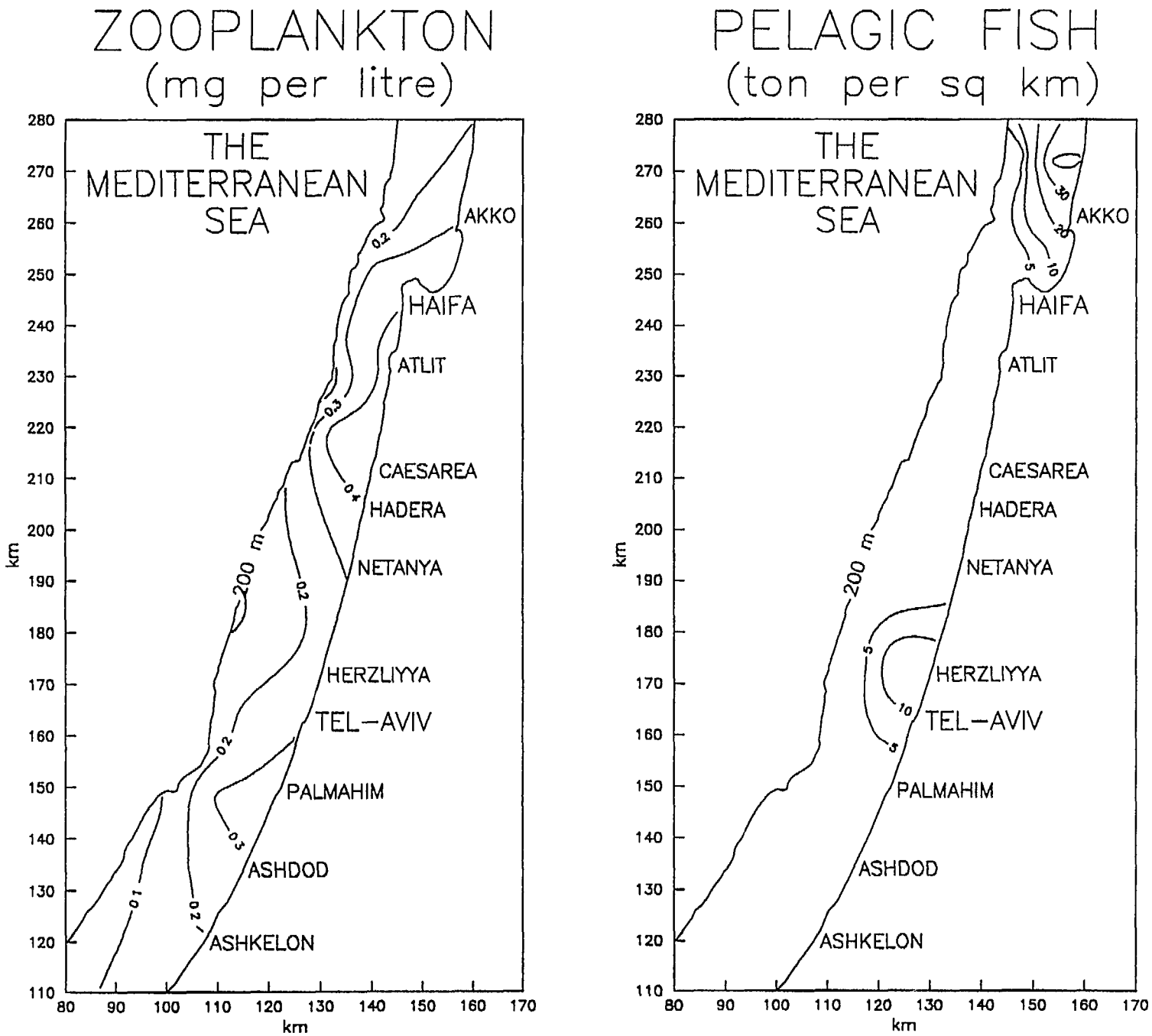
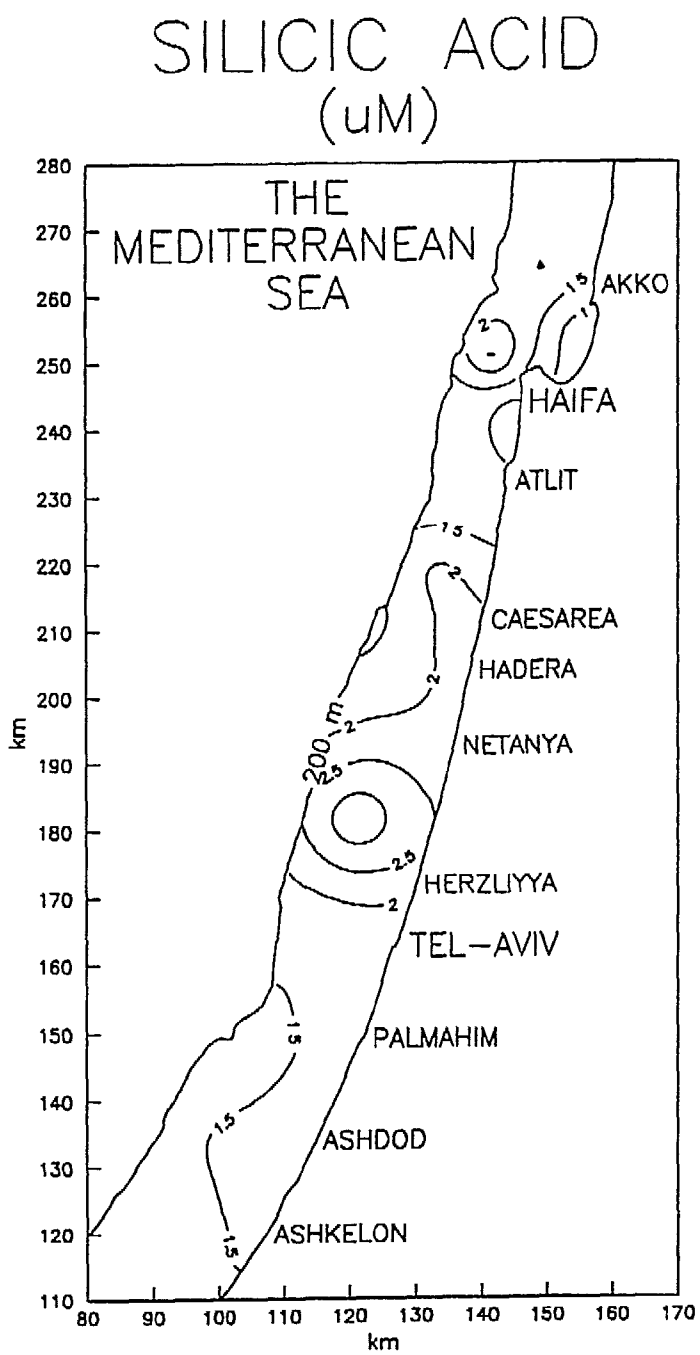


Fig 21

B=12500 ton


SILICIC ACID
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL–AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
km

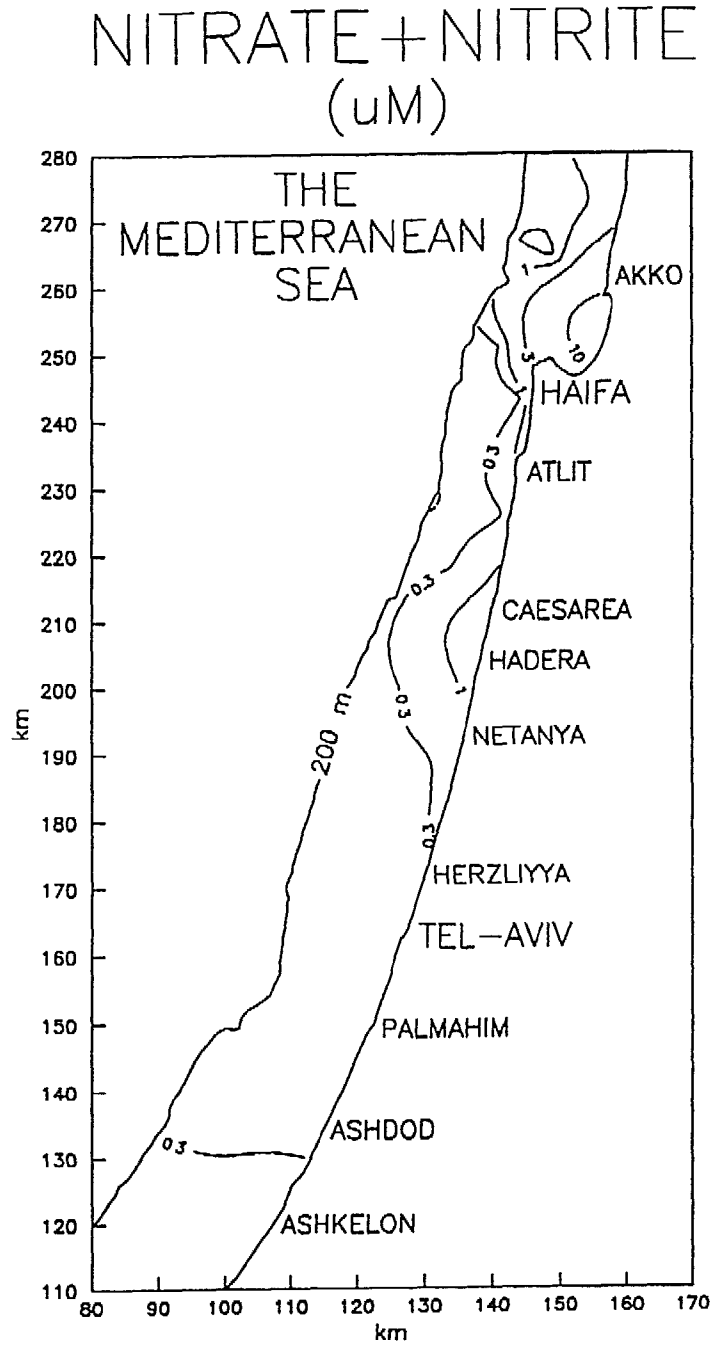

NITRATE+NITRITE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL–AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
km

Fig 22

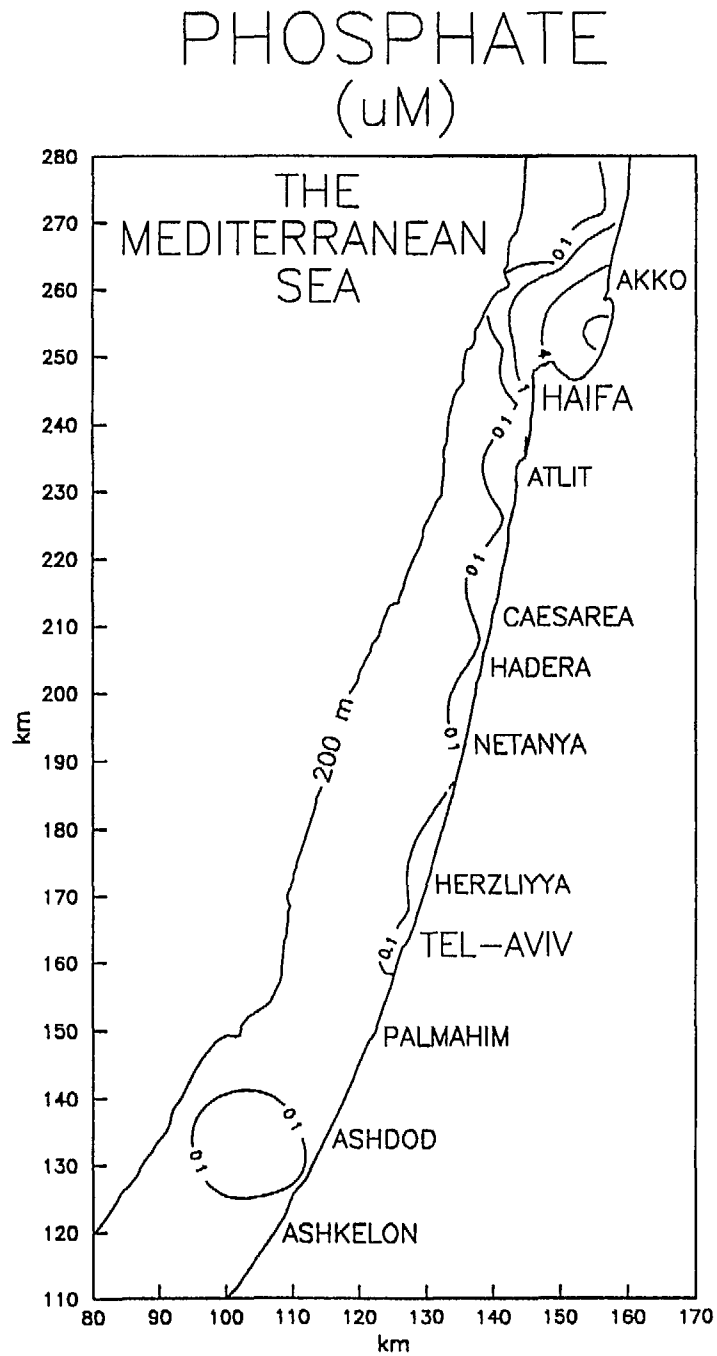

PHOSPHATE
(uM)
THE
MEDITERRANEAN
SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL–AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
0.1
1.0
km
km
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
80
90
100
110
120
130
140
150
160
170

Fig 23

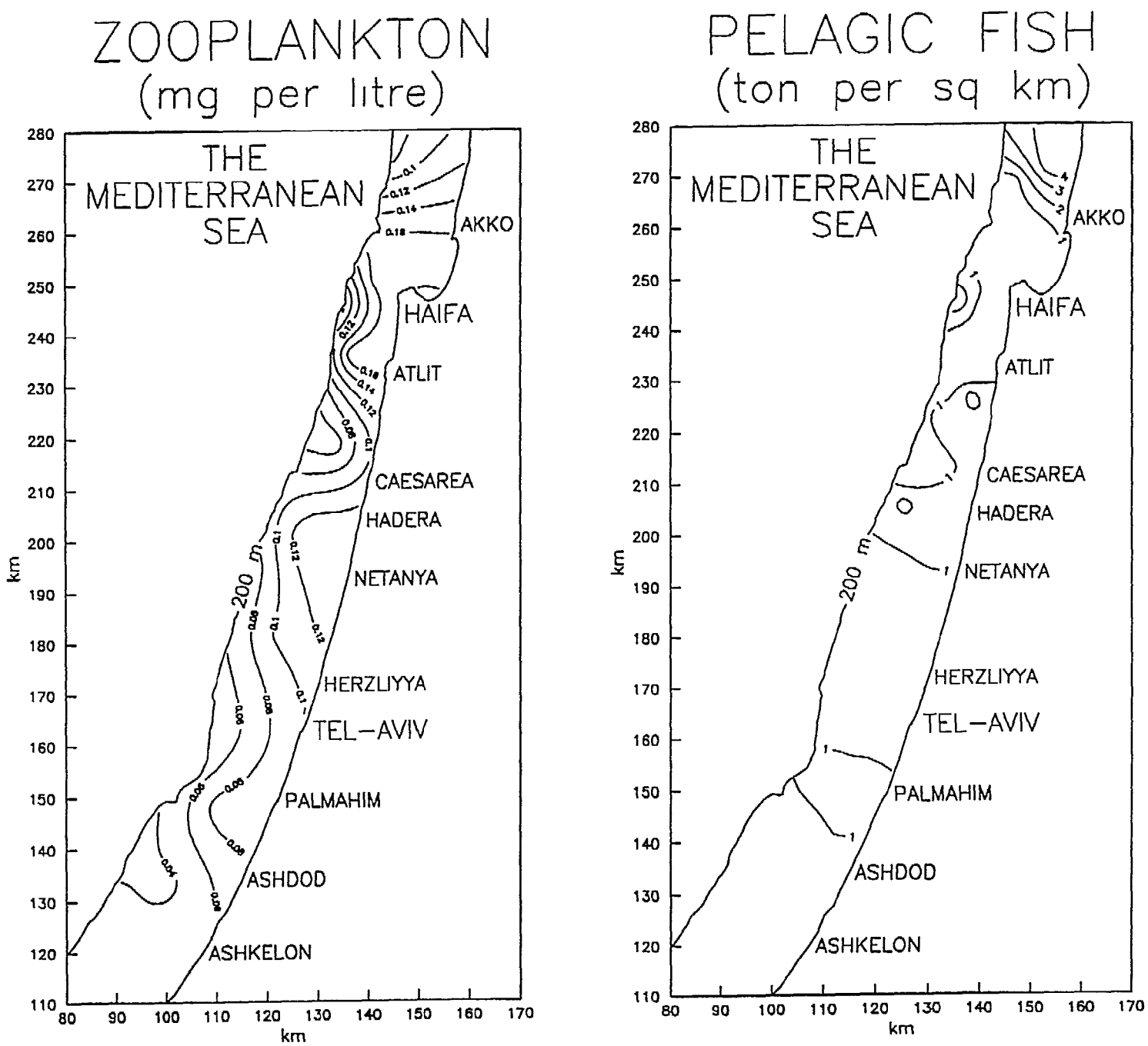

ZOOPLANKTON
(mg per litre)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
PELAGIC FISH
(ton per sq km)
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
B=2250 ton

Fig 24

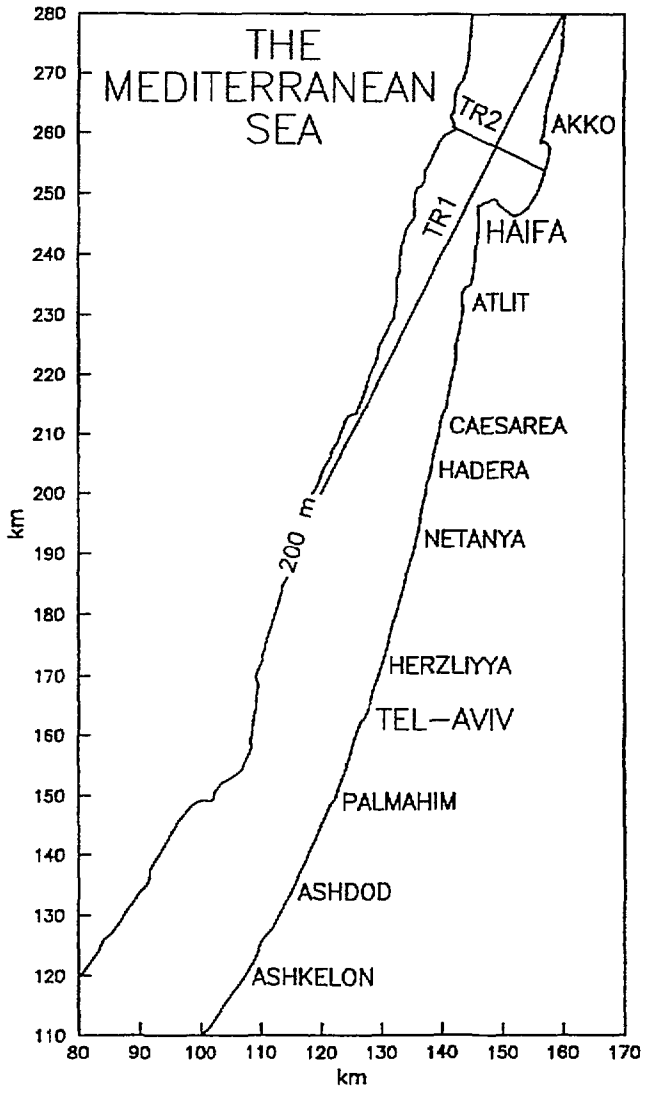

THE
MEDITERRANEAN
SEA
TR2
TR1
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL—AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
km
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
80
90
100
110
120
130
140
150
160
170

Fig 25

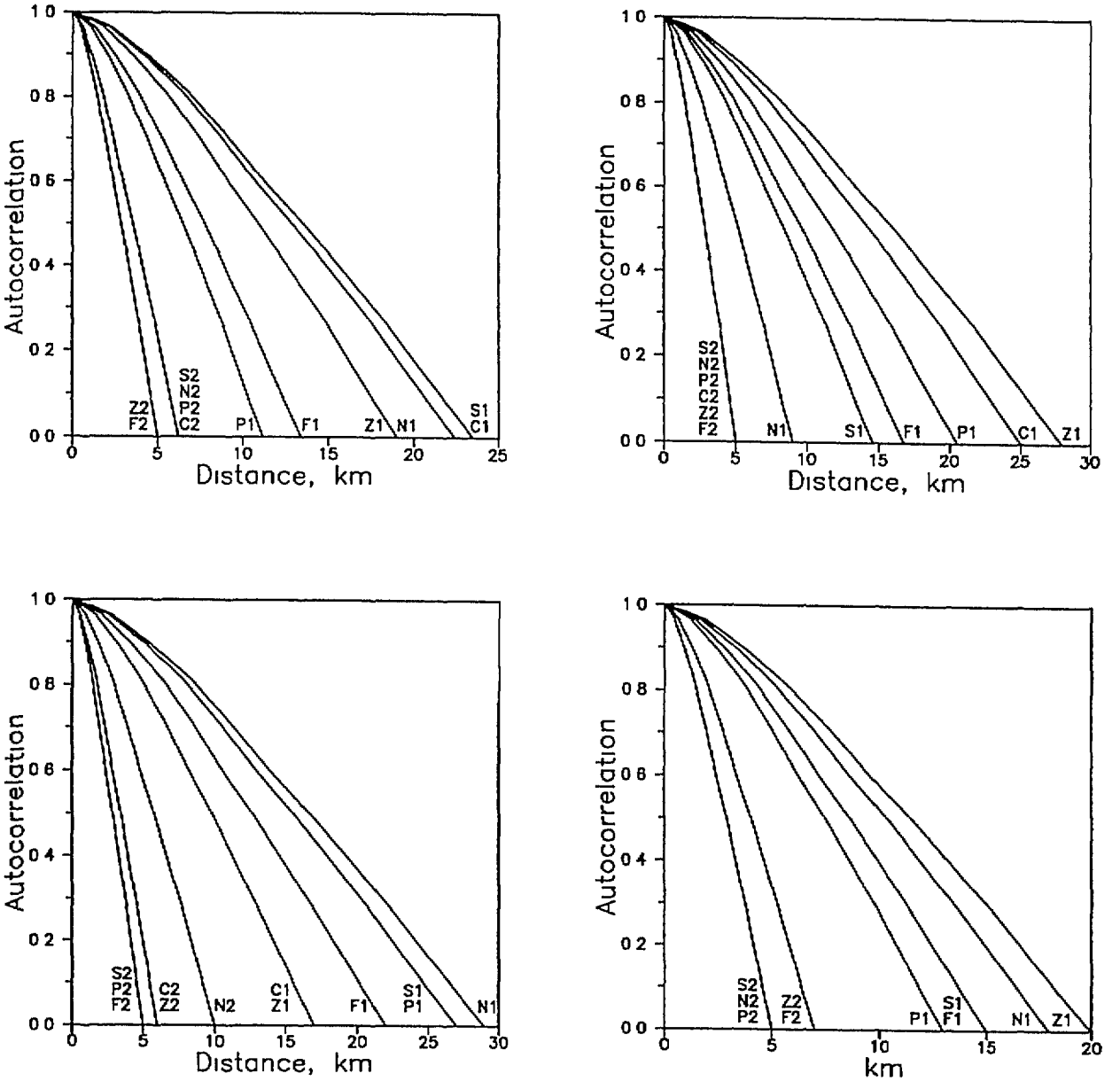

Autocorrelation
Distance, km
Z2
F2
S2
N2
P2
C2
P1
F1
Z1
N1
S1
C1
S2
N2
P2
C2
Z2
F2
N1
S1
F1
P1
C1
Z1
S2
P2
F2
C2
Z2
N2
C1
Z1
F1
S1
P1
N1
S2
N2
P2
Z2
F2
P1
S1
F1
N1
Z1
km

Fig 26

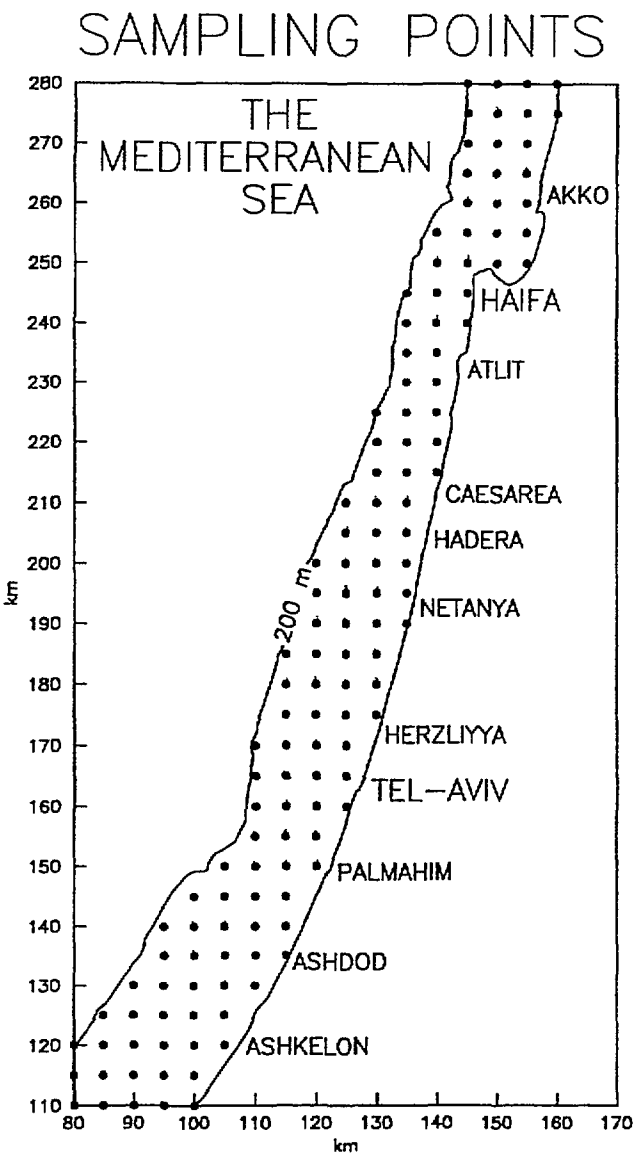

SAMPLING POINTS
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL–AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
km
km
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
80
90
100
110
120
130
140
150
160
170

Fig 27

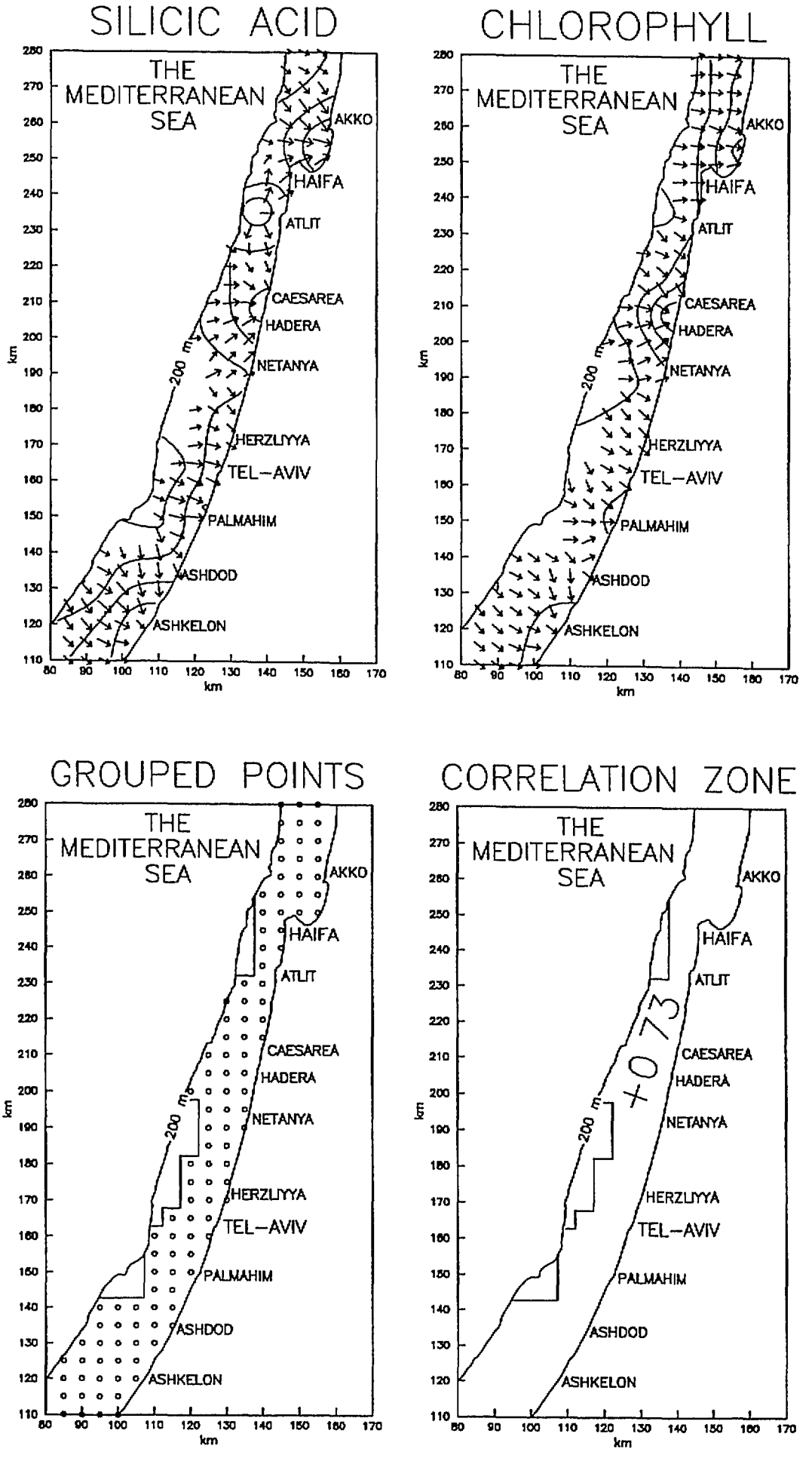

SILICIC ACID
CHLOROPHYLL
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.73
km

Fig 28

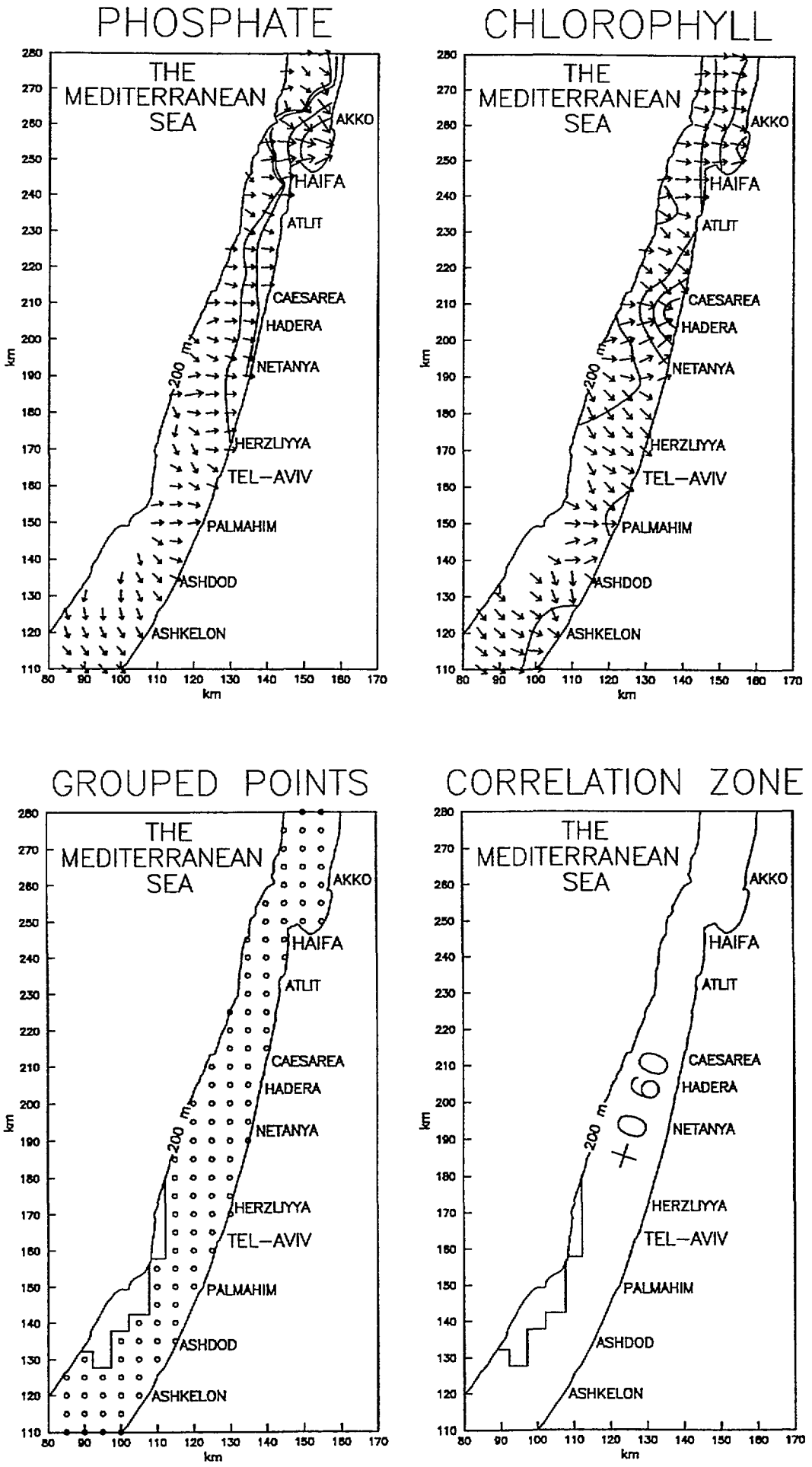

PHOSPHATE
CHLOROPHYLL
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.60
km

Fig 29

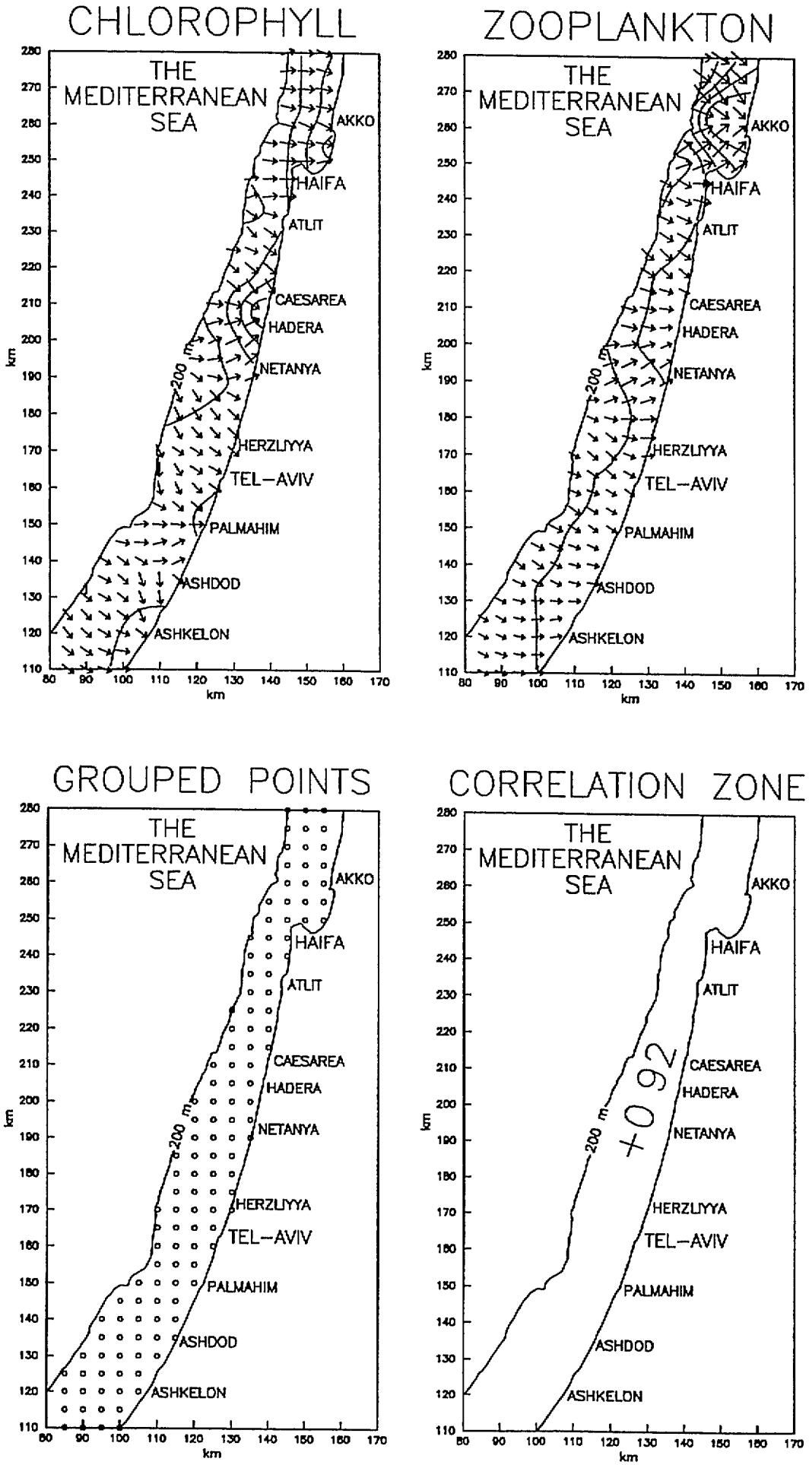

CHLOROPHYLL
ZOOPLANKTON
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.92
km

Fig 30

61

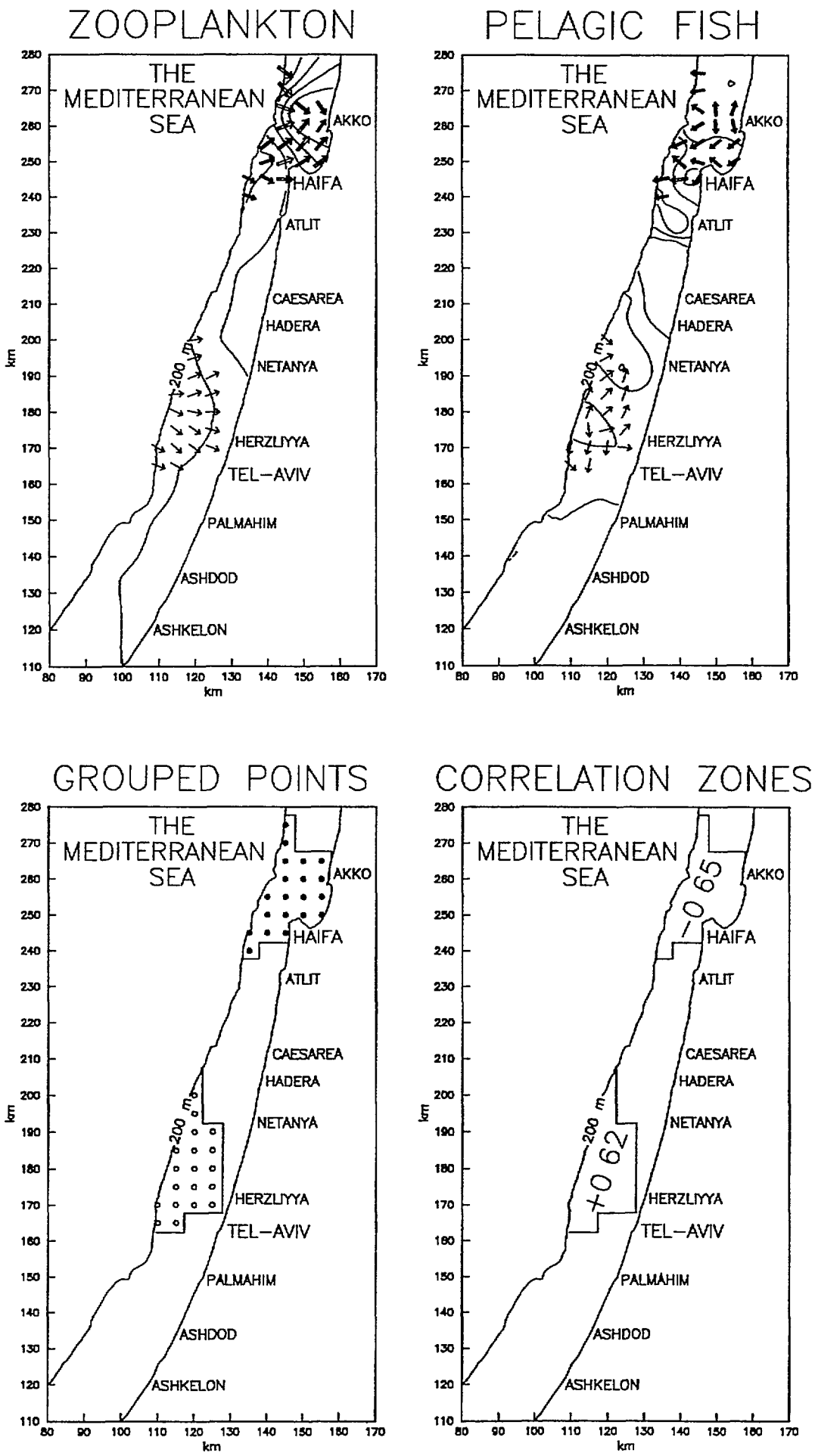

ZOOPLANKTON
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONES
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
-0.65
+0.62
km

Fig 31

65

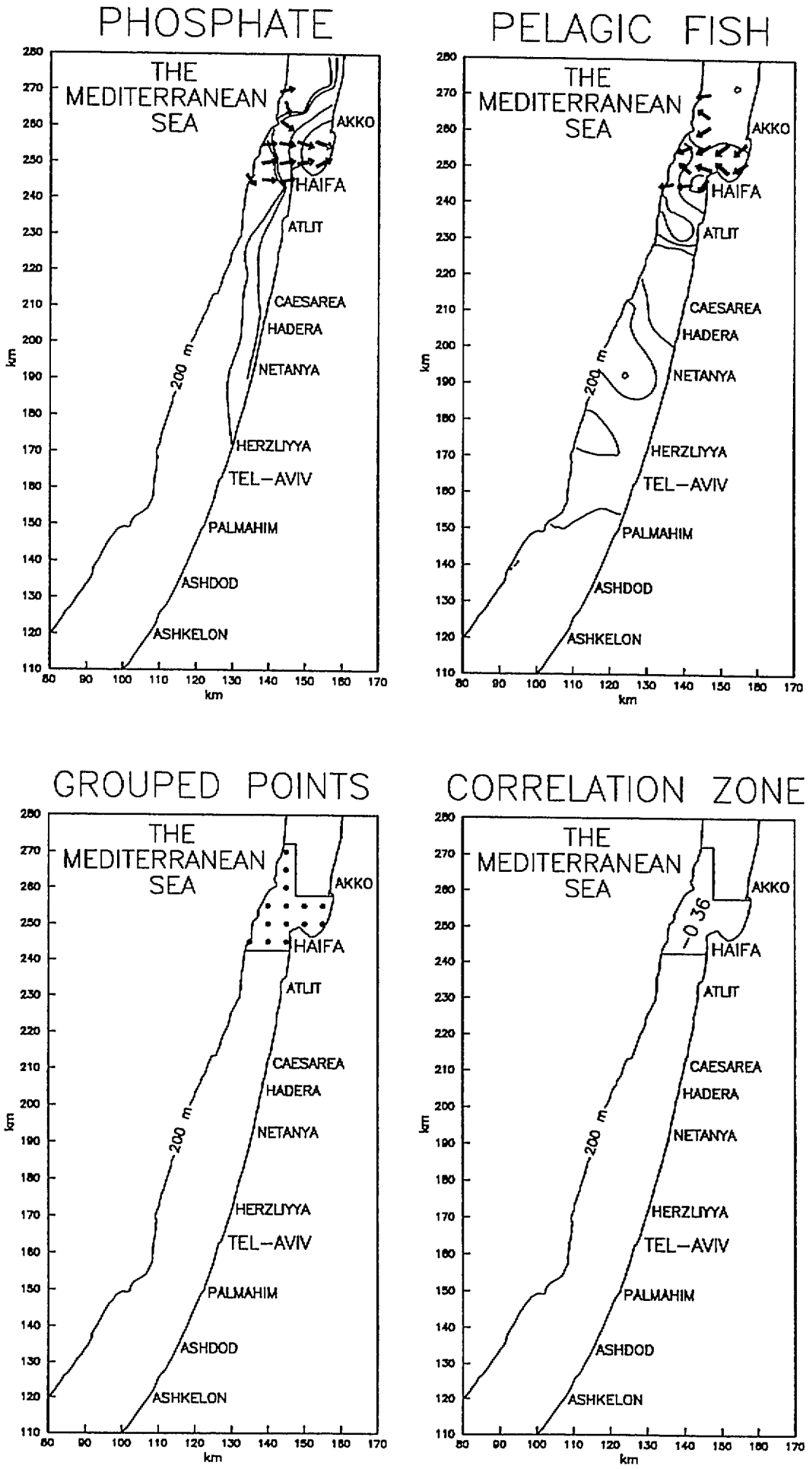

PHOSPHATE
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
-0.36
km

Fig 32

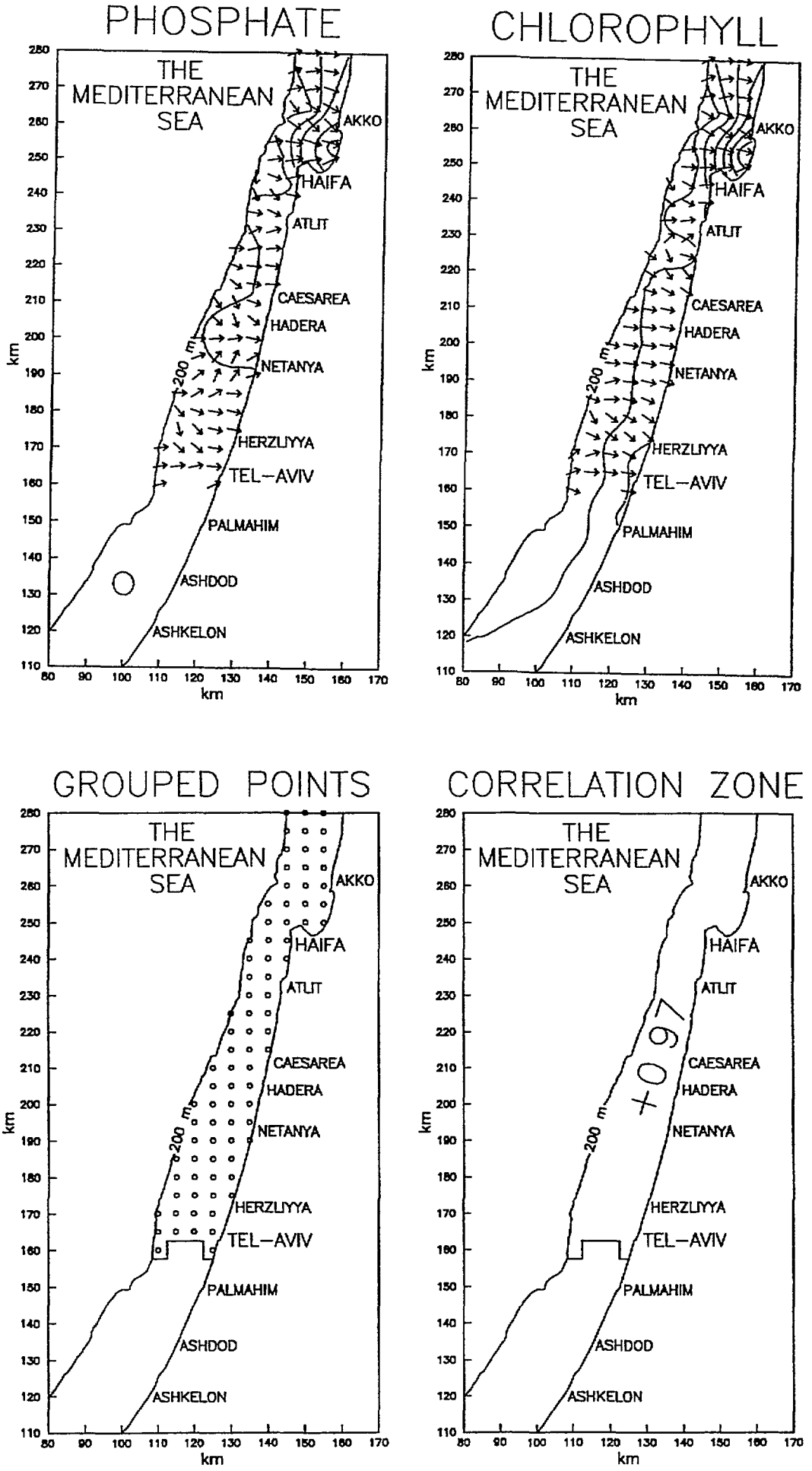

PHOSPHATE
CHLOROPHYLL
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.97
km

Fig 33

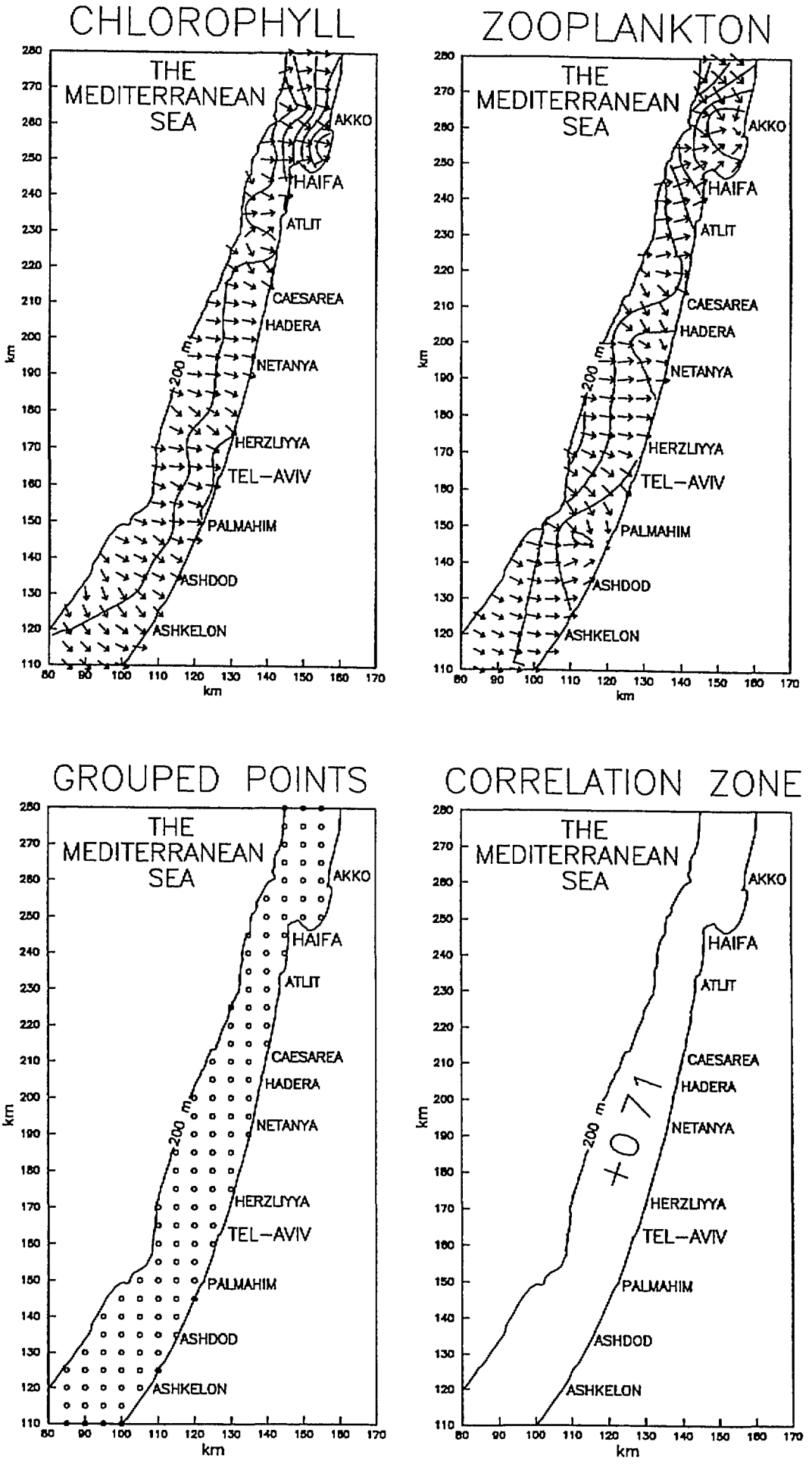

CHLOROPHYLL
ZOOPLANKTON
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.71
km

Fig 34

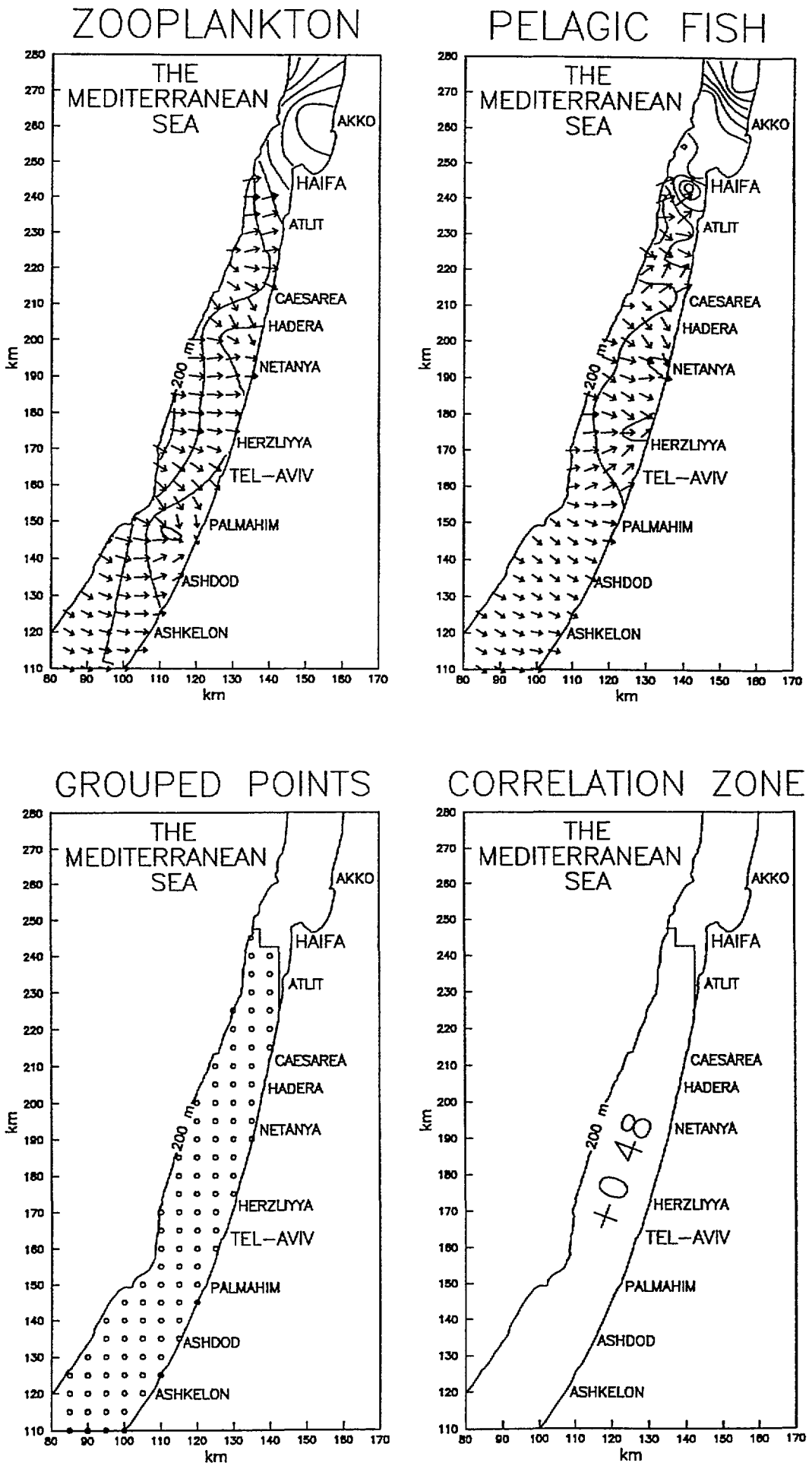

ZOOPLANKTON
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.48
km

Fig 35

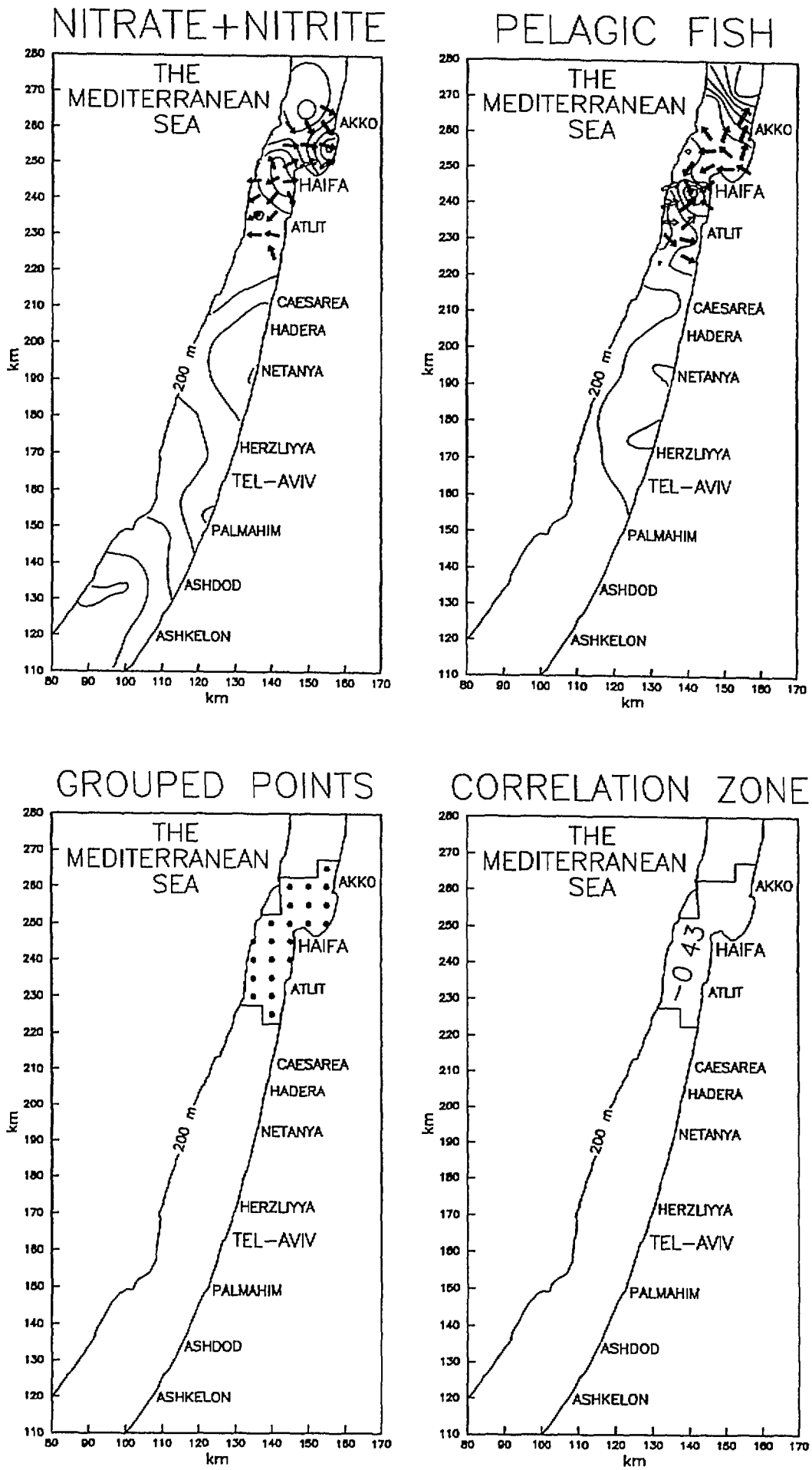

NITRATE+NITRITE
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
0.43
km

Fig 36

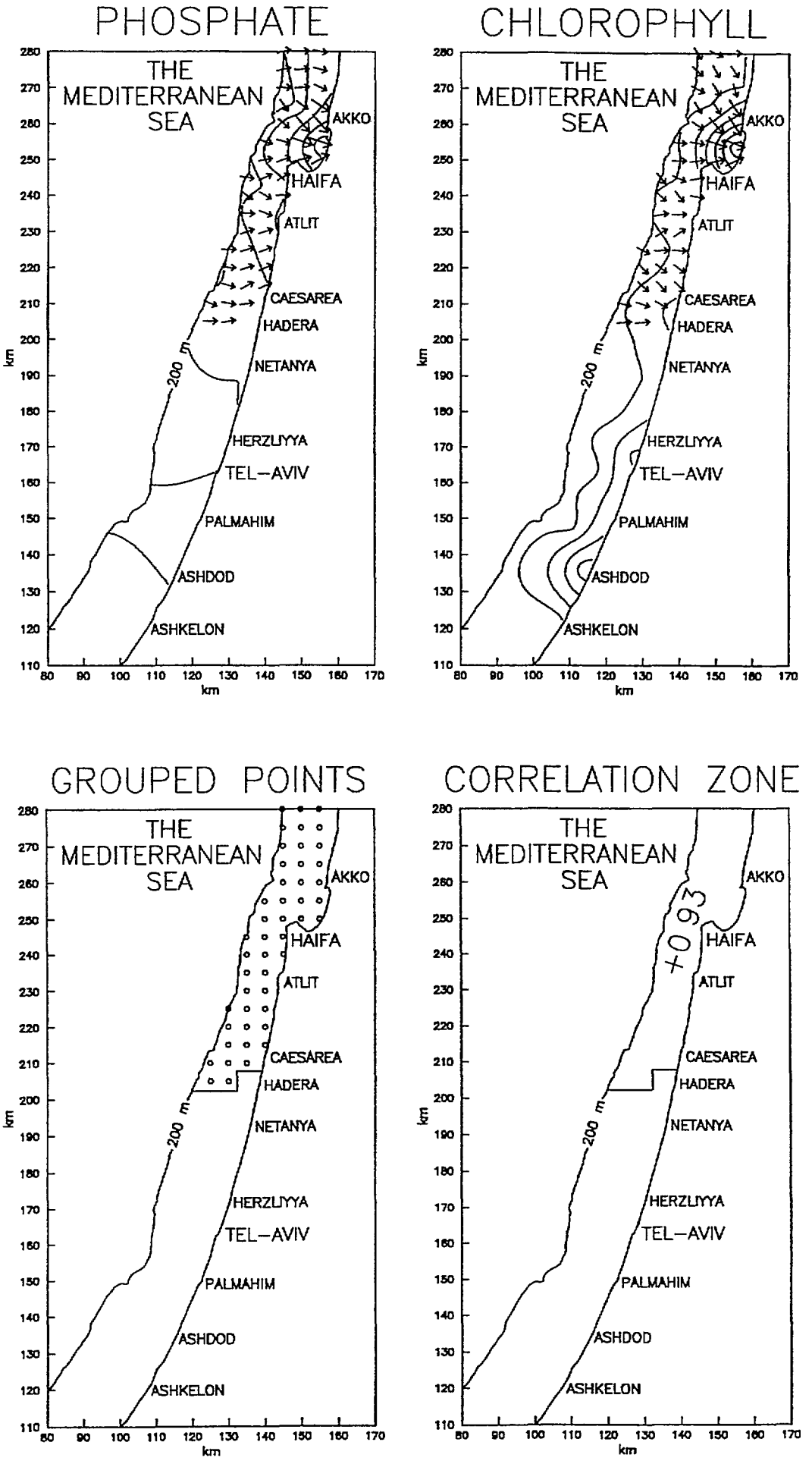

PHOSPHATE
CHLOROPHYLL
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.93
km

Fig 37

7-1

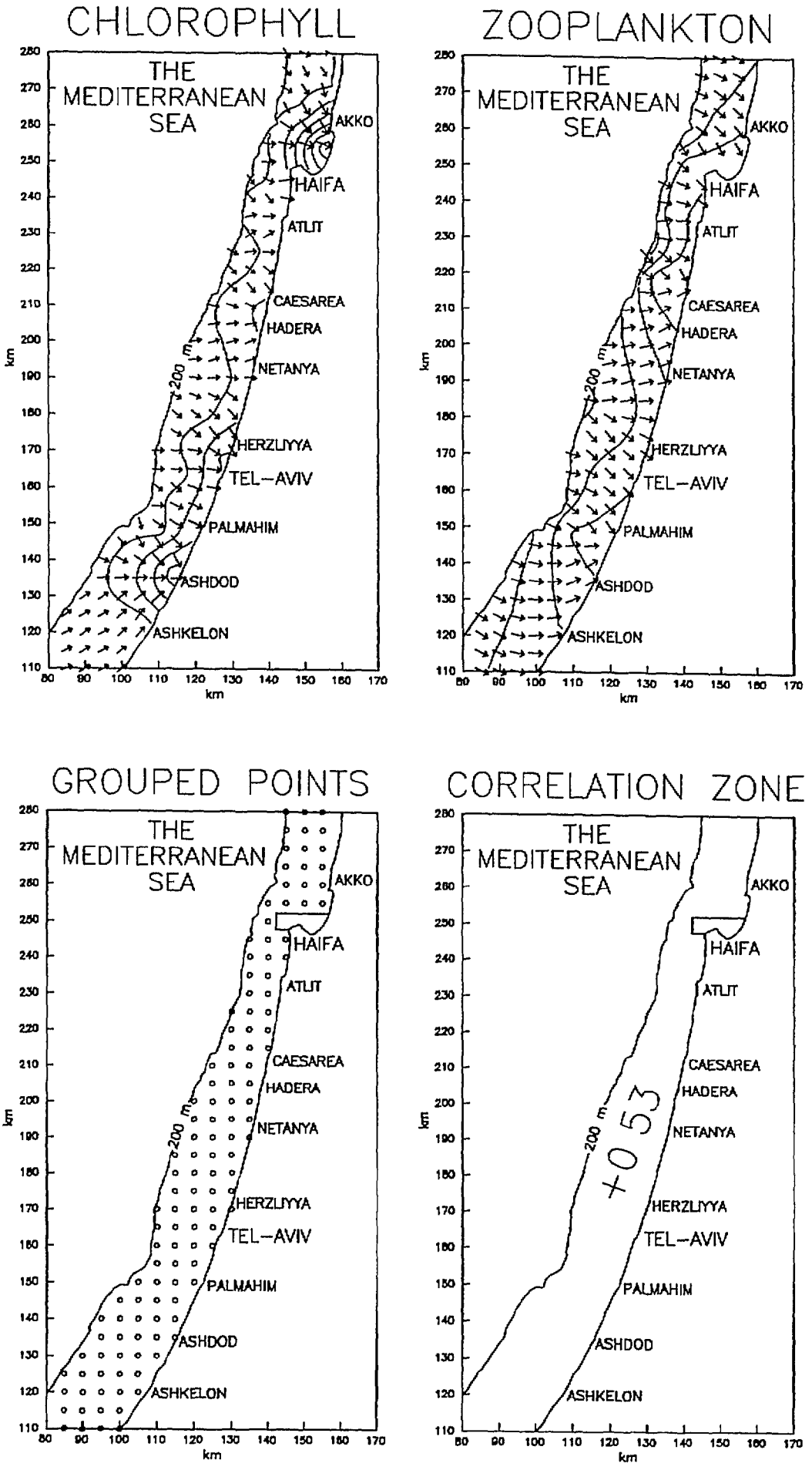

CHLOROPHYLL
ZOOPLANKTON
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.53
km

Fig 38

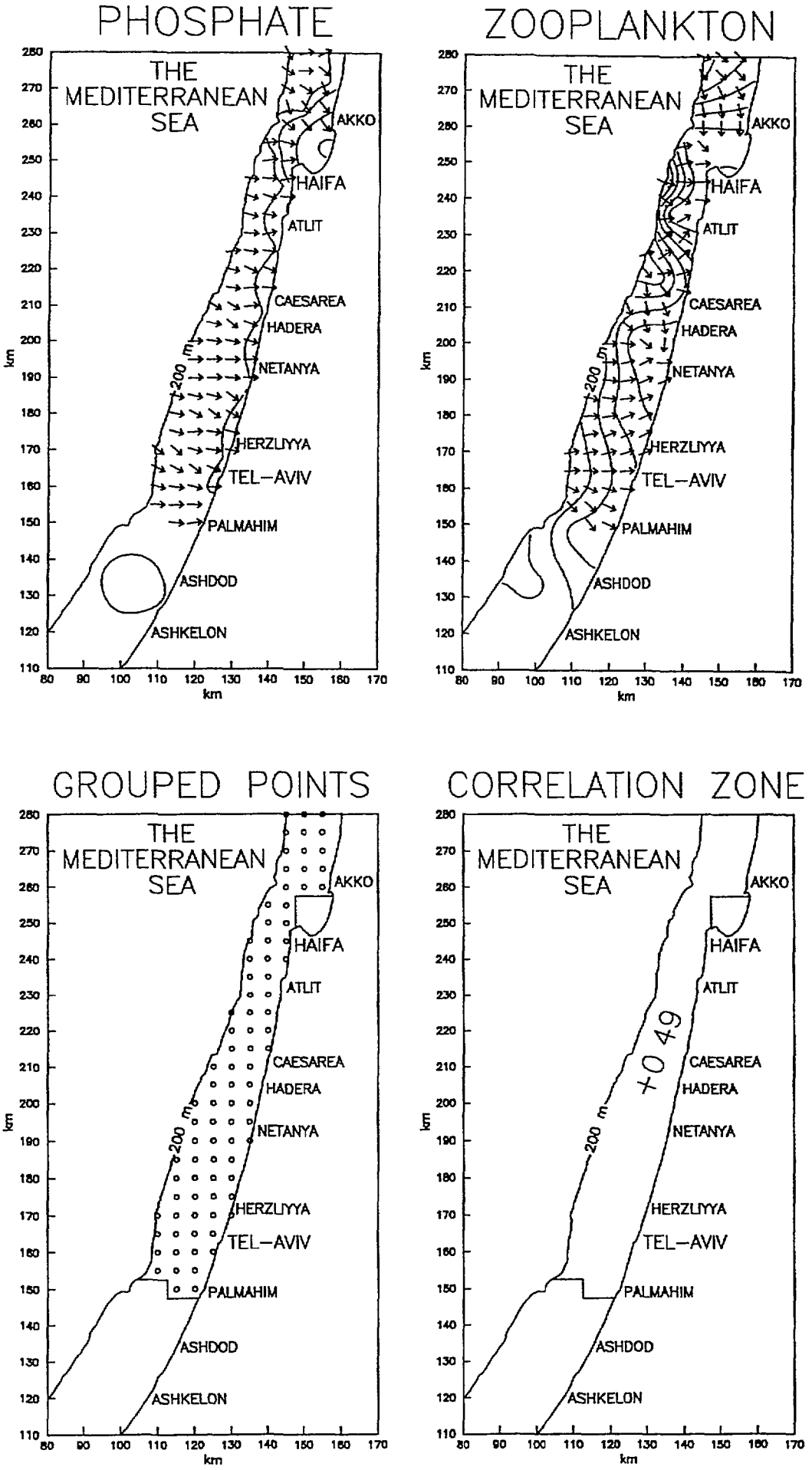

PHOSPHATE
ZOOPLANKTON
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
+0.49
km

Fig 39

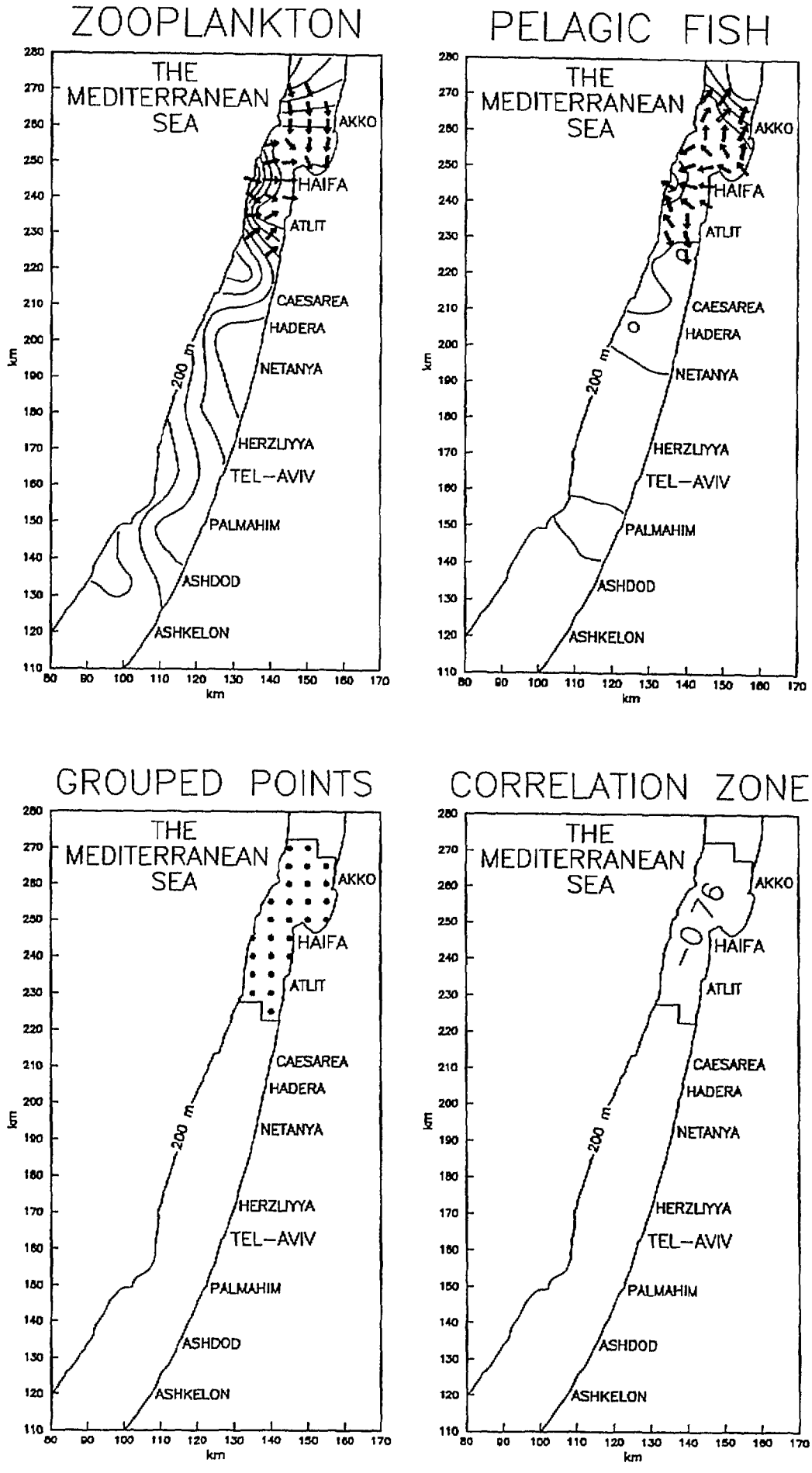

ZOOPLANKTON
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
-0.76
km

Fig 40

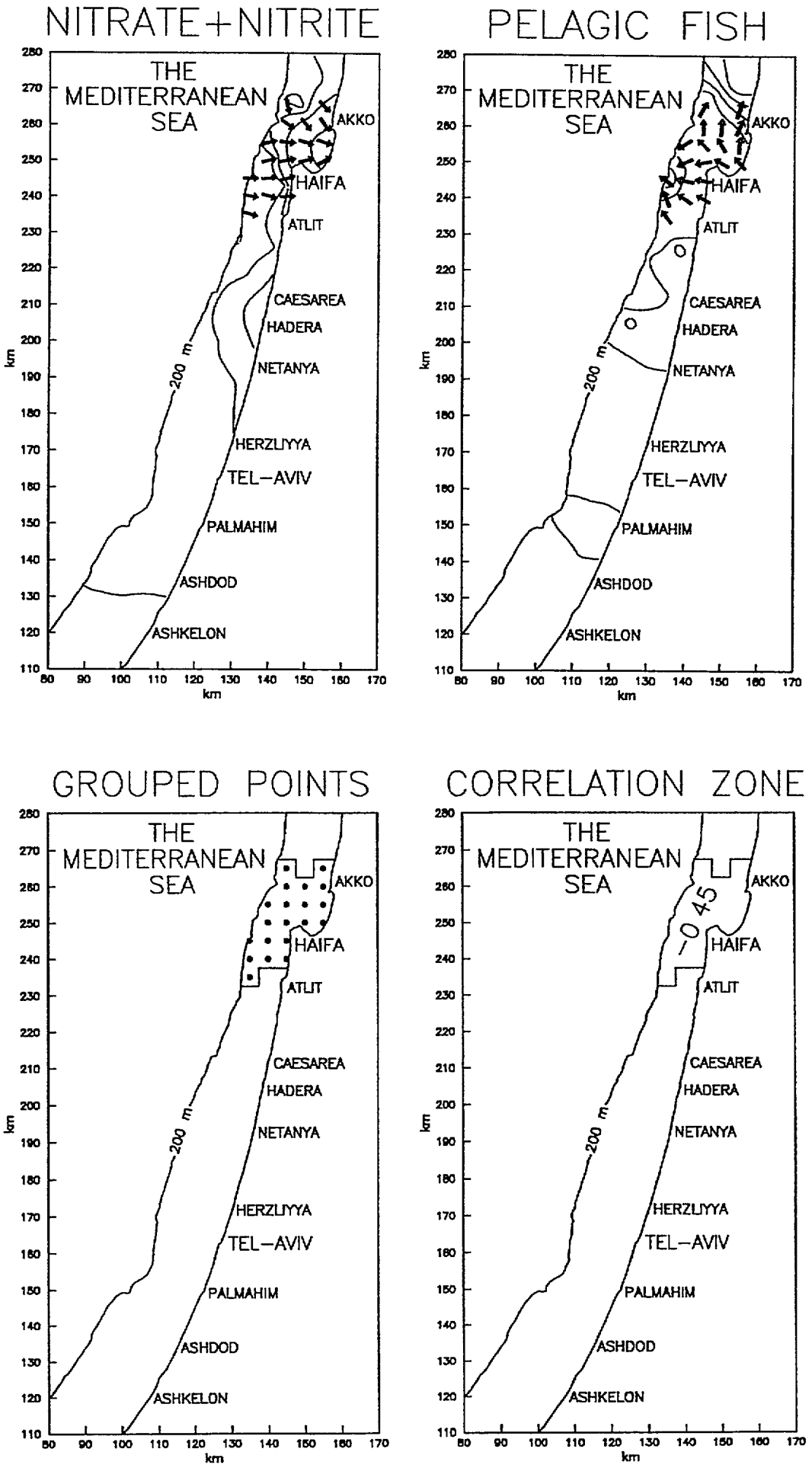

NITRATE+NITRITE
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
-0.45
km

Fig 41

78

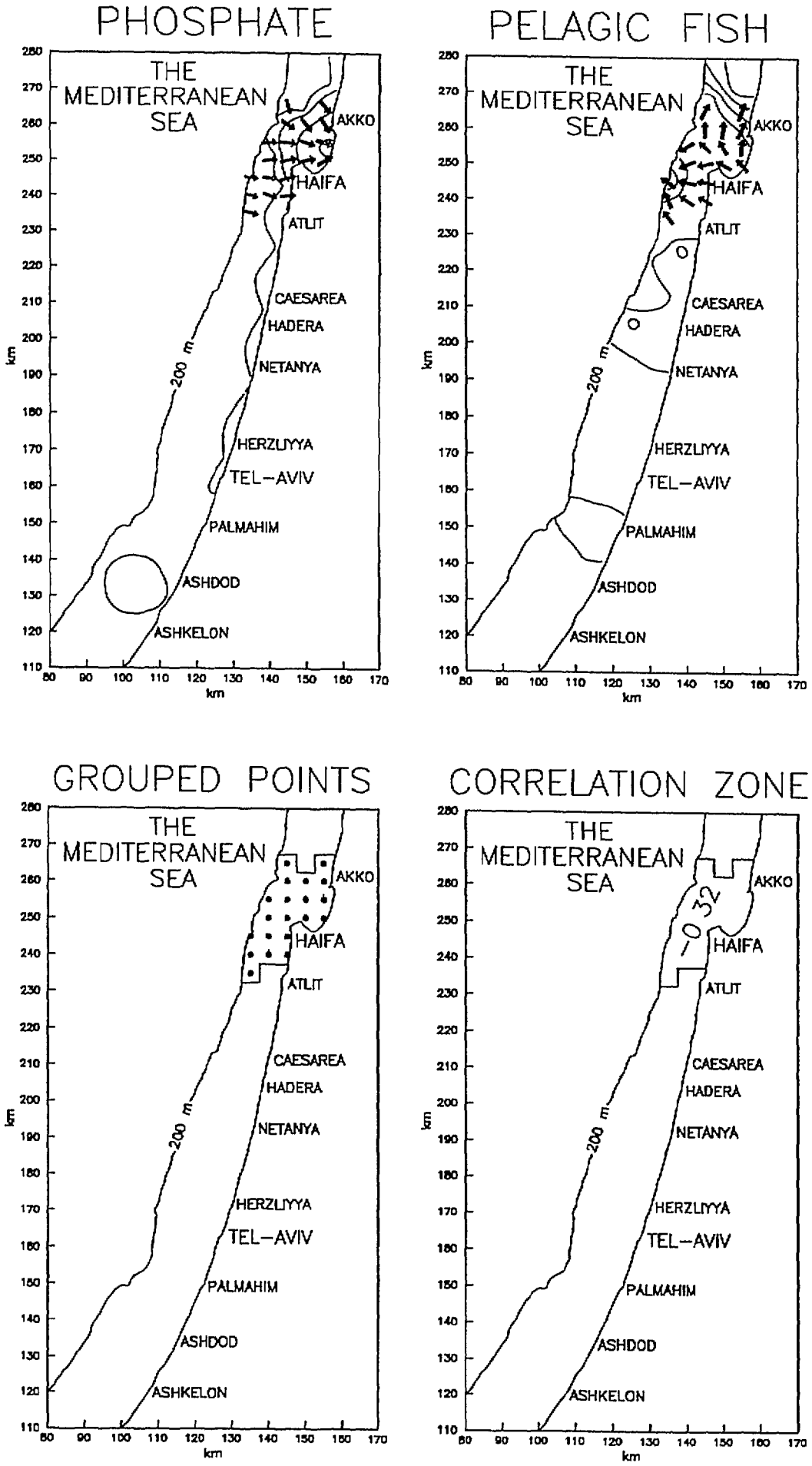

PHOSPHATE
PELAGIC FISH
GROUPED POINTS
CORRELATION ZONE
THE MEDITERRANEAN SEA
AKKO
HAIFA
ATLIT
CAESAREA
HADERA
NETANYA
HERZLIYYA
TEL-AVIV
PALMAHIM
ASHDOD
ASHKELON
200 m
-0.32
km

Fig 42

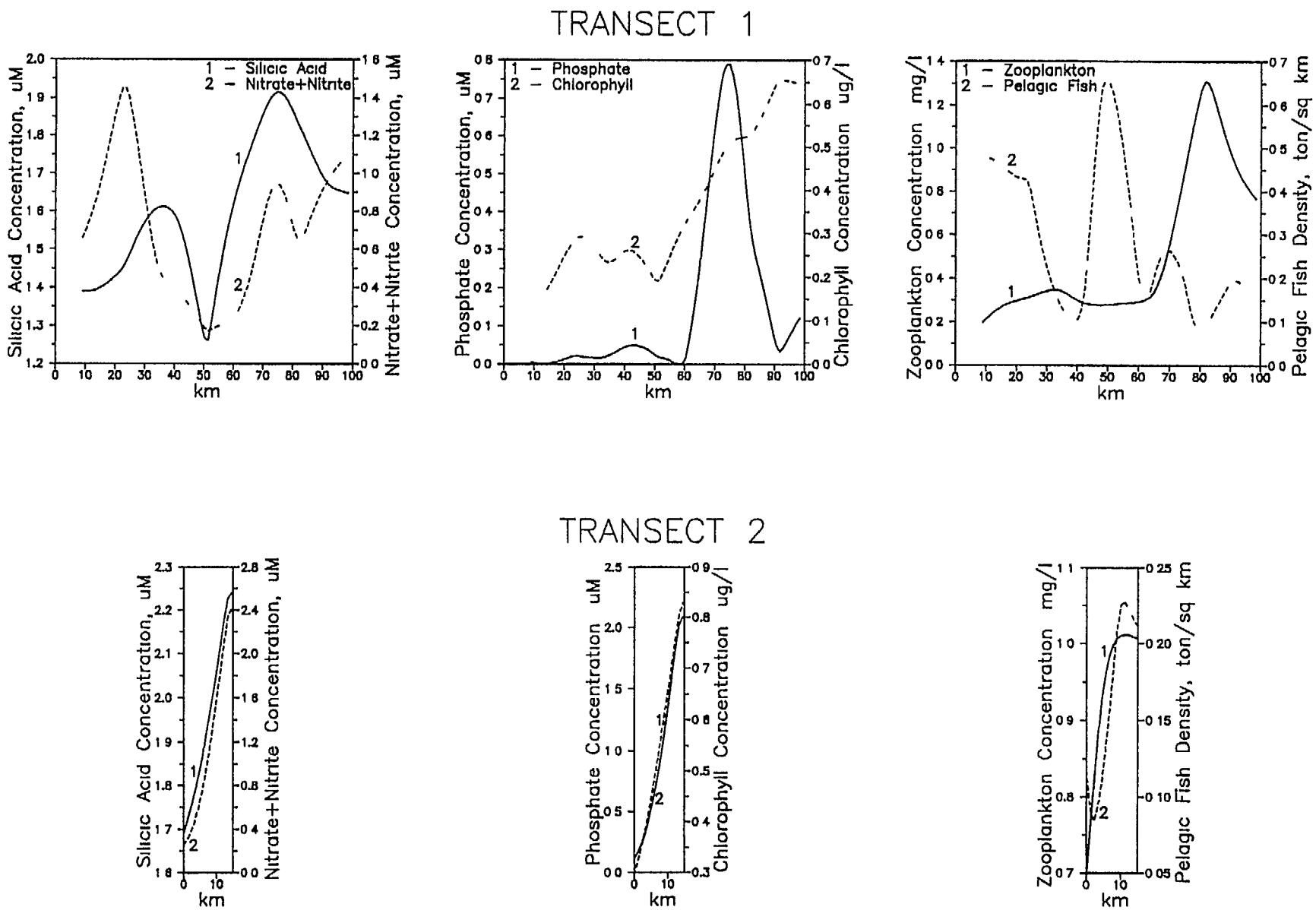

TRANSECT 1
1 – Silicic Acid
2 – Nitrate+Nitrite
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
1 – Phosphate
2 – Chlorophyll
Phosphate Concentration, uM
Chlorophyll Concentration ug/l
km
1 – Zooplankton
2 – Pelagic Fish
Zooplankton Concentration mg/l
Pelagic Fish Density, ton/sq km
km
TRANSECT 2
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
Phosphate Concentration uM
Chlorophyll Concentration ug/l
km
Zooplankton Concentration mg/l
Pelagic Fish Density, ton/sq km
km

Fig 43

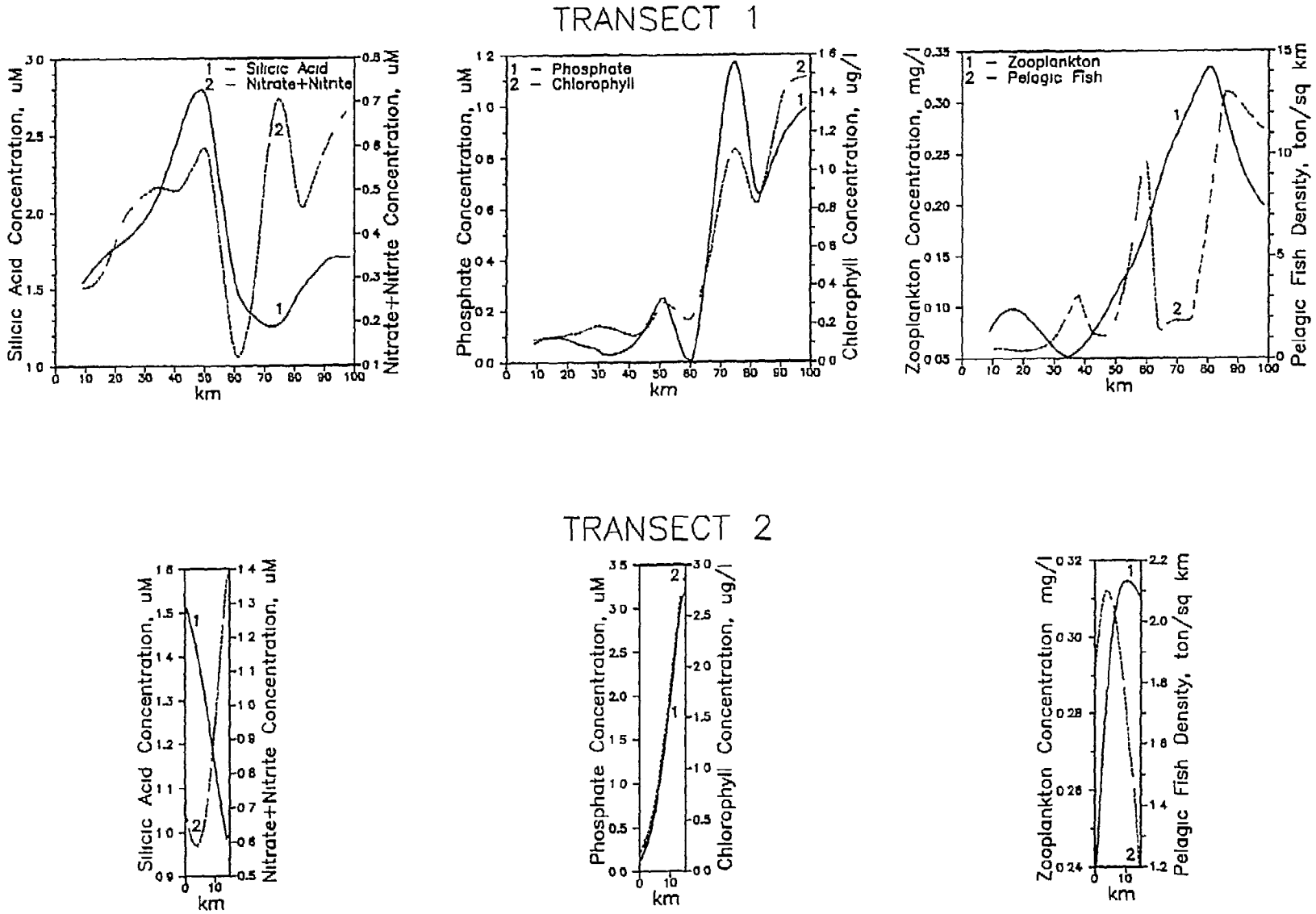

TRANSECT 1
1 – Silicic Acid
2 – Nitrate+Nitrite
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
1 – Phosphate
2 – Chlorophyll
Phosphate Concentration, uM
Chlorophyll Concentration, ug/l
km
1 – Zooplankton
2 – Pelagic Fish
Zooplankton Concentration, mg/l
Pelagic Fish Density, ton/sq km
km
TRANSECT 2
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
Phosphate Concentration, uM
Chlorophyll Concentration, ug/l
km
Zooplankton Concentration mg/l
Pelagic Fish Density, ton/sq km
km

Fig 44

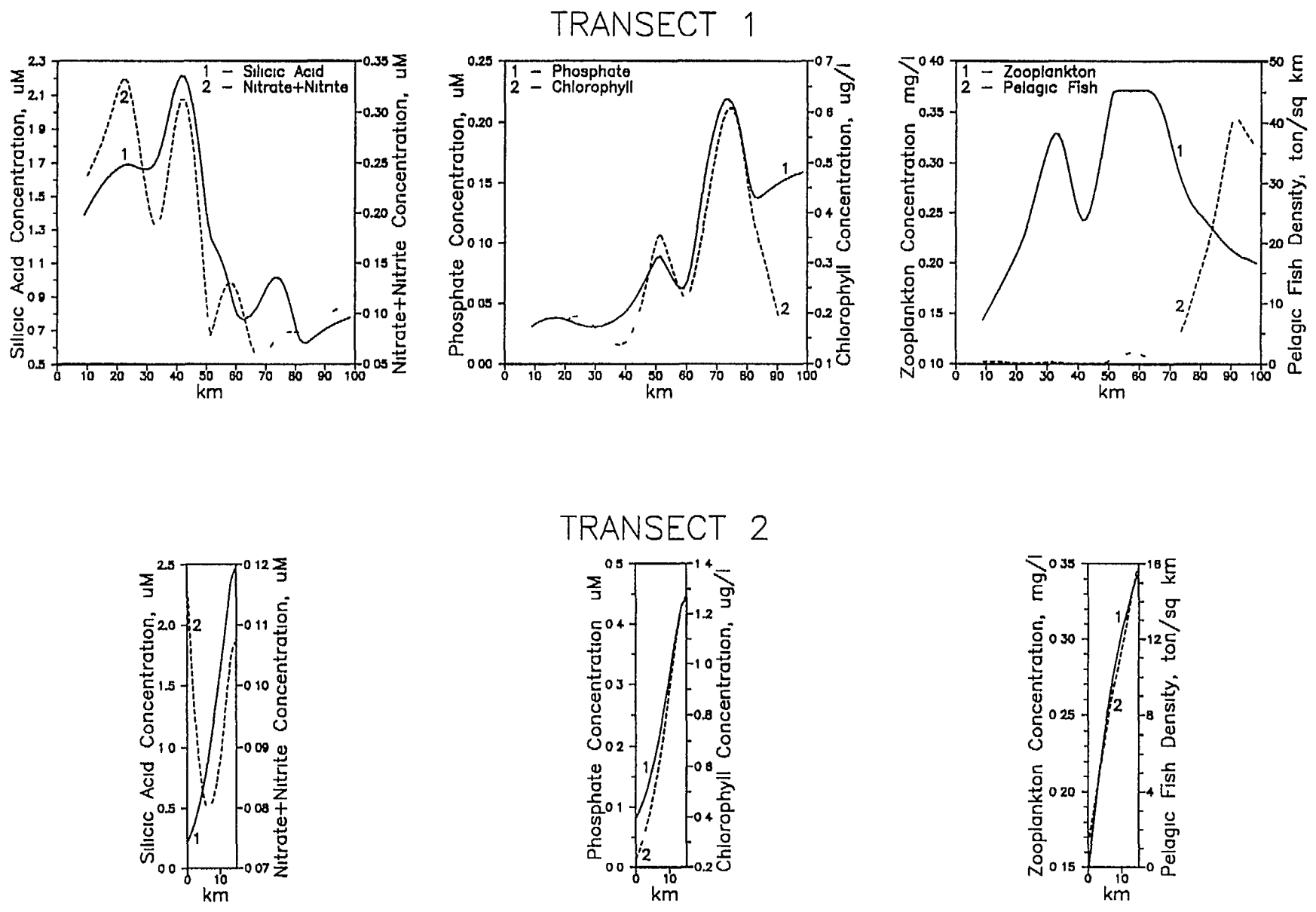

TRANSECT 1
1 – Silicic Acid
2 – Nitrate+Nitrite
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
1 – Phosphate
2 – Chlorophyll
Phosphate Concentration, uM
Chlorophyll Concentration, ug/l
km
1 – Zooplankton
2 – Pelagic Fish
Zooplankton Concentration mg/l
Pelagic Fish Density, ton/sq km
km
TRANSECT 2
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
Phosphate Concentration uM
Chlorophyll Concentration, ug/l
km
Zooplankton Concentration, mg/l
Pelagic Fish Density, ton/sq km
km

Fig 45

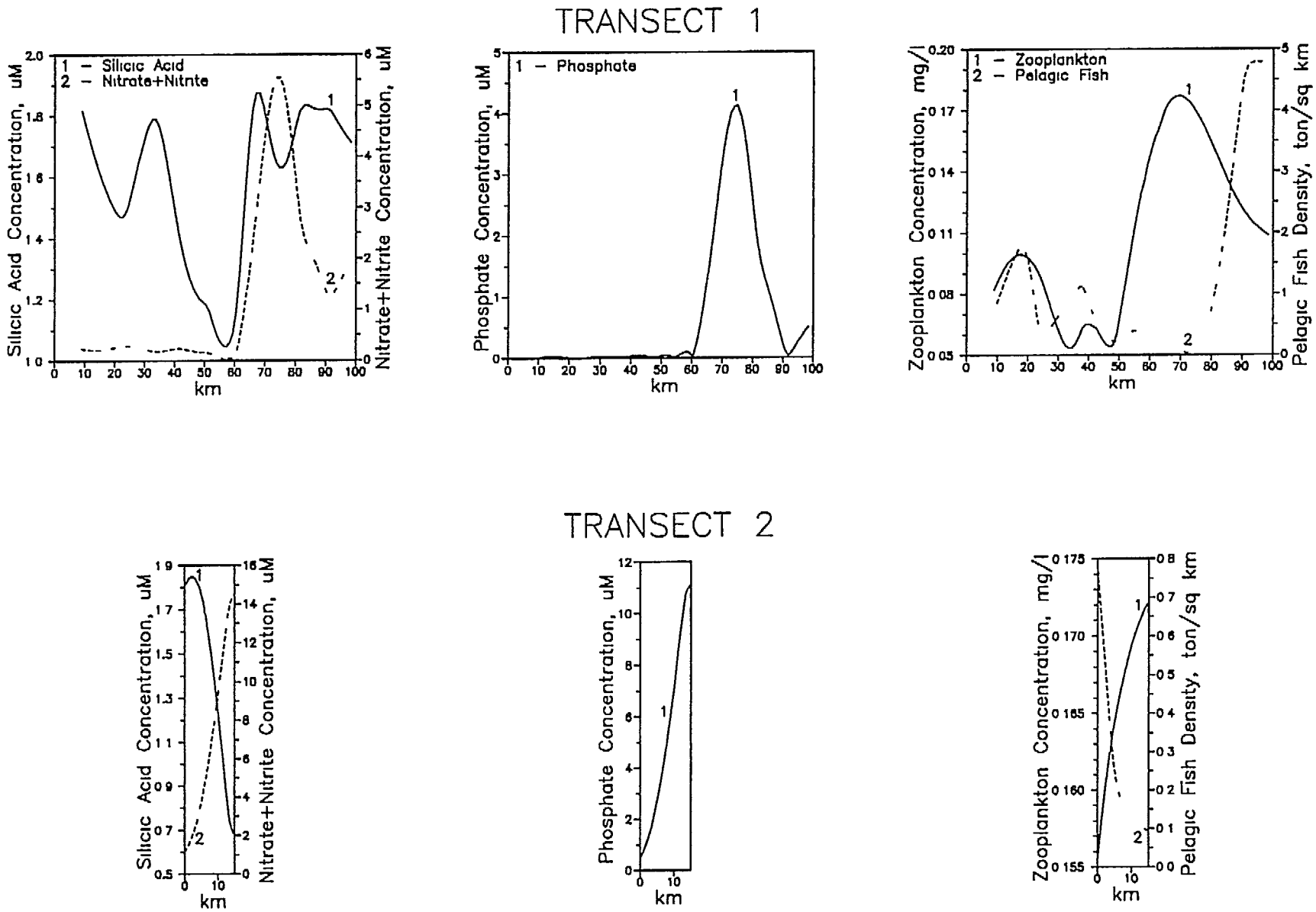

TRANSECT 1
1 – Silicic Acid
2 – Nitrate+Nitrite
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
1 – Phosphate
Phosphate Concentration, uM
km
1 – Zooplankton
2 – Pelagic Fish
Zooplankton Concentration, mg/l
Pelagic Fish Density, ton/sq km
km
TRANSECT 2
Silicic Acid Concentration, uM
Nitrate+Nitrite Concentration, uM
km
Phosphate Concentration, uM
km
Zooplankton Concentration, mg/l
Pelagic Fish Density, ton/sq km
km

Fig 46

83

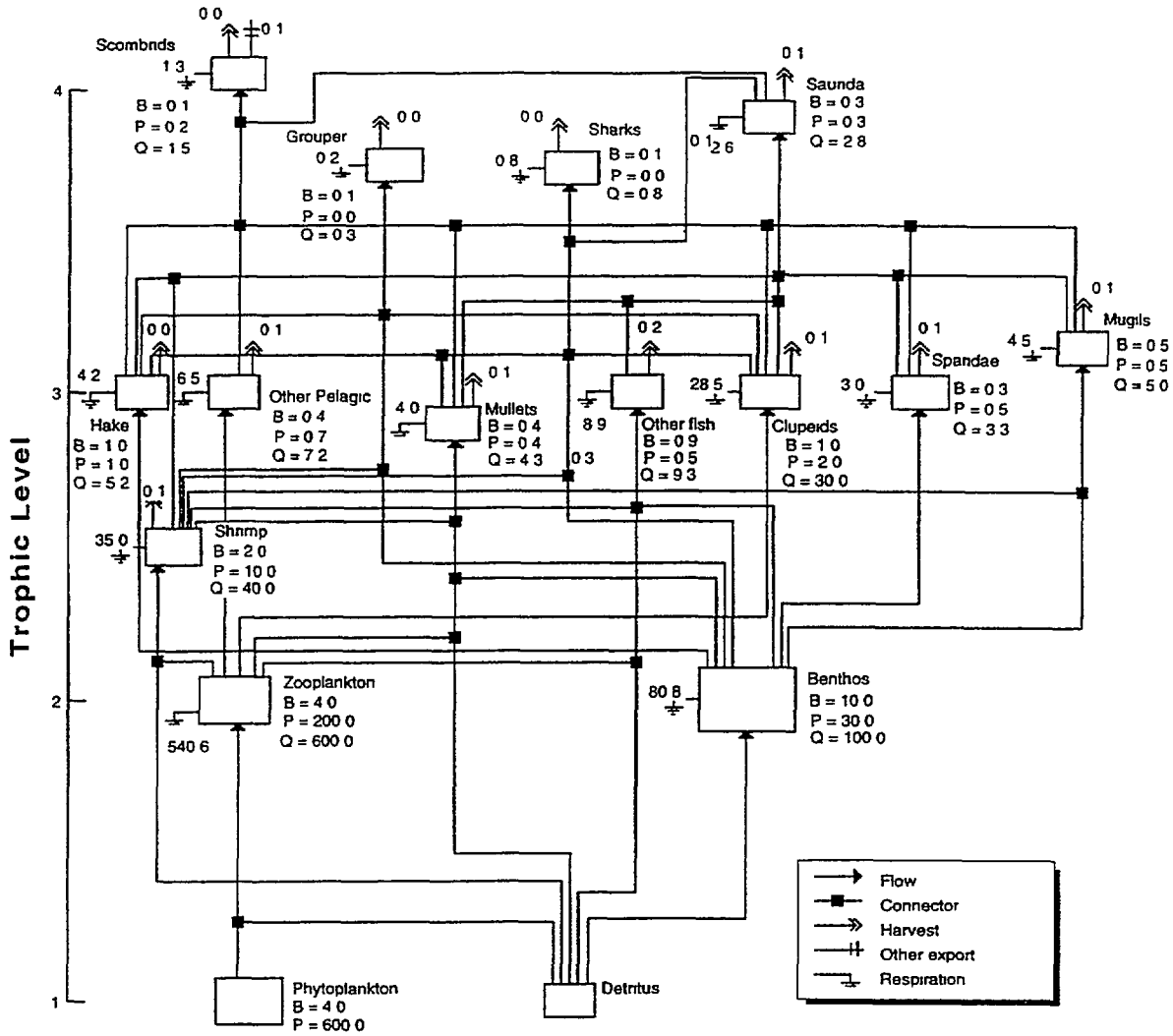

Trophic Level
4
3
2
1
Scombrids
B = 0 1
P = 0 2
Q = 1 5
Grouper
B = 0 1
P = 0 0
Q = 0 3
Sharks
B = 0 1
P = 0 0
Q = 0 8
Saunda
B = 0 3
P = 0 3
Q = 2 8
Mugils
B = 0 5
P = 0 5
Q = 5 0
Spandae
B = 0 3
P = 0 5
Q = 3 3
Hake
B = 1 0
P = 1 0
Q = 5 2
Other Pelagic
B = 0 4
P = 0 7
Q = 7 2
Mullets
B = 0 4
P = 0 4
Q = 4 3
Other fish
B = 0 9
P = 0 5
Q = 9 3
Clupeids
B = 1 0
P = 2 0
Q = 30 0
Shrimp
B = 2 0
P = 10 0
Q = 40 0
Zooplankton
B = 4 0
P = 200 0
Q = 600 0
Benthos
B = 10 0
P = 30 0
Q = 100 0
Phytoplankton
B = 4 0
P = 600 0
Detritus
Flow
Connector
Harvest
Other export
Respiration

Fig 47

IV-2 TROPHODYNAMICS OF THE SOUTHEASTERN MEDITERRANEAN WITH SPECIAL REFERENCE TO COMMERCIALLY IMPORTANT FISHES

Principal Investigator Sayed Z El-Sayed
Associate Investigator Gert van Dijken

Department of Oceanography
Texas A&M University
College Station, Texas 77843

85

Table of Contents

I	Abstract	40
II	Introduction	41
III	Objectives	41
IV	Material and Methods	42
	Physical Data	43
	Chemical Data	43
	Biological Data	43
	Remote Sensing	44
V	Results	45
	Cruise I December 5-9, 1993	45
	Cruise II February 27-March 2, 1994	45
	Cruise III August 14-18, 1994	47
	Cruise IV January, 1995	49
	Cruise V May 14-18, 1995	49
	Cruise VI September 17-20, 1995	50
	Remote Sensing	52
VI	Discussion	53
	Seasonal Variation	53
	Spatial Variation	54
	Nutrient Limitation	56
	Remote Sensing	56
	Trophic Efficiency and Potential Yield	57
	Impact of the Aswan High Dam on Israeli Coastal Ecosystem	58
VII	References	58
VIII	International Cooperation	60
IX	Acknowledgements	60
X	Legends to Figures	61

I Abstract

The overall objective of our research effort is to study the spatial and temporal distribution of the phytoplankton biomass and primary production off the Israeli coast and to correlate their distribution with the prevailing hydrographic conditions, optical properties of the water column, inorganic nutrients, as well as with the distribution of the pelagic fish and zooplankton populations Another objective is to assess the effects of the construction of the Aswan High dam on the marine ecosystem off the Israeli coast

Six cruises were undertaken between December 1993 and September 1995 Unfortunately two cruises were cut short due to the malfunctioning of the hydroacoustic equipment The remaining four cruises can be regarded as the first integrated biological oceanographic cruises aimed at studying the Israeli continental shelf

The results of the investigation indicated that the waters off the Israeli coast are strongly stratified in summer and early fall, with the upper mixed layer depths around 45-80 m Since little influx of new nutrients takes place, the nutrients in the surface waters were depleted by the phytoplankton In winter, the water column becomes completely mixed (due to thermal overturning) resulting in high nutrient concentration and enhanced phytoplankton biomass

As expected, the highest (average of 0 40 gC m^{2} day^{1}) productive regions were those nearest to the Israeli coast (bottom depth ~ 15 m), and the lowest (average of 0 15 gC m^{2} day^{1}) were in the deeper 'oceanic' regions (bottom depth > 50 m)

Using our estimate of primary production and applying different levels of trophic efficiency, we were able to calculate the potential yield (in terms of fish production) Comparing the calculated potential yield with the 'actual' fish catch showed that the ecosystem of the Israeli continental shelf can easily sustain a greater fishing pressure

As to the effect of the Aswan High Dam, comparing the results of our investigation with the 'historical' data, it would seem that the construction of the High Dam has had little effect on the Israeli continental shelf ecosystem

II Introduction

The catastrophic decline of the commercial fish catch, especially sardines, off the Mediterranean coast of Egypt following the construction of the Aswan High Dam in 1964 together with a lack of sufficient understanding of the impact of the curtailment of Nile flood waters on the SE Mediterranean ecosystem, prompted us to launch in 1981 a USAID-funded investigation, "Biological Productivity of the SE Mediterranean in the Post High Dam (Aswan) Period " As a result of this investigation we now have for the first time quantification of primary production as well as the spatial and temporal distribution of the phytoplankton populations The investigation also provided some understanding of the physical and chemical factors that govern the distribution and abundance of the primary producers The results of the investigation indicate that the food chain leading to fish in the coastal waters is more complex than the diatom → copepod → fish model which may be appropriate in other more productive areas Other findings show that the SE Mediterranean is characterized by extreme oligotrophy and that the majority of the phytoplankton standing crop and primary production is in the picoplankton (<2 0 μm) size fraction, which should increase the number of trophic links and further limit production of fish (Ryther, 1969)

The data generated during the above-mentioned investigation pointed to the need for further research and for a better understanding of the trophodynamics of the coastal shelf ecosystem Thus in efforts to improve our understanding of the trophodynamics of the marine ecosystems off the Egyptian and Israeli coasts, in 1993 another USAID-funded joint (Egypt, Israel, U S A) investigation was launched The objective of the new project were (a) to assess the standing stocks of commercially important fish species, (b) to evaluate the potential for increasing the fish harvest and (c) to contribute to a better understanding of the role of the primary and secondary producers in coastal shelf ecosystems

III Objectives

The overall objective of our research effort is to study the spatial and temporal distribution of the phytoplankton biomass and primary production off the Israeli coast and to correlate their distribution with the prevailing hydrographic conditions, as well as with the distribution of the pelagic fishes and zooplankton populations Since the study of the size distribution of the

phytoplankton is of paramount importance in the study of the trophodynamics of the marine food web, special emphasis in our study was on assessing the contributions of the different sizes of the phytoplankton to the standing crop and primary production To this end fractionated primary production experiments were carried out, as well as size-fractionated phytoplankton pigment analyses

The specific objectives are

- Study the spatial and temporal distribution of phytoplankton biomass and primary production of the continental shelf of Israel
- Study the contributions of the net-, nano-, and picophytoplankton to the standing crop and primary production, and the roles these photoautotrophic organisms play in the oligotrophic waters of the southeastern Mediterranean Sea
- Correlate the horizontal and vertical distribution of the phytoplankton standing crop and primary production with the hydrographic conditions, optical properties of the water column, and inorganic nutrients
- Study the correlation of algal biomass and productivity in relation to the distribution of pelagic fishes and zooplankton populations

IV Material and Methods

Six cruises on board the R/V *Shikmona* were undertaken off the coast of Israel during December, 1993, February/March, 1994, August, 1994, January, 1995, May, 1995 and September, 1995 Unfortunately the December, 1993 and January, 1995 cruises were cut short due to failure of the acoustical equipment During the cruises data were collected along a preset grid of 29 stations covering the continental shelf of Israel (Figure 1) The stations on the transects were characterized by the bottom depth, they were either located at the edge of the continental shelf (bottom depth 200 m), or on the middle of the shelf (bottom depth 50 m) or nearshore (bottom depth around 15 m) At these stations, hydrographical data (temperature and salinity depth profiles) were collected together with optical (Secchi disc depth), biological (algal pigments, fluorescence profiles, zooplankton abundance) and chemical (nutrient concentrations) data A BioSonics dual beam echosounder was used for underway surveying of pelagic fish biomass For more details of the fish stock assessment study see Section II-1 in this Report

Physical Data - Samples were collected with a rosette system consisting of six 5 liter Niskin bottles on which a Seabird CTD was mounted Depth profiles were recorded of sea water temperature and conductivity These data were processed at the Israel Oceanographic and Limnological Research Institute in Haifa (IOLR) and the Kinneret Limnological Laboratory in Tiberias (KLL) Transparency of the water column was determined by a standard Secchi disk depth reading Irradiance during the day and during primary production incubations was recorded with a Biospherical Instruments QSI-140 lightmeter

Chemical Data - Water samples were taken for the measurement of the concentration of dissolved inorganic nutrients (nitrate, phosphate and silicate) Analysis was done at IOLR on an auto-analyzer using standard analytical methods (Strickland and Parsons, 1972)

Biological Data

Phytoplankton Standing Crop

Algal biomass in terms of chlorophyll *a* (chl *a*), was determined at several depths at every station of the sampling grid Filters were extracted in 90% acetone, and measured fluorometrically using a Turner Design fluorometer according to Holm-Hansen *et al* (1965) At the stations where primary production was measured, water samples were size-fractionated by sequential filtration over 20 µm Nitex, 2 0 µm Poretics polycarbonate and Whatman GF/F filters, respectively The working definitions of these three size fractions are netplankton are those cells retained on the 20 µm filter nanoplankton those cells that pass through the 20 µm filter but are retained by 2 µm filter and picoplankton are those cells passing through the 20 and 2 µm filter, but are retained on the GF/F filter The size-fractionated chlorophyll *a* analysis was carried out at Texas A&M University Texas, the remainder was processed by KLL

At some stations, profiles of chlorophyll fluorescence were obtained with a SeaTech Fluorometer These profiles were used to study the *in situ* distribution of phytoplankton with depth, and to determine the depths of the chlorophyll maximum layers

Primary Production

Simulated-*in situ* primary production experiments were carried out using the ^{14}C-radiocarbon tracer technique according to Steemann Nielsen (1952) Water samples were collected at a number of depths in the euphotic zone and incubated in UV-transparent Whirlpack® bags (200 mL) wrapped with a number of neutral density filters to mimic their depth of sampling, they were then placed, after inoculation with 40µ Ci ^{14}C, in an on-deck incubator Sampling depths

corresponded to 100% (surface), 59%, 37%, 13%, 4%, 1% and 0 2% of incident light The actual sampling depth was calculated using the attenuation coefficient obtained by Secchi disk depths After incubation the samples were size-fractionated in a similar manner as for the chlorophyll analyses

Because of the short duration of the cruises (around 5 days), and because only one primary production experiment can be carried out on a given day, two different sampling approaches were employed in order to increase the spatial sampling coverage The first approach is the 'conventional' way, i e , samples were taken from 6-7 different depths at one specific station, and incubated using the simulated-*in situ* method mentioned above The second approach can be regarded as 'primary productivity transects', where vertical resolution was sacrificed for horizontal resolution Thus instead of sampling at one specific station, three different stations were occupied within a relatively short time interval Those stations were chosen to represent the shallow (bottom depth ~ 15 m), the middle (50 m), and outer limits (200 m) of the continental shelf The drawback to this method is that due to space constraints in the on-deck incubator, samples could only be taken from two (instead of 6-7) different depths, i e , at the surface and at the depth corresponding to 13% of the incoming solar irradiance

Fish and Zooplankton Stocks

Pelagic fish densities were estimated using a BioSonics ES1000 Dual-Beam Echosounder Acoustic surveys of pelagic fish were carried out along 19 different transects, connecting the stations of the sampling grid (Figure 1) The transects were surveyed either once or twice during a cruise, time permitting (For details, see Section II-1) Simultaneous with these multidisciplinary cruises, trawling surveys of the demersal fish stocks were carried out on fishing vessels by experts from the Fisheries Department of the Israeli Ministry of Agriculture Zooplankton samples were collected with vertical net tows (diameter 50 cm, mesh size 75 μm) and fixed in formaldehyde for later analysis

Remote Sensing

The large-scale distribution of phytoplankton pigments can be assessed through remote sensing of the color of the ocean from space Unfortunately no color sensors were mounted on satellites during the period of our fieldwork. The only data available were collected by the Coastal Zone Color Scanner (CZCS) which was launched in November 1978 and ceased operating in 1986 All available images of ocean color covering a part of the SE Mediterranean, bounded by 30 0° and 34 5°N and 28 0° and 36 0°E were processed starting with the original data in raw format in order

to retain the highest spatial resolution possible The raw data were kindly provided by the DAAC (Distributed Active Archive Center) at NASA/GSFC The area of interest is larger than that covered by the cruises as it included the Egyptian continental shelf, as well as the open ocean waters Statistical analyses were carried out on three specific areas of interest open ocean, the Nile plume area, Israeli coastal zone Standard algorithms were used for atmospheric corrections, calculation of biomass (surface pigment concentration) and estimation of primary production (Gordon *et al* 1983, Eppley *et al* 1985)

V Results

Cruise I December 5-9, 1993

This cruise was cut short due to problems with the acoustic equipment Therefore, we were not able to do primary productivity or any other experiments at sea on this cruise However, a large water sample was collected twice off Haifa in order to carry out preliminary test-experiments at the Kinneret Limnological Lab Primary productivity experiments were carried out in a photosynthetron in order to determine the correct amount of the radioactive tracer, ^{14}C, to be inoculated in future primary production experiments

Cruise II February 27 - March 2, 1994

Physical Data

The water column in the whole continental shelf area of Israel was well mixed Even at the stations on the outer edge of the shelf (bottom depth ~200 m) there was little change in temperature with depth The water temperature was around 17 0-17 5 °C Due to the relative cold air-temperature only the temperature of the upper 5 meters was significantly different from the remainder of the water column (on average about 0 5 °C lower) Figures 2, 3 and 4 show the North-South vertical depth profiles of temperature salinity and density of the deep, middle and nearshore stations, respectively

Nutrient Chemistry (Figures 5, 6 and 7)

Nitrate concentrations were relatively high at the edge of the continental shelf Despite the well-mixed water column, a zone of relatively high nitrate concentration of about 20 m thick was

found at a depth ranging from 60-110 m, with concentrations higher than 0 50 μM Above and below this zone nitrate concentrations were generally below 0 25 μM This zone of high nitrate seemed to be unrelated to phytoplankton biomass or hydrographic conditions In the middle of the shelf nitrate concentrations were lower (0 10-0 20 μM) than in the deeper waters, however, higher concentrations were found near the bottom (> 0 50 μM) Nearshore nitrate concentrations were generally between 0 2-0 8 μM

Phosphate concentrations at the edge and middle of the shelf waters were very low, mostly below 0 02 μM and often below 0 01 μM or even below the detection limit In the middle of the shelf phosphate concentrations were higher in the northern half of the shelf (> 0 01 μM) This was more pronounced at the shallow stations Here a clear gradient was found, from below 0 03 μM in the south to 0 2-0 4 μM in the northern part of the shelf

Silicate was high throughout the water column, ranging from 1-2 μM, with higher values nearshore than offshore

Phytoplankton biomass

Algal biomass (Figure 8) was highest at the stations close to the shore ([chl *a*] = 0 2-0 6 μg L^{-1}) At the deep stations chl *a* concentrations were much lower (0 14 to 0 22 μg chl *a* L^{-1}) Biomass was slightly higher in the middle of the shelf Since the waters were well mixed, the distribution of algal biomass with depth was rather uniform, no deep chlorophyll maxima were found

Primary Productivity

During this cruise primary production experiments were carried out at Station 11 (200 m), Station 14 (200 m) and Station 23a (600 m) Production rates ranged from 0 016-0 031 gC m^{-2} $hour^{-1}$ (average 0 023 gC m^{-2} $hour^{-1}$, Figure 9A-C) Daily primary production ranged from 0 15-0 25 gC m^{-2} (average 0 20 gC m^{-2}) P_{max} (maximum photosynthesis rate) ranged from 0 23-0 74 mgC m^{-3} $hour^{-1}$, at depths ranging from 10-30 m There was some photoinhibition at the surface (at some stations more pronounced than others) The percentage contribution of the pico-, nano-, and netplankton at Stations 11, 14 and 23a are given in Figure 10 In general, the phytoplankton in the smallest size group (picoplankton, < 2 0 μm) was responsible for 56% of the total production, nanoplankton for 29%, and cells larger than 20 μm, the netplankton, for 15%

9

Production rates were also measured on a transect perpendicular to the coast, from Haifa Bay (Figure 11) It was found that in the middle of the shelf, rates were about twice as high at the edge of the shelf Nearshore rates at the surface were about 20 times higher, at 13% of the incoming irradiance almost four times, as compared to similar optical-depths at the off-shore stations

Cruise III August 14-18, 1994

Physical Data

The water column at the edge of the continental shelf was strongly stratisfied, with mixed layer depths ranging from 60-80 m in the north to 40-60 m in the southern part of the shelf (Figure 12) Surface temperature ranged from 27 0 to 28 5°C, below the mixed layer temperatures were below 18°C At the middle of the shelf water temperatures ranged from 21°C near the bottom to 29°C at the surface (Figure 13) Nearshore temperatures ranged from over 28 5°C to almost 30°C at the surface (Figure 14)

At most stations an intrusion of a water mass with a lower salinity (< 38 8 PSU) was detected This zone was found just below the pycnocline at about 70-80 m This relatively fresh water is westward-flowing Atlantic water

Nutrient Chemistry (Figures 15, 16, 17)

For all three major nutrients there was a significant increase in concentrations at 175 m depth, however there was no marked change in concentrations above and below the mixed layer depth

Nitrate concentrations in the upper 80 m at the deep stations were mostly below 0 4 μM Concentrations in the middle of the shelf were higher, generally above 0 4 μM Nearshore concentrations were quite variable, but surprisingly low for these shallow waters Here, average concentrations were even below those found more offshore

Unlike the distribution of nitrate, the distribution of phosphate at the shelfbreak was quite patchy While the concentration was mostly below 0 03 μM, at some stations the concentration at certain depths could be higher than 0 1 μM In the middle of the shelf concentrations were quite variable but mostly below 0 08 μM, at some places even below the detection limit

Concentrations at the shallow stations were relatively high, especially in the northern part of the shelf

Silicate concentrations ranged from 0 8-1 8 μM at the deep stations Deeper in the water column concentrations increased to over 2 0 μM to maximal 4 8 μM Concentrations were higher at the middle of the shelf (average ~ 2 0 μM), and nearshore (average ~ 3 0 μM)

Phytoplankton Biomass

Surface chlorophyll *a* concentrations at the deep stations were mostly below 0 10, and often below 0 06 μg chl *a* L^{-1} (Figure 18) A deep chlorophyll maximum was present at all stations In the northern part of the Israeli continental shelf this layer was shallower than in the southern half (40-80 vs 100-140 m) In the middle of the shelf chl *a* concentrations were generally lower in the southern part (0 05-0 10 vs 0 10-0 25 μg chl *a* L^{-1}) At some of the northern stations the concentration near the bottom was very high compared to the rest of the water column (0 5-0 8 μg chl *a*/L) At the nearshore stations it was also found that chl *a* was generally lower in the southern part

Primary Productivity

During this cruise four primary production experiments were carried out (Figure 19A-D) at Station 8 (depth 200 m), Station 23 (depth 200 m), Station 26 (depth 200 m) and Station 14a (depth 600 m) Production rates at the off-shore stations ranged from 0 011-0 023 gC m^{-2} $hour^{-1}$ (average 0 016 gC m^{-2} $hour^{-1}$) Daily production ranged from 0 12-0 24 gC m^{-2} $hour^{-1}$ Picoplankton was responsible, on average, for 44% of the total production, nanoplankton 39% and the netplankton 17% (Figure 20) Maximum photosynthesis rates (P_{max}) ranged from 0 12-0 46 mgC m^{-3} $hour^{-1}$ (average 0 27) at depths ranging from the surface to 43 m At 3 of the 4 stations photoinhibition was detected at the surface

Since no primary production transects were carried out on this cruise, no direct measurements were taken in the more nearshore part of the shelf

Cruise IV January, 1995

This cruise was unfortunately canceled shortly after the R/V *Shikmona* left the harbor of Haifa due to failure of the echosounder Therefore, no primary productivity or other experiments could be done on board However water samples were collected on January 23 to carry out nutrient-enrichment experiments at the Kinneret Limnological Laboratory in order to study the effects of phosphate, iron and oxine (a chelating agent, which makes trace metals unavailable to the phytoplankton) on carbon incorporation

The results of our experiments indicated that the addition of phosphate and iron increased the carbon incorporation rate by 55% and 22%, respectively (Figure 21A) Further, the addition of both iron and phosphate doubled the carbon incorporation rate On the other hand, the addition of oxine lowered the carbon incorporation by 77% This suggests that the phytoplankton production in the waters of the SE Mediterranean is both phosphate and iron limited However, it seems that phosphate is the most important limiting factor of the two nutrients (see below)

A second similar nutrient-enrichment experiment was carried out with water collected on January 25 off Haifa This time the samples were size fractionated after incubation in order to determine if the difference in carbon incorporation rate was dependent on a specific size-class of phytoplankton During this experiment the addition of phosphate again significantly enhanced the carbon incorporation rate while the addition of iron had no significant stimulating effect No significant differences in response were noted between the carbon incorporation rates of the different size-classes (Figure 21B,C)

Cruise V May 14-18, 1995

Physical Data

With the seasonal increase in air-temperature, the water column started to show some thermal stratification Mixed layer depths were still shallow (around 15-22 m) or completely mixed (at the shallow stations) At some stations a 'step-like' temperature profile was evident, indicating deepening of the upper mixed layer Surface temperatures were around 21°C

Nutrient Chemistry (Figures 22, 23 and 24)

The nitrate concentrations in the upper 100 m at the deep stations were mostly between 0 05 μM and 0 10 μM Below 150 m nitrate concentrations were higher than 0 7 μM, with maximum values of 2 0 μM near 200 m Nitrate concentrations were lower at the stations sampled in the middle of the shelf where concentrations in the upper 40 m were mostly below 0 08 and often < 0 06 μM Higher nitrate concentrations were found at the most southern stations sampled (> 0 2 μM) The vertical variation was not conspicuous At the shallow stations surface concentrations were mostly between 0 1 and 0 2 μM, while near the bottom concentrations as high as 0 55 μM were measured

Phosphate concentrations were very low In the upper 100 m concentrations were mostly < 0 02 μM, and often below detection limit In the middle of the shelf concentrations were somewhat higher, however, in the southernmost stations phosphate was mostly below the detection limit This coincided with relatively high nitrate concentrations This abundance of nitrate while phosphate has been depleted, indicates strong phosphate-limitation Nearshore concentrations were mostly < 0 05 μM

Silicate concentrations in the top 100 meters ranged from 1 0-1 8 μM while below about 125 m much higher concentrations were found (2 0-4 0 μM) Silicate concentrations in the middle of the shelf ranged mostly from 1 0-1 8 μM with slightly higher concentrations nearshore

Phytoplankton Biomass

At the stations at the edge of the shelf a deep chlorophyll maximum was found between 60 and 140 meters (most often around 110 m, see Figure 25) Surface values were mostly below 0 10 μg chl *a* L^{-1}, and often below 0 6 μg chl *a* L^{-1} In the middle of the shelf, chlorophyll values in the upper 20-30 m were mostly below 0 2 μg chl *a* L^{-1}, and in the southern part mostly below 0 1 μg chl *a* L^{-1} Nearshore the chlorophyll concentration was quite variable, with higher values in the north (average about 0 5 μg chl *a* L^{-1}) and lower in the south (around 0 1 μg chl *a* L^{-1})

Primary Productivity

During this cruise four primary productivity experiments were carried out at Station 9a (depth 200 m) and Station 11-2 (depth 200 m), as well as two transects The daily production at the deep stations averaged 0 017 gC m^{-2} day^{-1} (0 19 mgC m^{-2} $hour^{-1}$, see Figure 26) Picoplankton was responsible for 45% of the total production, nanoplankton for 38% and the netplankton accounted

for 17% (Figure 27) P_{max} averaged 0 59 mgC m^{-3} $hour^{-1}$ at depths ranging from 6-10m Photoinhibition was found at the surface

Production in the middle of the shelf was only slightly higher as compared to off-shore (Figure 11) Nearshore production was more than double Production rates by specific size class of phytoplankton were very similar for the middle of the shelf and off-shore Nearshore, however, the contribution of netplankton was lower, nanoplankton higher and picoplankton slightly lower, although picoplankton was still the dominant size-class

Cruise VI September 17-20, 1995

Physical Data

The off-shore waters were very strongly stratified Upper mixed layer depths ranged between 45-65 m averaging around 50 m (Figure 28) Temperature of the surface waters were higher than 27°C and often even above 28°C Below the thermocline waters temperatures were 16-17°C As in August, a zone of relatively low salinity (< 38 9 PSU) was seen below the pycnocline, at around 80-100 m In the middle of the shelf temperatures were mostly above 28°C in the upper 30 m (Figure 29) At some places temperatures at the bottom were below 24°C Nearshore waters were fairly well mixed (Figure 30) Water temperatures ranged from 28 2-30°C

Nutrient Chemistry (Figures 31, 32, 33)

Nitrate concentrations at the off-shore stations were very low in the upper mixed layer, at the surface the concentration was often below the detection limit of 0 08 μM Below the pycnocline NO_3 was higher (> 0 8 μM) Values were generally higher in the northern part of the shelf In the middle of the shelf concentrations were also higher in the north (> 0 2 μM) than in the south (< 0 15 μM and occasionally below detection limit) No clear vertical distribution pattern was found Nearshore the same pattern was detected with higher concentrations north (> 0 2 μM) and lower in the south (< 0 2 μM, sometimes even below the detection limit)

Phosphate was mostly below the detection limit of 0 02 μM or just above it for a large part of the upper mixed layer Even below the pycnocline concentrations were low (mostly < 0 05 μM) In the middle of the shelf and nearshore phosphate concentrations were low (mostly below 0 06 μM, and sometimes below detection limit)

At the deep stations silicate concentrations were mostly below 1 4 μM, but ranged from just below 1 0 μM to > 3 0 μM There was no clear pattern in either the vertical or horizontal distribution of silicate In the middle of the shelf silicate concentrations were higher (mostly > 1 8 μM, with somewhat lower values in the southern part) Concentrations nearshore were high as well (ranging from 1 0 to over 2 2 μM)

Phytoplankton Biomass

At the off-shore stations a deep chlorophyll maximum was usually found between 60 and 90 meters (see Figure 34) Surface concentrations were mostly below 0 12 μg chl *a* L^{-1}, and below 0 04 μg chl *a* L^{-1} at the more southern stations In the middle of the shelf chl *a* concentrations were higher (mostly between 0 25 and 0 50 μg chl *a* L^{-1}) with lower values (< 0 25 μg chl *a* L^{-1}) in the south Nearshore concentrations were mostly between 0 3 and 1 0 μg chl *a* L^{-1}

Primary Productivity

During this cruise three primary production experiments were carried out at Station 8 (depth 200 m) and Station 20a (depth 200 m) and one transect At the deep stations primary production averaged 0 010 gC m^{-2} day^{-1} (0 10 mgC m^{-2} $hour^{-1}$, see Figure 35) Picoplankton accounted for 43% of the production, nanoplankton 52% and netplankton 5% (Figure 36) P_{max} averaged 0 29 mgC m^{-3} $hour^{-1}$, at depths ranging from 5-11m

Production at the surface in the middle of the shelf was about 50% higher, but similar at the 13% optical depth as compared to the off-shore waters (see Figure 11) Nearshore production was much higher, though (surface 3 2 mgC m^{-3} $hour^{-1}$, vs 0 20 mgC m^{-3} $hour^{-1}$ offshore) Production rates for the different size classes were very similar in the middle of the shelf and off-shore Nearshore, however, nanoplankton's share of total production was almost 70%, while picoplankton's contributed only 27% to the total production. Netplankton concentration was somewhat lower when compared to the more off-shore locations

Remote Sensing

The total number of ocean-color images processed was 114, rendering a time series starting on November 22, 1978 and ending on December 31, 1985 Unfortunately, the dates of the images

97

taken were not equally distributed over the 7 year period, especially in later years when the data were not as frequently collected and were often not of good quality due to sensor degradation

It is noteworthy that all the images looked more or less similar, the general characteristics they share are (see Figure 37)

- a very low pigment concentration in the open waters of the Levantine Basin
- high pigment concentrations in the 'Nile Stream' along the Egyptian and Israeli coasts
- the boundary of the Nile River plume and open ocean water was well delineated
- the outflow of the River Nile was always eastward
- along the boundary between the Nile River plume and the open water turbulences occurred

In the open ocean waters a clear seasonal trend in pigment concentration was found, maxima (averaging 0 25 μg pigment L^{-1}) were found in winter (January), and minima (averaging 0 05 μg pigment L^{-1}) in summer months (Figure 38A) No clear seasonal variation was noted in the coastal waters of Egypt and Israel (Figure 38B, C)

VI Discussion

Seasonal Variation

The hydrographic data collected during the 4 cruises in February, 1994, August, 1994, May, 1995 and September 1995 confirm earlier investigations in this area The waters off Israel are strongly stratified in the summer and early fall, with upper mixed layer depths around 45 to 80 m During this period sea surface temperatures are high, 27-28 5°C In winter, cooling at the surface results in sinking of the now colder and thus denser surface waters The water column becomes completely mixed, resulting in lower sea surface temperatures (17-17 5°C in February) In spring the waters become stratified again, with a slowly deepening of the thermocline depth This was noted during the May, 1995 cruise where mixed layer depths of 15-22 m were still shallow as compared to summer values A summary of biological, chemical and physical data collected on the cruises is shown in Figure 39 and Tables 1-4

These physical characteristics have their profound effects on the biology of the region The mixing of the water column is responsible for increased nutrients availability to the phytoplankton Combined with the increased light availability in spring this results in a relatively

high phytoplankton biomass Not surprisingly though, the highest chlorophyll concentrations were measured in February, followed by May The strong thermocline which develops in the summer months prevents upwelling of nutrients from the nutrient-rich waters below the thermocline to the by now phytoplankton nutrient-depleted surface waters Very low nitrate concentrations were found in the surface waters in May, August and September, often their concentrations were even below the detection limit of the method used Phytoplankton biomass, especially during the summer months, were, therefore, quite low (surface values were on average below 0 1 μg chl *a* L^{-1})

Phytoplankton biomass is but one of the factors governing primary production The amount of available light (both in terms of peak irradiance and length of photic period) is important as well Hourly production rates were highest in February, mainly due to the relatively high phytoplankton biomass, however, integrated over the day, the difference in primary productivity over the different seasons becomes much smaller, since day length is much greater in the summer months

Spatial Variation

East-West Trend

Coastal waters are generally noted for their high productivity, since they receive nutrient replenishment from a variety of sources, e g , coastal runoff, bottom regeneration and upwelling The Israeli continental shelf seems to be an exception, though Not only is the shelf relatively narrow (at places not more than 8 km wide), it is also devoid of any upwelling, furthermore the arid climate of the region results in little coastal discharge It is, therefore, not unusual to find open-ocean oligotrophic conditions just a few kilometers off-shore

The water column of the nearshore stations (bottom depths between 5-25 m) was usually well mixed the year-round Off-shore CTD-measurements at the middle stations (bottom depth ~ 50 m) show some weak horizontal stratification, especially in the summer months At the off-shore stations (bottom depth 200 m) however, a well defined mixed layer was found during cruises between May and September (see above - *Seasonal Variation*) Even in summer, surface temperatures are quite uniform across the continental shelf

Nutrient concentrations at the middle and offshore stations are often very similar, though nitrate, phosphate and silicate concentrations are normally somewhat higher in the middle of the shelf Concentrations are highest at the shallow nearshore stations, although differences are small in winter and spring, however in summer phosphate and nitrate can easily be a magnitude higher than further offshore

The same holds true for phytoplankton biomass, surface chl *a* concentrations are about equally low in the middle and offshore stations, while nearshore algal biomass was between 2-5 times higher

Despite their limited vertical resolution, the primary productivity transects provided a good insight into the spatial variation of phytoplankton productivity Production rates were only slightly lower at the edge of the shelf in waters of 200 m when compared to those stations in the middle of the shelf (bottom depth 50 m) At the nearshore stations, however, productions rates were 2 to > 10 times higher when compared to the other stations This correlates remarkably well with the chlorophyll *a* concentrations and nutrient availability The size-distribution of the phytoplankton was, in general, similar for the off-shore stations and middle of the shelf Nearshore, the contribution of nanoplankton to total production was often considerably higher, however, the contributions of the pico- and netplankton were lower

North-South Trend

There were not many clear north-south trends of the measured parameters The distribution of nutrients and phytoplankton biomass was often quite patchy However, it is clearly seen that in the summer months the mixed layer depth was about 5-20 meters shallower in the southern part of the shelf as compared to the northern part Also in summer, nutrient concentrations and biomass were mostly lower in the south, they peaked year-round off Haifa Bay

Other field-data are relatively scarce for this area In Figure 40A and B, the available literature data and the data collected during this project are plotted by Julian day, regardless of the year sampled The data by Berman *et al* (1984, 1986) and Azov (1986), who carried out a biweekly sampling program in 1983, are measurements made off the Israeli coast Dowidar's (1984) data were from off the Egyptian coast, and Weber & El-Sayed's (1985) data were taken off the Egyptian and Israeli coasts, while Yacobi *et al* 's (1995) data covered the whole southern Levantine Basin Since the Israeli continental shelf is very narrow, it is sometimes hard to define

'coastal waters' Our data indicate that the nearshore stations (i e , with bottom depths shallower than 25 m) are much more eutrophic than the stations with bottom depths of around 50 m The middle stations, which still could be considered 'coastal waters', were very similar to the off-shore stations (bottom depth 200 m) The strong seaward gradient in [chl *a*] could account for the relatively high variability in pigment concentrations for coastal waters as seen in Figure 40B Dowidar's (1984) data in the Nile River plume (off the Egyptian coast), apparently were more productive than the data taken in Israeli coastal waters Overall, the data from the present study fit remarkably well with the 'historic' data

Nutrient Limitation

In most marine environments nitrate is the limiting nutrient for phytoplankton growth, whereas in the freshwater milieu phosphorus seems to be more limiting The Eastern Mediterranean seems to be an exception to this general rule Phosphate concentrations are very low in this region The N P ratio is often much higher than the Redfield ratio 16 1 This is especially the case for the waters below the upper mixed layers which show high P deficiencies relative to N with ratios of 40-45 1 all the year round Further, it was often observed that when phosphate concentrations were below the detection limit, nitrate concentrations were still relatively high, indicating that the phytoplankton was severely limited by phosphate Our nutrient enrichment experiments also confirmed the apparent P-limitation Since the upwelled water from below the mixed layer (which has a relatively high N P ratio) is the main source of 'new' nutrients, the phytoplankton seem to be under constant P-limitation In the central Levantine Basin it was also found that phosphate and nitrate concentrations were very low (Yacobi *et al* , 1995, Krom *et al* , 1991, 1992) The nutricline was found at around 400 m depth, which is far below the upper mixed layer depth and the euphotic zone Below these depths phosphate concentrations were constant at around 0 20 μM, and 5 μM for nitrate It is noteworthy that the high N P ratio of 25 1 was found in these deeper waters

Remote Sensing

Satellite remote sensing confirmed the annual variation in phytoplankton biomass at the off-shore stations, this despite the fact that the images were dated over 10 years before the initiation of the present study In fact, the ocean-color data depicted the annual variation of phytoplankton much better than the available field-data. Satellite-derived winter maxima were very similar to the data collected on our cruises Summer lows, however, were considerably higher than those estimated by the CZCS (0 08-0 10 vs 0 05 μg pigment L^{-1}) The satellite data did not correspond well with

the coastal data This is probably due to the presence of other colored material in the waters for which the used pigment algorithm did not properly correct for (Van Dijken, 1994, Van Dijken and Arrigo, 1995)

Trophic Efficiency and Potential Yield

The estimated annual primary production, derived from data collected during all the cruises was as follows 60 2 gC m^{-2} $year^{-1}$ for the outermost part of the continental shelf, for the middle part 65 5 gC m^{-2} $year^{-1}$, and nearshore production is estimated at 130 1 gC m^{-2} $year^{-1}$ These values are very close to those calculated from chlorophyll surface concentrations, using Eppley *et al* 's (1985) algorithm Results of these calculations can be found in Section II-1 of this report In summary when an average chlorophyll *a* concentration of 0 14 mg chl *a* m^{-3} was used, the annual primary production was 51 1 g C m^{-2}, which compares very well with the above calculated values for the middle and outermost part of the shelf

The Israeli continental shelf area, bounded by the Lebanese border in the north and the city of Ashqelon in the south, excluding the waters off the Gaza Strip, covers around 2360 km^2 This translates in a total primary production of $190x10^3$ tons C $year^{-1}$ In a simple case scenario it can be assumed that this carbon ends up in fishes in two steps, i e , three trophic levels can be identified (phytoplankton → zooplankton → fishes) How much carbon is transferred from one trophic level into the next ultimately depends on the 'ecological efficiency factor' used This factor is unknown for the SE Mediterranean but an average efficiency factor of 10% is generally used (Ryther 1996) Using the simple three trophic level scenario the fact is neglected that some fishes are herbivorous (i e , eat phytoplankton), thus skipping the zooplankton trophic level and increasing overall efficiency, and that other fishes are piscivorous, adding a fourth trophic level, thereby decreasing the overall ecosystem efficiency In Table 5 it is summarized how much the potential yield is at the various trophic levels Using a trophic efficiency factor of 10% the fisheries production of the continental shelf of Israel is estimated to be around $19x10^3$ tons w/w $year^{-1}$ This is much higher than the current annual fisheries catch which is estimated at 3 $8x10^3$ tons w/w $year^{-1}$ (see Section II-1 in this report) If we limit our calculations to the nearshore waters, the overall fish production is estimated at 7 $7x10^3$ tons w/w $year^{-1}$ Since the ecological efficiency factor is not exactly known, different scenarios are given in Table 5 Not surprisingly higher efficiency factor yields higher fish-production It seems, that therefore the ecosystem of the Israeli continental shelf can easily sustain a greater fishing pressure In light of the above, it does not seem likely that the area is overfished However, since we are only

considering the overall picture, this does not preclude that certain species of commercial importance are being overfished

Impact of the Aswan High Dam on the Israeli Coastal Ecosystem

The impact of the River Nile on the ecosystem of the SE Mediterranean has drastically changed after the completion of the Aswan High Dam in 1965 (Halim *et al*, 1967, Halim, 1973, Sharaf El Din, 1977) The annual discharge through its main branches, Rosetta and Damietta, dropped from approximately $44x10^9$ m^3 to only $4\ 4x10^9$ m^3 in the years 1965-1979 After the filling of the newly formed Lake Nasser the Nile's discharge has increased to approximately $10x10^9$ m^3 (Dowidar, 1984) We were unfortunately unable to obtain current discharge estimates Halim *et al* (1995) has estimated the present day level at 2 5 to $4x10^9$ m^3 The Egyptian Ministry of Irrigation reported in 1996 a Nile River discharge into the Mediterranean of $2x10^9$ m^3 $year^{-1}$ However, more recently it has been suggested that the current discharge is non-existent due to increased irrigation en-route to the River Delta and to increased irrigation and evaporation in the Delta itself, with its dense network of canals and drains (R G Johnson, U of Minnesota, pers comm , Stanley, 1996) From the satellite images taken between 1978 and 1985 the eastward flowing Nile River plume could always easily be detected Recently a new ocean-color sensor, SeaWiFS, has been launched into space It would be interesting to examine these new images, which, in all probability, would show the absence of a clear river plume with its turbulences at the interface between coastal and open ocean waters

In light of the above, however, it would seem that, when comparing 'historical' data with the data collected during this project that little has changed over the last 10 years Despite the limited 'historical' data available, nutrients, phytoplankton biomass, primary productivity and fish catch have not significantly changed Therefore, it would seem that the ecosystem of the Israeli continental shelf to have been little affected by the changes in Nile River discharge, as a result of the construction of the Aswan High Dam

VII References

AZOV, Y 1986 Seasonal patterns of phytoplankton productivity and abundance in nearshore oligotrophic waters of the Levant Basin (Mediterranean) J Plankton Res 8(1) 41-53

BERMAN, T , Y AZOV, A SCHNELLER, P WALLINE AND D W TOWNSEND 1986 Extent, transparency, and phytoplankton distribution of the neritic waters overlying the Israeli coastal shelf Oceanol Acta 9(4) 439-447

BERMAN T , D W TOWNSEND, S Z EL-SAYED, C C TREES AND Y AZOV 1984 Optical transparency, chlorophyll and primary productivity in the Eastern Mediterranean near the Israeli coast Oceanol Acta 7(3) 367-372

DOWIDAR, N M 1984 Phytoplankton biomass and primary productivity of the south-eastern Mediterranean Deep-Sea Res 31 983-1000

EPPLEY R W , E STEWART, M R ABBOTT AND U HEYMAN 1985 Estimating ocean primary production from satellite chlorophyll Introduction to regional differences and statistics for the Southern California Bight J Plankton Res 7(1) 57-70

GORDON H R , D K CLARK J W BROWN, O B BROWN, R.H EVANS AND W W BROENKOW 1983 Phytoplankton pigment concentrations in the Middle Atlantic Bight Comparison of ship determinations and CZCS estimates Appl Opt 22 20-36

HALIM Y S K GUERGUES AND H H SALEH 1967 Hydrographic conditions and plankton in the south east Mediterranean during the last normal Nile flood (1964) Int Revue ges Hydrobiol 52(3) 401-425

HALIM Y 1972 The Nile and the East Levantine Sea, past and present In recent Researches in Estuarine Biology R Natarajan [ed] Hindustan Publishing Corporation (I), Delhi, India pp 76-84

HOLM-HANSEN, O , C J LORENZEN, R W HOLMES AND J D H STRICKLAND 1965 Fluorometric determination of chlorophyll J Cons Perm Int Explor Mer 30 3-15

KROM M D , S BRENNER, N KRESS, A NEORI AND L I GORDON 1992 Nutrient dynamics and new production in a warm-core eddy from the Eastern Mediterranean Sea Deep-Sea Res 39(3/4) 467-480

KROM M D N KRESS, S BRENNER AND L I GORDON 1991 Phosphorus limitation of primary productivity in the eastern Mediterranean Sea Limnol Oceanogr 36(3) 424-432

RYTHER J H 1969 Photosynthesis and fish production in the sea Science 166 72-76

SHARAF EL DIN, S H 1977 Effect of Aswan High Dam on the Nile flood and on the estuarine and coastal circulation pattern along the Mediterranean Egyptian coast Limnol Oceanogr 22 197-207

STANLEY, D J 1996 Nile Delta extreme case of sediment entrapment on a delta plain and consequent coastal land loss Marine Geology 129 189-195

STEEMANN NIELSEN, E 1952 The use of radioactive carbon (^{14}C) for measuring organic production in the sea J Cons Perm Int Explor Mer 8 117-140

STRICKLAND, J D H AND PARSONS, T R. 1972 A practical handbook of seawater analysis Fish Res Bd Can Bull 167 1-172

VAN DIJKEN, G L AND K.R. ARRIGO, 1996 Ocean Color Remote Sensing of the Southeastern Mediterranean Sea. Eos, Transactions, AGU 76(3, suppl) 167

VAN DIJKEN, G L 1994 CZCS Imagery of the Southeastern Mediterranean NASA/University of Maryland. Summer Fellowship Program in Remote Sensing of the Oceans – Compilation of Student Reports

WEBER, L H AND S Z EL-SAYED 1985 Biological productivity of Southeast Mediterranean in Post High Dam (Aswan) period Phytoplankton studies during the April 1985 cruises on *Noor Yanabi* and *Shikmona* Technical Report, Texas A&M University, College Station p 1-23

YACOBI, Y Z , T ZOHARY, N KRESS, A HECHT, R.D ROBARTS, M WAISER, A.M WOOD AND W K W LI. 1995 Chlorophyll distribution throughout the Southeastern Mediterranean in relation to the physical structure of the water mass J Mar Sys 6 179-190

VIII International Cooperation

Mr Gert van Dijken, a doctoral student at Texas A&M University participated on all the *Shikmona II* cruises mentioned in this report He also assisted in the pre-cruise preparation and used the facilities and equipment at the Kinneret Limnological Lab to complete some of the productivity experiments and to analyze the phytoplankton collected during the various cruises

Dr Sayed Z El-Sayed participated on the August 1994 cruise and assisted in the collection of the data and in running the primary productivity experiments Dr El-Sayed convened and participated in all the Project Workshops held and gave Progress reports on the results obtained during the cruises

IX Acknowledgements

We wish to extend our thanks to our Israeli colleagues, and especially Paul Walline and Yosi Yacobi, for their assistance and cooperation while participating on the R/V *Shikmona* cruises, and while working at the Kinneret Limnological Lab We are most grateful to them for sharing the

physical chemical and fish stock assessment data with us and for permission to use them in our report

Grateful acknowledgements are expressed to the US Agency for International Development for the financial support of this project

X Legends to Figures

Figure 1 The sampling grid of the multidisciplinary cruises in the continental shelf of Israel, showing the sampling stations and hydroacoustic transects

Figure 2 February, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the deep stations, from north (left) to south (right)

Figure 3 February, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the middle stations, from north (left) to south (right)

Figure 4 February, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the shallow stations, from north (left) to south (right)

Figure 5 February, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the deep stations, from north (left) to south (right)

Figure 6 February, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the middle stations, from north (left) to south (right)

Figure 7 February, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the shallow stations, from north (left) to south (right)

Figure 8 February, 1994 cruise depth profiles of chlorophyll *a* going from north (left) to south (right)

Figure 9 February, 1994 cruise primary productivity profiles of Station 11 (a), Station 14 (b) and Station 23a (c)

Figure 10 February 1994 cruise contribution of different size classes to total production at each of the sampled stations

Figure 11 Summary of primary productivity transects conducted during the four cruises Results are shown for the two sampled optical depths, 100% of incoming irradiance, I(0), and 13% of I(0)

Figure 12 August, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the deep stations, from north (left) to south (right)

Figure 13 August, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the middle stations, from north (left) to south (right)

Figure 14 August, 1994 cruise depth profiles of temperature (°C), salinity (PSU) and density of the shallow stations, from north (left) to south (right)

Figure 15 August, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the deep stations, from north (left) to south (right)

Figure 16 August, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the middle stations, from north (left) to south (right)

Figure 17 August, 1994 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the shallow stations, from north (left) to south (right)

Figure 18 August, 1994 cruise depth profiles of chlorophyll *a* going from north (left) to south (right)

Figure 19 August, 1994 cruise primary productivity profiles of Station 8 (a), Station 23 (b), Station 26 (c) and Station 14a (d)

Figure 20 August, 1994 cruise contribution of different phytoplankton size classes to total production at each of the sampled stations

Figure 21 January, 1995 Response of phytoplankton carbon incorporation to different nutrient-treatments (A) Figure (B) shows the absolute response for each size-class of phytoplankton and Figure (C) the relative response

Figure 22 May, 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the deep stations, from north (left) to south (right)

Figure 23 May, 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the middle stations, from north (left) to south (right)

Figure 24 May, 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the shallow stations, from north (left) to south (right)

Figure 25 May, 1995 cruise depth profiles of chlorophyll *a* going from north (left) to south (right)

Figure 26 May, 1995 cruise primary productivity profiles of Station 9a (a) and Station 11-2 (b)

Figure 27 May, 1995 cruise contribution of different size classes to total production at each of the sampled stations

Figure 28 September, 1995 cruise depth profiles of temperature (°C), salinity (PSU) and density of the deep stations, from north (left) to south (right)

Figure 29 September, 1995 cruise depth profiles of temperature (°C), salinity (PSU) and density of the middle stations, from north (left) to south (right)

Figure 30 September, 1995 cruise depth profiles of temperature (°C), salinity (PSU) and density of the shallow stations, from north (left) to south (right)

Figure 31 September 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the deep stations, from north (left) to south (right)

Figure 32 September 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the middle stations, from north (left) to south (right)

Figure 33 September 1995 cruise depth profiles of silicate (Si, μM), phosphate (P, μM) and nitrate (N, μM) of the shallow stations, from north (left) to south (right)

Figure 34 September, 1995 cruise depth profiles of chlorophyll *a* going from north (left) to south (right)

Figure 35 September, 1995 cruise primary productivity profiles of Station 8 (a) and Station 20a (b)

Figure 36 September, 1995 cruise contribution of different size classes to total production at each of the sampled stations

Figure 37 CZCS ocean color satellite map taken on July 14, 1979 By combining this image with band 5 the land features become visible, of these the Nile River delta, the Dead Sea and Lake Kinneret can be easily identified Also note the very low open ocean pigment-concentration and the meandering of the Nile Stream The ocean color is related to pigment concentration (in mg m^{3}) as shown in the scale bar

Figure 38 Average pigment concentration of each processed satellite image for the open ocean waters of the Levantine Basin (A), the waters off the coast of Egypt (B) and the waters off the coast of Israel (C)

Figure 39 Summary of the chlorophyll *a*, nutrients, temperature and primary productivity data collected during four cruises Average values for the surface waters and total water column for the deep stations are shown

Figure 40 Variation in chlorophyll *a* concentration over several years in pelagic (A) and coastal waters (B) as compiled from the open literature and the data collected during this project

Table 1 Summary of the chlorophyll *a*, nutrients (NO_3, PO_4 and SiO_4) temperature, and primary productivity data (per hour and per day) collected during the February 1994 cruise Averages standard deviation and median are listed for the surface waters and total water column for the deep middle and shallow stations

Chl *a*	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 2416	0 2140	0 2521	0 2950	0 4548	0 4847
st dev	0 1208	0 0503	0 0711	0 0822	0 2474	0 2429
median	0 2123	0 2130	0 2574	0 2876	0 3968	0 4064

NO_3	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 4572	0 3967	0 1654	0 1890	0 5970	0 5215
st dev	0 6788	0 3268	0 1964	0 0936	0 3528	0 3212
median	0 1721	0 3164	0 1000	0 2025	0 5732	0 4586

PO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0223	0 0187	0 0164	0 0151	0 0395	0 0476
st dev	0 0239	0 0117	0 0147	0 0161	0 0254	0 0287
median	0 0149	0 0163	0 0175	0 0064	0 0368	0 0424

SiO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	1 3914	1 3900	1 4101	1 3438	1 5967	1 6439
st dev	0 2512	0 2606	0 2501	0 3484	0 2783	0 2098
median	1 3844	1 3870	1 3470	1 3642	1 5507	1 6151

Temp	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	16 8669	17 3127	16 8016	17 3188	16 4153	17 1334
st dev	0 7662	0 0679	0 6436	0 0455	0 9021	0 2850
median	16 9145	17 3075	16 8370	17 3134	16 9100	17 2086

PP-hour	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	0 2926	0 0231	0 4613	0 5637	4 2160	1 1480
st dev	0 2571	0 0078				
median	0 2148	0 0226				

PP-day	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	2 6208	0 2016	4 6861	5 7258	42 8271	11 6615
st dev	2 0294	0 0536				
median	2 1382	0 1977				

Table 2 Summary of the chlorophyll *a* nutrients (NO_3 PO_4 and SiO_4) temperature and primary productivity data (per hour and per day) collected during the August 1994 cruise Averages standard deviation and median are listed for the surface waters and total water column for the deep middle and shallow stations

Chl *a*	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0853	0 1059	0 1222	0 1483	0 7738	0 7729
st dev	0 0572	0 0266	0 1132	0 1031	0 8810	0 8818
median	0 0548	0 1064	0 0680	0 0916	0 4410	0 4410

NO_3	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 187*	0 6102	0 4840	0 4610	0 4346	0 4243
st dev	0 1891	0 2198	0 3130	0 2959	0 4512	0 4544
median	0 1145	0 5274	0 4423	0 4539	0 3042	0 3785

PO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0399	0 0391	0 0573	0 0925	0 4937	0 5465
st dev	0 0424	0 0154	0 0673	0 0810	1 0578	1 1084
median	0 0308	0 0399	0 0184	0 0598	0 0728	0 0747

SiO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	1 6729	1 6460	1 8233	1 8564	2 3110	2 3860
st dev	0 4346	0 3684	0 7948	0 4174	0 9083	0 9300
median	1 5568	1 5839	1 4956	1 5952	2 3777	2 4313

Temp	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	28 1316	20 5744	28 2646	26 2737	29 4103	29 2997
st dev	0 3870	1 6495	0 5165	2 4916	0 3039	0 3289
median	28 1085	20 2129	28 0355	26 8566	29 3825	29 3328

PP-hour	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 2249	0 0158				
st dev	0 1484	0 0050				
median	0 2015	0 0149				

PP-day	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	2 4289	0 1707				
st dev	1 6028	0 0539				
median	2 1758	0 1609				

*Omitted one outlier

Table 3 Summary of the chlorophyll *a* nutrients (NO_3 PO_4 and SiO_4) temperature and primary productivity data (per hour and per day) collected during the May 1995 cruise Averages standard deviation and median are listed for the surface waters and total water column for the deep, middle and shallow stations

Chl *a*	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 1396	0 1514	0 1547	0 1890	0 4763	0 4527
st dev	0 1114	0 0338	0 0831	0 0815	0 4007	0 3866
median	0 1131	0 1489	0 1405	0 2017	0 2409	0 2409

NO_3	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 1113	0 3163	0 0975	0 1041	0 1650	0 1881
st dev	0 0660	0 1418	0 0665	0 0999	0 1321	0 1518
median	0 1200	0 2855	0 0950	0 0670	0 1100	0 1100

PO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0250	0 0273	0 0500	0 0505	0 1000	0 0956
st dev	0 0193	0 0157	0 0568	0 0412	0 1479	0 1488
median	0 0150	0 0261	0 0250	0 0488	0 0500	0 0475

SiO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	1 1575	1 6537	1 2600	1 1694	2 0300	1 9850
st dev	0 4403	0 4111	0 9366	0 5447	0 7110	0 6782
median	1 1900	1 5620	1 3450	1 3750	2 0550	2 0150

Temp	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	20 8895		21 8750		21 4400	
st dev	0 3264		0 9392		0 5542	
median	20 9000		22 2000		21 4000	

PP-hour	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	0 5413	0 0166	0 4045	0 5550	1 1603	1 0507
st dev	0 1650	0 0004	0 1043	0 1457	0 5647	0 5553
median	0 5218	0 0166				

PP-day	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	6 2302	0 1911	4 6551	6 3873	13 3515	12 0977
st dev	1 9009	0 0042	1 1942	1 6690	6 4838	6 4068
median	5 9977	0 1911				

Table 4 Summary of the chlorophyll *a* nutrients (NO_3 PO_4 and SiO_4) temperature and primary productivity data (per hour and per day) collected during the September 1995 cruise Averages standard deviation and median are listed for the surface waters and total water column for the deep middle and shallow stations

Chl *a*	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0981	0 1205	0 3047	0 3015	0 8663	0 8867
st dev	0 1105	0 0258	0 2718	0 2378	0 8346	0 8198
median	0 0500	0 1175	0 1650	0 2263	0 4900	0 4817

NO_3	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0636	0 5104	0 2710	0 1849	1 8955	1 8595
st dev	0 0388	0 3519	0 2452	0 1009	4 4706	4 4834
median	0 0400	0 3641	0 2300	0 1668	0 3700	0 2600

PO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	0 0255	0 0289	0 0360	0 0345	1 1264	1 1374
st dev	0 0262	0 0174	0 0430	0 0179	3 5371	3 5334
median	0 0200	0 0255	0 0200	0 0389	0 0600	0 0800

SiO_4	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	1 7710	1 3525	1 9210	1 7136	1 8244	1 8226
st dev	0 9001	0 2390	0 5614	0 5983	0 8954	0 9197
median	1 4200	1 2245	1 8250	1 5354	1 8400	1 8100

Temp	*deep surface*	*deep column*	*middle surface*	*middle column*	*shallow surface*	*shallow column*
average	27 9200	19 9564	28 1195	27 6502	28 5235	28 4715
st dev	0 3683	0 3319	0 4396	0 5783	0 2811	0 3174
median	28 1124	20 1727	28 2454	27 4482	28 4921	28 4087

PP-hour	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	0 2022	0 0100	0 3076	0 2092	3 2301	3 3722
st dev	0 0522	0 0015				
median	0 1878	0 0100				

PP-day	*deep surface*	*deep column*	*middle surface*	*middle 0 1300*	*shallow surface*	*shallow 0 1300*
average	2 0893	0 1027	3 1679	2 1543	33 2696	34 7339
st dev	0 5455	0 0151				
median	1 9401	0 1027				

Table 5 Estimates of potential yield (per year) at various trophic levels in metric tons using different ecological efficiency factors for different sections of the Israeli continental shelf

Total Shelf

efficiency	5%	5%	10%	10%	15%	15%	20%	20%
trophic level	carbon	wet wt	carbon	wet wt	carbon	wet wt	carbon	wet wt
phytoplankton	189 679 52	1 896,795 25	189 679 52	1 896,795 25	189,679 52	1,896,795 25	189,679 52	1,896,795 25
zooplankton	9,483 98	94,839 76	18,967 95	189,679 52	28,451 93	284,519 29	37,935 90	379 359 05
primary carnivores	474 20	4,741 99	1,896 80	18,967 95	4,267 79	42,677 89	7,587 18	75,871 81

Middle & Shallow part only

efficiency	5%	5%	10%	10%	15%	15%	20%	20%
trophic level	carbon	wet wt	carbon	wet wt	carbon	wet wt	carbon	wet wt
phytoplankton	154 110 35	1,541,103 50	154,110 35	1,541,103 50	154,110 35	1,541,103 50	154,110 35	1,541,103 50
zooplankton	7,705 52	77,055 18	15,411 04	154,110 35	23,116 55	231,165 53	30,822 07	308 220 70
primary carnivores	385 28	3,852 76	1,541 10	15 411 04	3,467 48	34,674 83	6,164 41	61,644 14

Shallow part only

efficiency	5%	5%	10%	10%	15%	15%	20%	20%
trophic level	carbon	wet wt	carbon	wet wt	carbon	wet wt	carbon	wet wt
phytoplankton	76,760 77	767,607 70	76 760 77	767,607 70	76 760 77	767,607 70	76,760 77	767,607 70
zooplankton	3,838 04	38,380 38	7,676 08	76,760 77	11 514 12	115,141 15	15 352 15	153,521 54
primary carnivores	191 90	1 919 02	767 61	7,676 08	1 727 12	17,271 17	3 070 43	30,704 31

מספרי תחנות - 1,2,

מספרי תחנות - 1,3

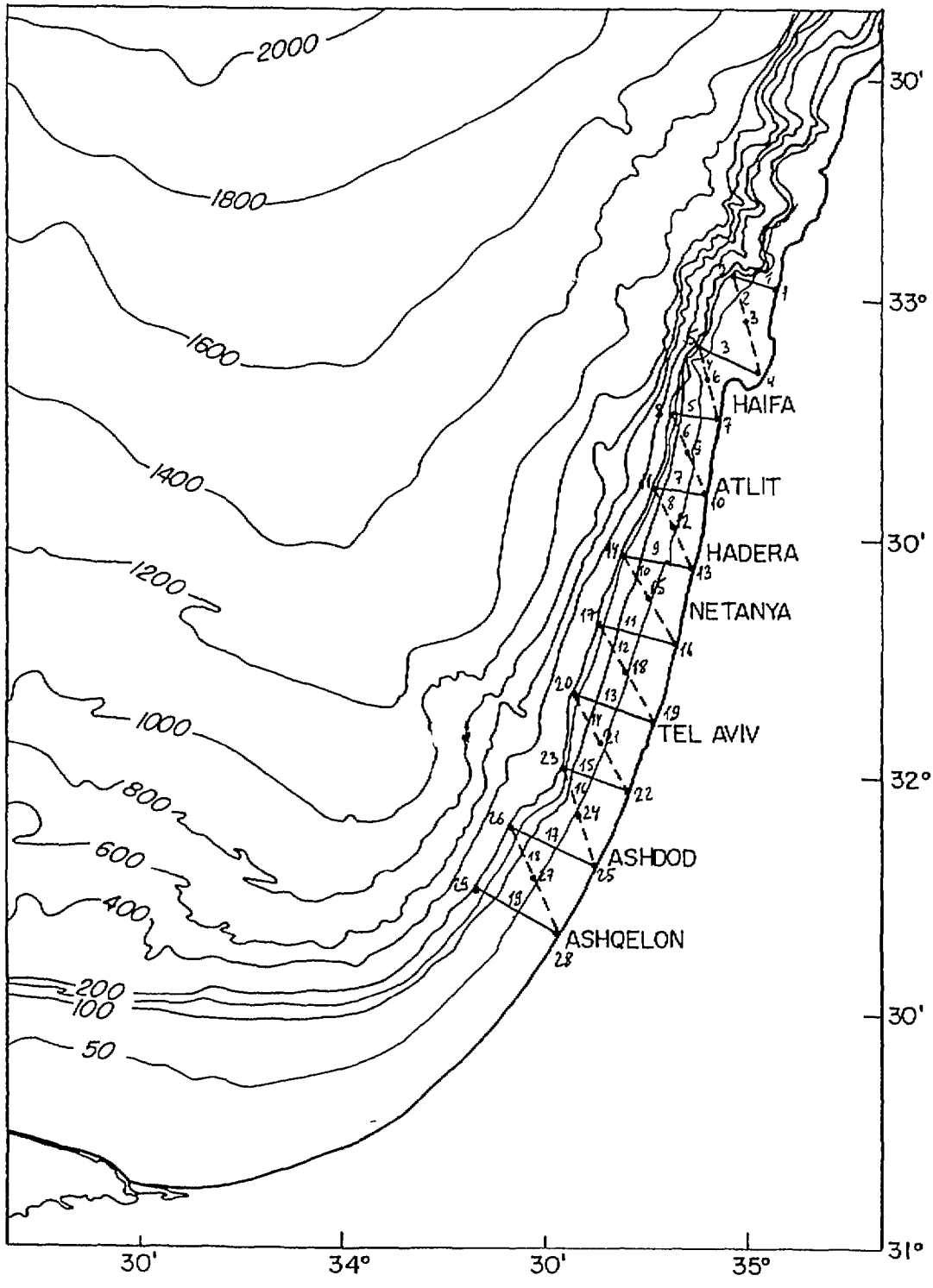


Figure 1

116

february94 deep ctd

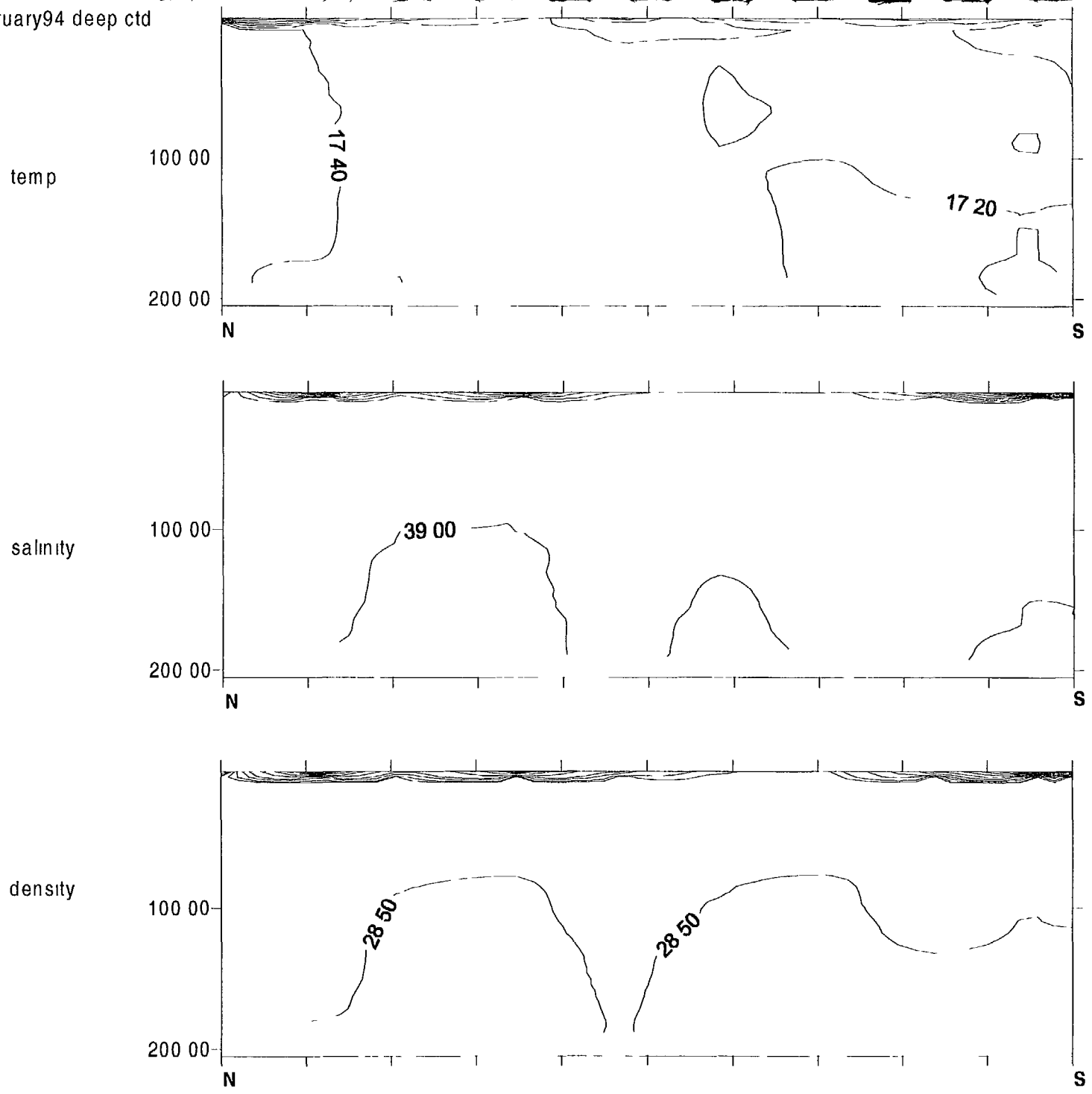


figure 2

117

CTD February 94 Middle

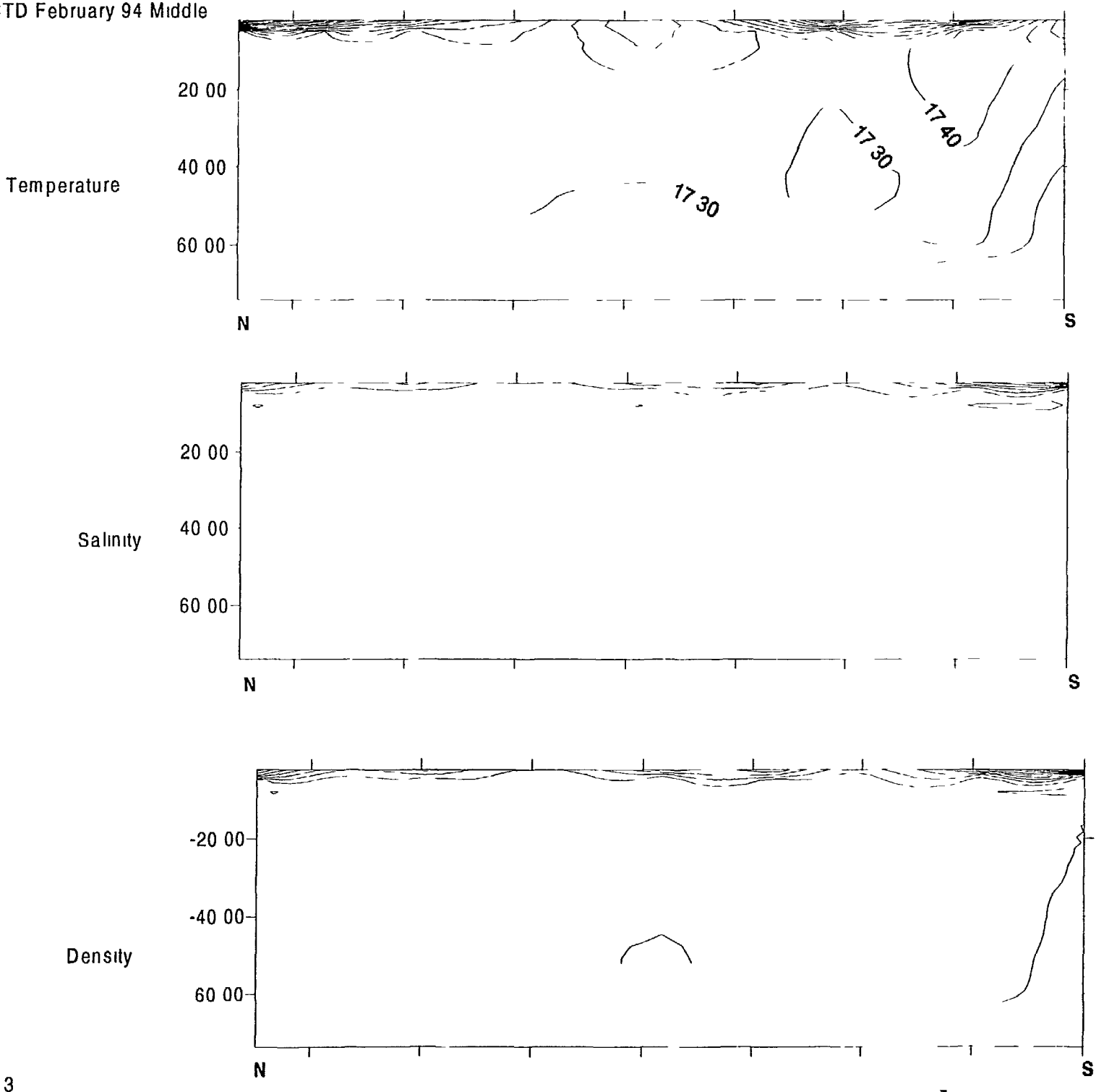


figure 3

CTD february 94 shallow

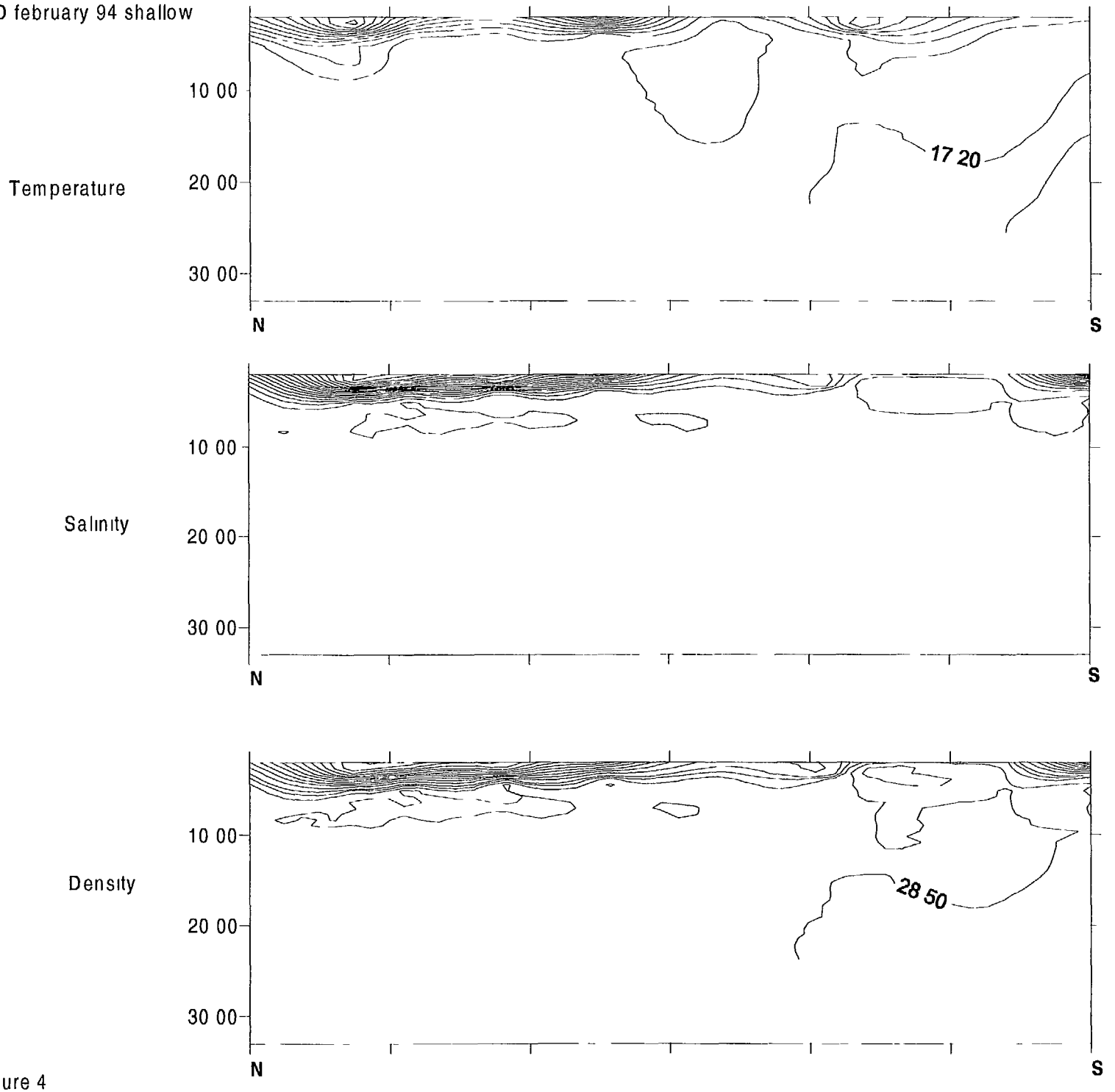


figure 4

Nutrients February 1994
Deep Stations

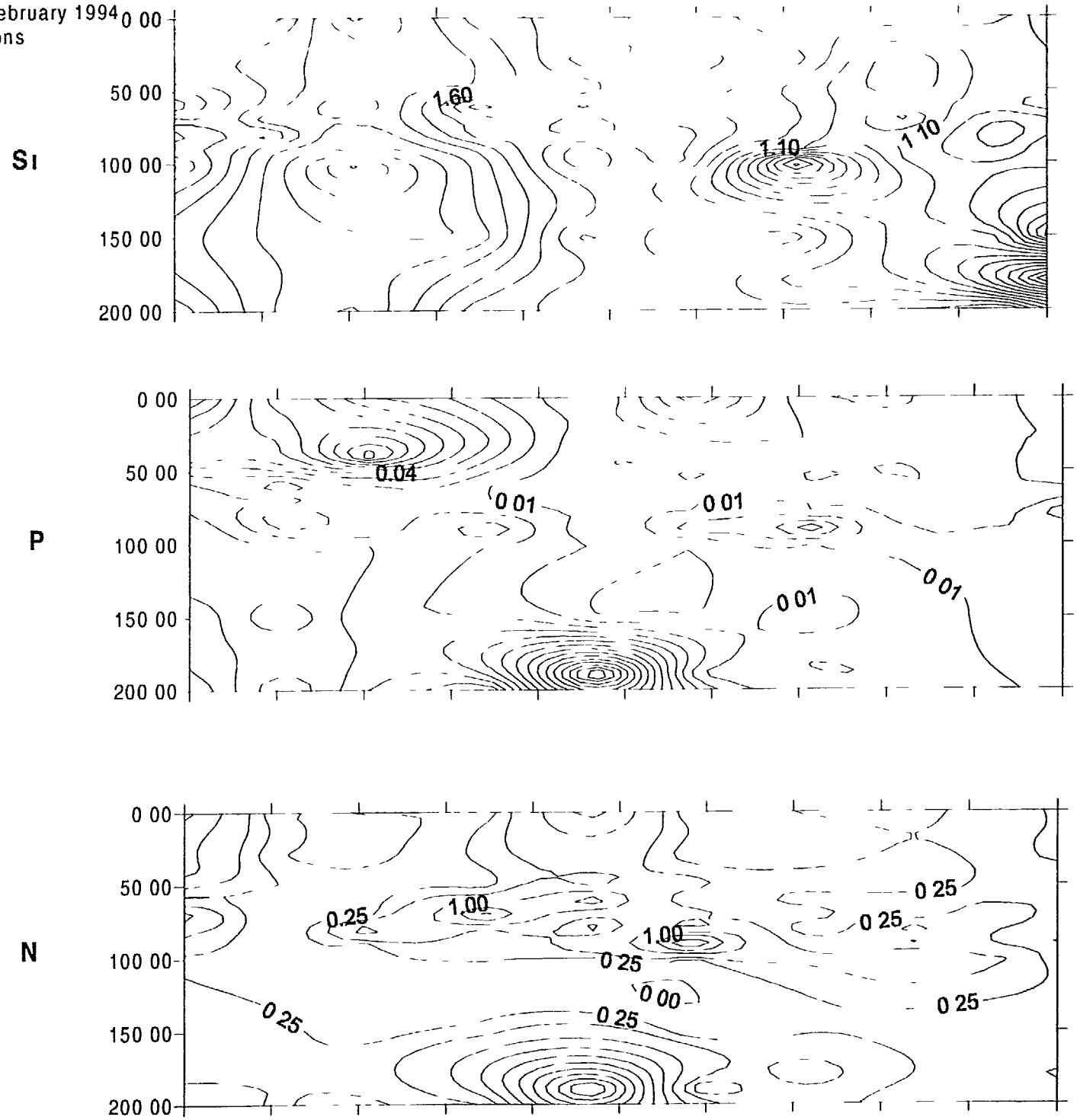


figure 5

Nutrients February 1994
Middle Stations

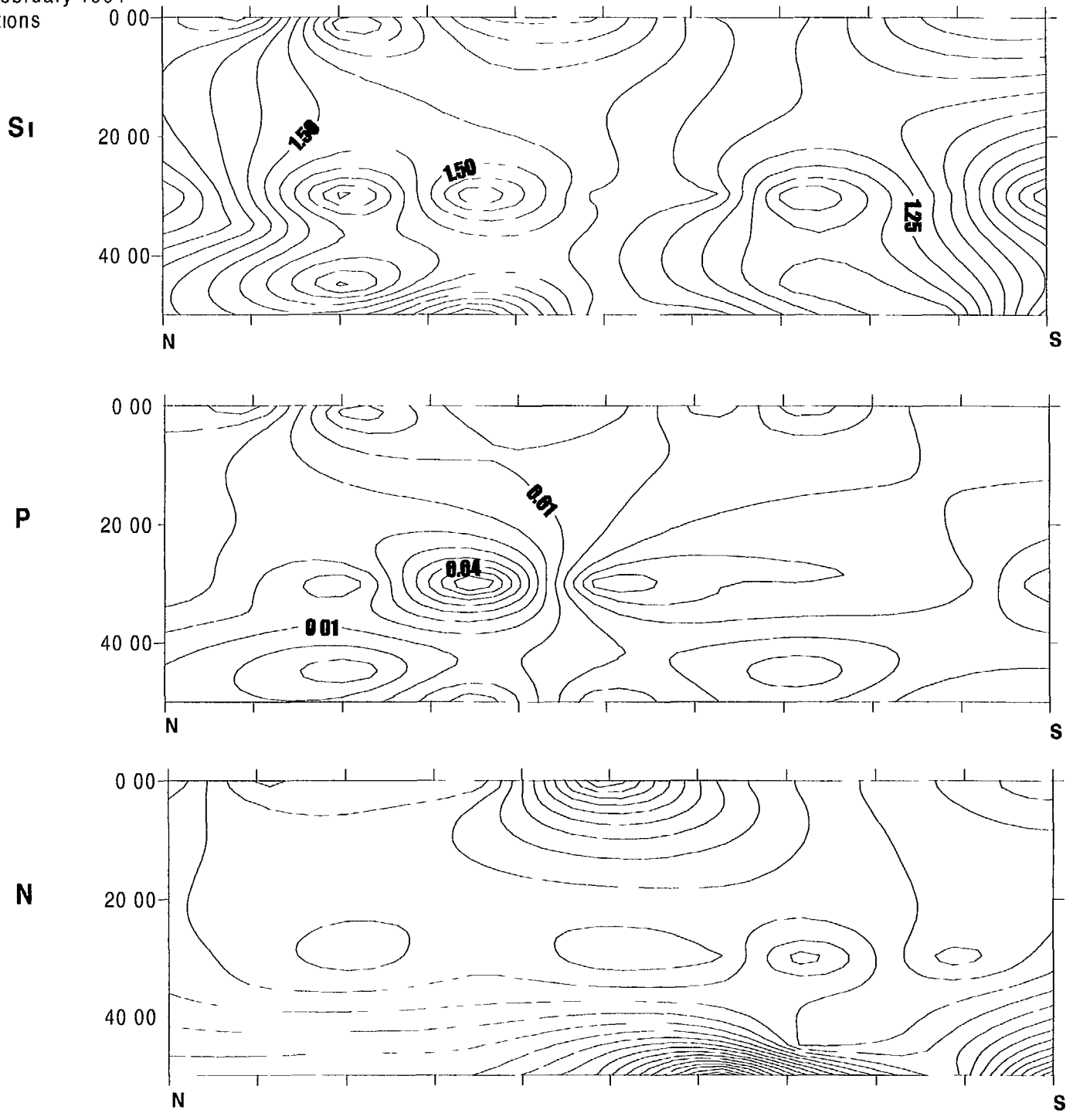


figure 6

Nutrients February 1994
Shallow Stations

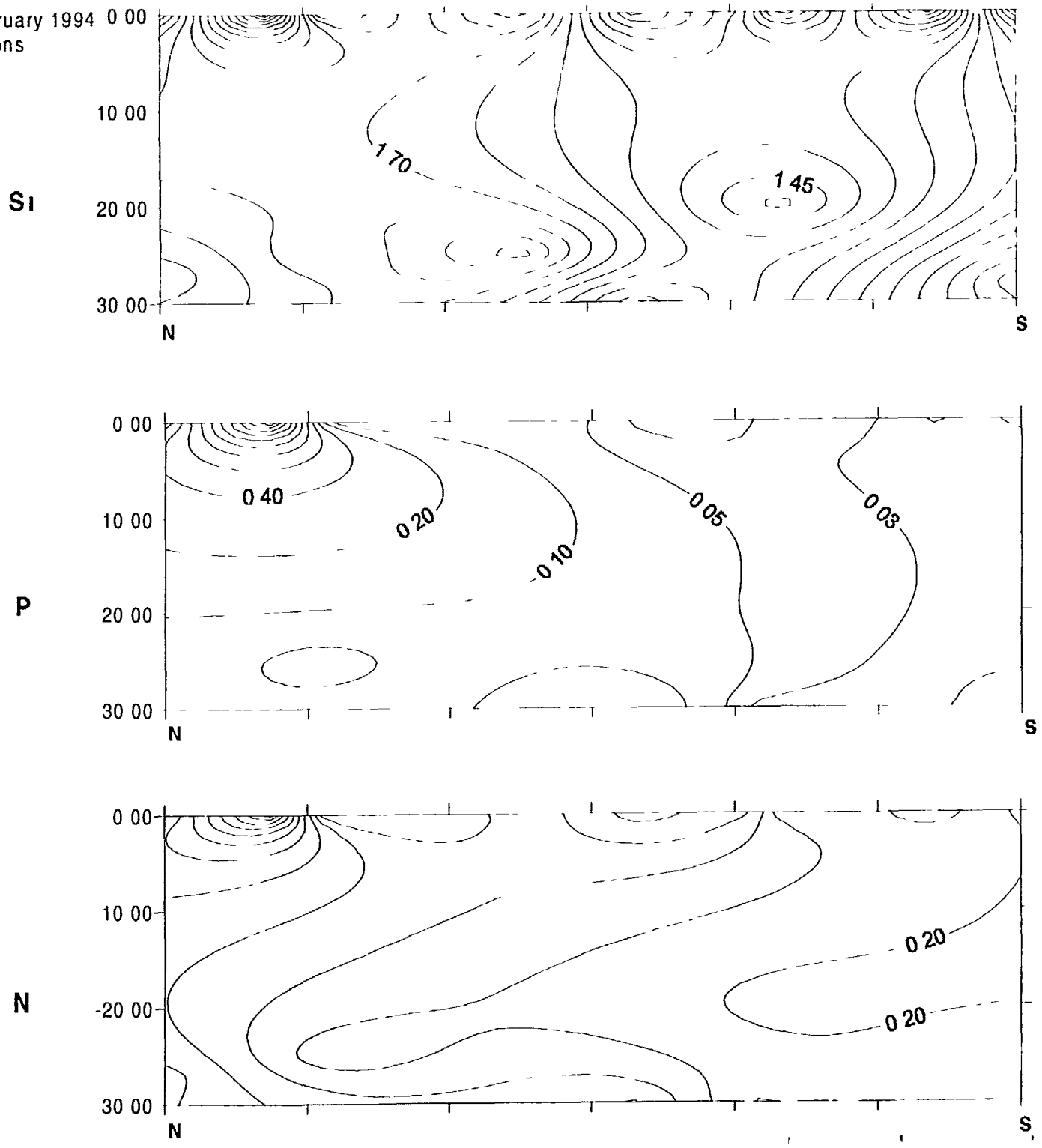


figure 7

February 1994
Chlorophyll

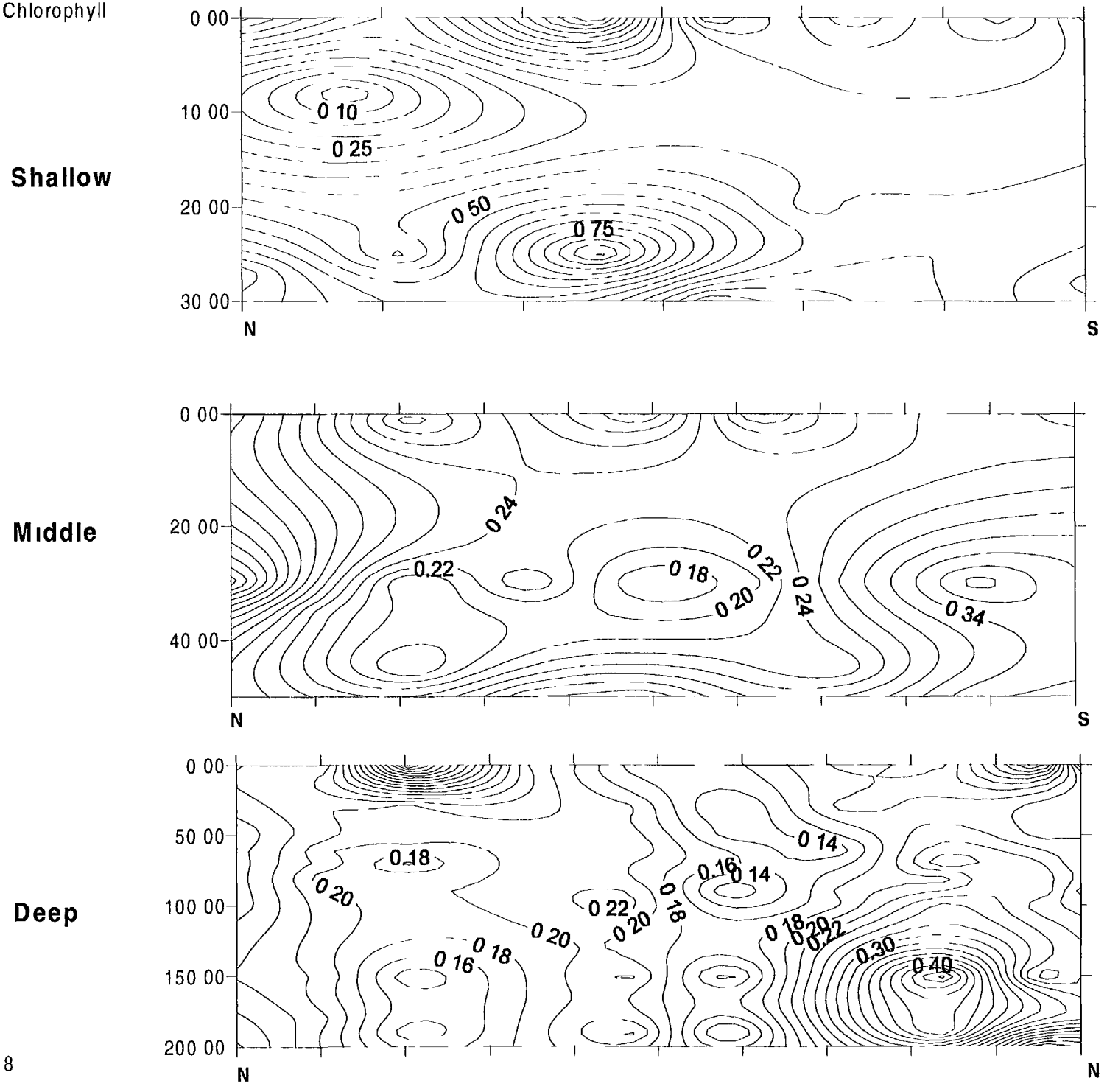


figure 8

12

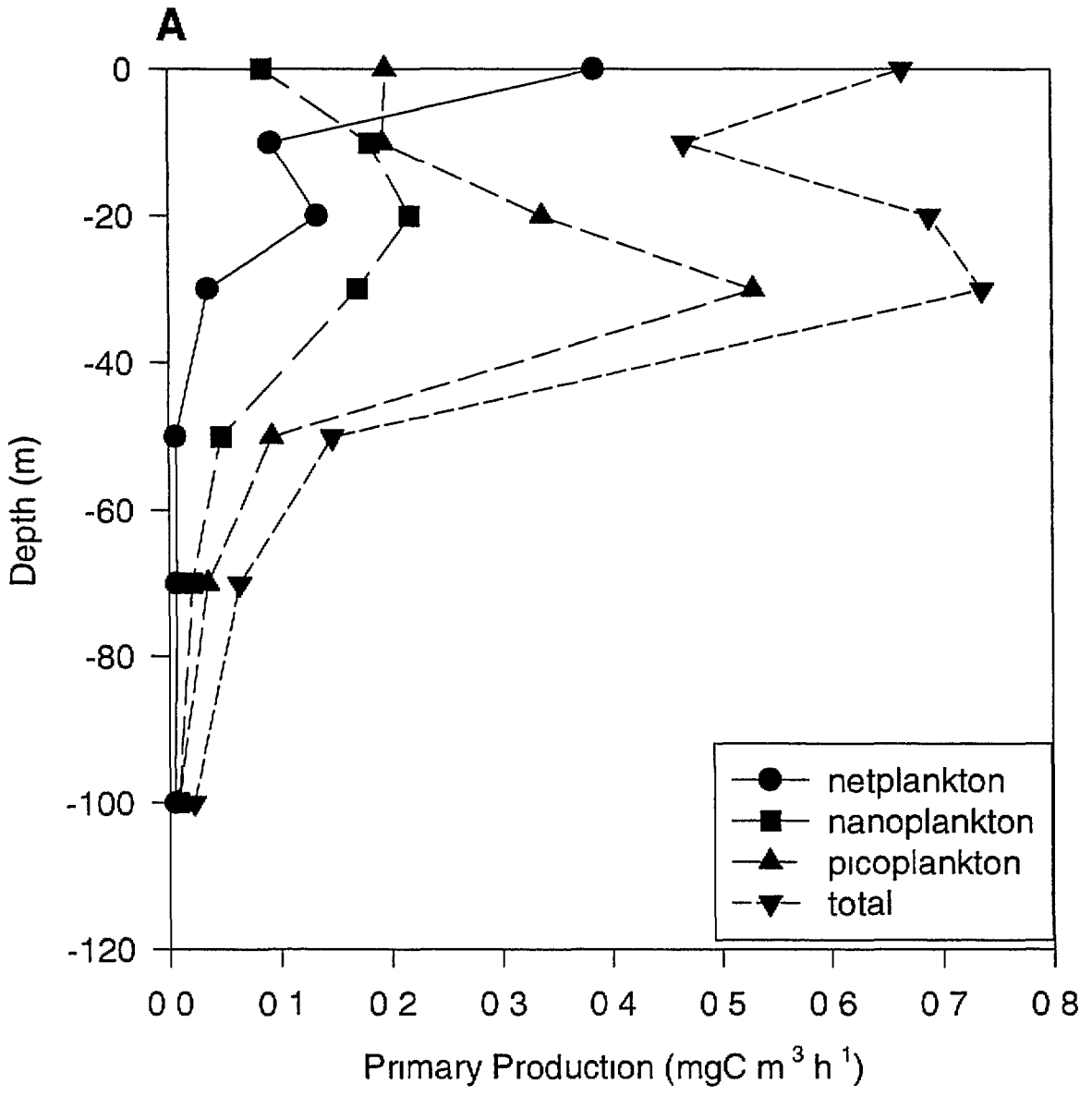

A
0
-20
-40
-60
-80
-100
-120
Depth (m)
0 0
0 1
0 2
0 3
0 4
0 5
0 6
0 7
0 8
Primary Production (mgC m 3 h 1)
netplankton
nanoplankton
picoplankton
total

Figure 9A

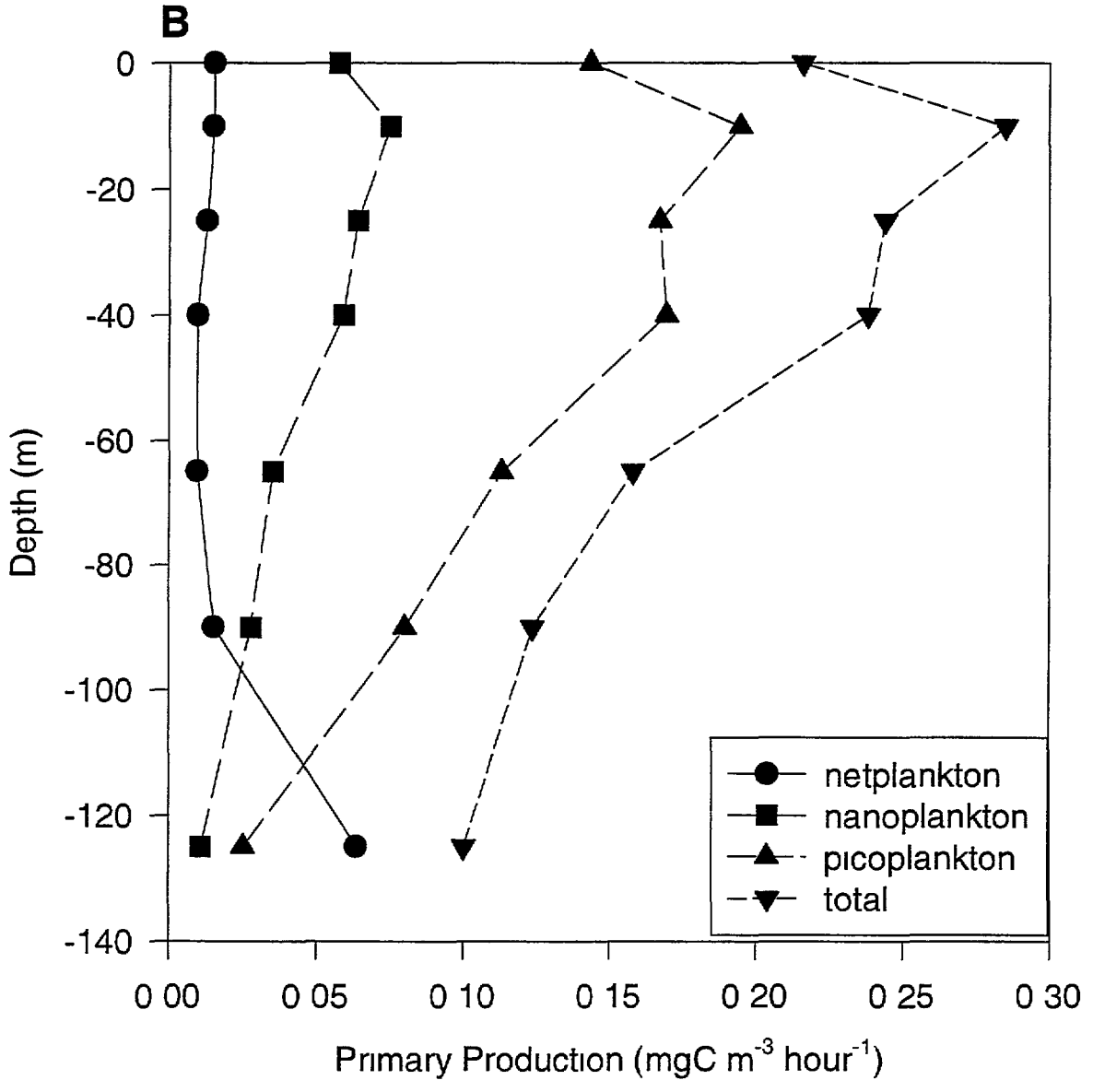

B
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
0 00
0 05
0 10
0 15
0 20
0 25
0 30
Primary Production (mgC m-3 hour-1)
netplankton
nanoplankton
picoplankton
total

Figure 9B

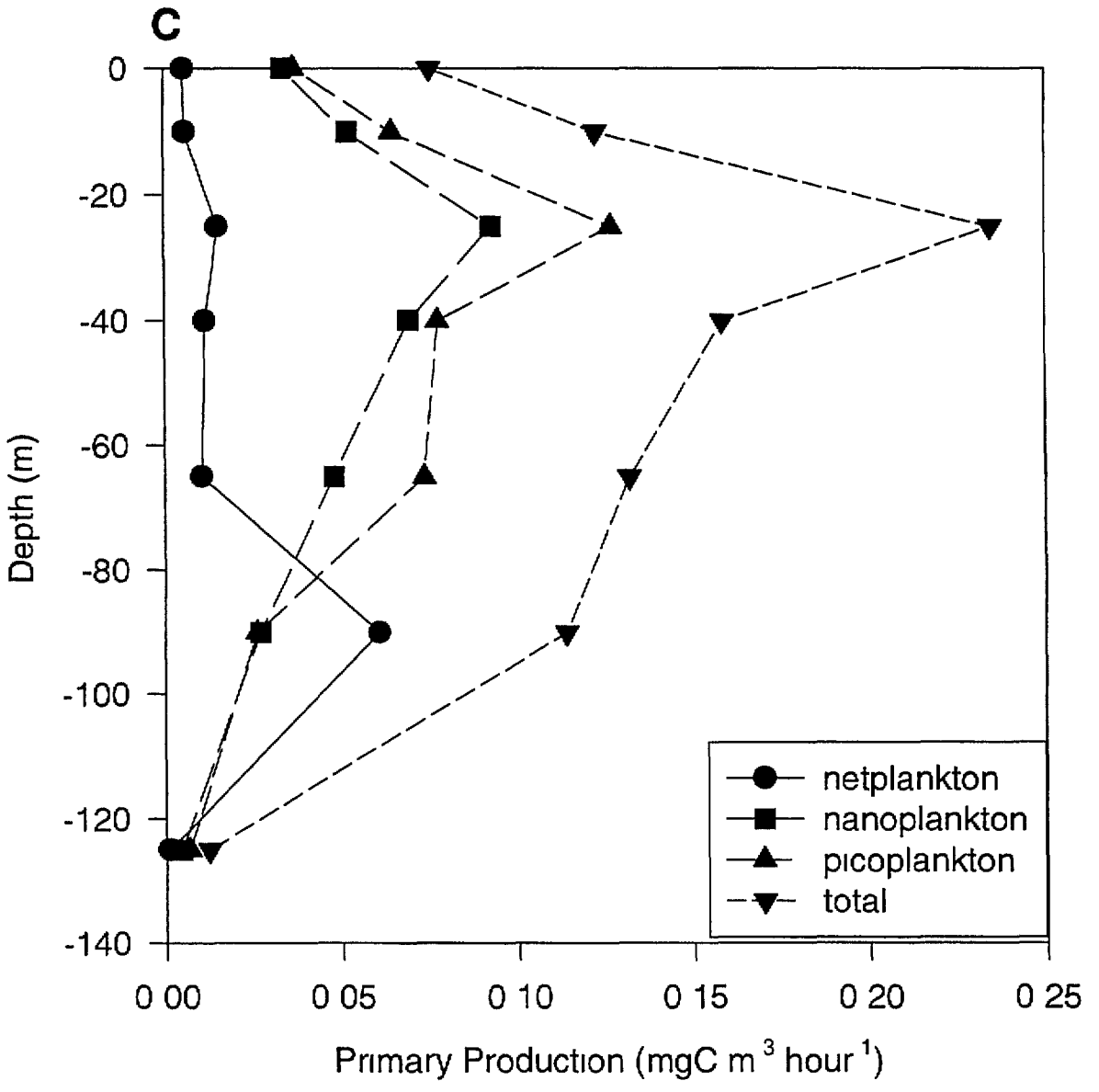

C
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
0 00
0 05
0 10
0 15
0 20
0 25
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 9C

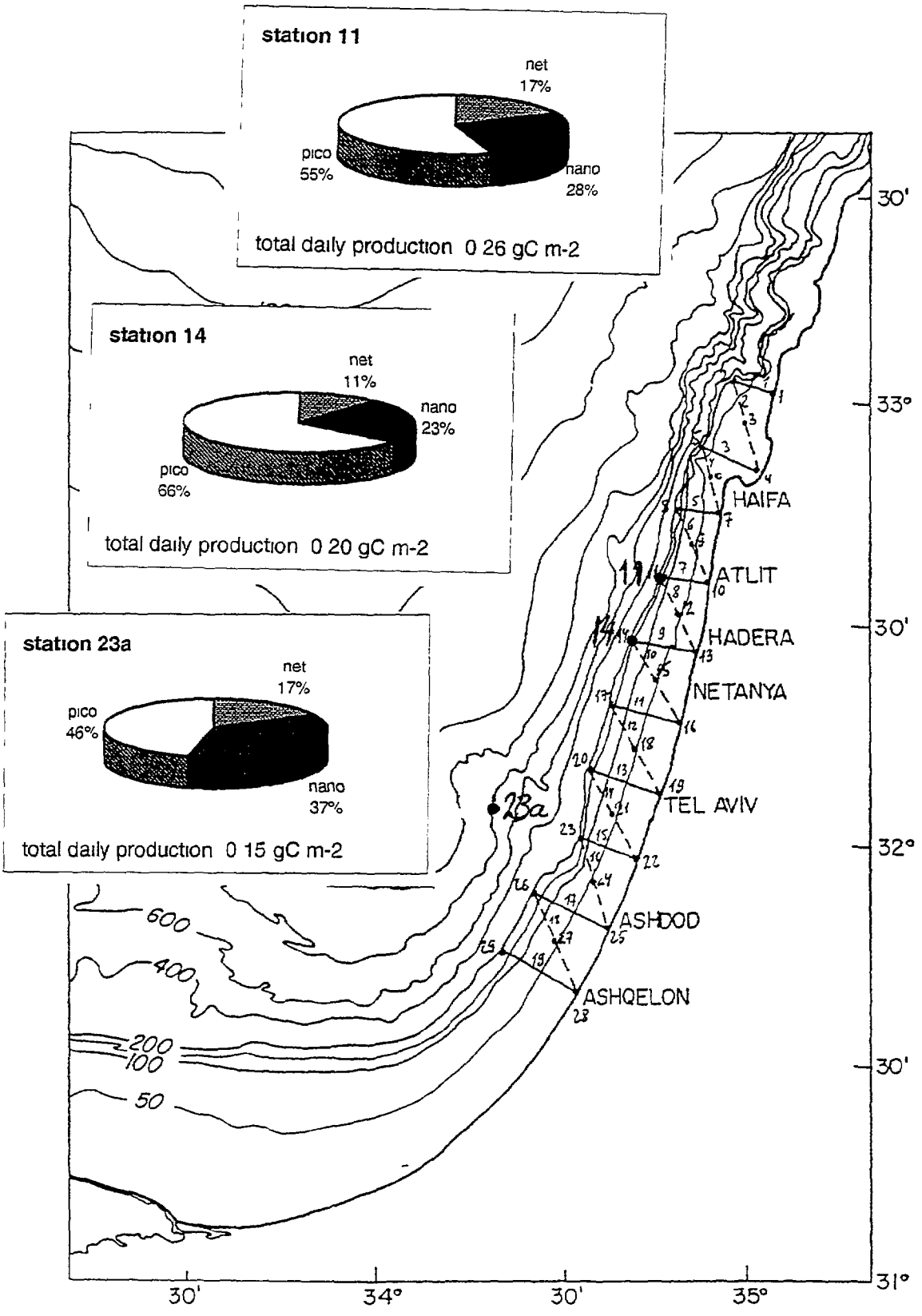

station 11
net
17%
pico
55%
nano
28%
total daily production 0 26 gC m-2
station 14
net
11%
nano
23%
pico
66%
total daily production 0 20 gC m-2
station 23a
net
17%
pico
46%
nano
37%
total daily production 0 15 gC m-2
HAIFA
ATLIT
HADERA
NETANYA
TEL AVIV
ASHDOD
ASHQELON
600
400
200
100
50
30'
33°
30'
32°
30'
31°
30'
34°
30'
35°

Figure 10

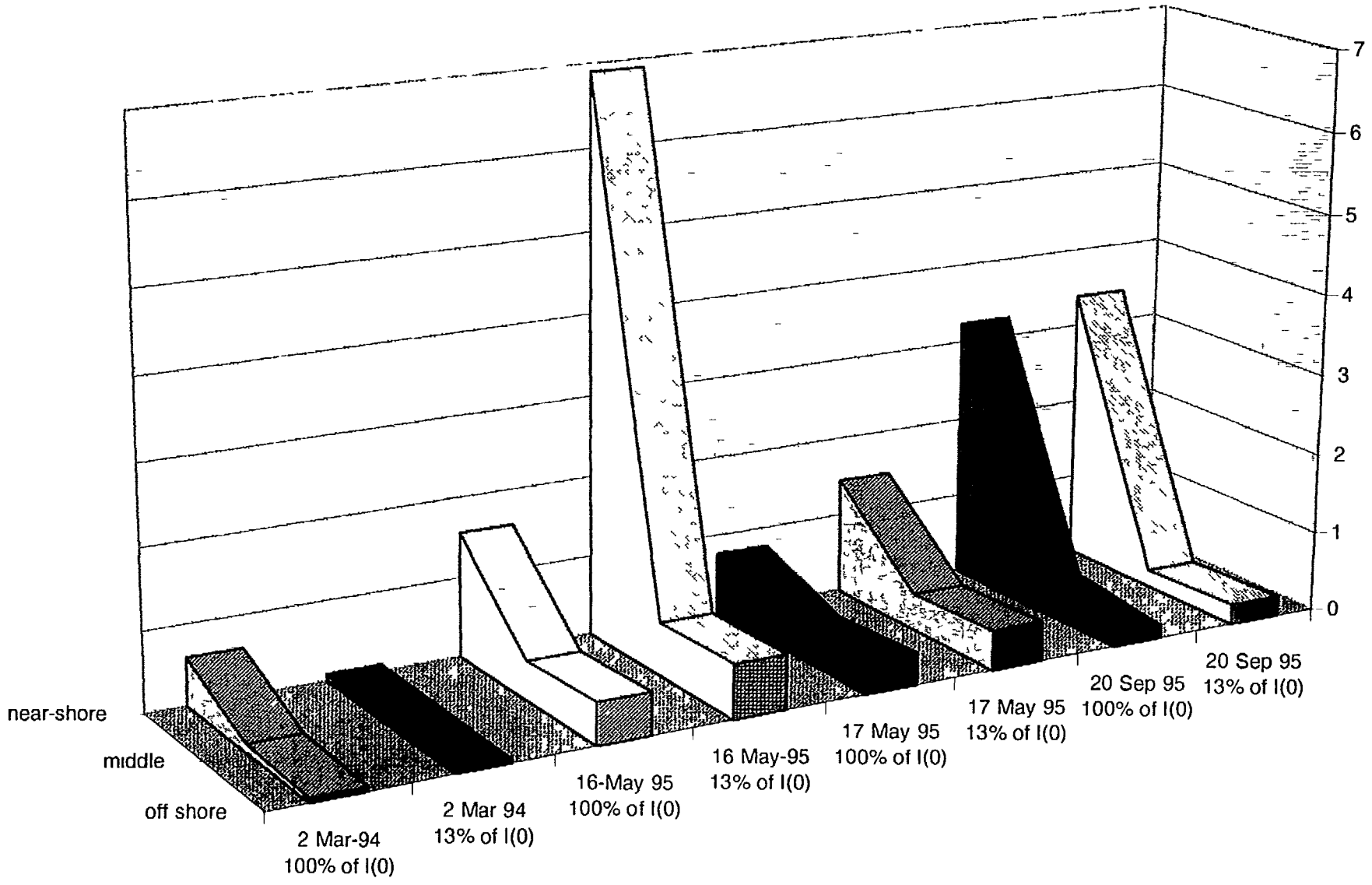
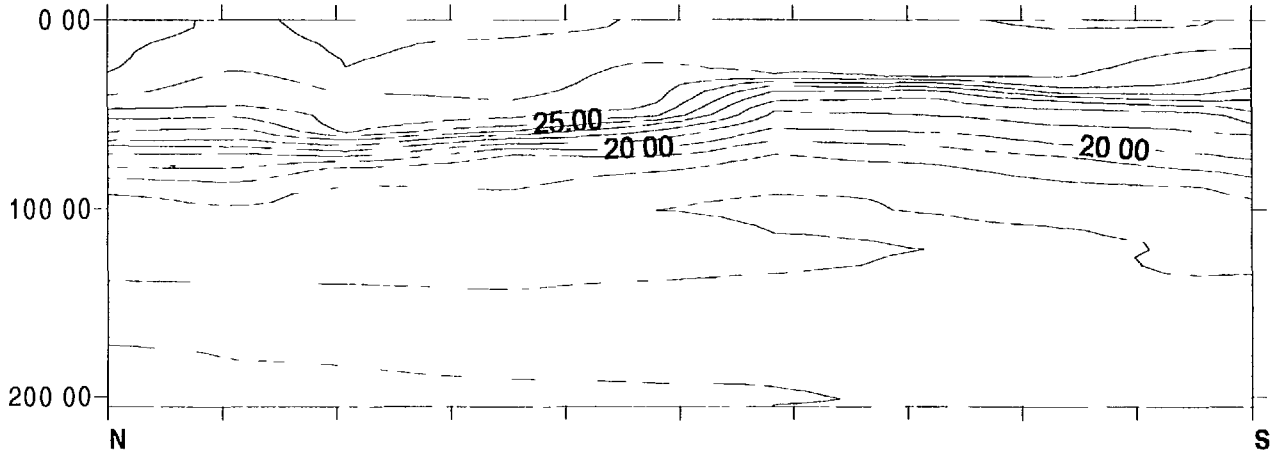

7
6
5
4
3
2
1
0
near-shore
middle
off shore
2 Mar-94
100% of I(0)
2 Mar 94
13% of I(0)
16-May 95
100% of I(0)
16 May-95
13% of I(0)
17 May 95
100% of I(0)
17 May 95
13% of I(0)
20 Sep 95
100% of I(0)
20 Sep 95
13% of I(0)

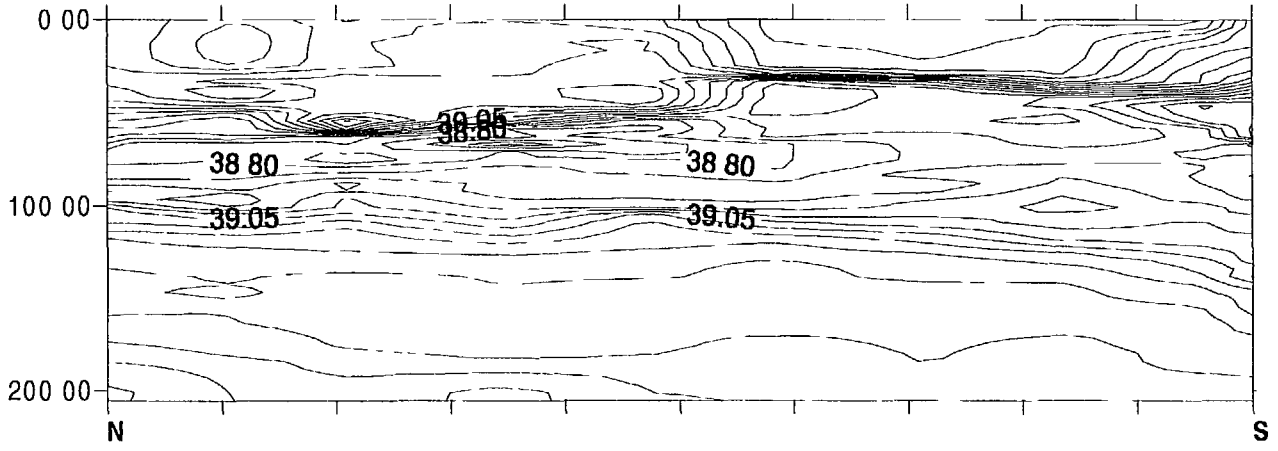
Figure 11

deep august, 1994

temp



salinity



density

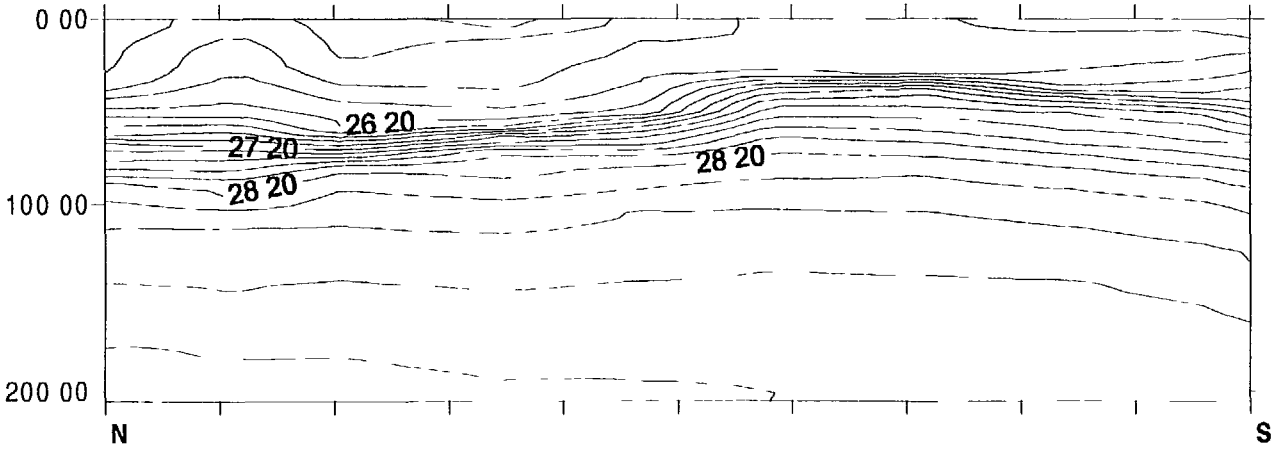


figure 12

ctd august 1994 middle

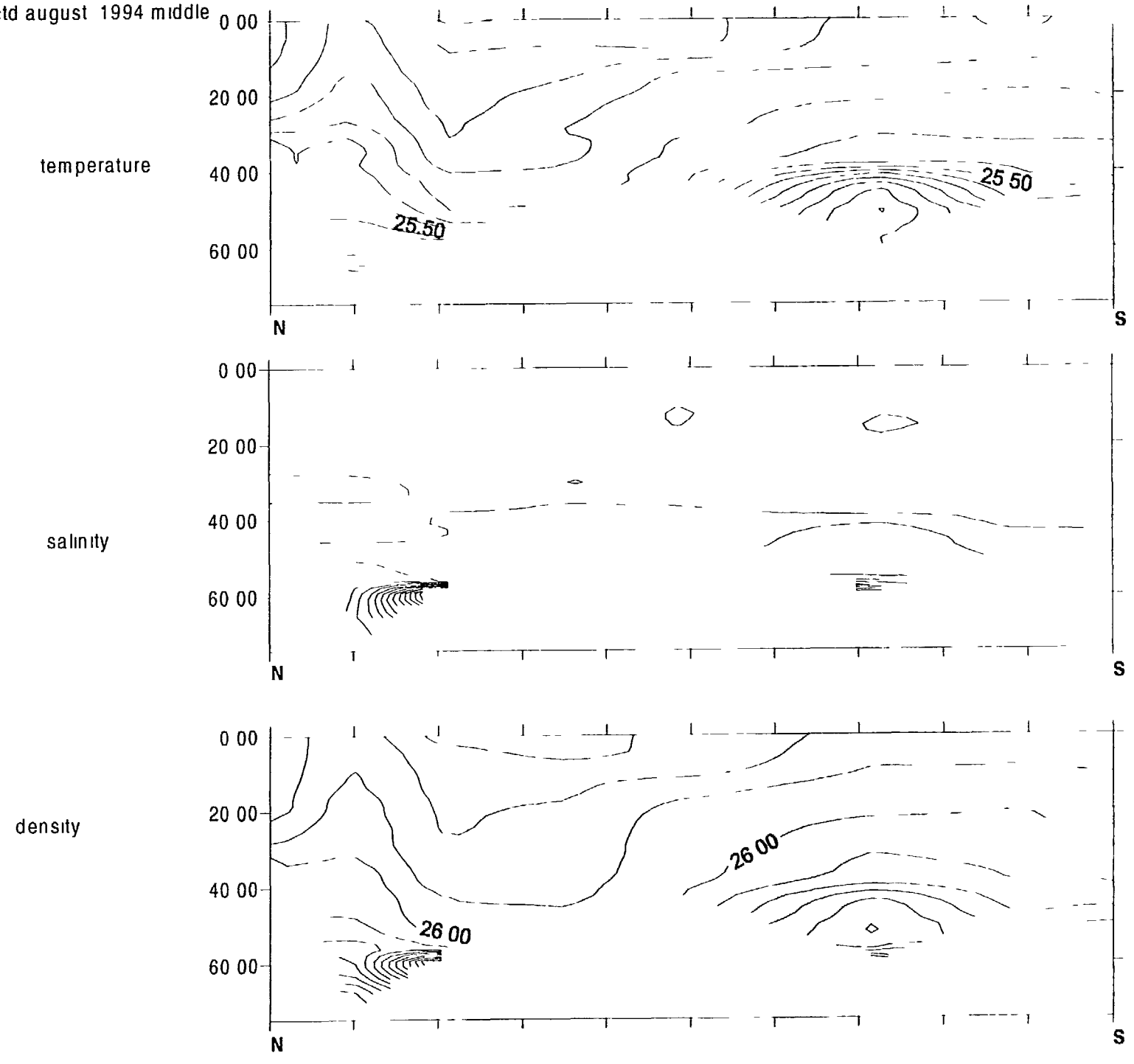


figure 13

ctd august shallow

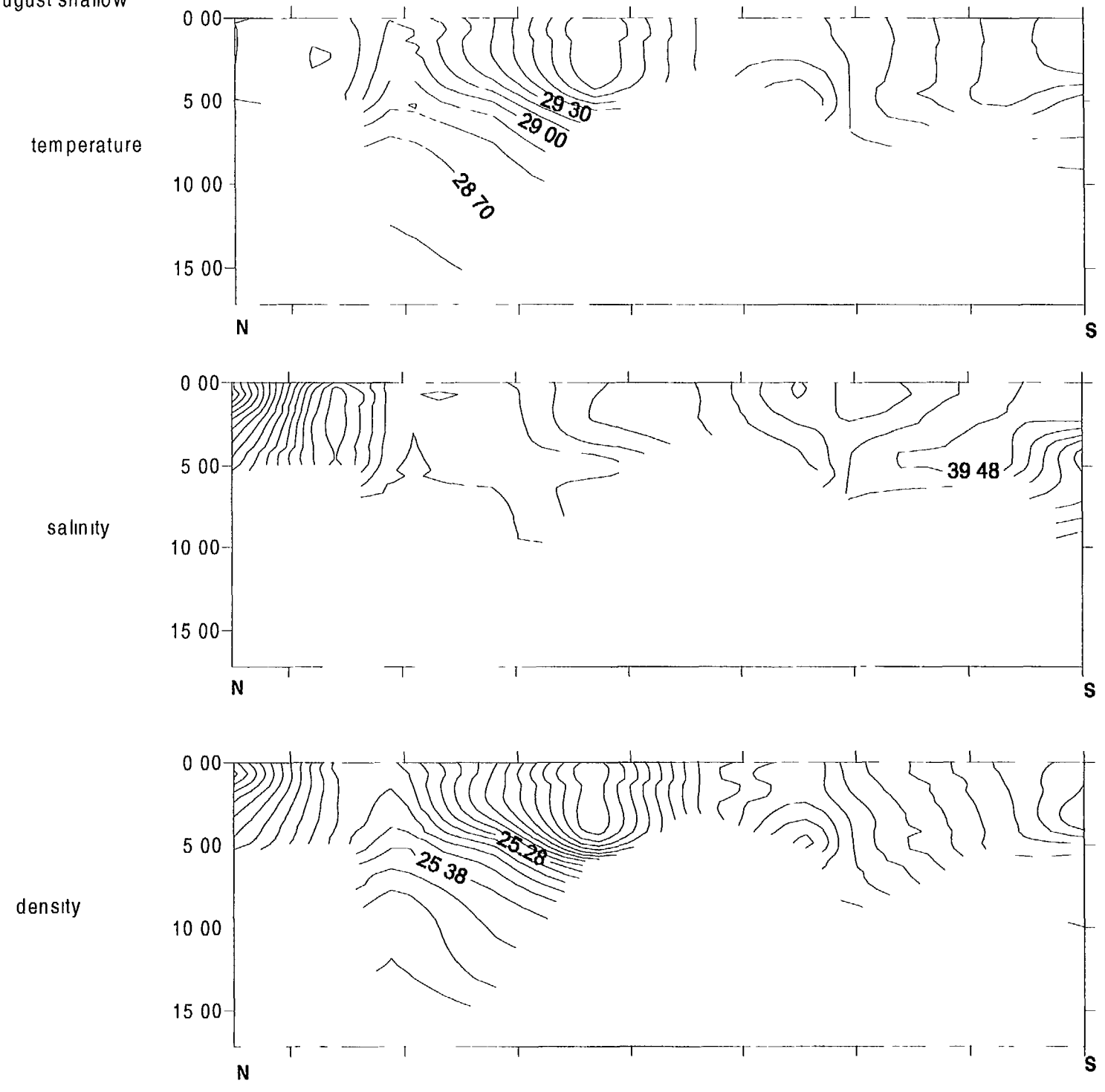


figure 14

Nutrients August 94
Deep Stations

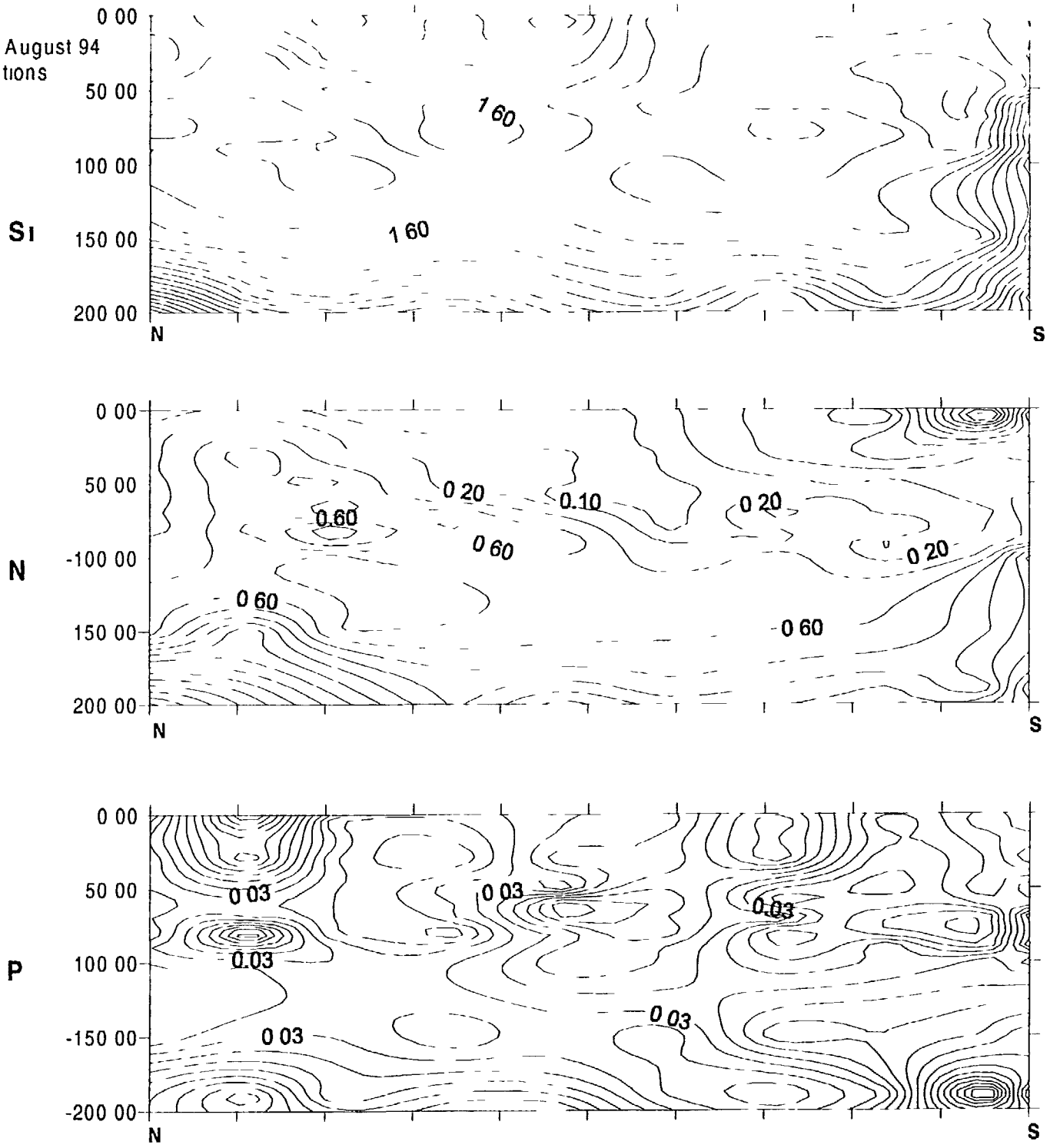


figure 15

132

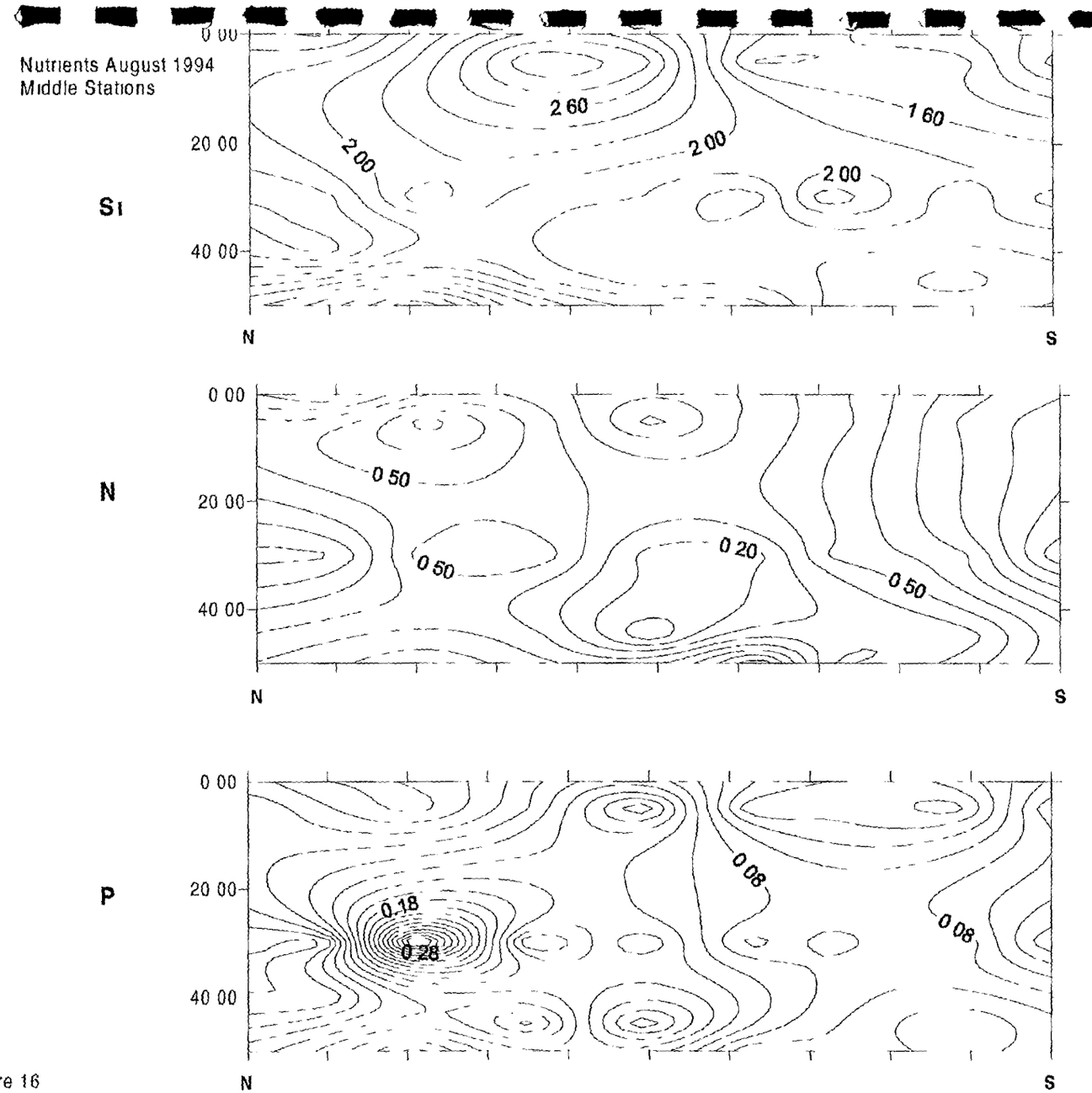

Nutrients August 1994
Middle Stations
Si
N
P
0 00
20 00
40 00
N
S
2 60
2 00
1 60
0 50
0 20
0.18
0 28
0 08

figure 16

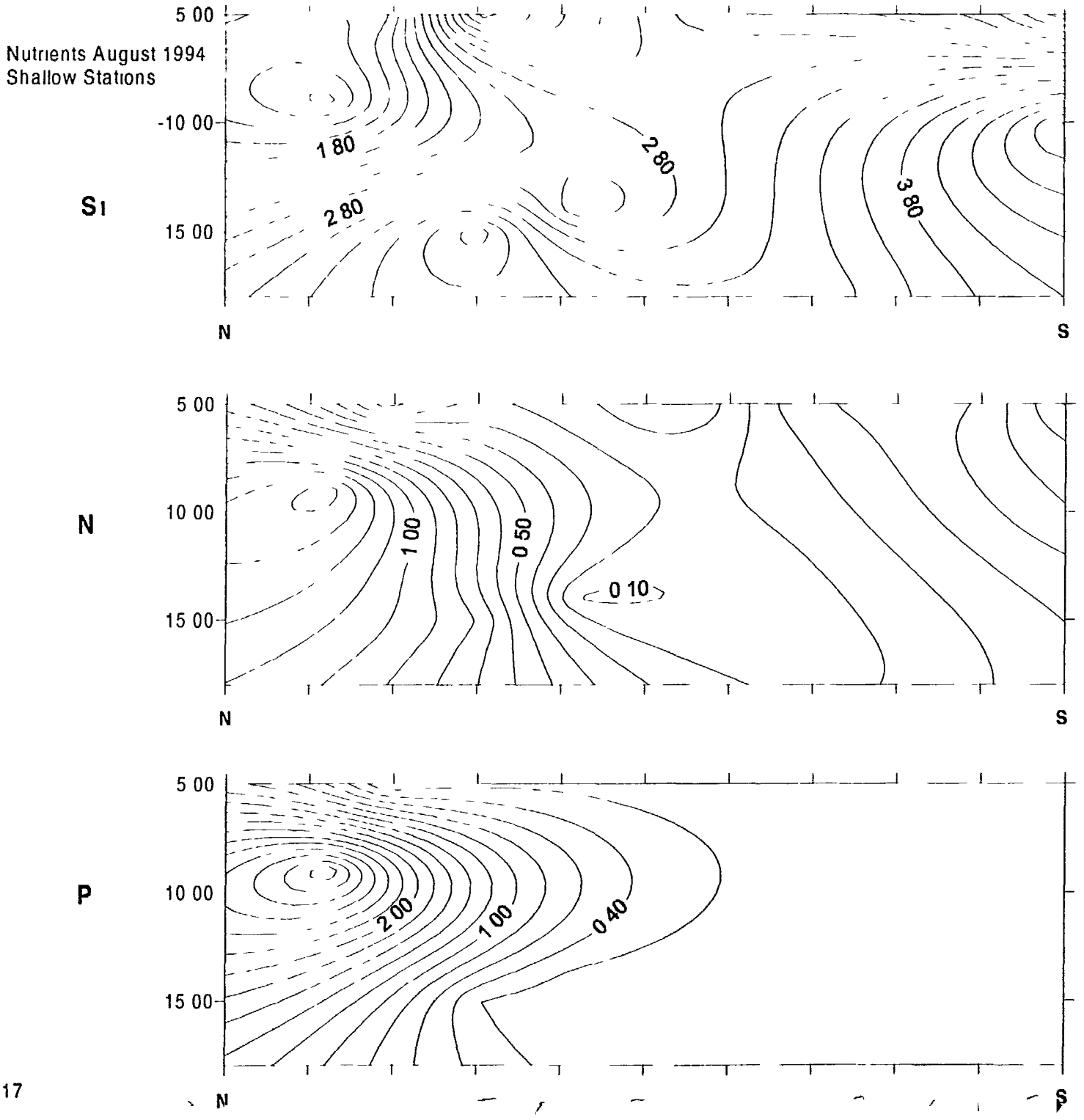

Nutrients August 1994
Shallow Stations
Si
N
P
5 00
-10 00
15 00
10 00
1 80
2 80
3 80
1 00
0 50
0 10
2 00
0 40
N
S

figure 17

chl august, 1994

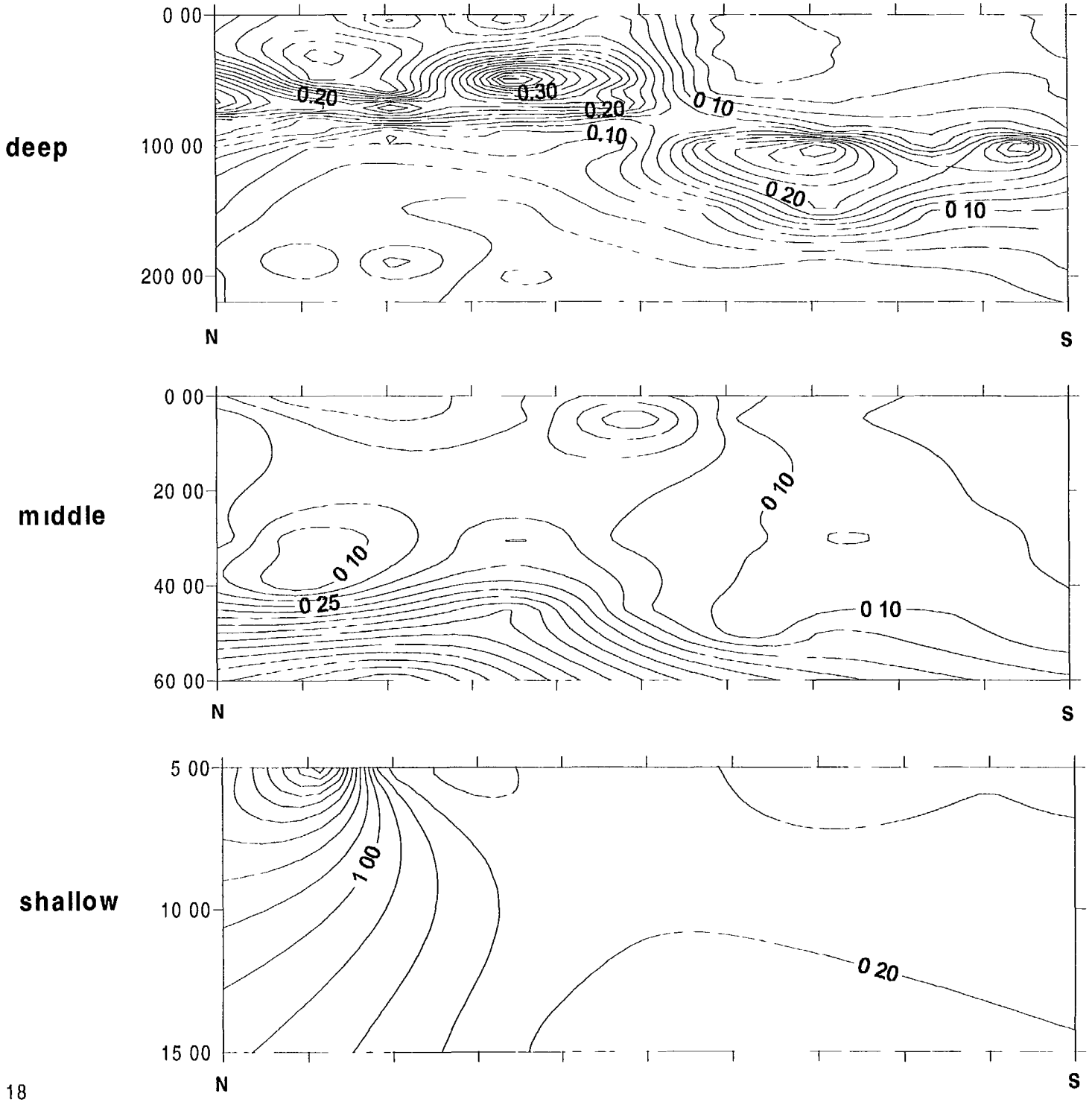


figure 18

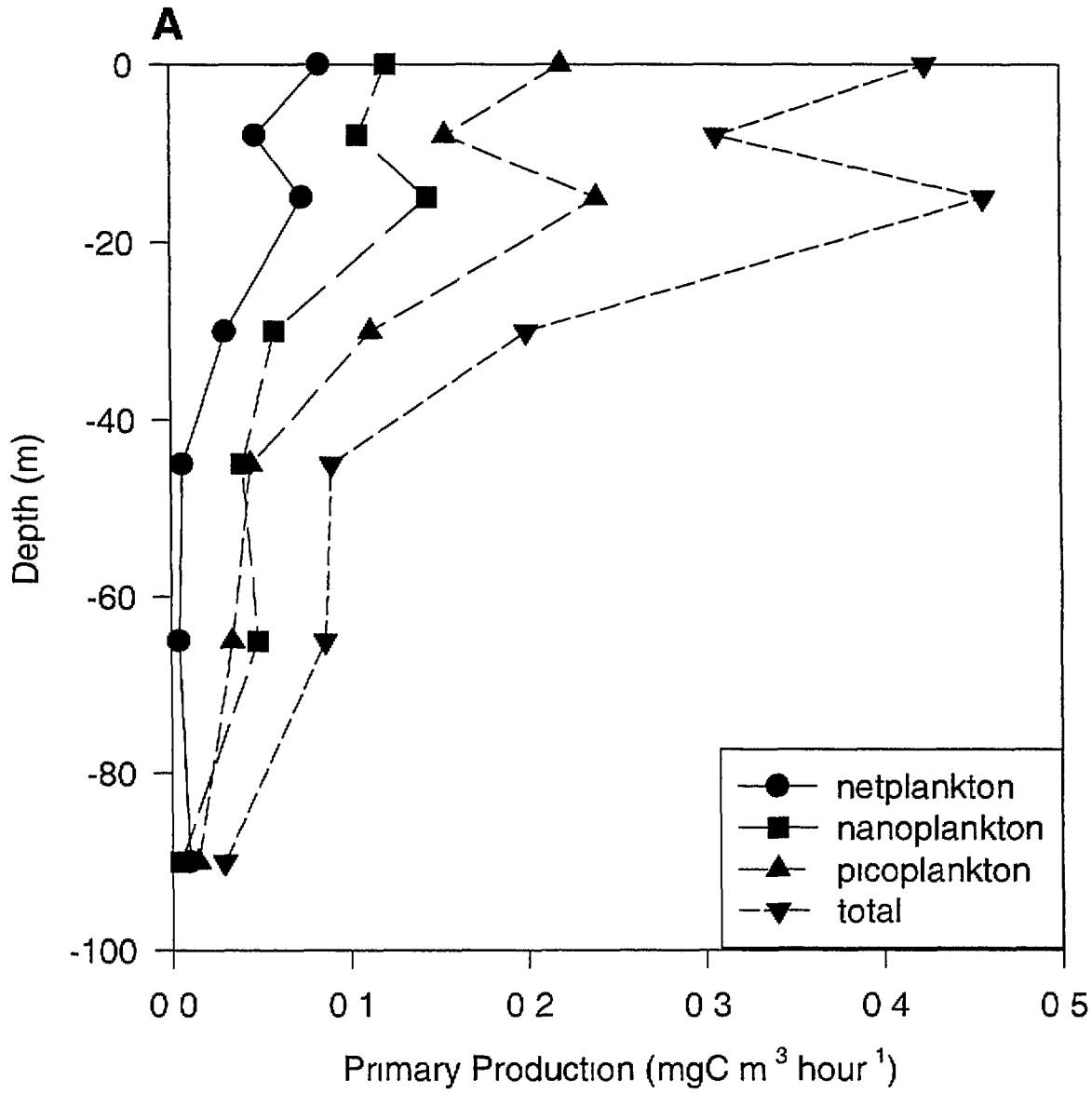

A
0
-20
-40
-60
-80
-100
Depth (m)
0 0
0 1
0 2
0 3
0 4
0 5
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 19A

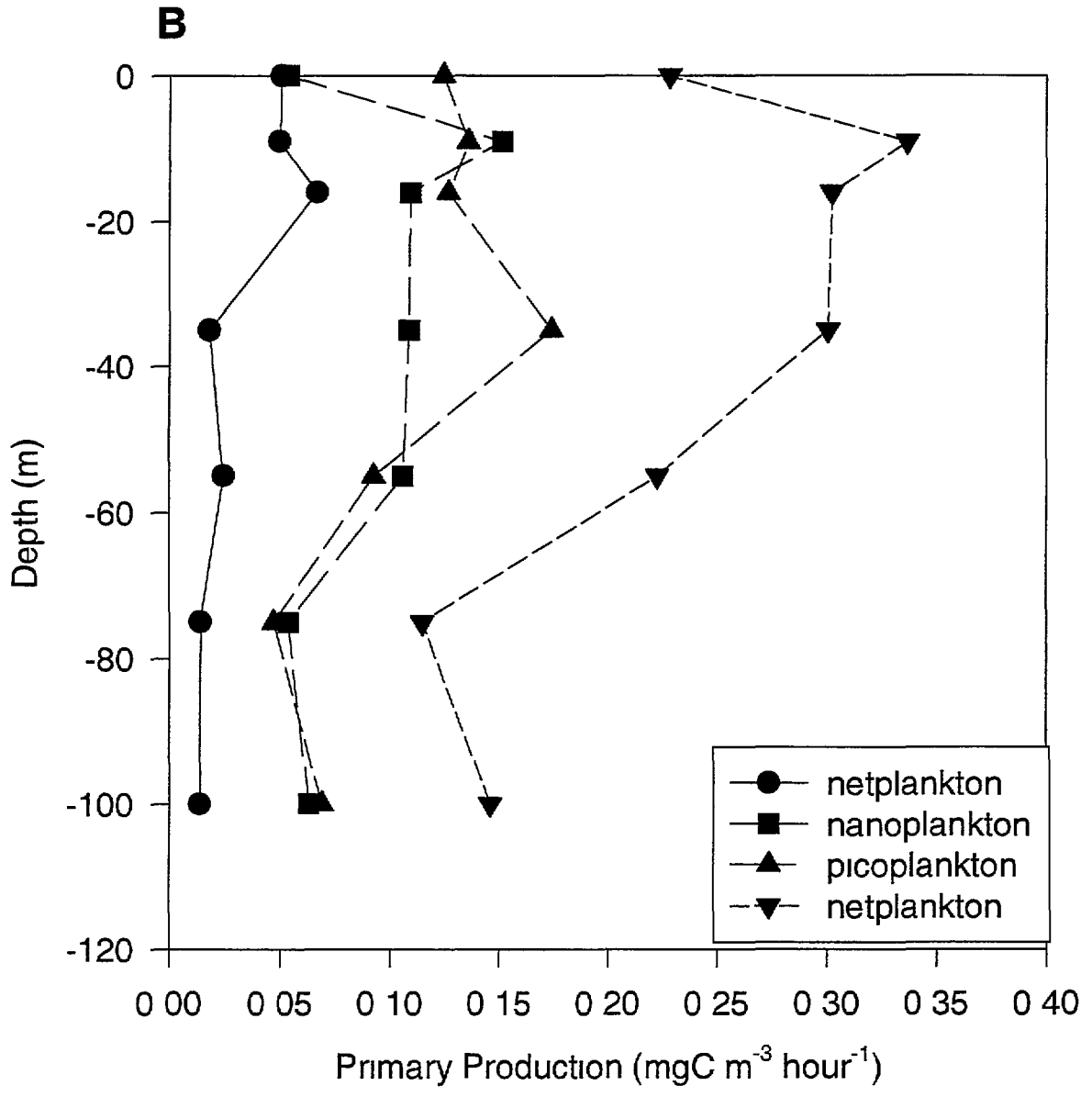

B
0
-20
-40
-60
-80
-100
-120
Depth (m)
0 00
0 05
0 10
0 15
0 20
0 25
0 30
0 35
0 40
Primary Production (mgC m-3 hour-1)
netplankton
nanoplankton
picoplankton
netplankton

Figure 19B

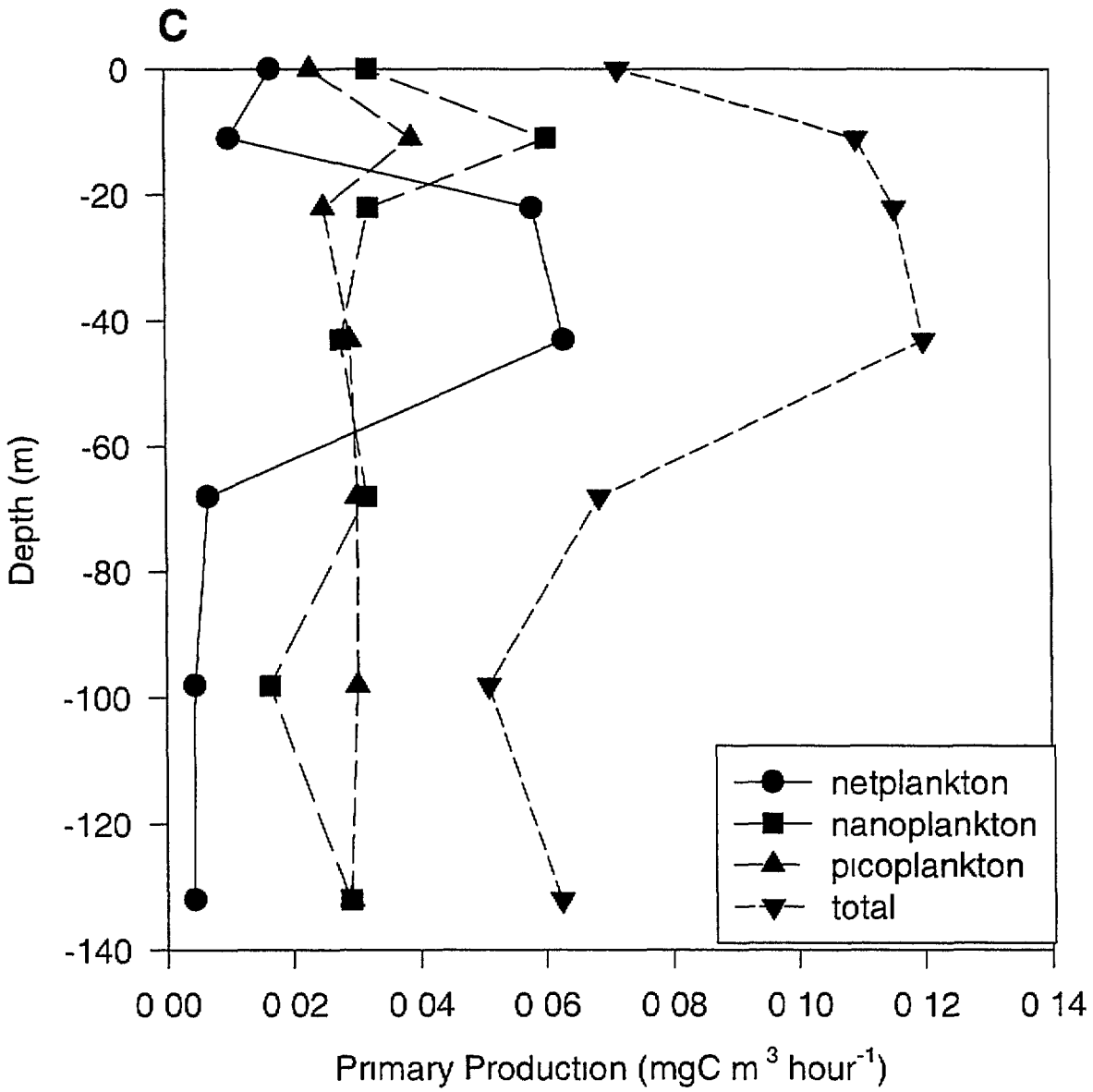

C
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
0 00
0 02
0 04
0 06
0 08
0 10
0 12
0 14
Primary Production (mgC m 3 hour-1)
netplankton
nanoplankton
picoplankton
total

Figure 19C

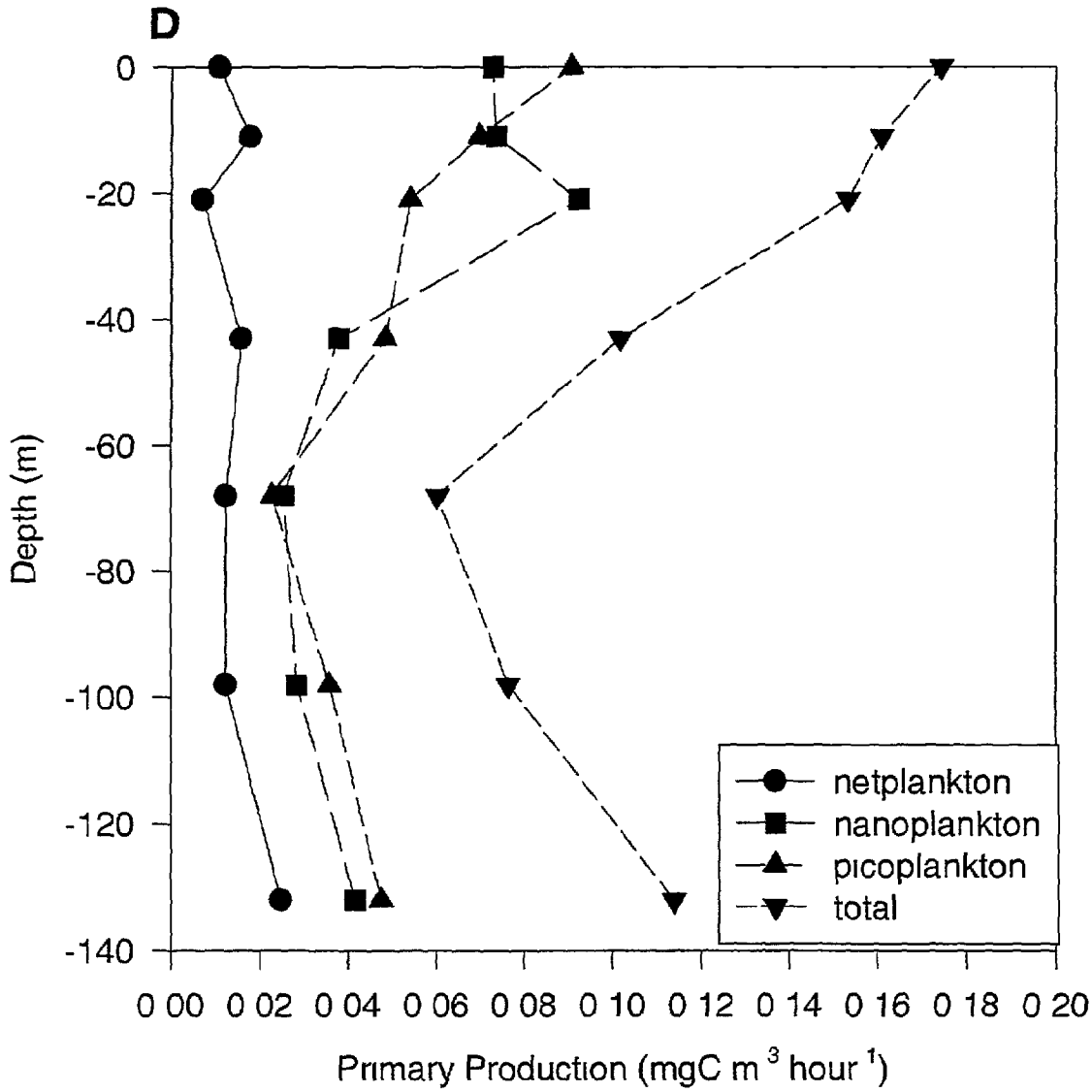

D
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
0 00
0 02
0 04
0 06
0 08
0 10
0 12
0 14
0 16
0 18
0 20
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 19D

1,2, - מספר תרגיל

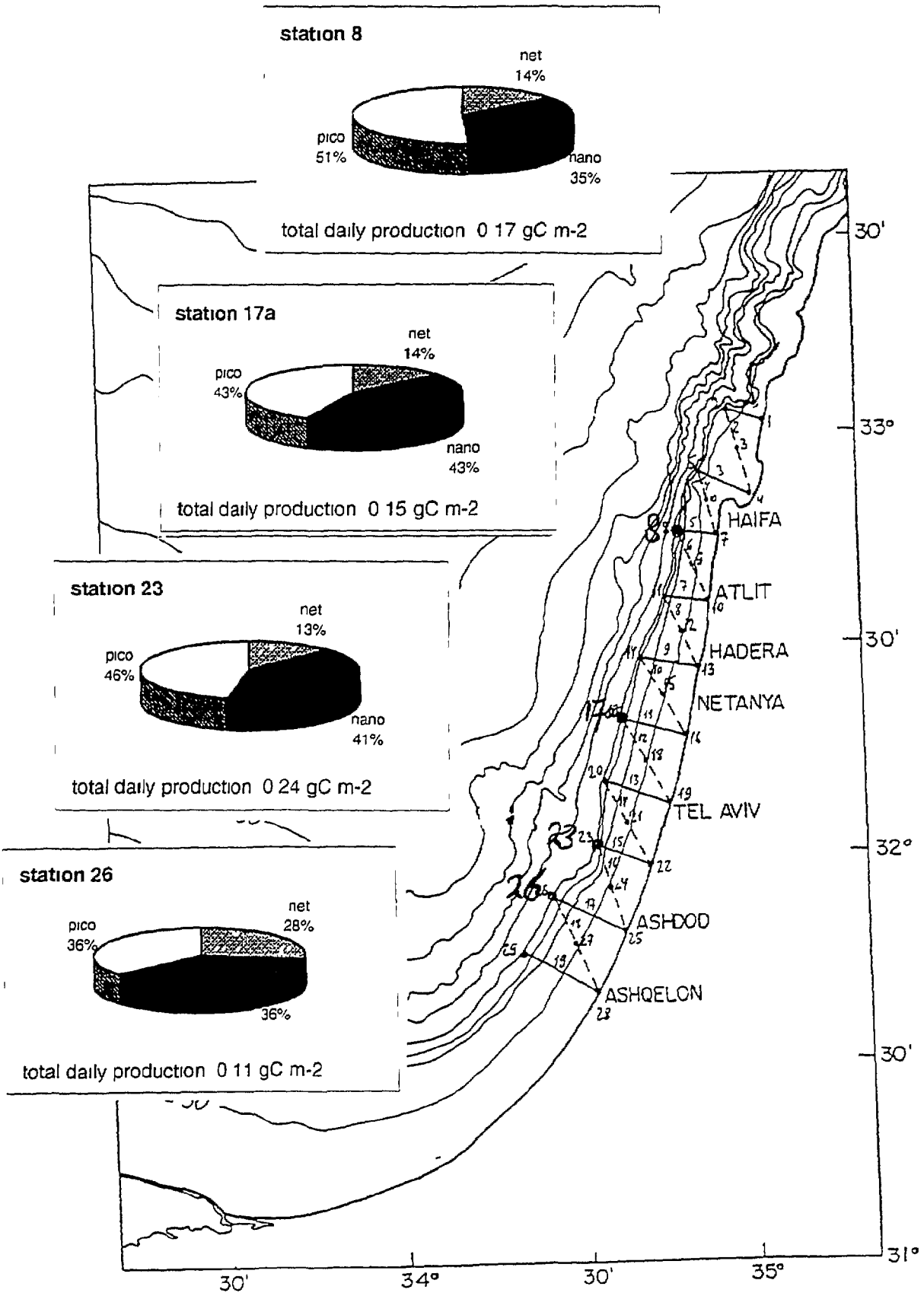
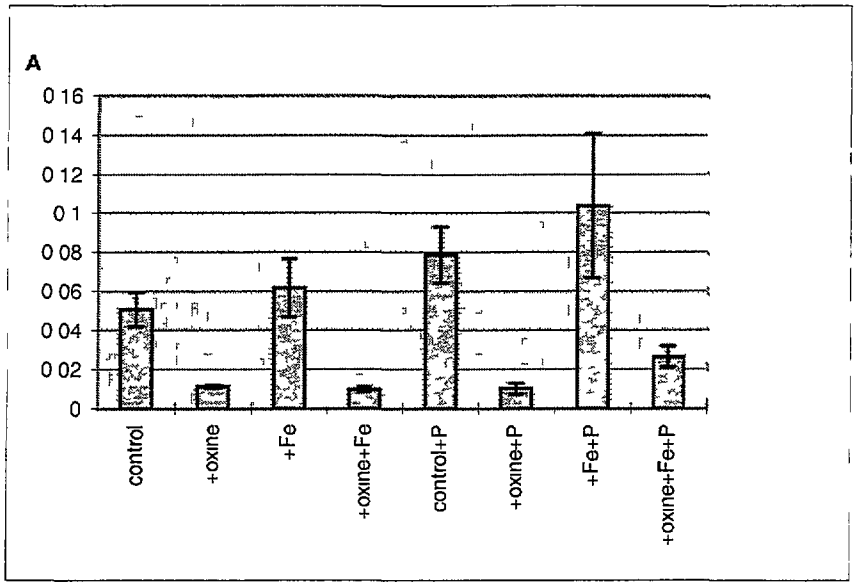
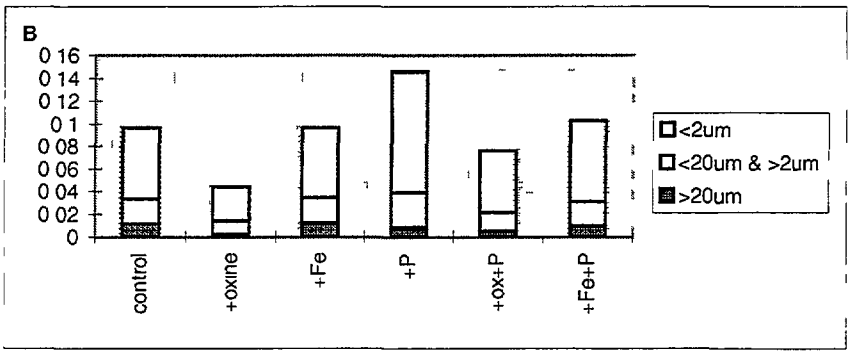


Figure 20

140


A
0 16
0 14
0 12
0 1
0 08
0 06
0 04
0 02
0
control
+oxine
+Fe
+oxine+Fe
control+P
+oxine+P
+Fe+P
+oxine+Fe+P


B
0 16
0 14
0 12
0 1
0 08
0 06
0 04
0 02
0
control
+oxine
+Fe
+P
+ox+P
+Fe+P
<2um
<20um & >2um
>20um

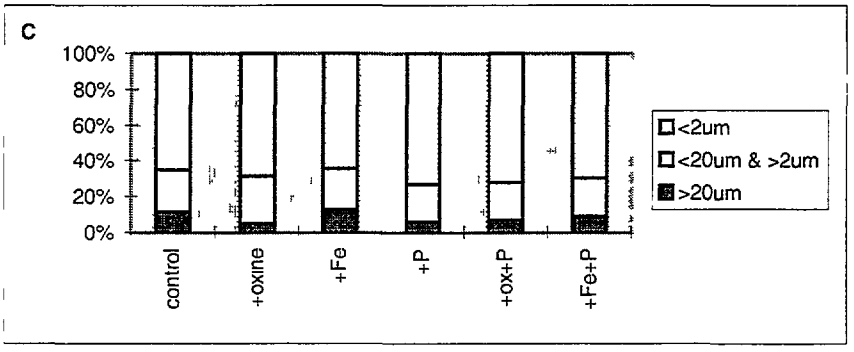

C
100%
80%
60%
40%
20%
0%
control
+oxine
+Fe
+P
+ox+P
+Fe+P
<2um
<20um & >2um
>20um

Figure 21

Nutrients
May 1995
Deep

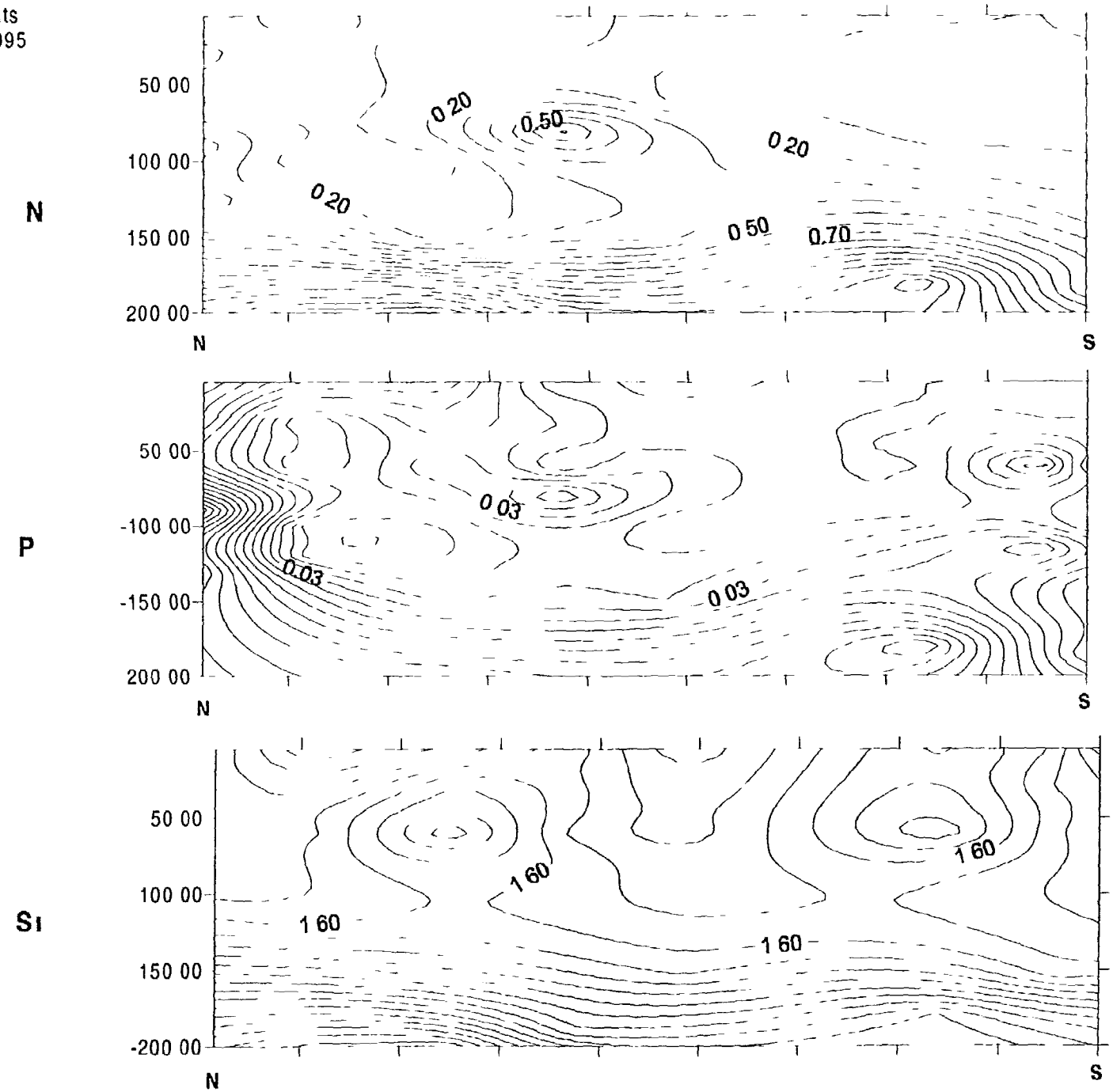


figure 22

142

May 95
Nutrients
Middle

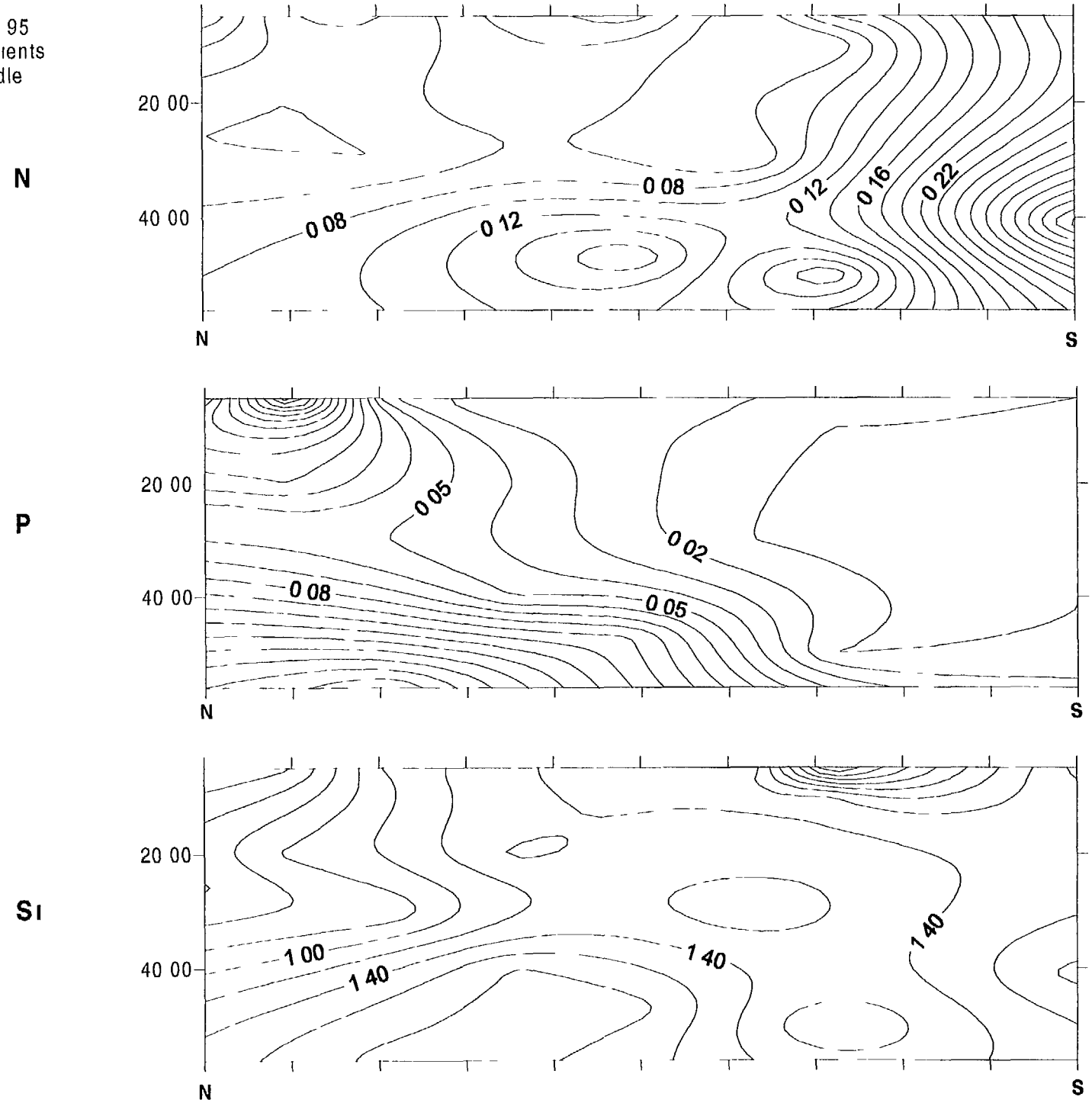


figure 23

May 1995
Nutrients
Shallow

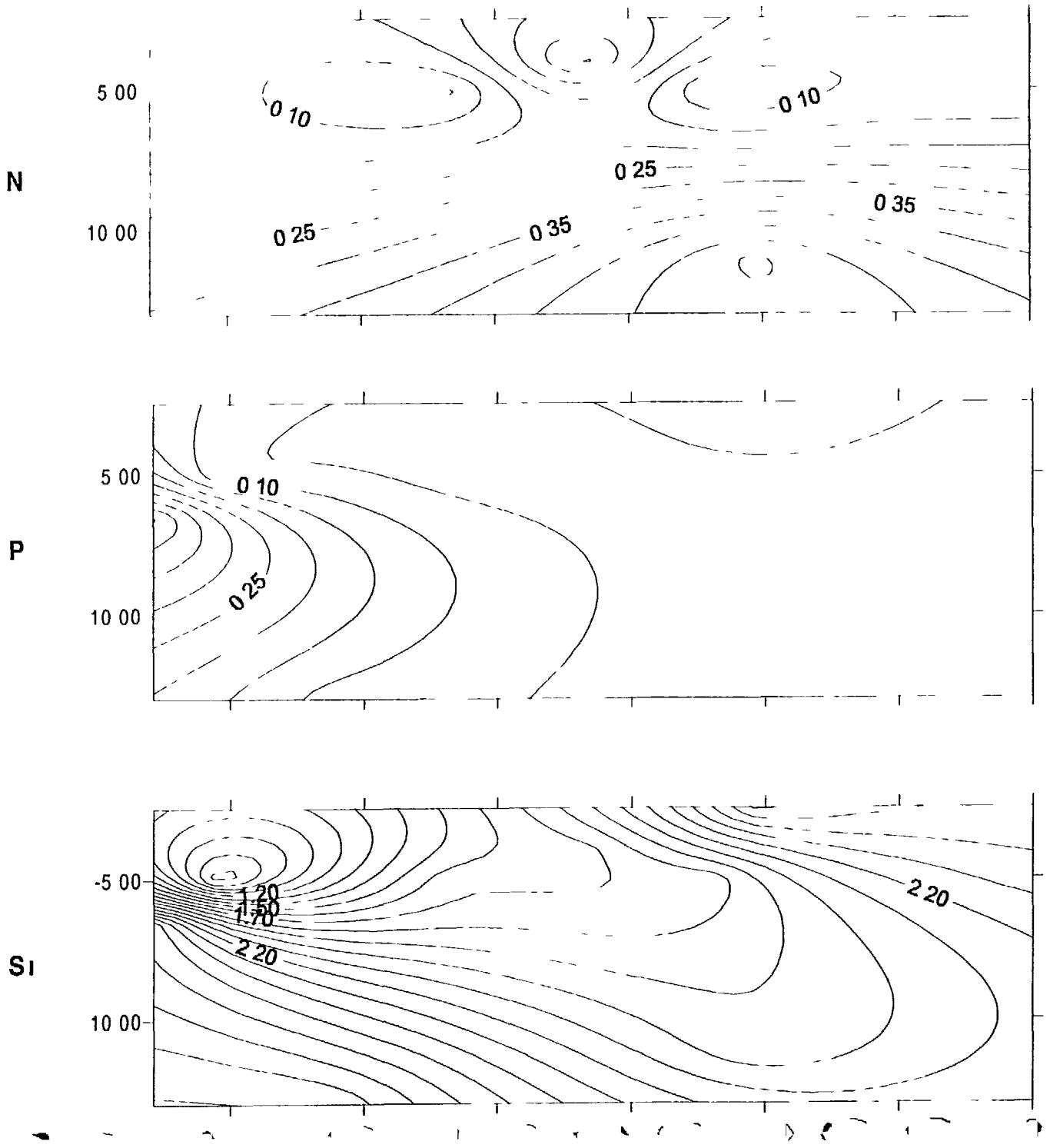


figure 24

May 1995
Chlorophyll

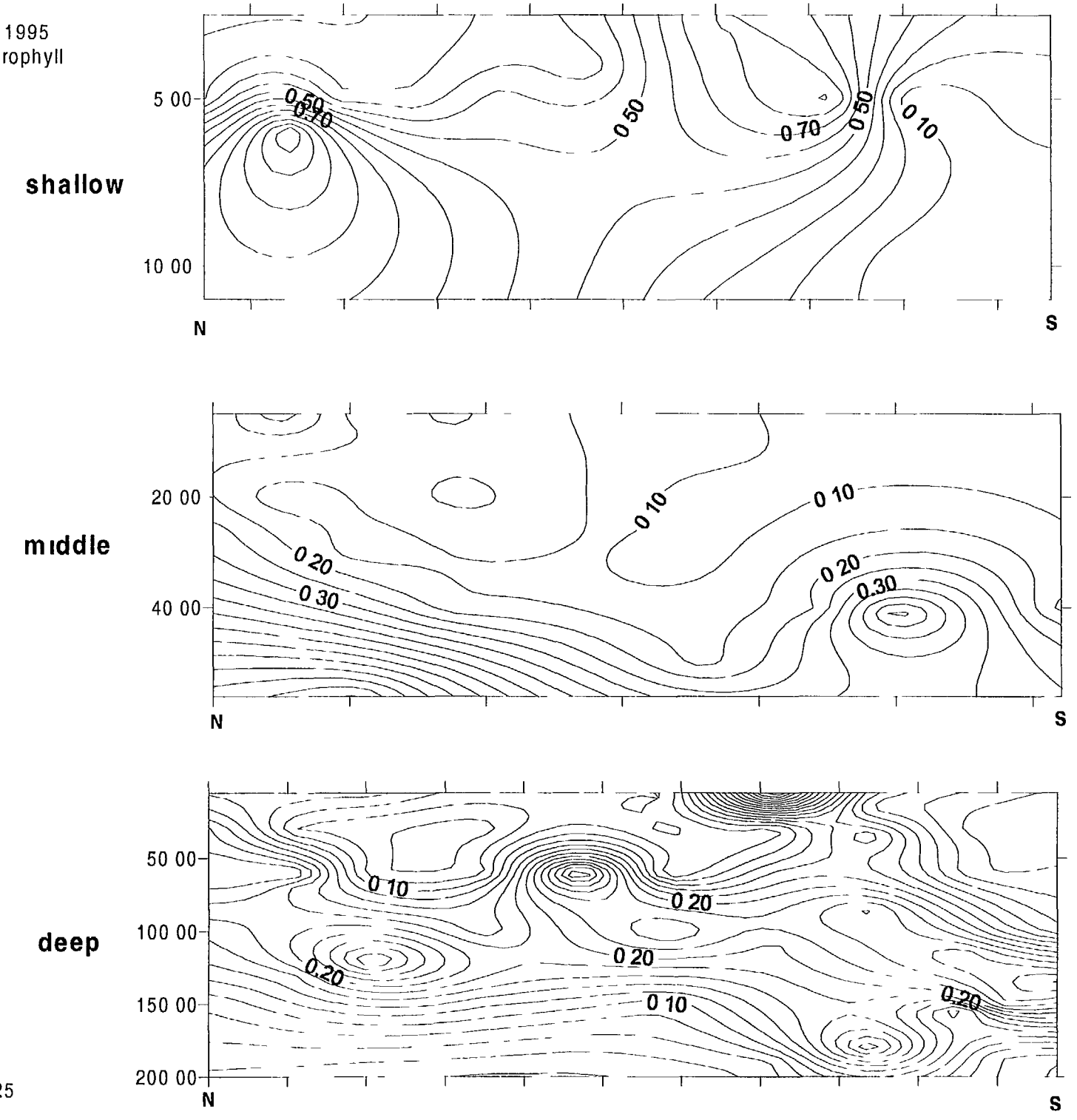


figure 25

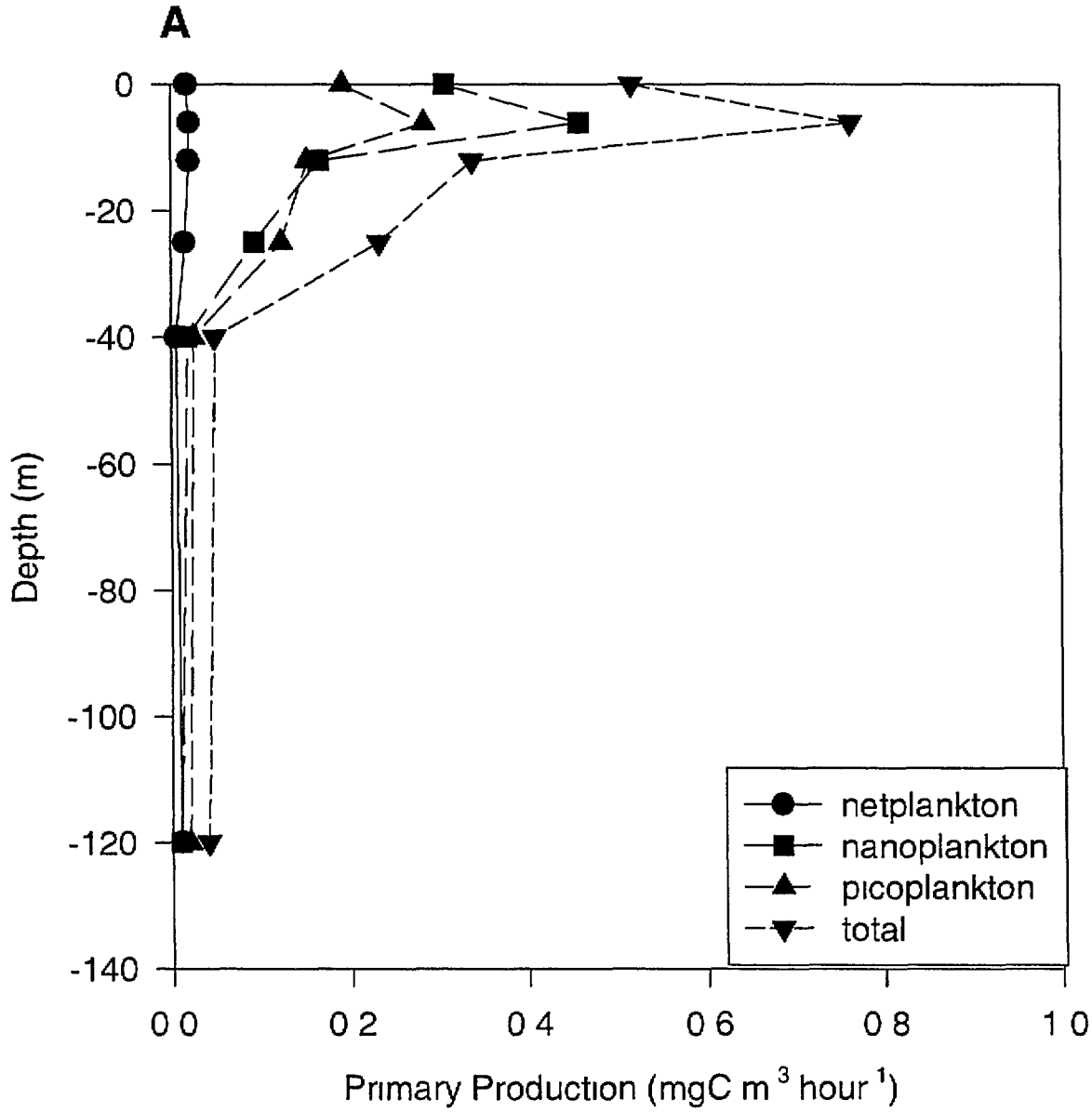

A
0
-20
-40
-60
-80
-100
-120
-140
Depth (m)
0 0
0 2
0 4
0 6
0 8
1 0
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 26A

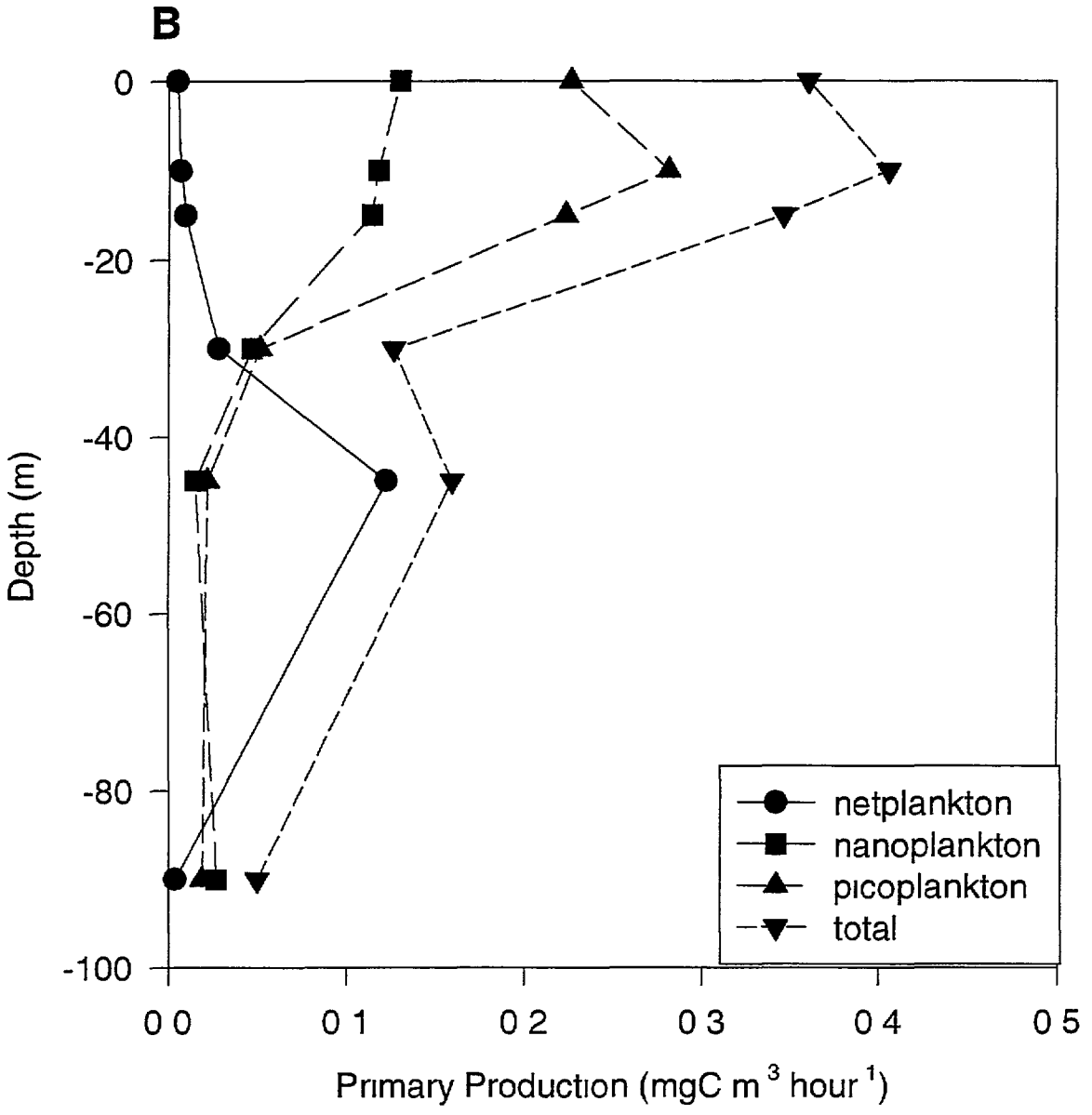

B
0
-20
-40
-60
-80
-100
Depth (m)
0 0
0 1
0 2
0 3
0 4
0 5
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 26B

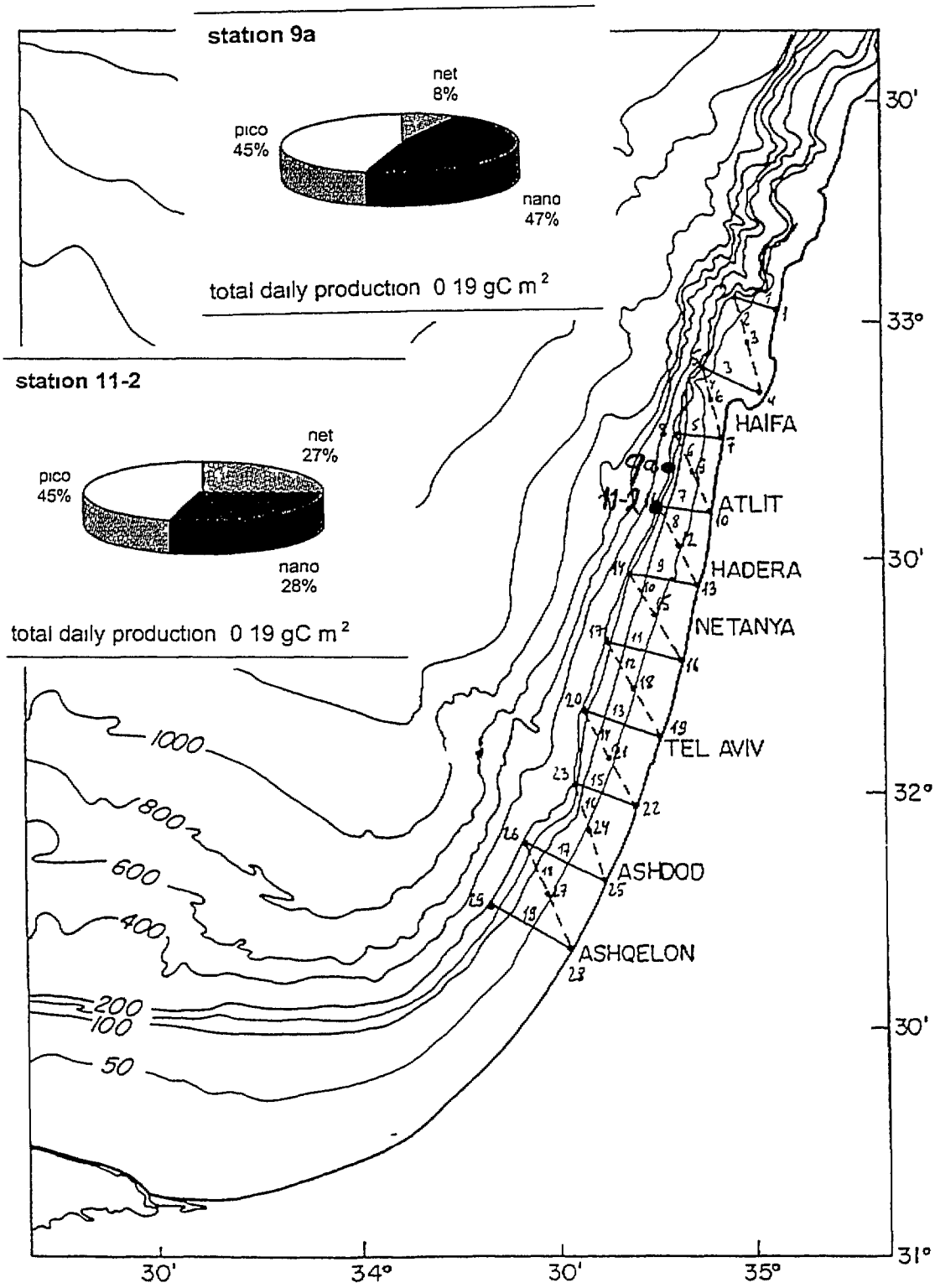

station 9a
net
8%
pico
45%
nano
47%
total daily production 0 19 gC m 2
station 11-2
net
27%
pico
45%
nano
28%
total daily production 0 19 gC m 2
HAIFA
ATLIT
HADERA
NETANYA
TEL AVIV
ASHDOD
ASHQELON
1000
800
600
400
200
100
50
30'
33°
30'
32°
30'
31°
30'
34°
30'
35°

Figure 27

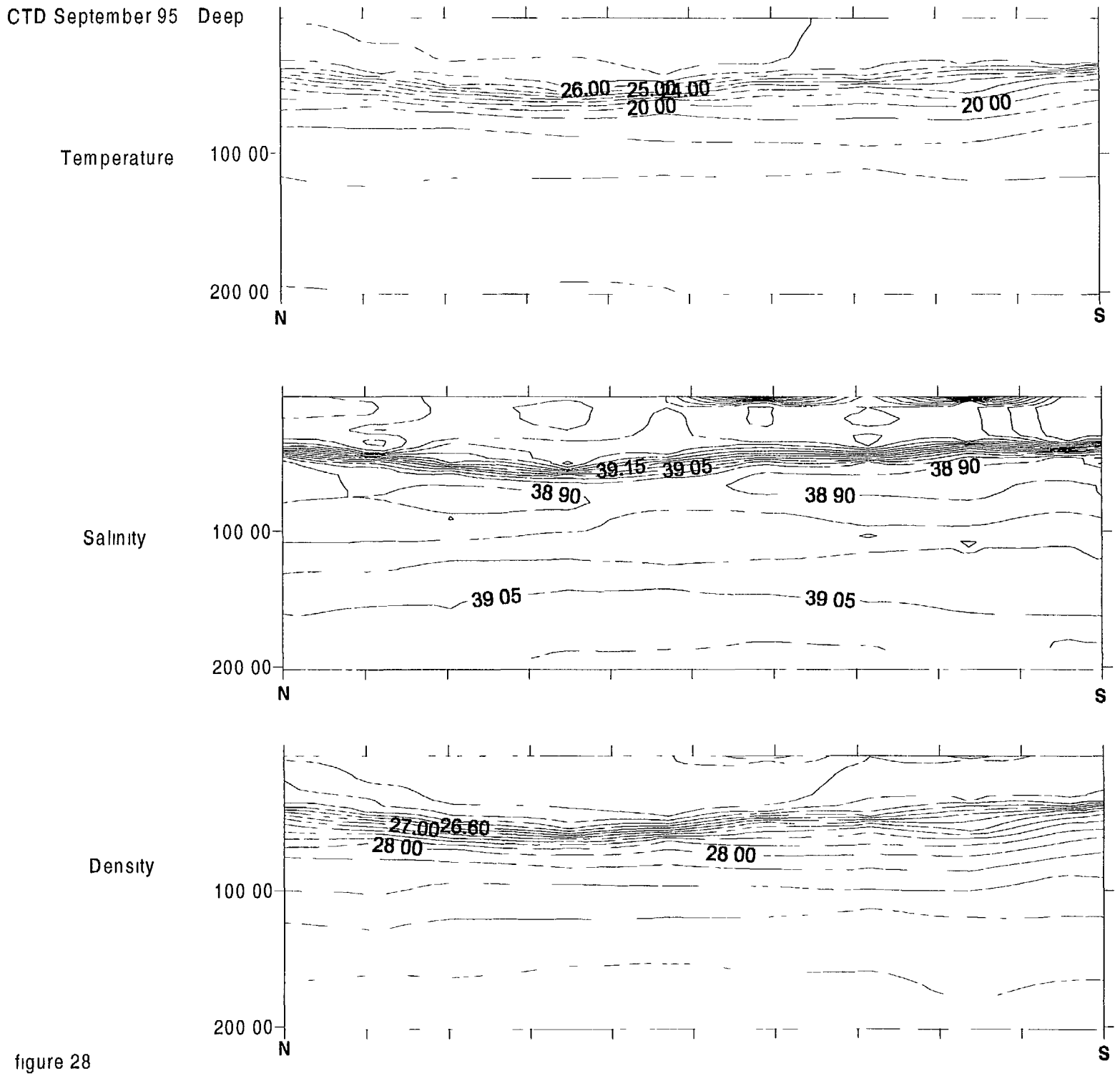

CTD September 95 Deep
Temperature
100 00
200 00
N
S
26.00
25.00
24.00
20 00
20 00
Salinity
100 00
200 00
N
S
39.15
39 05
38 90
38 90
38 90
39 05
39 05
Density
100 00
200 00
N
S
27.00
26.60
28 00
28 00

figure 28

CTD September 95 Middle

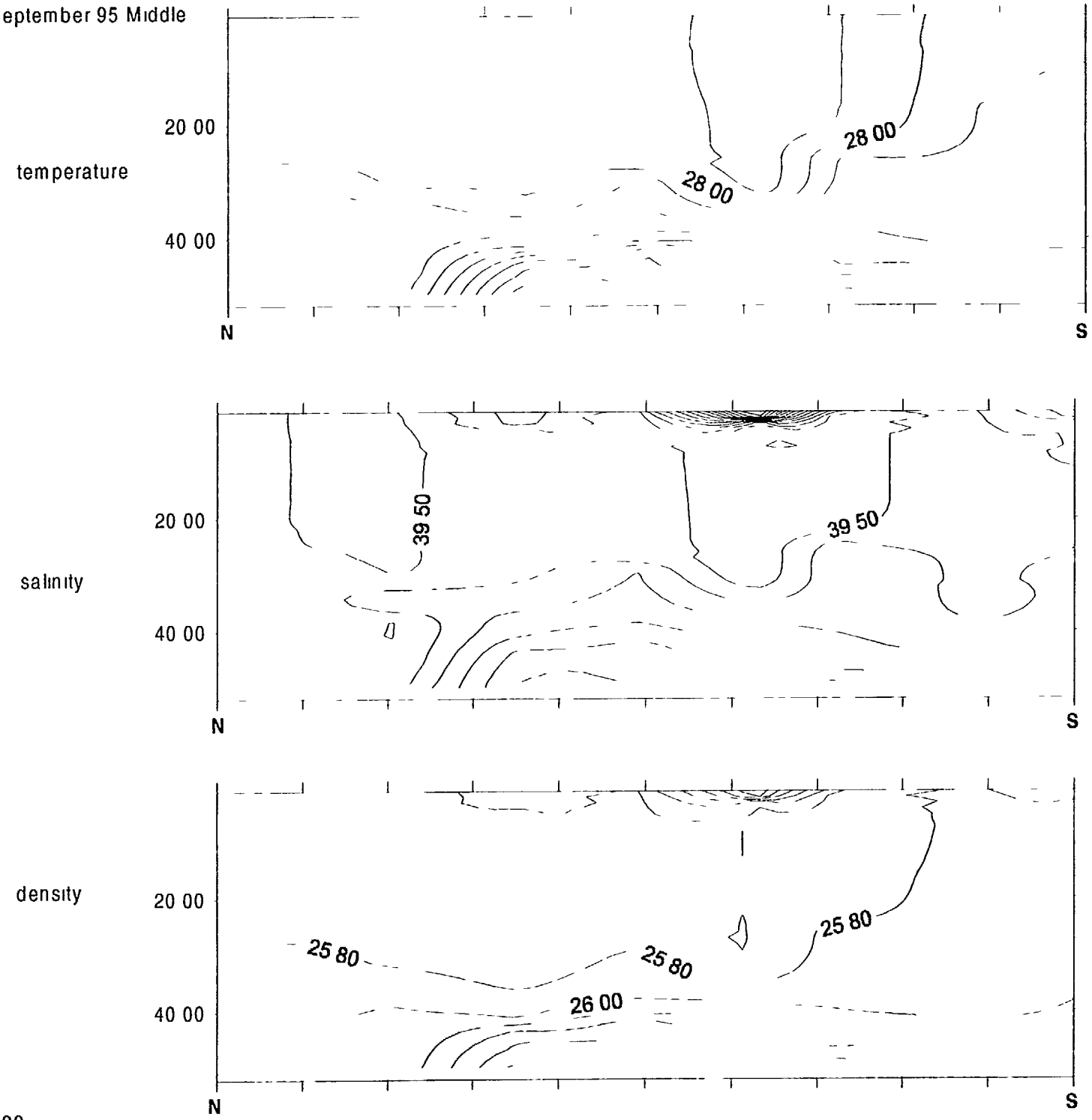


figure 29

ctd september 95
shallow

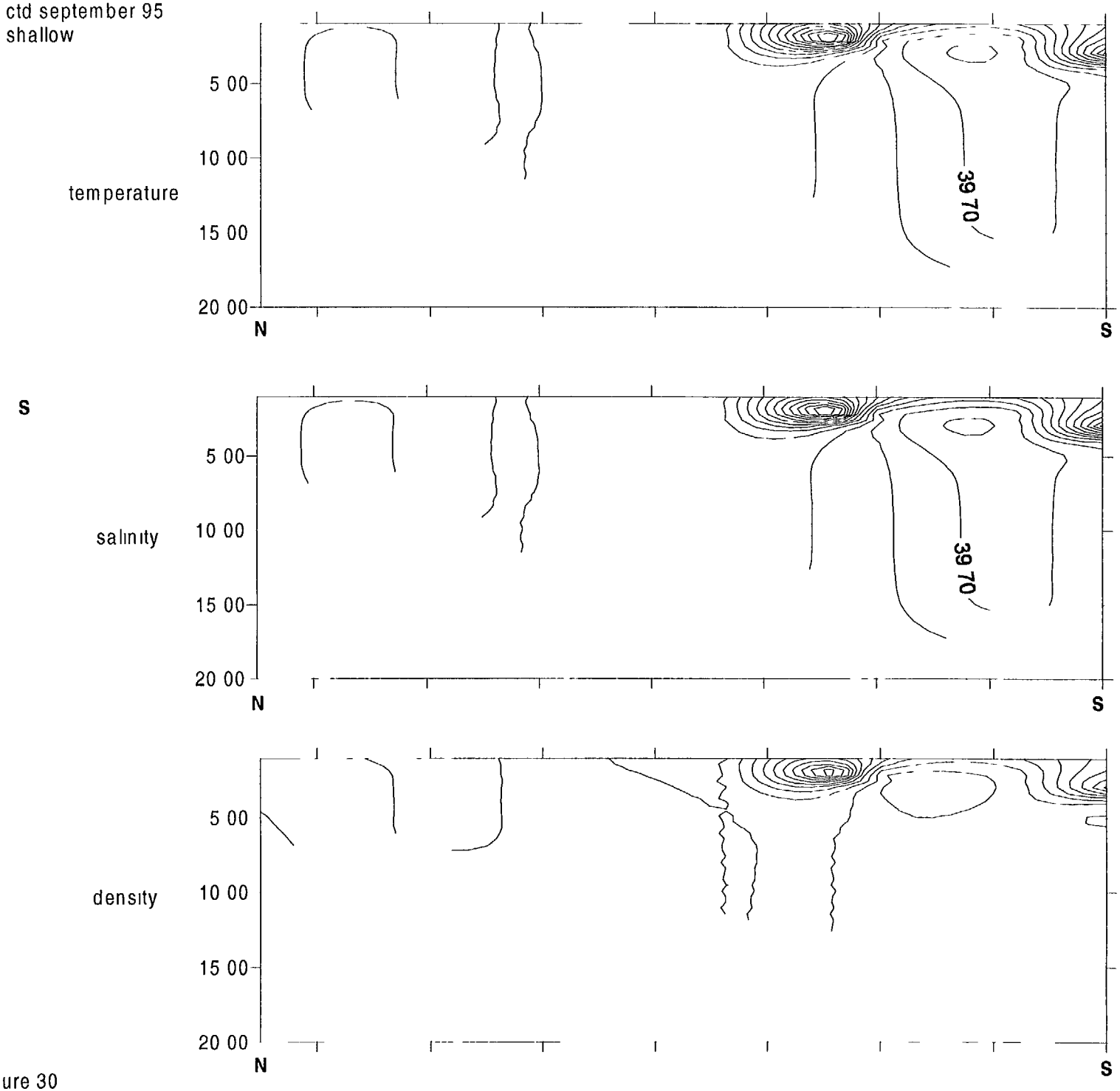


figure 30

September 95
Nutrients
Deep

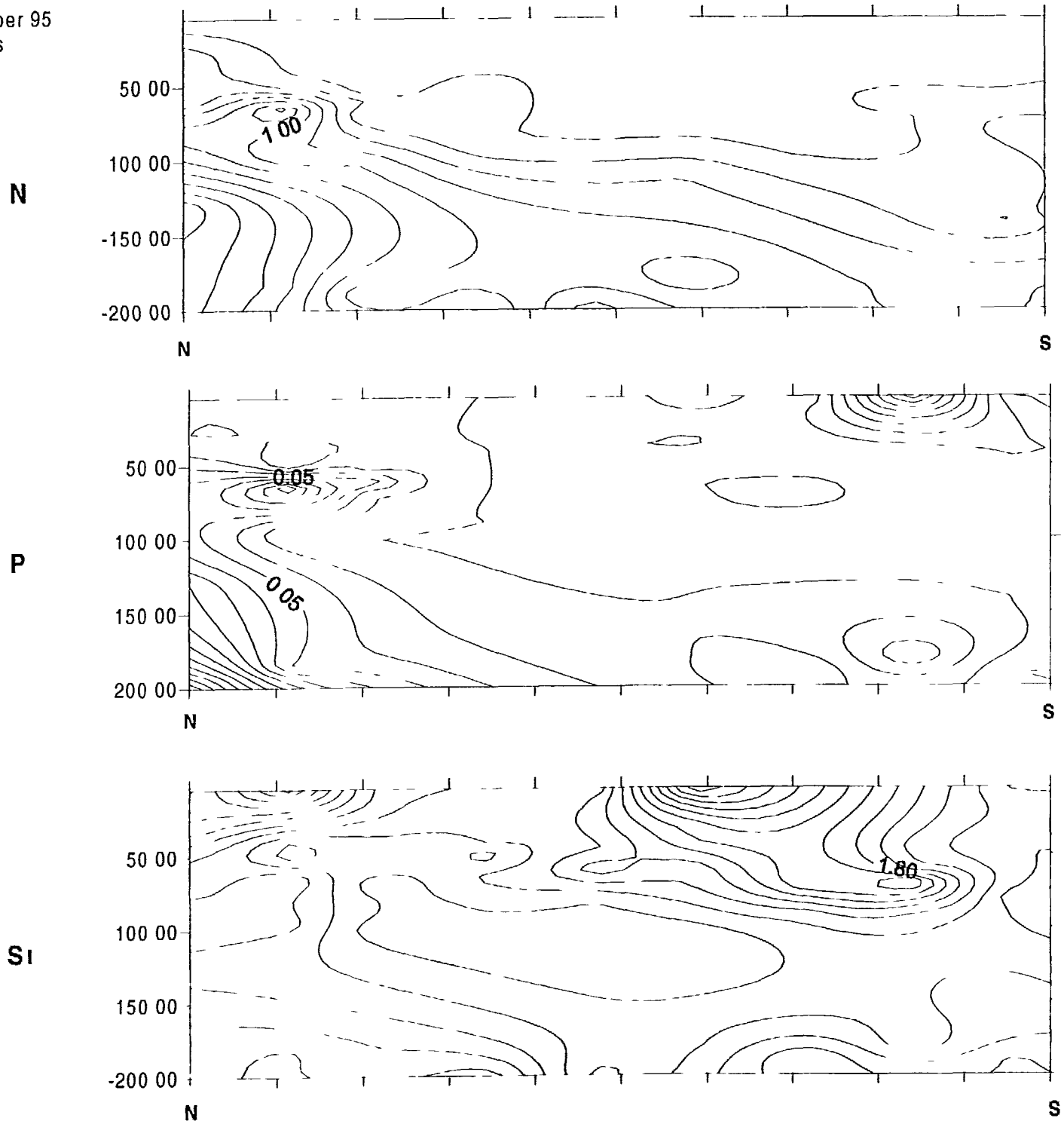


figure 31

September95
Nutrients
Middle

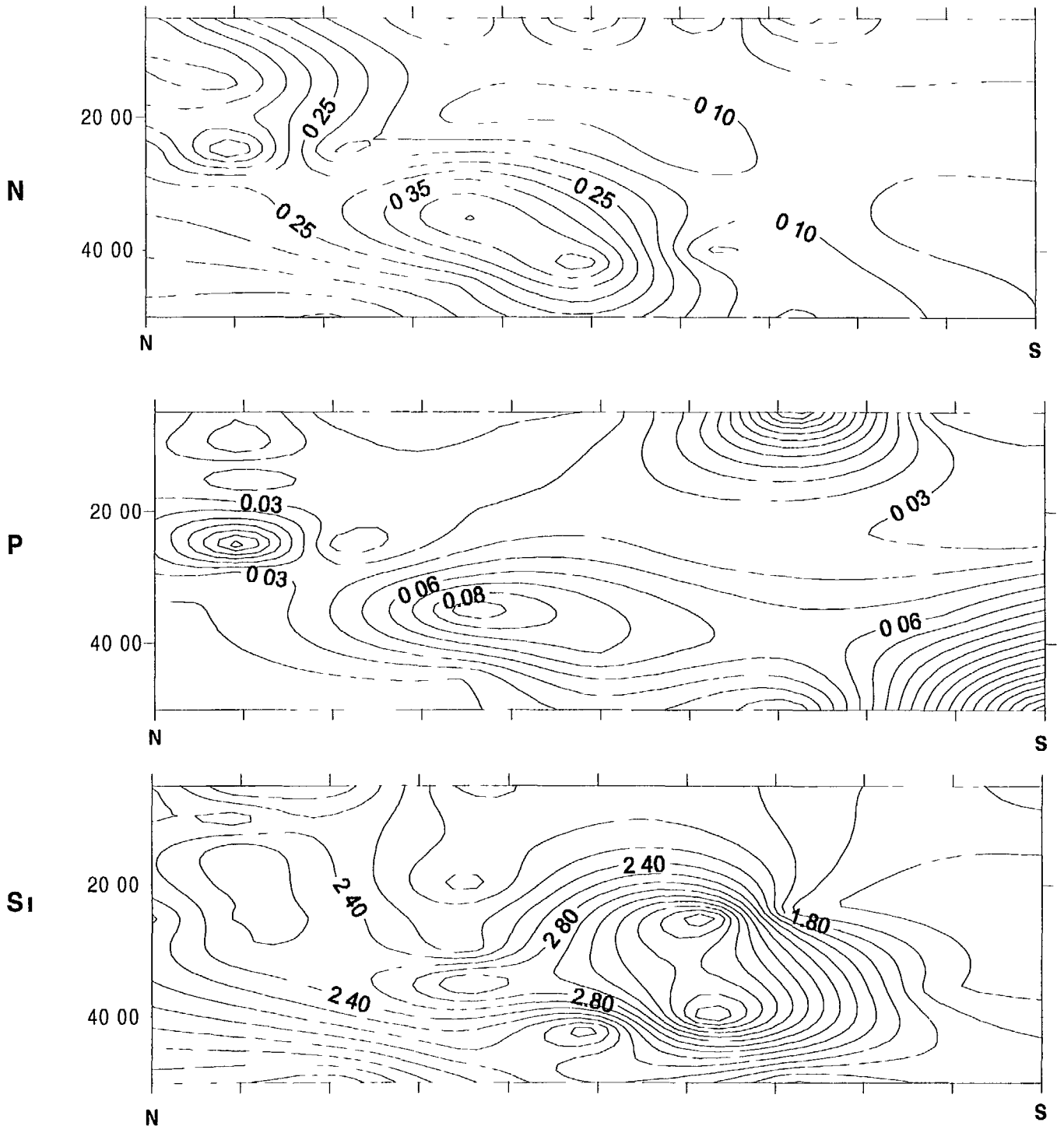


figure 32

September95
Nutrients
Shallow

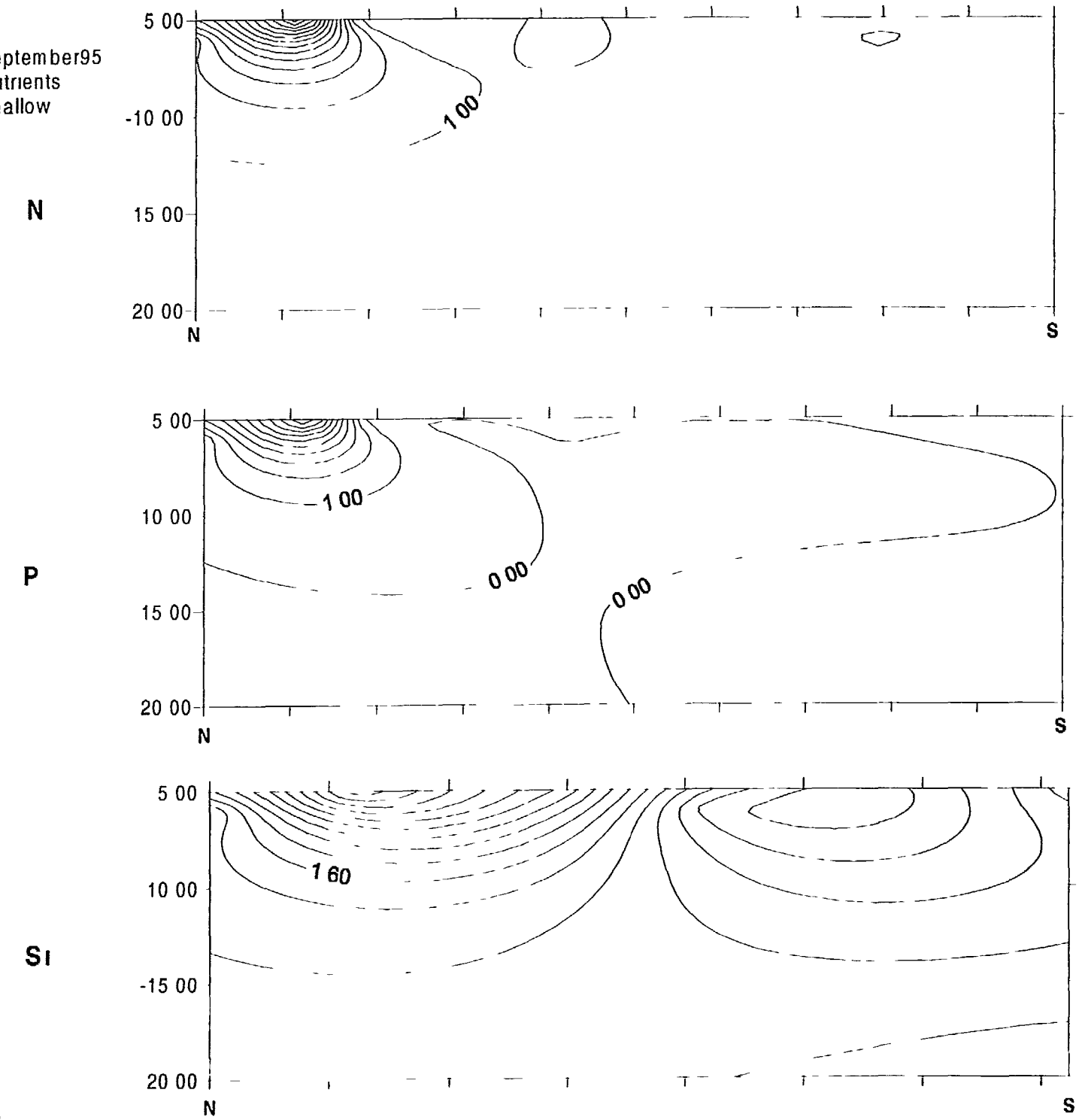


figure 33

September 1995
Chlorophyll

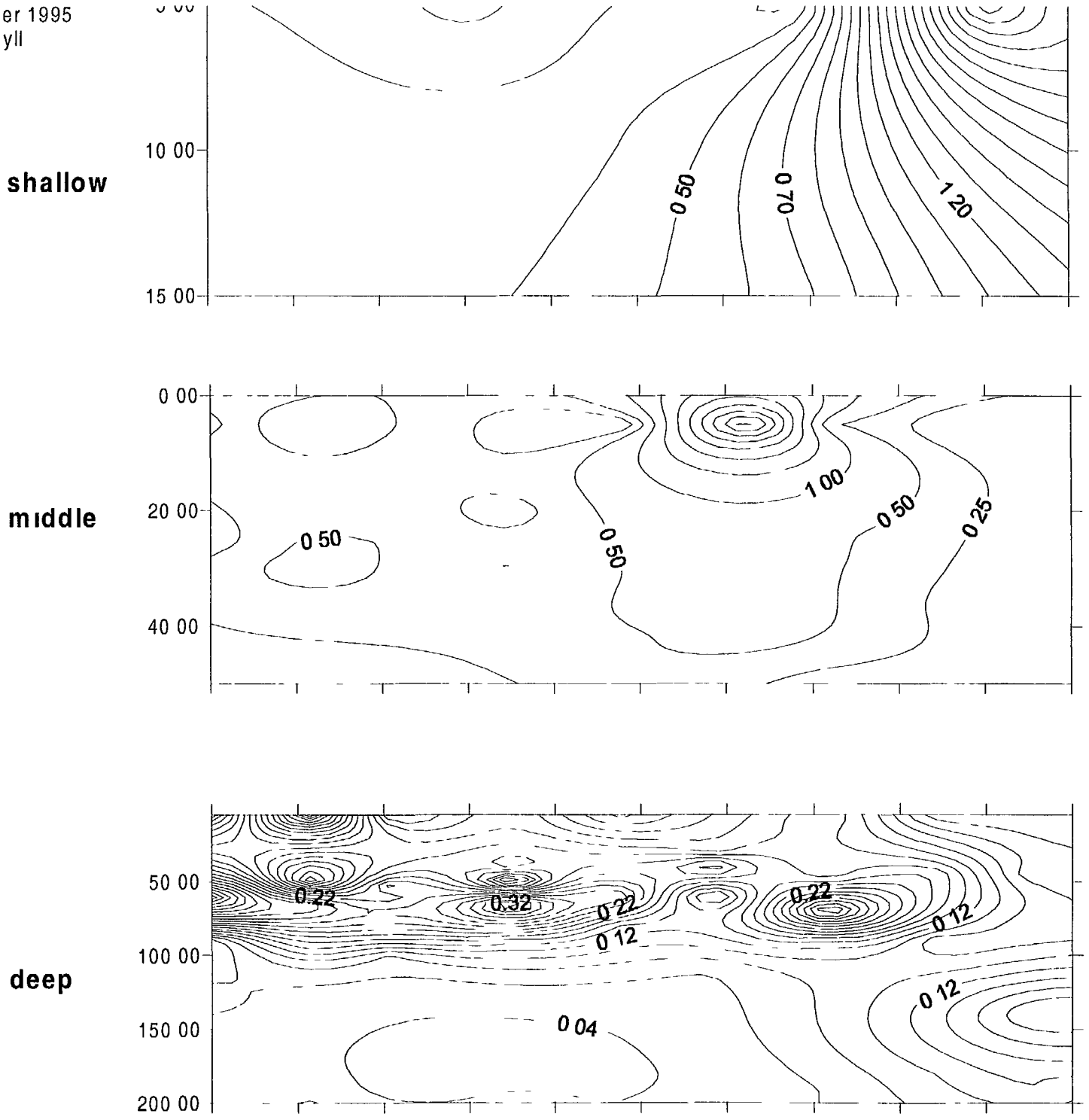


figure 34

151

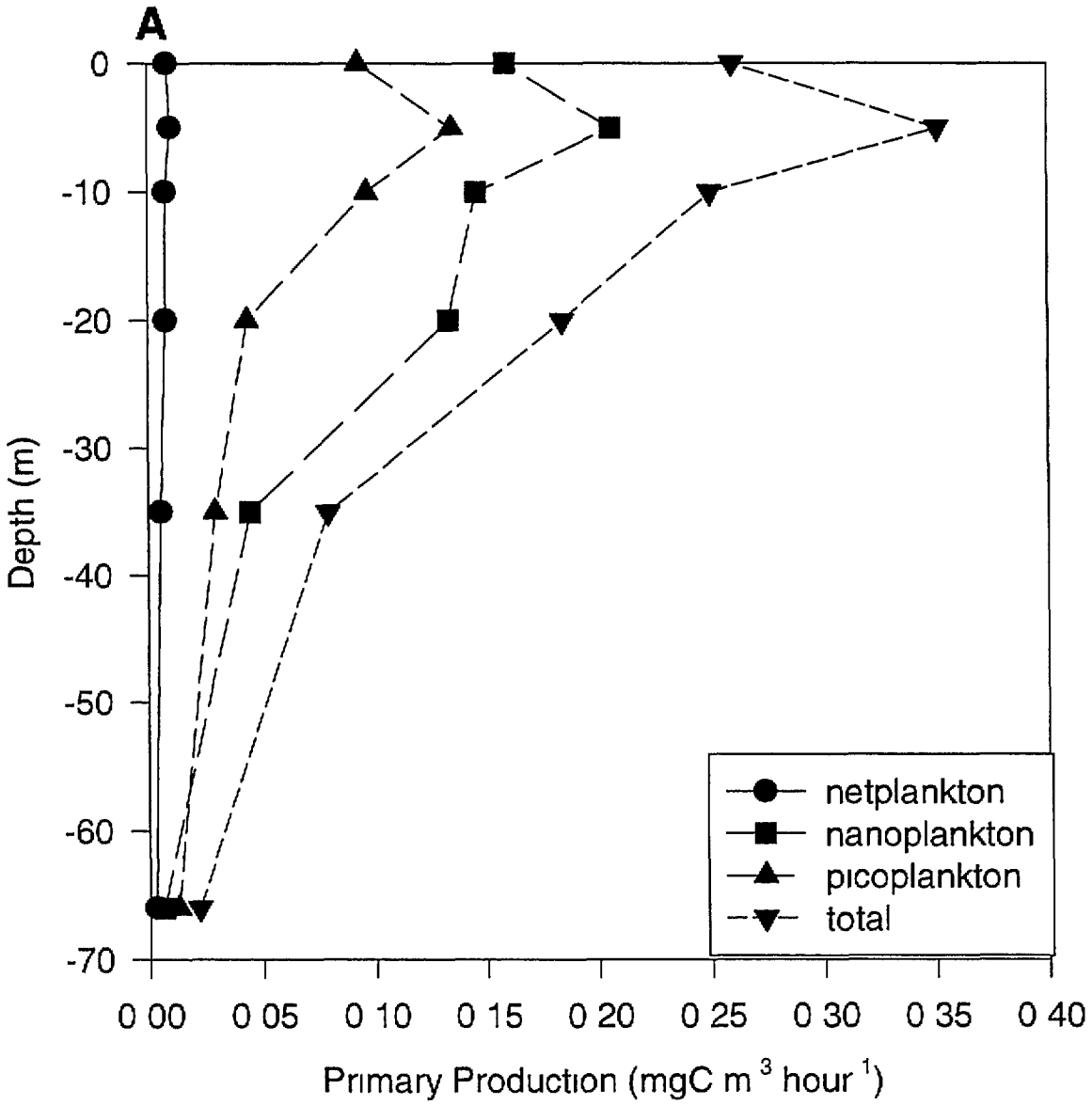

A
0
-10
-20
-30
-40
-50
-60
-70
Depth (m)
0 00
0 05
0 10
0 15
0 20
0 25
0 30
0 35
0 40
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 35A

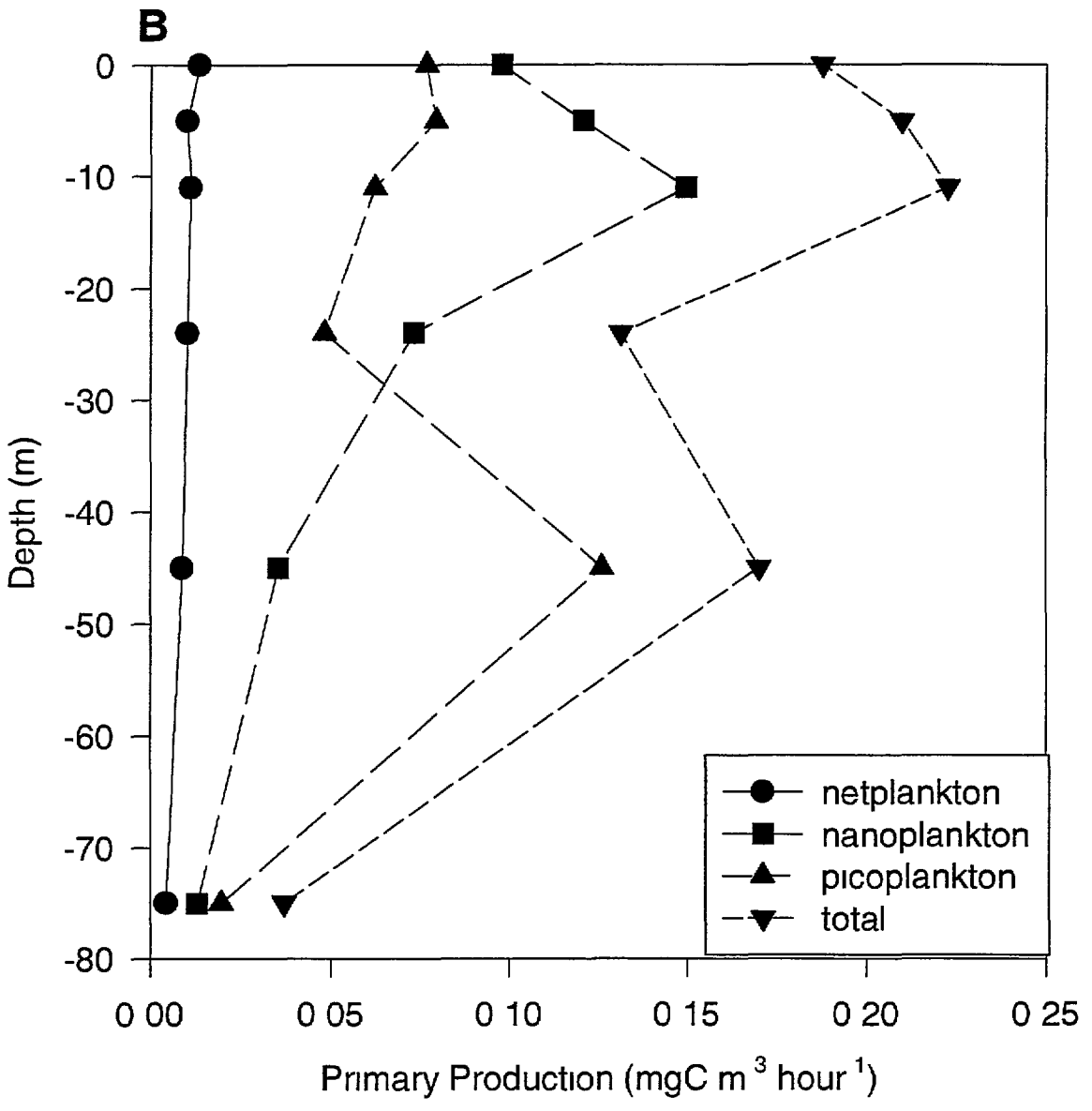

B
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth (m)
0 00
0 05
0 10
0 15
0 20
0 25
Primary Production (mgC m 3 hour 1)
netplankton
nanoplankton
picoplankton
total

Figure 35B

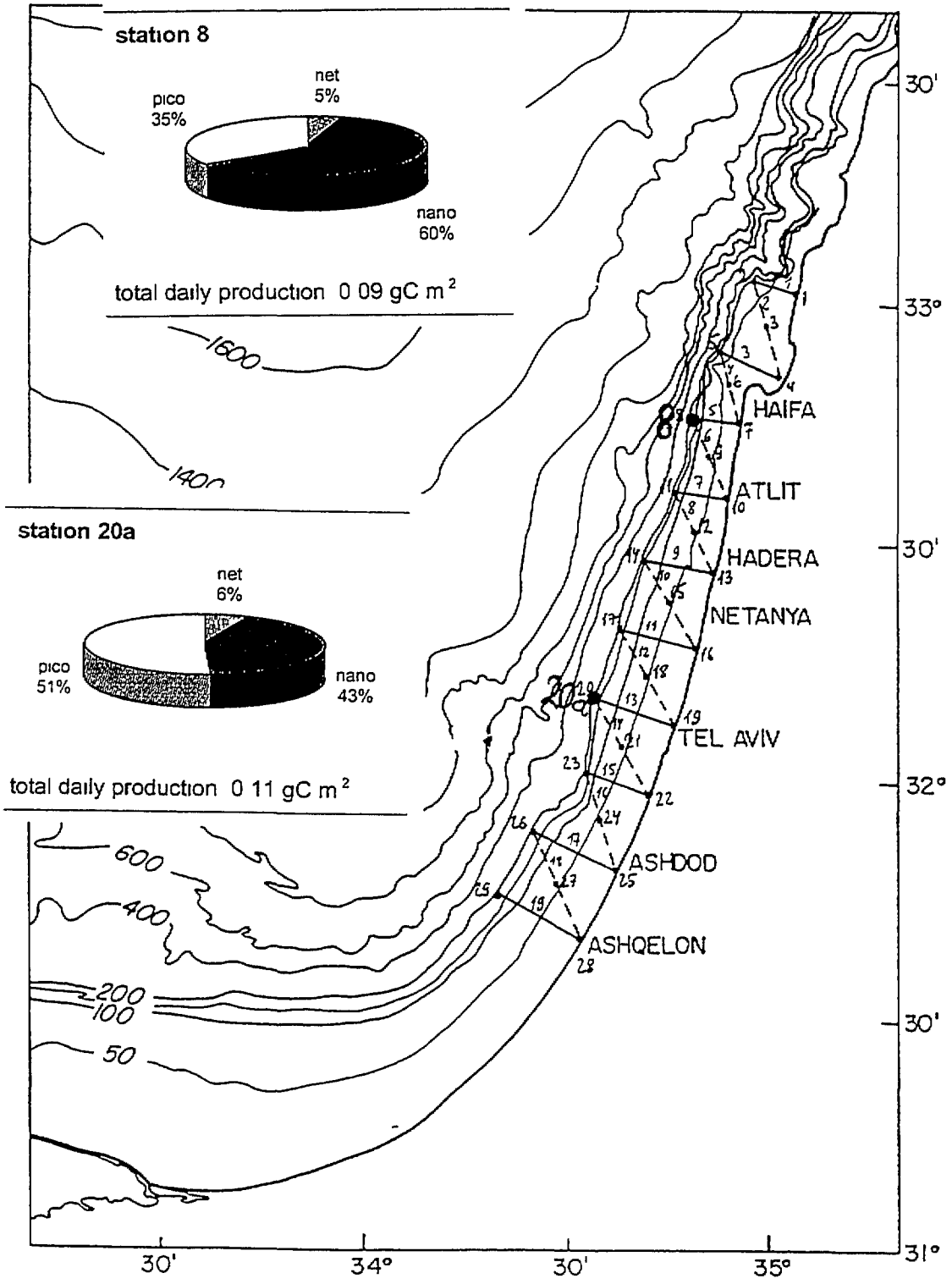

station 8
pico
35%
net
5%
nano
60%
total daily production 0 09 gC m 2
1600
1400
station 20a
net
6%
pico
51%
nano
43%
total daily production 0 11 gC m 2
600
400
200
100
50
HAIFA
ATLIT
HADERA
NETANYA
TEL AVIV
ASHDOD
ASHQELON
30'
33°
30'
32°
30'
31°
30'
34°
30'
35°

Figure36

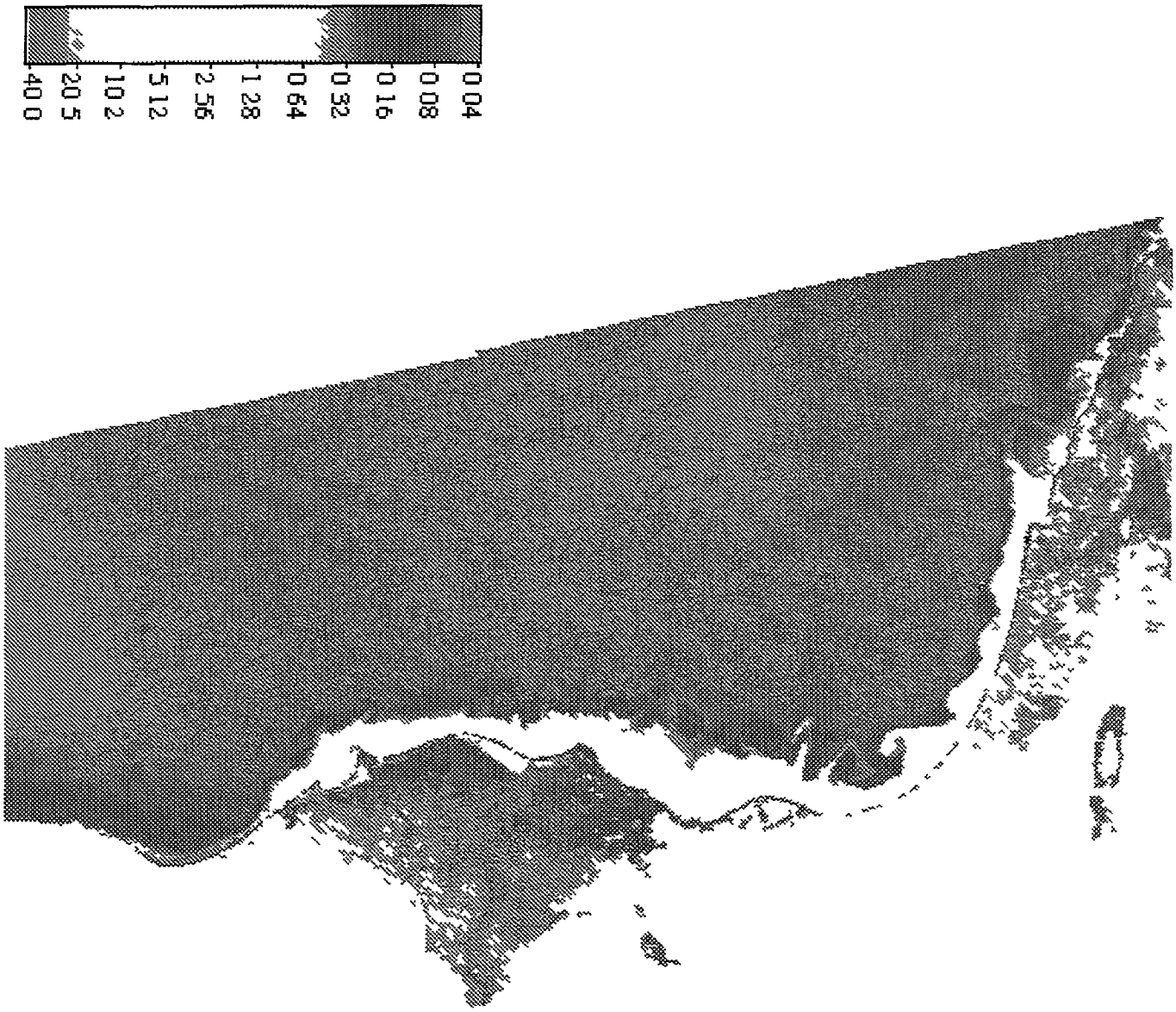


Figure 37

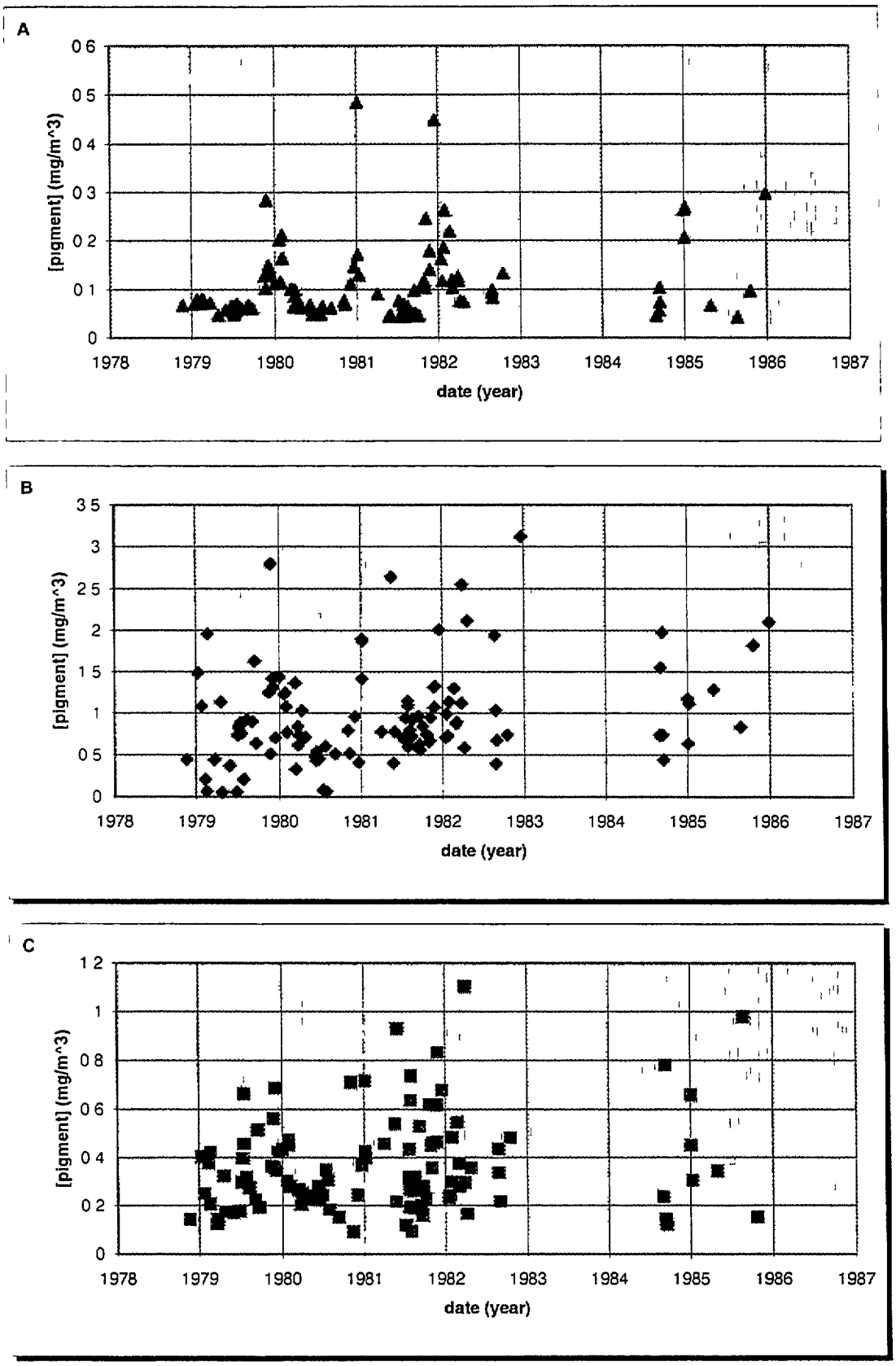

A
0 6
0 5
0 4
0 3
0 2
0 1
0
[pigment] (mg/m^3)
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
date (year)
B
3 5
3
2 5
2
1 5
1
0 5
0
[pigment] (mg/m^3)
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
date (year)
C
1 2
1
0 8
0 6
0 4
0 2
0
[pigment] (mg/m^3)
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
date (year)

Figure 38

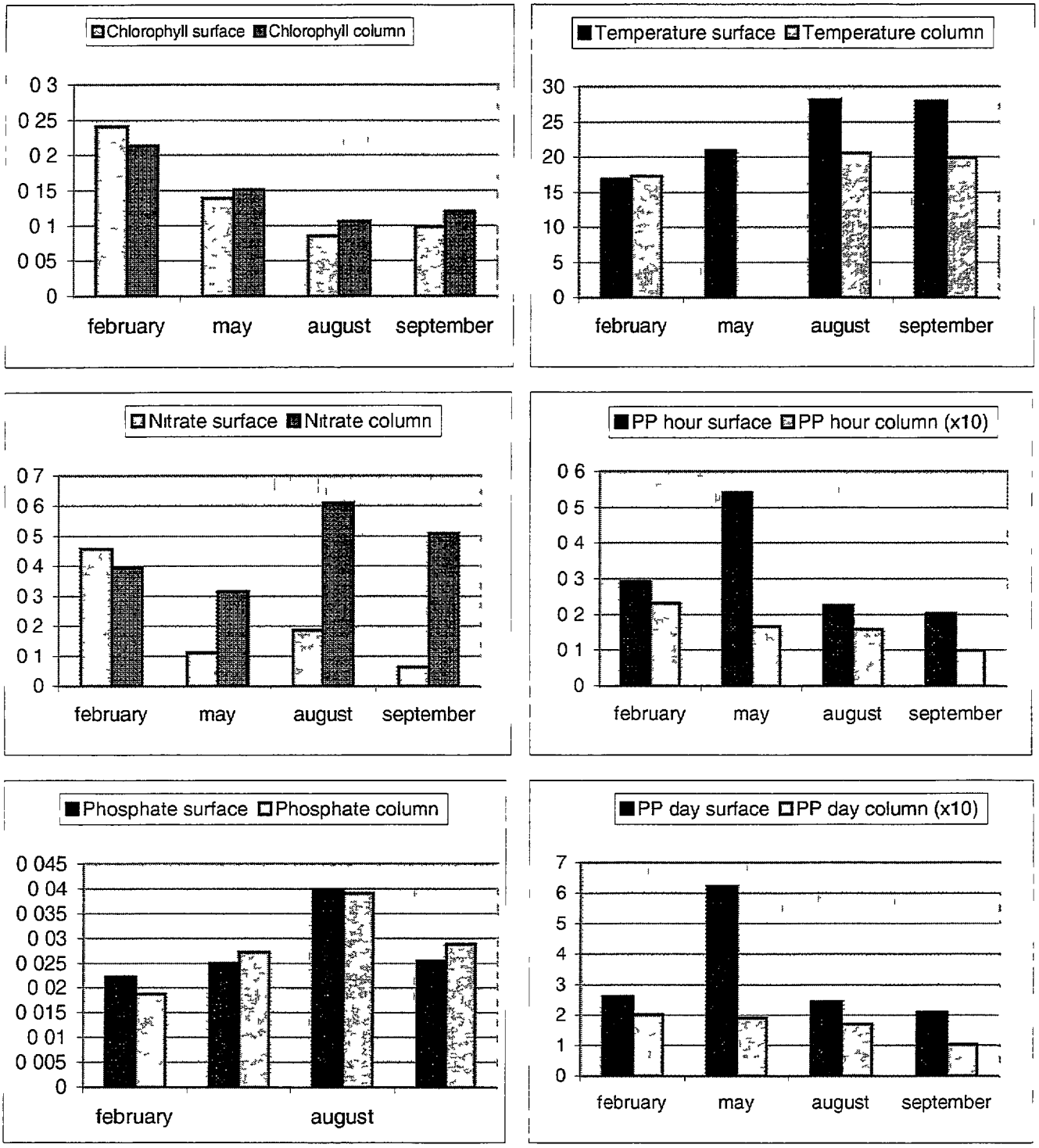
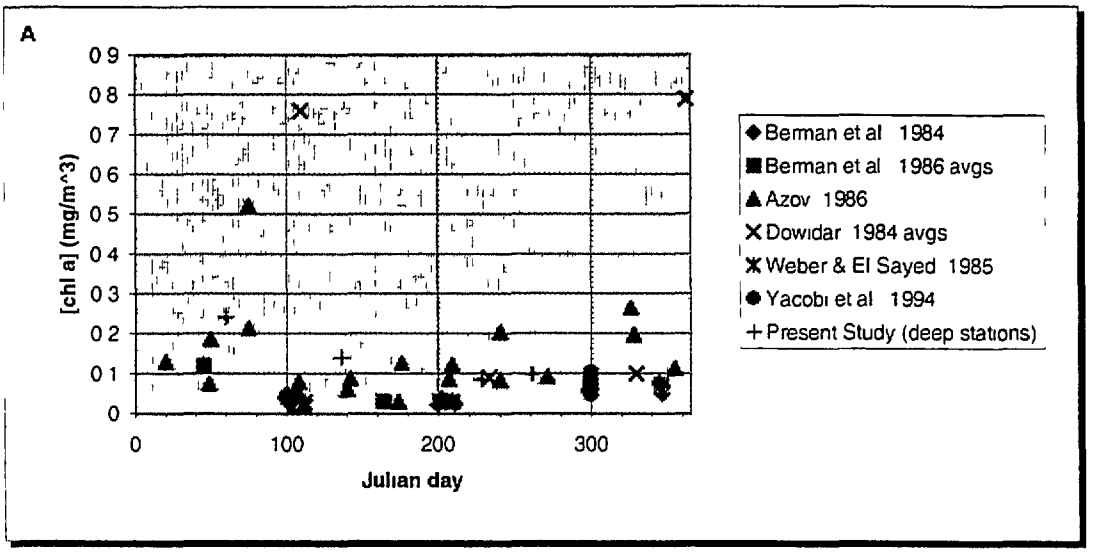

Chlorophyll surface
Chlorophyll column
0 3
0 25
0 2
0 15
0 1
0 05
0
february
may
august
september
Temperature surface
Temperature column
30
25
20
15
10
5
0
february
may
august
september
Nitrate surface
Nitrate column
0 7
0 6
0 5
0 4
0 3
0 2
0 1
0
february
may
august
september
PP hour surface
PP hour column (x10)
0 6
0 5
0 4
0 3
0 2
0 1
0
february
may
august
september
Phosphate surface
Phosphate column
0 045
0 04
0 035
0 03
0 025
0 02
0 015
0 01
0 005
0
february
august
PP day surface
PP day column (x10)
7
6
5
4
3
2
1
0
february
may
august
september

Figure 39


A
0 9
0 8
0 7
0 6
0 5
0 4
0 3
0 2
0 1
0
[chl a] (mg/m^3)
0
100
200
300
Julian day
Berman et al 1984
Berman et al 1986 avgs
Azov 1986
Dowidar 1984 avgs
Weber & El Sayed 1985
Yacobi et al 1994
Present Study (deep stations)

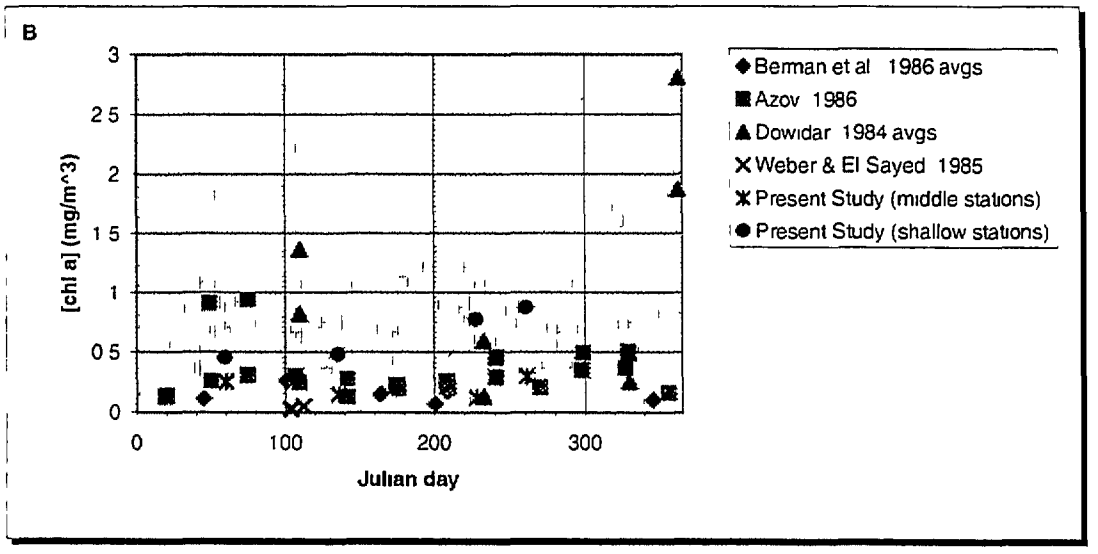

B
3
2 5
2
1 5
1
0 5
0
[chl a] (mg/m^3)
0
100
200
300
Julian day
Berman et al 1986 avgs
Azov 1986
Dowidar 1984 avgs
Weber & El Sayed 1985
Present Study (middle stations)
Present Study (shallow stations)

Figure 40

V INVESTIGATIONS OF LAKE ECOSYSTEMS IN ISRAEL AND EGYPT WITH IMPLICATIONS FOR FISHERIES AND WATER QUALITY MANAGEMENT

V INVESTIGATIONS OF LAKE ECOSYSTEMS IN ISRAEL AND EGYPT WITH IMPLICATIONS FOR FISHERIES AND WATER QUALITY MANAGEMENT

V-1 Lake Kinneret (Israel)

Principal Investigators: M Gophen, P Walline
Cooperating Investigators I Ostrovsky, J Easton, B Azoulay and I Kalikhman

FINAL REPORT, August 1997

Israel Oceanographic & Limnological Research,
Yigal Allon Kinneret Limnological Laboratory
P O Box 345, Tiberias, Israel

164

Table of Contents

I	Abstract	68
II	Introduction	69
III	Temporal changes of zooplankton biomass	71
IV	Invasion of the Kinneret pelagial by three zooplankters	71
V	The autecology and life cycle of the planktonic copepod *Eudiaptomus* cf *drieschi* (Copepoda, Calanoida), a recent invader of Lake Kinneret, Israel	72
VI	Relationships between zooplankton and Kinneret lavnun, *Acanthobrama terraesanctae*	74
VII	The lavnun (sardine) crisis (1993-1997)	76
VIII	Feeding mechanism of *Daphnia* high-speed camera analysis	78
VIIII	Hydroacoustic surveys of the pelagic fish populations of Lake Kinneret	79
X	ECOPATH 3 0 model of the Lake Kinneret ecosystem	81
XI	Summary	83
XII	References	84
XIII	International Cooperation	85
XIV	Publications and presentations	87
XV	Participants	88
XVI	Acknowledgements	88

I Abstract

Zooplankton biomass in Lake Kinneret has undergone a decline until 1993 and has increased gradually since then The 1997 level is similar to the concentrations found in the early 1970's The relative abundance of grazers (Cladocera) increased during 1994-97, as positive development for water quality This improvement is probably due in part to the intensive removal of zooplanktivorous lavnun (Kinneret sardines) In 1992 the number of lavnun in the lake reached an all-time low Immediately afterward, the population increased dramatically, but nearly all were of sub-commercial size A recommendation was made to subsidize the removal of sub-commercial sized lavnun Following the adoption of this recommendation, zooplankton biomass increased and grazing pressure on phytoplankton intensified

During the last 10 years three zooplankters previously found only rarely in the benthos invaded the Kinneret pelagial One of these, Eudiaptomus dreischi is presently common during winter months all over the lake Resting eggs of this species are common in the sediments During this project all life cycle stages were identified and the population dynamics of this species were analyzed

In a study of zooplankton migration, we found that they migrate upward at night in summer months and downward slightly at night in winter Lavnun migrate upward at night in all seasons Among the phytoplankton only Peridinium exhibited diel migrations During the stratification period lavnum stayed close to the thermocline during the day Gut content analysis of lavnun indicated that most of the zooplanktonic food was ingested during the day and only small quantities were taken at night

Analysis made with a high-speed video camera film indicated the patterns of flow through the appendages of Daphnia Some of the water is filtered and some is not Filtration takes place in the combs of the thoracic legs 3 and 4

Seven complete hydroacoustic surveys were made with the dual-beam system Total number of fish remains at the high level reached initially in 1993 In May 1996 total numbers reached the highest levels observed so far (381 x 106) Special net sampling accompanied acoustic surveys, and allowed calibration of the system so that biomass could be calculated from acoustic data Results indicate a biomass of 1200 tons in March 1996 and 4700 tons in September 1996 Acoustic surveys indicated that the lavnun dilution program achieved the goal of biomass suppression during the winter-spring season, allowing increased zooplankton biomass and enhanced grazing pressure on phytoplankton during the spring bloom Approximately 2000 tons of lavnun were removed during 1994-1997 As we hypothesized, fish became larger on average during the dilution program and the commercial fishery was renewed

The Ecopath model was implemented for both Lake Qarun and Lake Kinneret Results of the modeling exercise highlighted areas where data was insufficient (i e benthic production in Lake Kinneret) and led to various hypotheses concerning the food webs in the two ecosystems The model emphasized the importance of zooplankton as a consumer of phytoplankton in both systems

II Introduction

Lake Kinneret, Israel, is a warm monomictic lake (total volume 4 302 cubic kilometers, mean depth 26 meters) that exhibits stable stratification during May through mid-December each year and develops an anoxic hypolimnion Subtropical Lake Kinneret is the only natural freshwater lake in Israel, and it feeds the vital National Water Carrier system (NWC) and provides water for irrigation drinking commercial fisheries and recreation Therefore maintaining adequate water quality in the lake is of great national and international concern (Gophen 1992) The lake has been studied intensively for over 3 decades, and a wealth of information exists on its physics chemistry and biology During the period 1969-1991, both algal biomass and rates of primary production showed a consistent seasonal pattern of development within each year of record, although interannual oscillations in these parameters also were evident (Berman *et al* 1992, 1995)

Substantial changes also have occurred in the lake's watershed More than 20 reservoirs (total volume 14 million cubic meters) have been constructed in the drainage basin of Lake Kinneret during the past 27 years altering both the inflow water volume and its chemistry (Gophen *et al* 1990) As a result, nutrient inputs to the lake from the Jordan River have changed significantly One major natural source of nutrients is the peat soil of the Hula Valley, which now is managed by two major canal systems that prevent flooding and also restrict nutrient exports (primarily nitrogen) to Lake Kinneret In addition, the upstream reservoirs further restrict nutrient export by providing for conservation and re-use of domestic sewage effluent and fish pond wastes via farmland irrigation Ammonia and soluble phosphorus concentrations in the Jordan River waters have increased in recent years relative to other forms of nitrogen and phosphorus, and declines occurred in the inorganic N inorganic P ratio (Gophen 1992)

Not surprisingly, significant declines also have occurred in epilimnetic total nitrogen total phosphorus (TN TP) ratios in the lake itself (Gophen *et al* 1990) Because cyanobacteria are considered to be competitively favored over other phytoplankton species by low N P ratios (Schindler 1977 Smith 1983), it was predicted that these changes in Lake Kinneret water chemistry could result in undesirable summer cyanobacterial blooms (Gophen 1992) Consistent with this prediction the phytoplankton community of Lake Kinneret was altered in summers 1994 and 1995

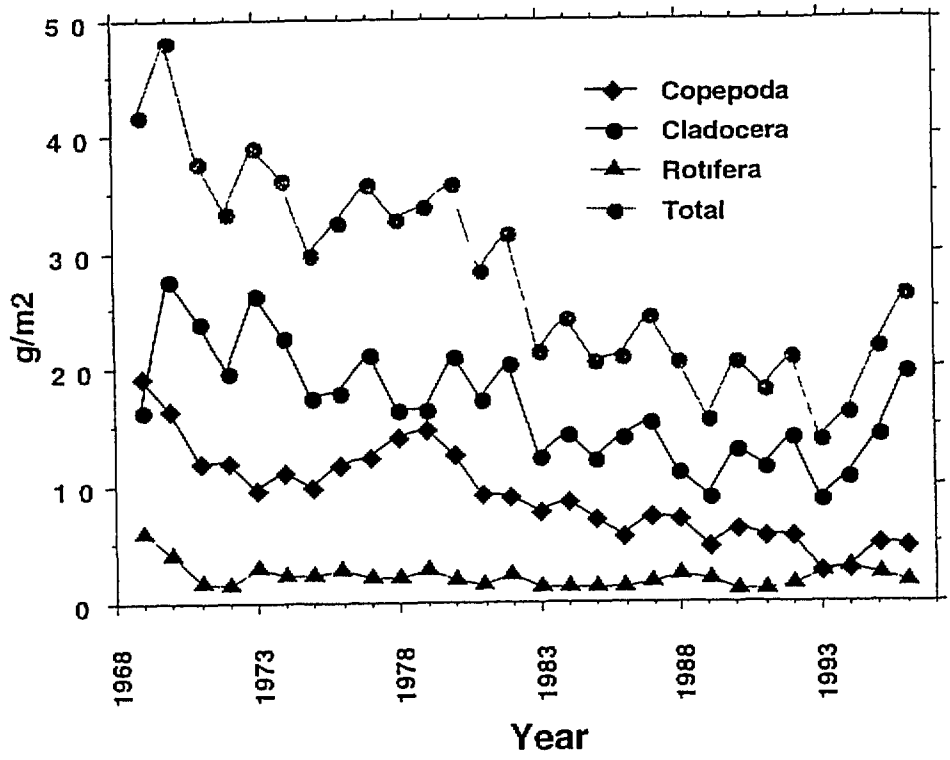
by a lake-wide invasion of the nitrogen-fixing cyanobacterium *Aphanizomenon ovalisporum* (Gophen 1994)

The sudden appearance of *Aphanizomenon ovalisporum* blooms in Lake Kinneret is of great concern because many cyanobacterial species can be toxic to animals and humans (Carmichael 1992), and their presence can necessitate expensive treatment prior to water use (National River Authority 1990) Furthermore, when ecosystem properties are changed by invasions, the basic rules of existence for all other organisms may also be altered (Vitousek 1990) *Aphanizomenon* and other cyanobacteria are typically poor quality food sources for aquatic consumers and their presence can lead to shifts in zooplankton community structure (DeMott *et al* 1992) These changes may potentially occur in Lake Kinneret in the future if cyanobacterial blooms continue

Disturbances to epilimnetic TN TP ratios in Lake Kinneret have created environmental conditions under which blooms of cyanobacteria are now increasingly likely, and suggest that the probability of such blooms will increase significantly if further decreases in the water column TN TP ratio are allowed to occur in the future

The exact mechanisms that are responsible for the changes in N P ratios are not yet well understood, but both external and internal factors may be contributing to the observed trend Reductions in epilimnetic N P ratios may reflect, in part, changes in river-borne nutrient loading that accompanied the major changes in the lake s watershed discussed above However, changes in N and P recycling may also have occurred within the water column of the lake For example, changes in the relative regeneration rates of N and P by epilimnetic zooplankton potentially could play an important role It has been documented that the mean body size of the zooplankton has declined significantly during 1970-1993 largely as a result of intensifying zooplanktivory by sardines and the stocking of several commercially important planktivorous fishes The most important of these fish are the native *Sarotherodon galilaeus*, Jordan Saint Peter s fish *Oreochromis aureus*, the exotic, silver carp, *Hypophthalmichtys molitrix,* and the mullet) Because a reduction in zooplankton body size is often accompanied by reductions in the N P ratio of zooplankton-regenerated nutrients (Elser *et al* 1988), zooplankton-mediated changes in N P stoichiometry could provide a potential biotic mechanism for the observed trends in epilimnetic N P ratios in Lake Kinneret Changes in recycling also may result from interannual variations in the vertical fluxes of N and P and in the rate of denitrification in the metalimnion External N and P loading and fish stocking rates are both controllable, however, and thus can be a practical means for water quality management

In order to prevent further blooms of cyanobacteria in Lake Kinneret and prevent further water quality deterioration, it is important to reverse the observed declines in water column N P ratios This goal could be accomplished by restricting the external phosphorus loading in order to reduce water column TP concentrations If differential nutrient regeneration by zooplankton (Elser



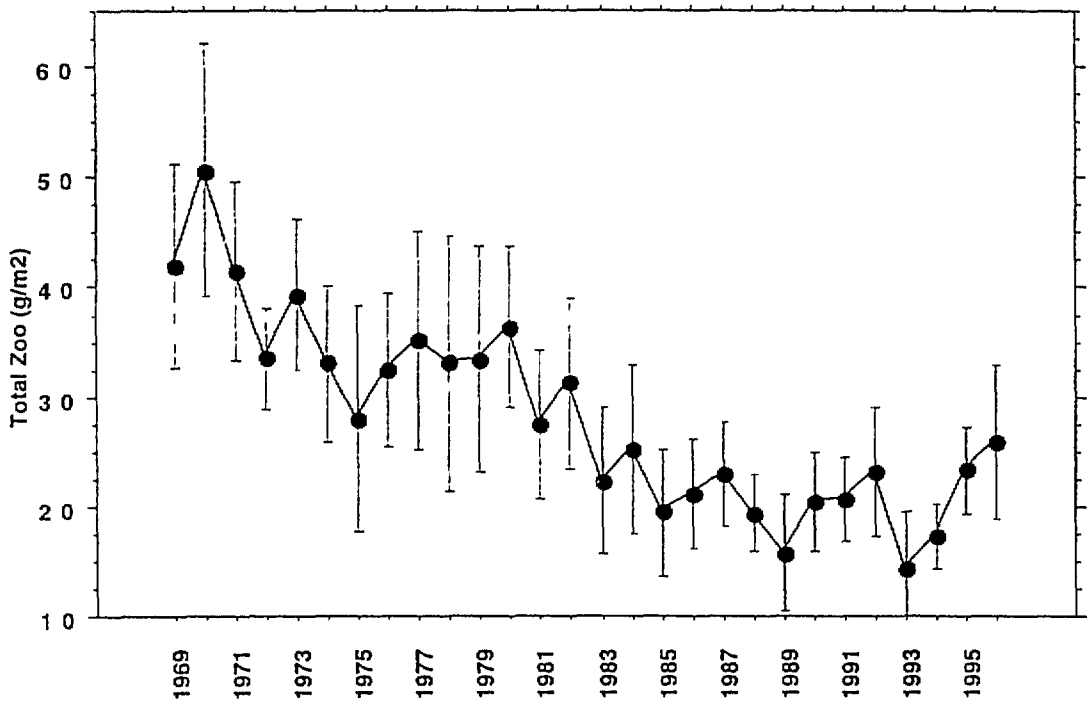


Fig 1 Annual averages of zooplankton biomass (g/m^2) in Lake Kinneret during 1969-1996. Upper panel, 3 groups and total, lower panel, total with error bars (95% confidence interval)

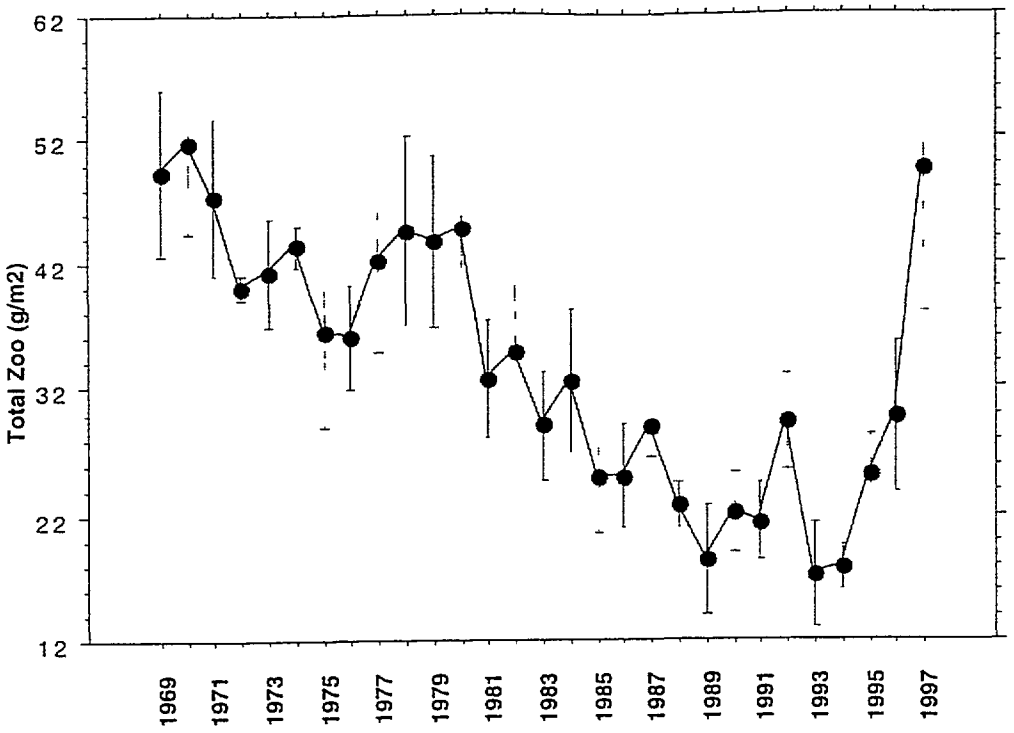


Fig 1a Total zooplankton biomass (g/m^2) Seasonal (I-VI) averages (error bars +SE) during 1969-1997

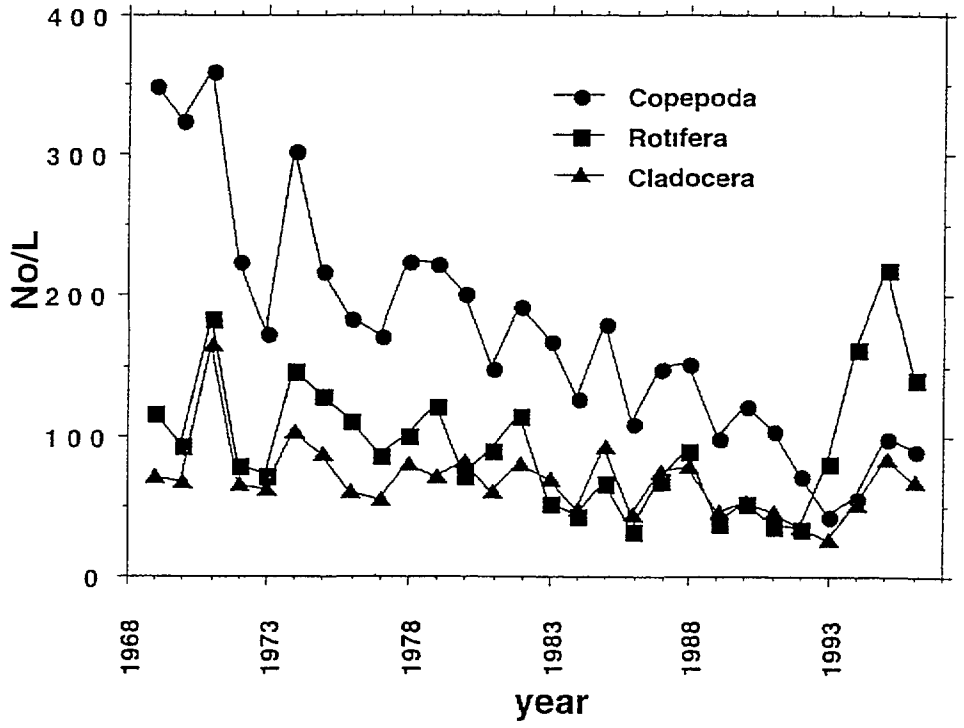


Fig 2 Annual averages of zooplankton group densities (No /L) during 1969-1996

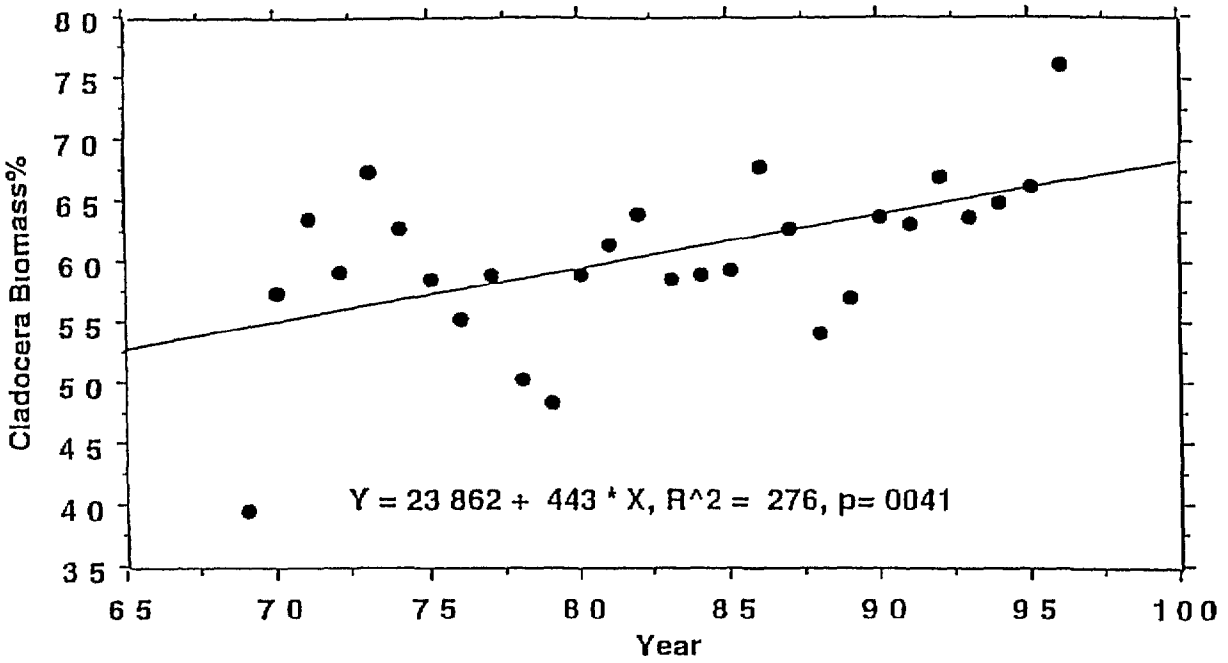


Fig 3 Linear regression between relative (%) abundance of Cladocera biomass of total zooplankton and time (years 1969-1995)

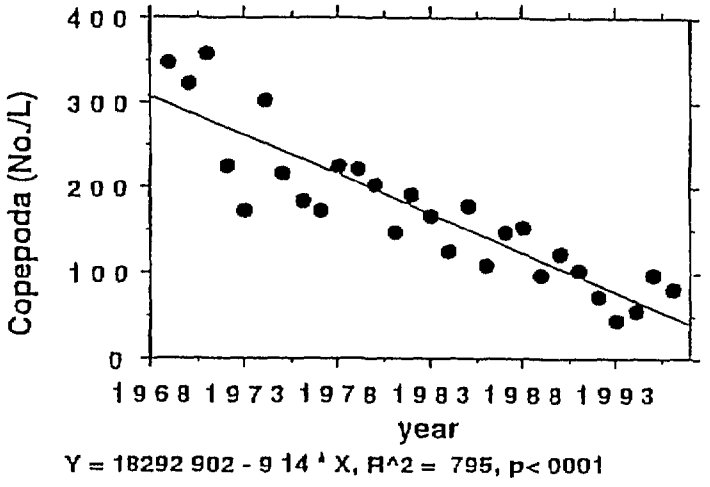


Fig 4 Linear regression between copepods (all stages) densities (No /L) and time (years 1969-1996)

et al 1988) is found to be an additional factor contributing to these changes in water column N P ratios, then reducing fish predation pressure on zooplankton by altering current fish stocking practices and fishing management may be another possible option (Gophen 1992, Gophen *et al* 1990)

III Temporal changes of zooplankton biomass

M Gophen, B Azoulay and J Easton

Annual averages of the biomass (g/m^2) of Copepoda, Cladocera, Rotifera and total zooplankton are given in Figs 1 and 1a Annual means of zooplankton densities in number of organisms per liter are shown in Fig 2 The data in Figures 1 and 2 indicate a multi-annual decline of zooplankton biomass and abundance The lowest value occurred in 1993 when the sardine crisis was most intensive During the last three years a trend of recovery of zooplankton communities was observed Zooplankton biomass gradually and consistently increased up to high levels during the first six months of 1997

Fig 3 shows the relative (%) abundance of herbivorous zooplankton (Cladocera) in relation (linear regression) to time (years 1969-1996) The increase in the relative abundance of cladocerans during 1994-1997 has a positive effect on water quality Consequently, it can be concluded that the sardines removal program (see Chapter VI) contributed to the increased grazing capacity of zooplankton during 1994-1997, with a positive effect on water quality

Unlike the recovery of the cladoceran population, the copepod biomass continuously declined (Fig 4) Rotifera comprise a negligible part (<10% by biomass) of total zooplankton. and therefore will not be discussed

Data shown in Figs 1-4 show a decline of copepods and a moderate decrease in cladoceran abundance during 1969-1996 During 1993-1996 the concentrations of Cladocera increased (Fig 5)

IV Invasion of the Kinneret pelagial by three zooplankters

B Azoulay, M Gophen and J Easton

During the last years three zooplankton invaders partly occupied a niche in the Kinneret pelagial the calanoid *Eudiaptomus dreischi* and two cladocerans, *Chydorus sphaericus* and *Moina rectirostris* It is likely that the invasion was a result of salinity decrease, changes in food conditions and fish predation pressure Calanoids have a higher escapability in comparison with

other common cyclopoid copepods, as does *Chydorus* in comparison with the more common *Ceriodaphnia* Recent changes in fish predation and food availability (nanoplankton) probably enhanced these invasions The three zooplankters are not new to the lake, but were never observed in such continuous high densities in open water We focused our study on the most common invader, *E dreischi*

V The autecology and life cycle of the planktonic copepod *Eudiaptomus*, cf *drieschi* (Copepoda, Calanoida), a recent invader of Lake Kinneret, Israel

B Azoulay, M Gophen and J Easton

The life cycles of major zooplankton species have long been the subject of intense and various studies Through knowledge of an organisms' life history, we are better able to understand their population dynamics, and inter- as well as intra-species relationships Variations in life history patterns may indicate adaptations to environmental changes such as predation pressure and food availability or abiotic factors like temperature and salinity

Food type and quality, as well as temperature and photoperiodicity, affect the lifespan and development time of many zooplankton species (Gophen 1976, Santer 1994) A species life cycle may respond and adjust to seasonal differences in day-length, while stressful conditions such as increased predation scarcity of preferred food or changes in salinity may also induce responses in the form of periods of diapause in many freshwater copepod species (Hairston and Munns 1986)

There has been a steady increase in the population density of the calanoid copepod *Eudiaptomus* cf *drieschi* in the pelagic zone of Lake Kinneret since its appearance in 1986 The new organism has an important role in modifying the previously existing food chain in the lake The ecology and physiology of this copepod was therefore studied

Early investigations of Lake Kinneret zooplankton have not consistently listed calanoid copepods in their species records Bodenheimer (1935) listed *Diaptomus salinus* Komarovsky (1959) however, notes "the complete absence of *Diaptomids* among the *Copepoda*" from the lake, although they were found in rain pools nearby Por (1968) mentioned *Eudiaptomus gracilis* (Sars) as appearing occasionally in the plankton as an accidental "visitor" Gophen recorded diaptomids in the lake (1978) and found diaptomids represented in the gut contents of gray mullet fingerlings collected from the littoral (1979) Dimentman and Por (1985) also found *Arctodiaptomus similis similis* in the lake during the winter months, but considered it to be the incidental result of winter floods

In the late 1980's a test survey of the lake zooplankton using a ROV (Remotely Operated Vehicle) was conducted Calanoid copepods of previously unrecorded densities were collected in a

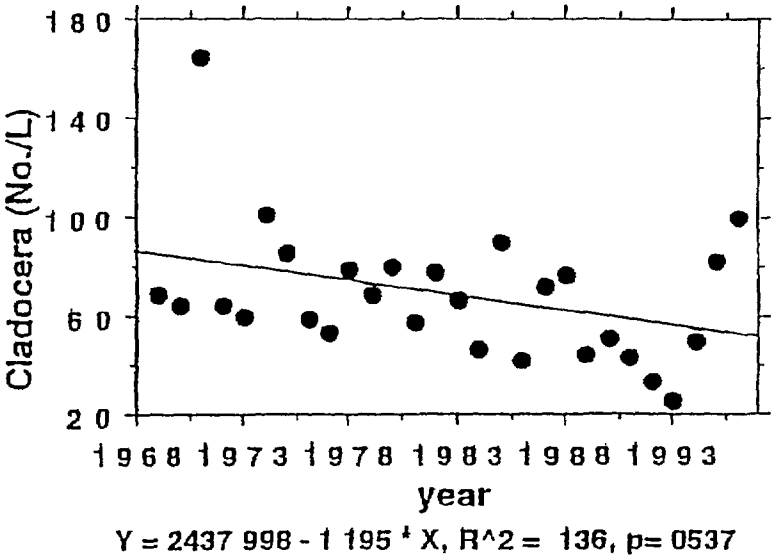


Fig 5 Linear regression between Cladocera densities (No.L) and time (years 1969-1996)

towed array of plankton nets (63 μ) These were identified in 1987 by Por (in litteris) as being very similar to *Eudiaptomus drieschi*

The routine bimonthly zooplankton sampling continues to record all life stages of *E drieschi* present in the lake year round Examination of preserved material from archive collections confirms the appearance of *E drieschi* in lake samples from 1986 to the present

The calanoid copepod *E drieschi* is a new component of the pelagic ecosystem in Lake Kinneret Prior to its appearance, there did not exist a filtering (herbivorous) copepod in such high densities It is predominant during the winter months in Lake Kinneret As to the possible reasons for its appearance, our working hypothesis is that it appeared from resting eggs which reached the lake passively when lake salinity dropped to favorable levels Recent changes in fish predation pressure may also have contributed to its increased abundance

For our studies zooplankton from Lake Kinneret were collected on a weekly basis using a 20 liter Schindler-Patalas trap for quantitative samples and 500μ, 335 μ, 100 μ, and 63 μ mesh plankton nets for qualitative analysis Plankton nets were towed obliquely for 5 minutes at fixed sampling sites on the lake Trap samples were taken at fixed depths (0, 5, 10, and 20 meters) from station Γ Samples were preserved in 4% sugar-formalin for counting and measurements Calanoid eggs obtained from bottom samples (sediment cores) were prepared and processed using a modification of the method described in Ban (1992)

Data from bimonthly routine samples were assembled and summarized (Figs 5, 6 and 7) Material from vertical net (63 μ) hauls from archive collections were examined Animals were measured using a video/computer assisted program CAPAS (Hambright and Fridman 1994)

Initial examination of available archive material indicates the absence of *E drieschi* prior to 1986 and an increase in calanoid density from 1987-present Examination of weekly collected material appears to indicate a pattern of seasonality as well spatial ontogenetic distribution (Figs 6 and 7) The animals are most abundant during winter-spring months (mean temperature 15-22°C) Nauplii are common in March-April and copepodites and adult stages in April-May

Approximately 100% hatching success was obtained with eggs from sediment cores Viable eggs were found at depths up to 6 cm in the sediment (Fig 8) These eggs were probably 10-12 years old (sedimentation rate of 0 5 cm/y according to Serruya 1978) However, only a very small percentage (5%) of these organisms survived to the adult stage

In summary, prior to the mid-eighties, calanoid copepods were not found on a routine basis in Lake Kinneret waters Early surveys reported sporadic appearances of calanoids in the lake, especially after winter floods Samples collected from offshore lake stations after 1986 consistently contained the calanoid tentatively identified as *Eudiaptomus dreischi* Strong seasonal periodicity was observed with densities highest in winter/spring and very low in the summer-fall

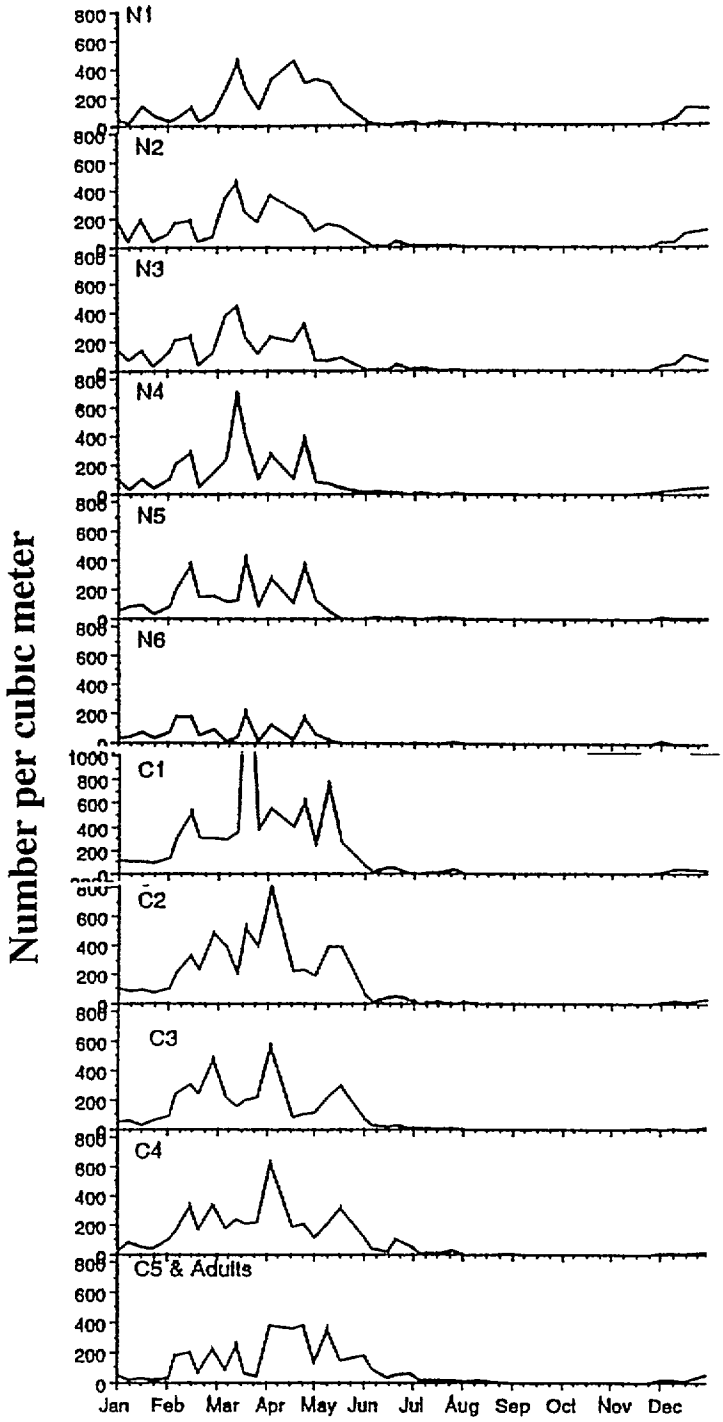


Fig 6 Temporal (monthly) distribution of nauplii (N), copepodite (C), and adult stage densities (No /m^3) of *Eudiaptomus dreischi*.

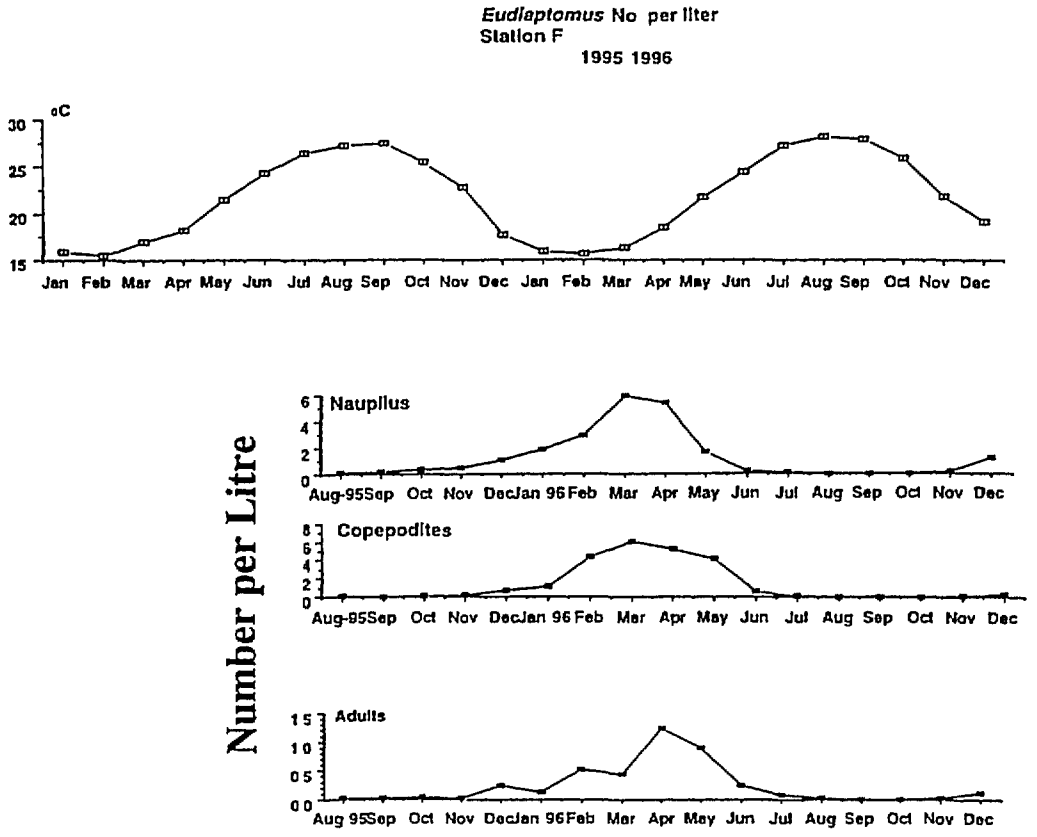


Fig 7 Temporal distribution of nauplius, copepodite and adult stages of *Eudiaptomus dreischi* (lower panel) and Kinneret mean epilimnetic temperatures (upper panel)

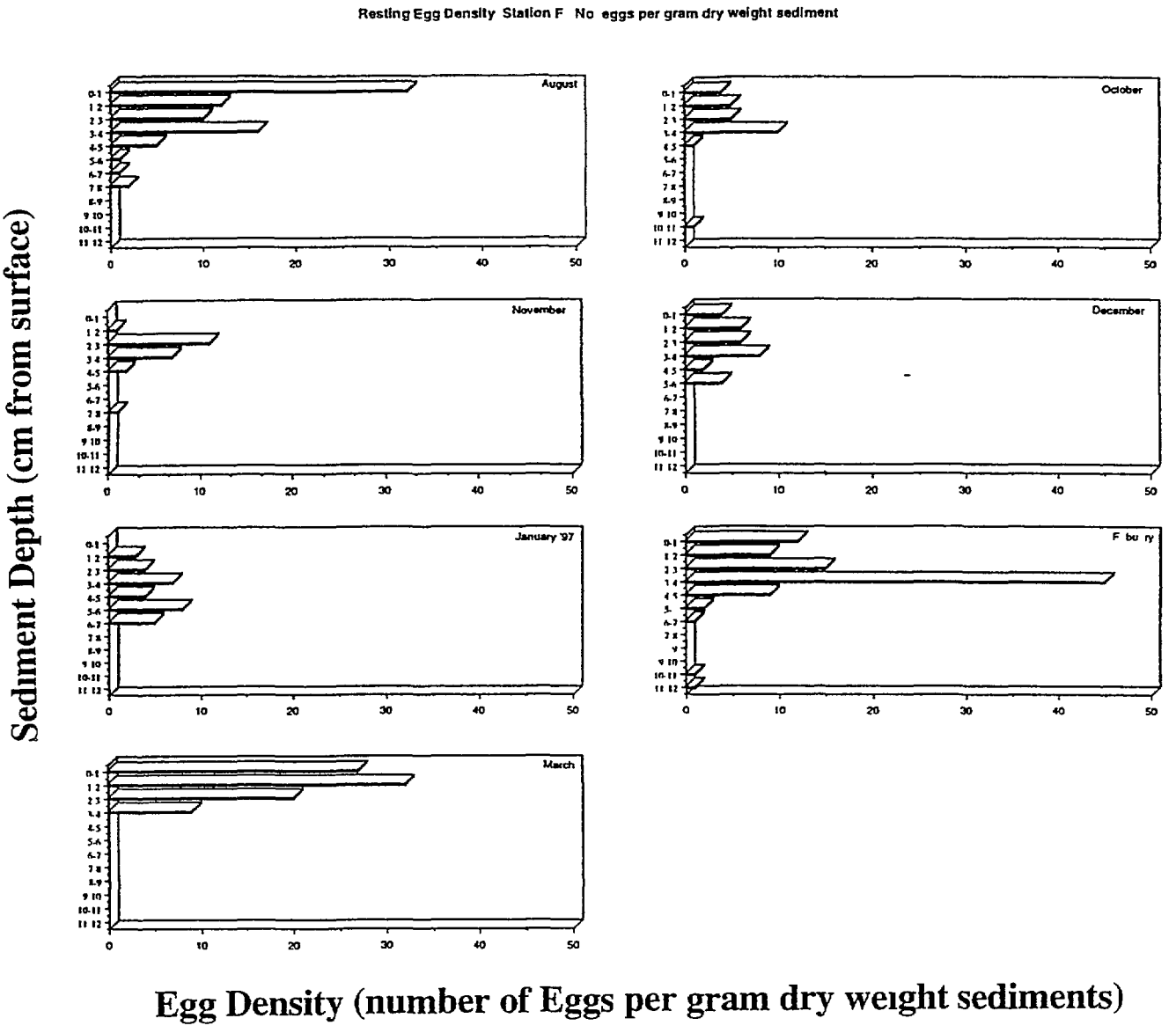


Fig 8 Vertical distribution of *Eudiaptomus dreischi* egg densities (No /g dry weight sediments) in Kinneret sediments at Station F

Biomass measurements of developmental life stages indicated a contribution of ca 5% by *Eudiaptomus* to the total zooplankton

High summer temperatures and intensive fish predation are apparently one of the pressures that drive *Eudiaptomus* to produce diapausing eggs Analysis of sediment layers from cores confirm the presence of these eggs to a depth of 10 cm, which is consistent with their appearance in the water column, based on known sedimentation rates

VI Relationships between zooplankton and Kinneret lavnun, *Acanthobrama terraesanctae*

J Easton, M Gophen, B Azoulay, and P Walline

Zooplankton distribution at four time intervals over 24 hours was studied Zooplankton made a diurnal vertical migration (DVM) at night with upward migration from dusk to midnight and downward migration during the day Calanoids migrated more strongly than copepods High correlation was found between Cladocera and phytoplankton concentrations at 2 m (Figs 9 and 10) (see Gophen, 1979)

Sampling of plankton during 24 hours, accompanied by an acoustic survey of fish distribution was made once a month for 12 months (Fig 11) Physical measurements (temperature light penetration, and dissolved oxygen (DO)) were taken simultaneously

Data showed no specific spatial relations between zooplankton and phytoplankton nor between lavnun and zooplankton Definite diel zooplankton spatial and vertical migratory behavior and seasonal effects on DVM of zooplankton were observed Zooplankton migrate up at night (mostly crustacea without nauplii) in summer, with little to no migration in the winter Copepoda and Cladocera concentrations were closely related Vertical fish migratory patterns are from deep to shallow water at night in all seasons, but more strongly in the winter season Of the phytoplankton only *Peridinium* displayed diel vertical migration within the photic zone, moving down at nighttime and up during daytime Nanoplankton did not migrate (Figs 12 and 13)

Two 24 h surveys were made to examine the effect of stratification on DVM (Figs 14-17) One was made in summer when the lake is stratified and one was made during the winter mixing period (Figs 12 and 19) Plankton and fish distributions were monitored as well as physical parameters

During the winter (mixing period) only the cladocerans *Diaphanosoma* and *Bosmina* (Fig 14) showed a weak vertical upward movement at night in the water column indicating that there is little to no vertical migration at this time of the year During this season, lavnun do not appear to have a spatial relation with zooplankton, except for a more pronounced (but not statistically confirmed) relation at dawn There is no apparent relation between fish and individual

May 1992, diel distribution

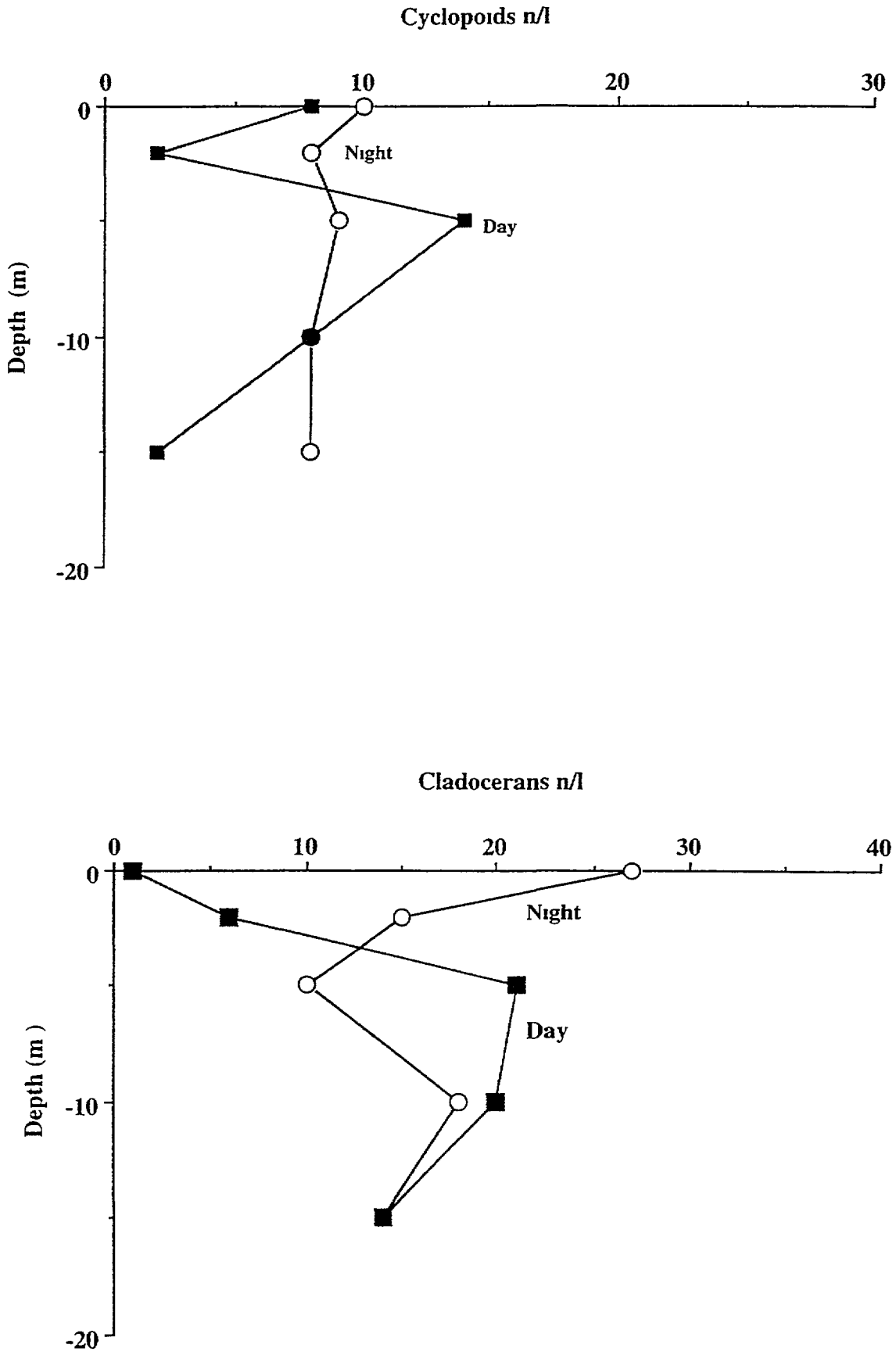


Fig 9 Vertical distribution of cyclopoid and cladoceran densities (No /L) during day and night in Lake Kinneret

Zooplankton
Vertical distribution
Oct 1994

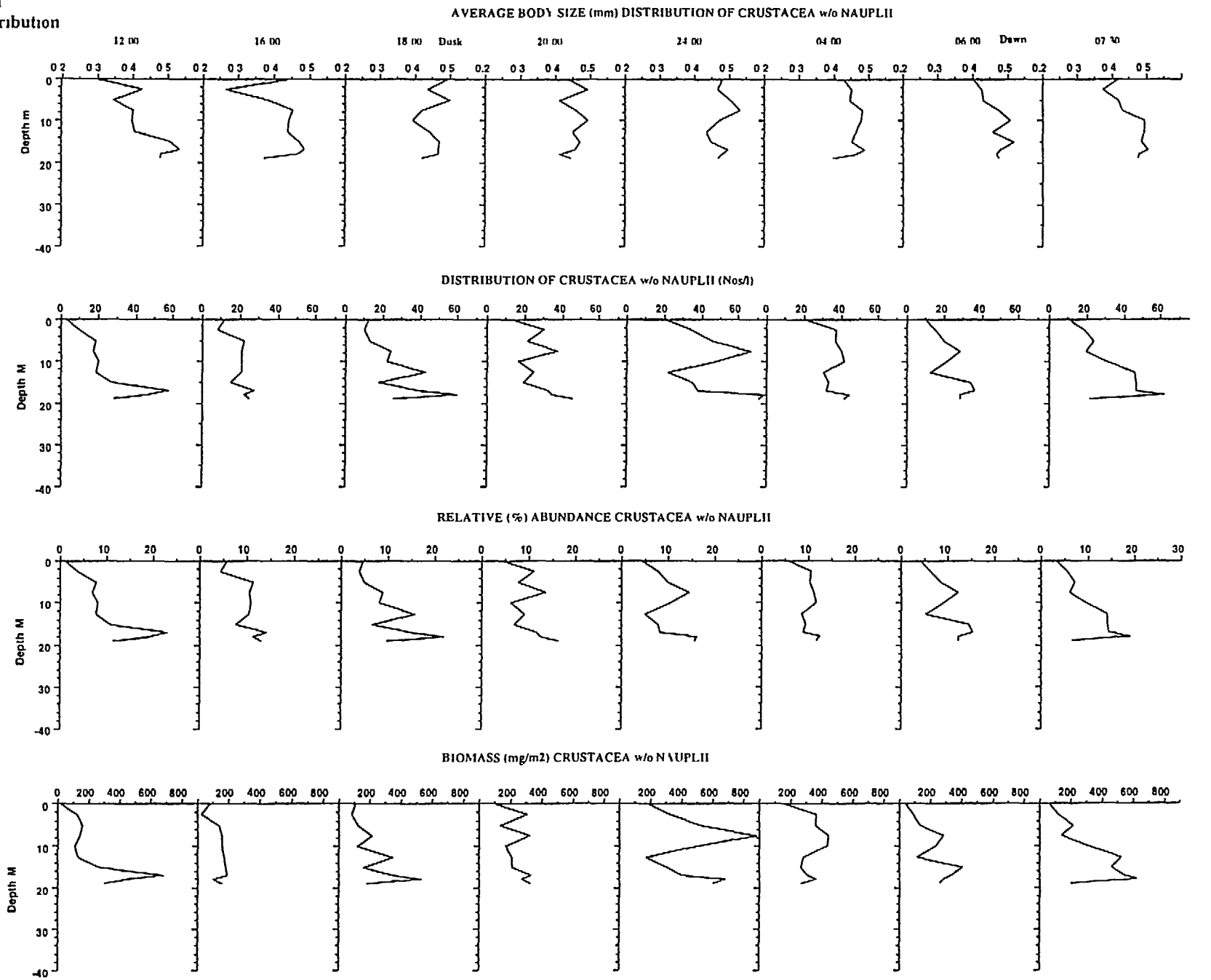


Fig 10 Vertical distribution over time (hours) of average body size (mm), densities (No /L), relative abundance (%) and biomass (mg/m^2) of crustaceans without nauplii in October 1994

Fish vertical distribution (March 1994)

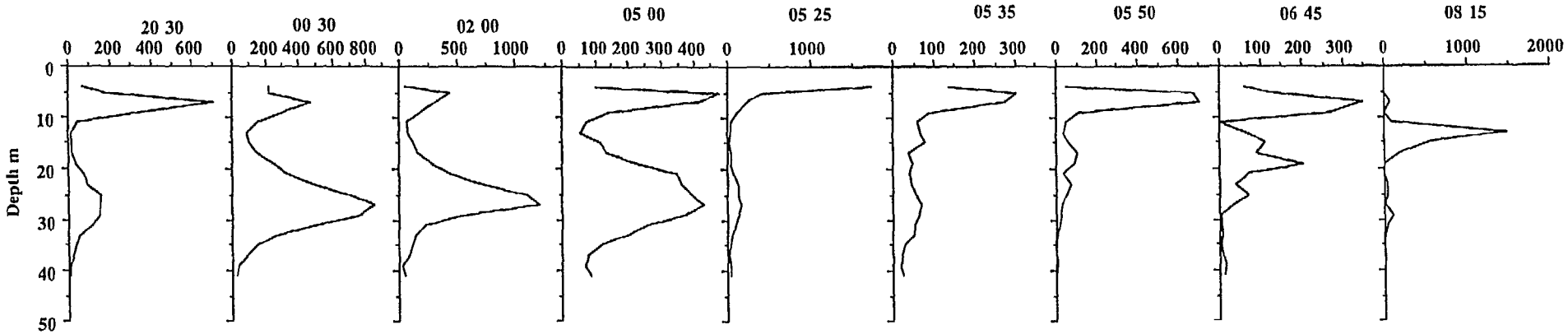


Fig 11 Diurnal vertical distribution of fish abundance (No /ha) in March 1994

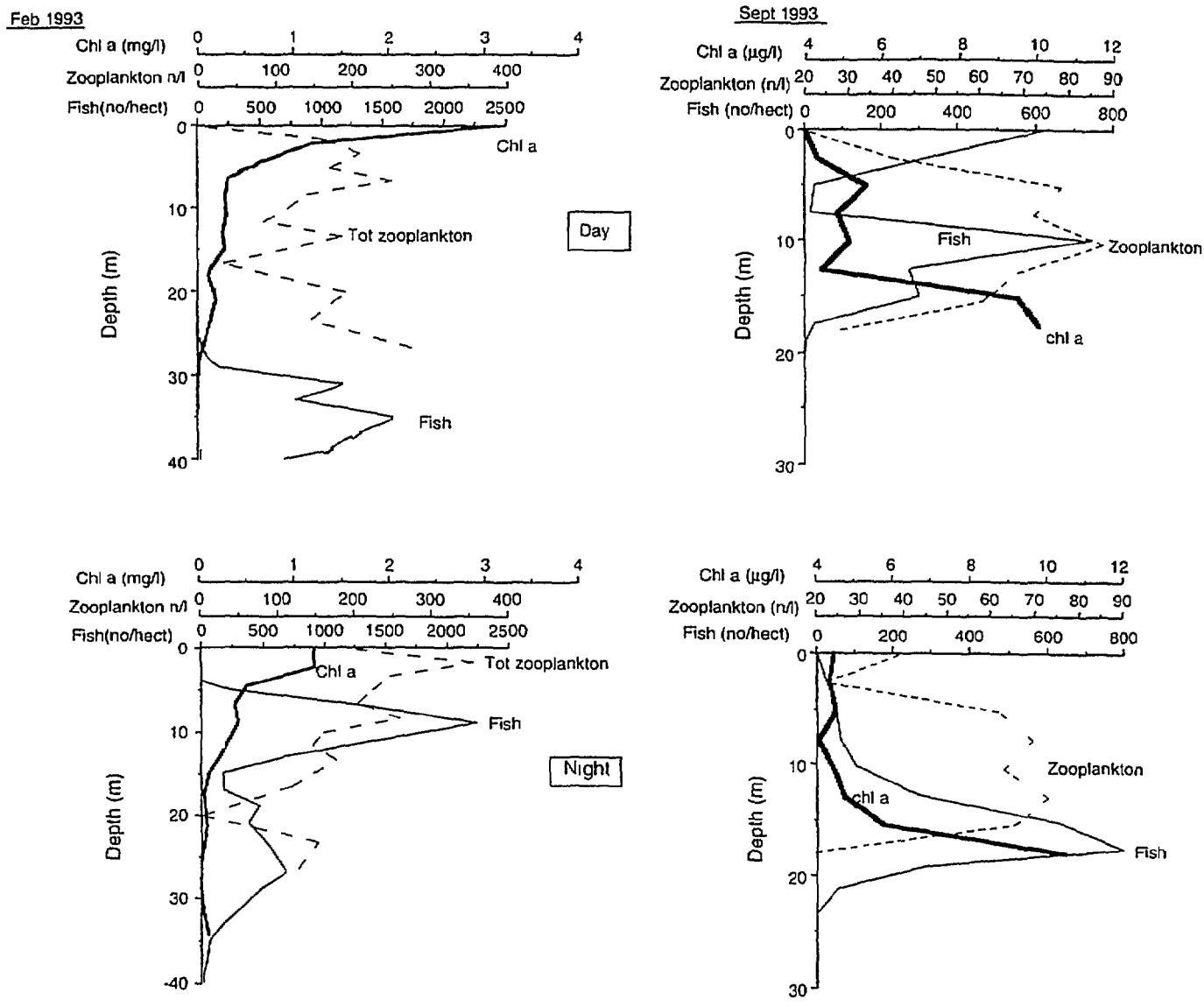


Fig 12 Vertical distribution of chlorophyll *a* (µg/L), zooplankton (No /L) and fish (No /ha) in February 1993 and September 1993 during day and night

Chl a vertical distribution
March 1994

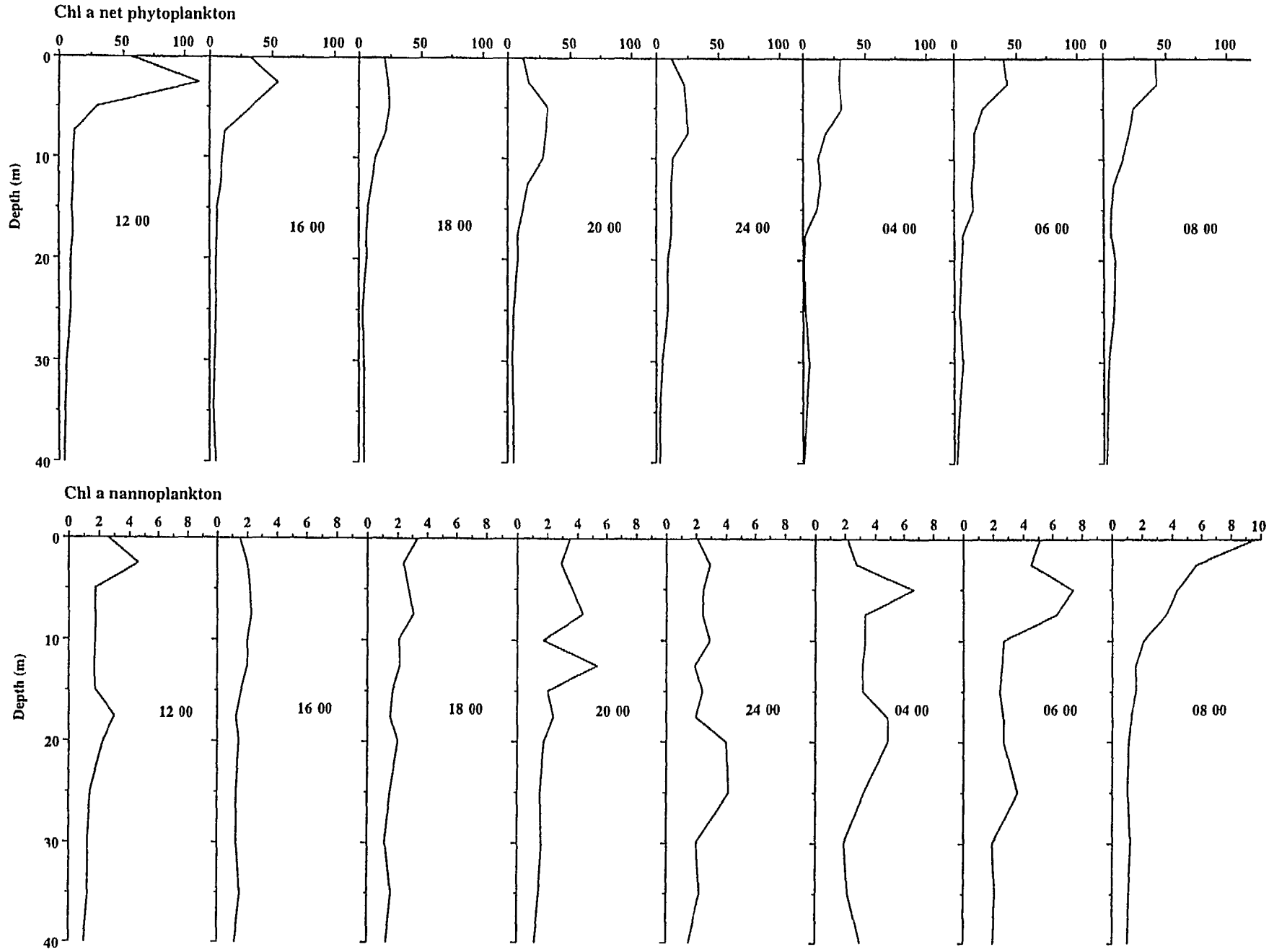


Fig 13 Vertical diurnal (hours are given) distributions of net (upper) and nano (lower) phytoplankton chlorophyll a (mg/L) during March 1994

Vertical distribution
of Ceriodaphnia
and bosmina
March 1994

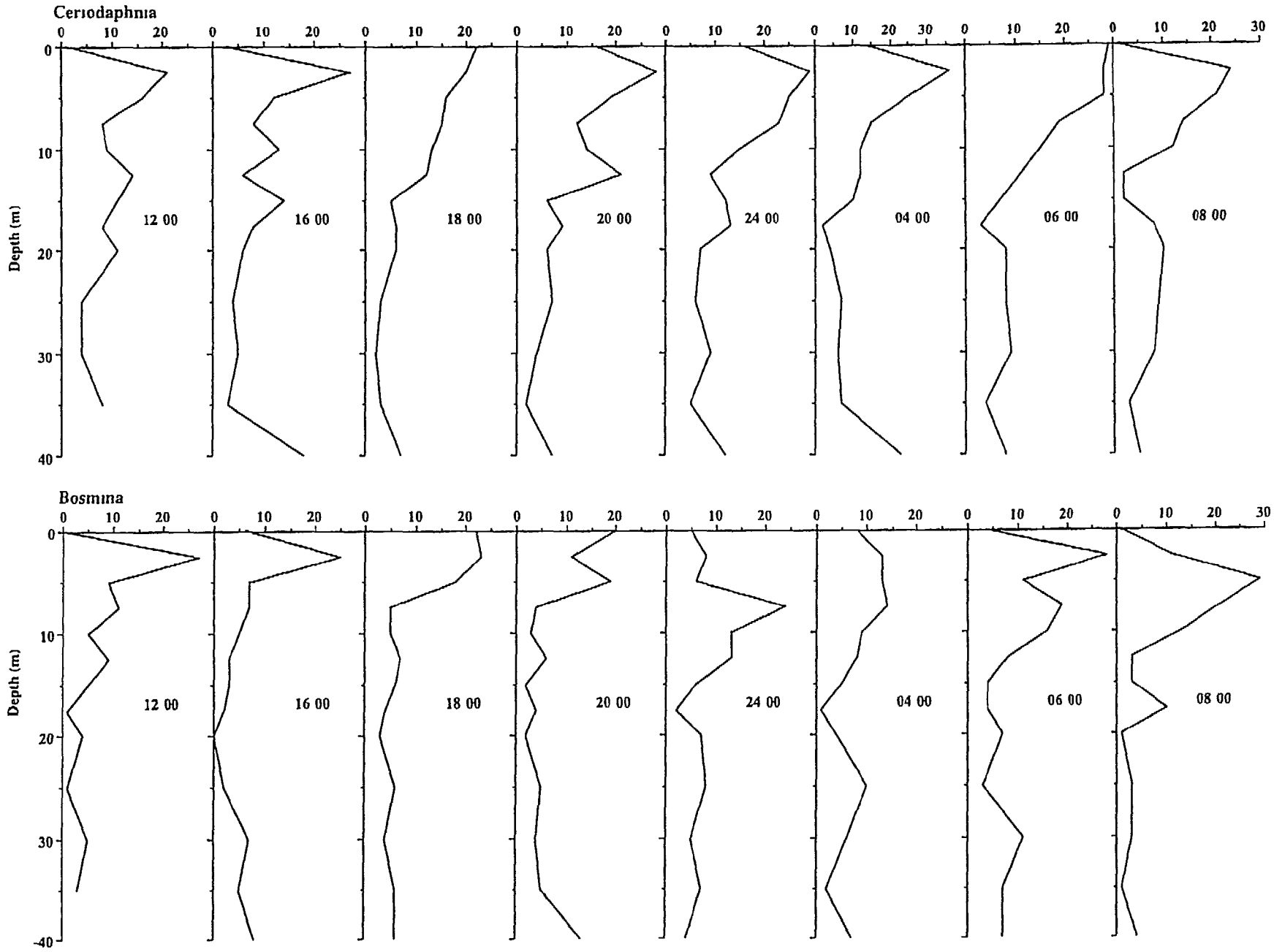


Fig 14 Vertical-diurnal (hours are given) distribution of *Ceriodaphnia* (upper) and *Bosmina* (lower) (No /L) during March 1994

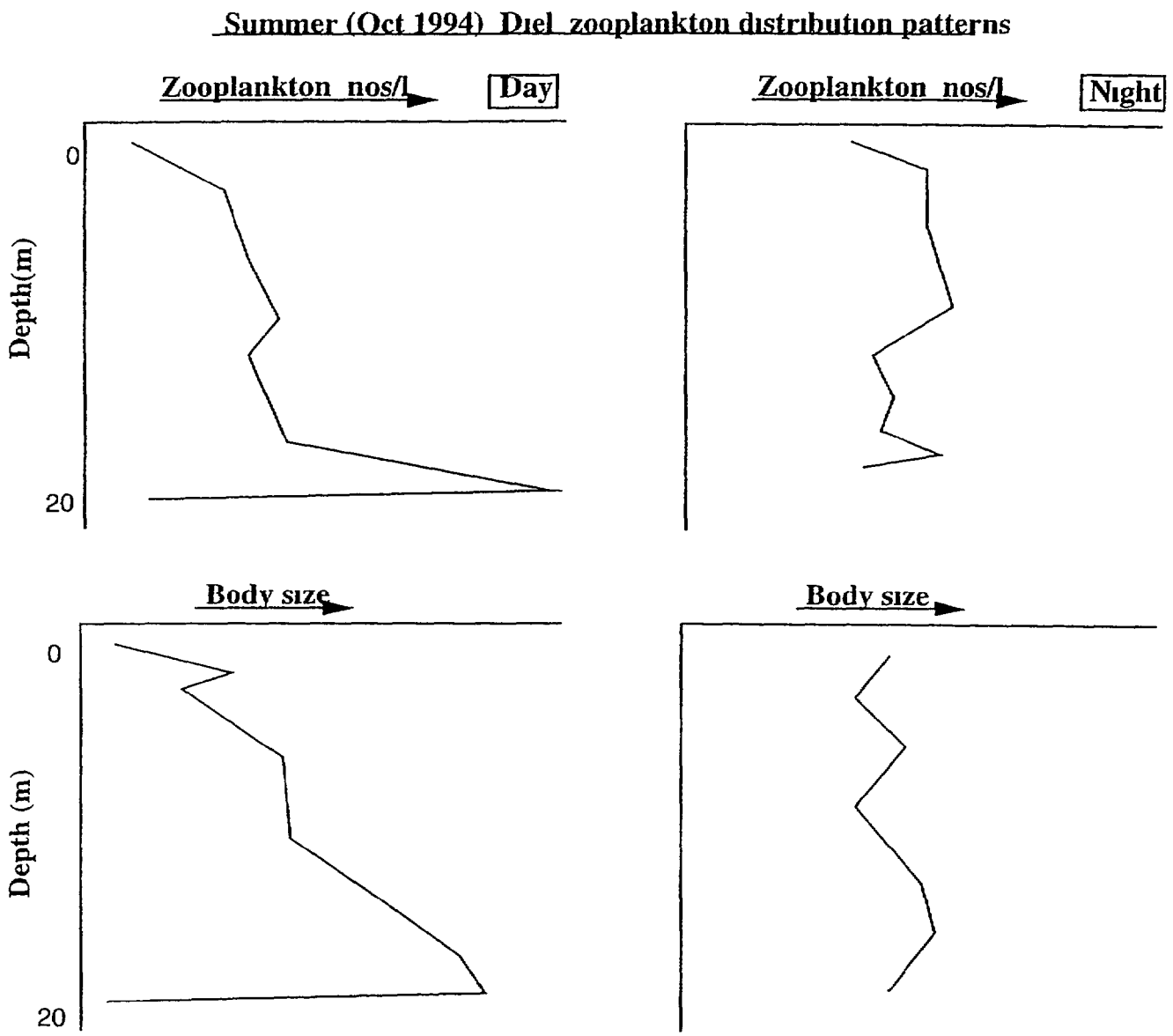
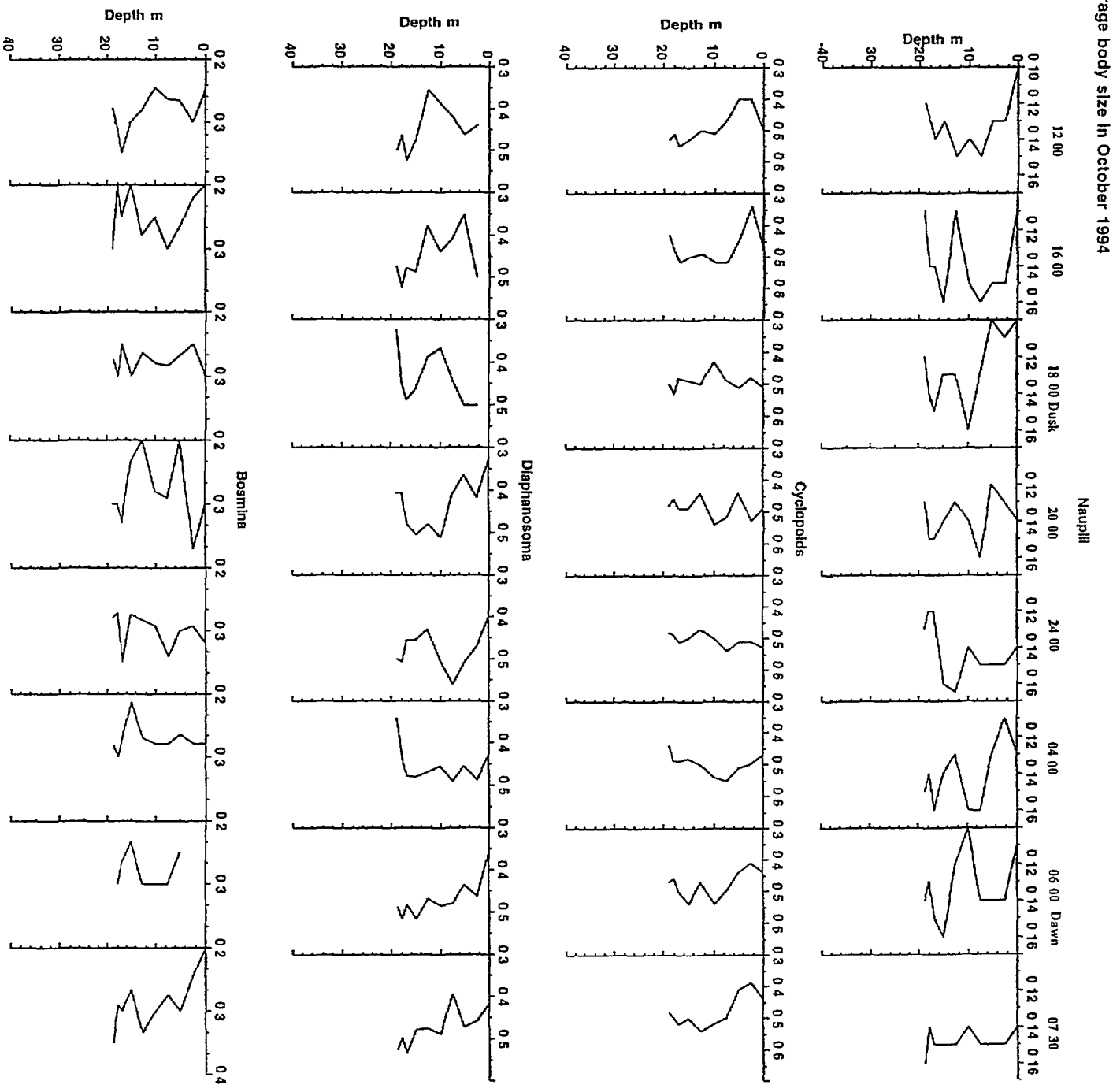
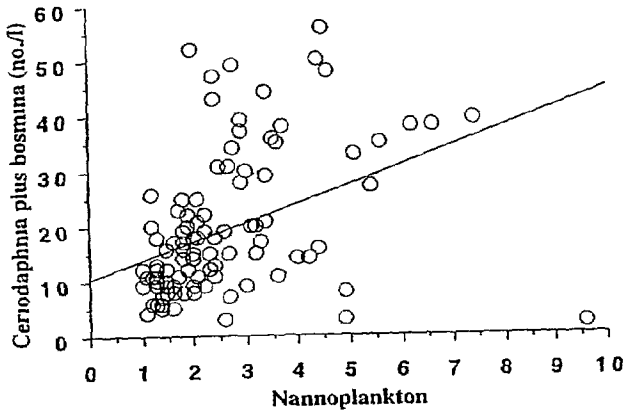


Fig 15 Schematic diel vertical distribution pattern of zooplankton densities (No /L) and body size in October 1994 day and night

Fig 16 Diel-vertical distribution of body size (mm) of nauplii (upper), copepodites and adult cyclopoids (2nd from top), *Diaphanosoma* (2nd from bottom) and *Bosmina* (lower) in October 1994 (hours are given on top)





Y = 10 595 + 3 389 * X, R^2 = 153, R=0 391, p< 0 0001

Fig 17 Linear regression between nanoplankton densities (chlorophyll *a*, µg/L) and densities (No /L) of *Ceriodaphnia* and *Bosmina*

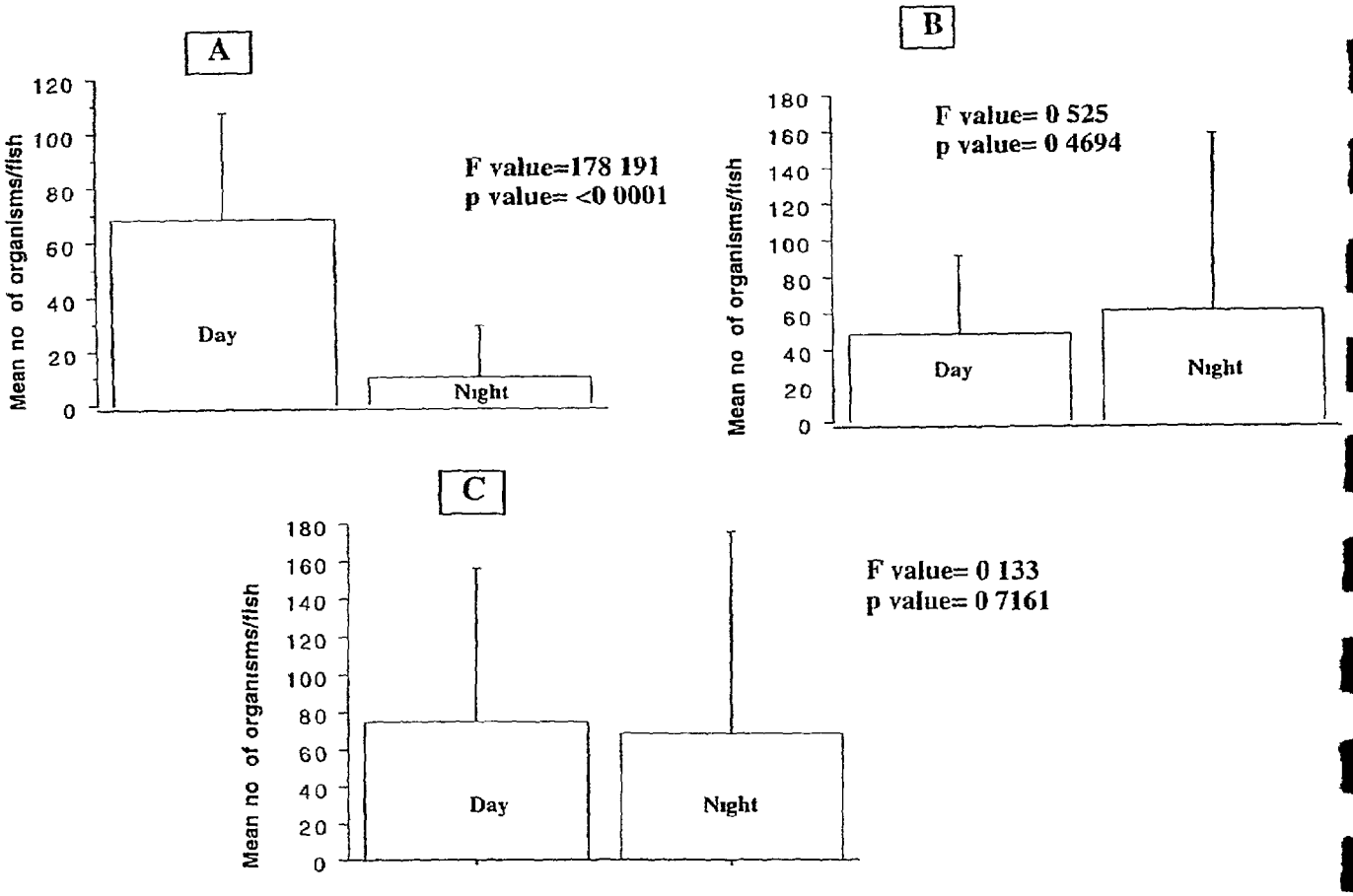


Fig 18 Mean number of organisms (bars - standard deviation) per fish during day and night July 1994 A all zooplankters without *Bosmina*, B *Bosmina* only, C all zooplankters including *Bosmina*

zooplankton species distribution, day or night Lavnun distribution showed a distinct migration to surface water at dawn, and albeit slightly weaker, also at dusk (Figs 11 and 12) There is consistently a strong correlation between cladoceran species and phytoplankton (nanoplankton) concentrations in the profiles both day and night (Fig 13) Only juvenile cyclopoids appear to correlate spatially with *Bosmina* and *Ceriodaphnia* (Figs 14 and 17), but have a lower correlation with nanoplankton (Fig 13), indicating that they are more closely associated with cladocera than with the nanoplankton Adult cyclopoids were not correlated spatially with the cladocerans

During the summer stratification period a distinct DVM pattern was discernable for the cyclopoids and *Diaphanosoma* (Fig 16) The strength of the DVM was related to organism size (Figs 15 and 19) There was an upward migration and a redistribution of larger individuals from the thermocline to the surface at nighttime (Figs 10 and 15)

During the stratification period, lavnun appear to remain close to the thermocline during the day and have a bimodal distribution at night (probably based on size) Lavnun have neither a positive spatial relation to phytoplankton nor to zooplankton (with the exception of *Diaphanosoma*) The cyclopoids have a close spatial relation with *Diaphanosoma*, *Ceriodaphnia*, small rotifers and nauplii (Figs 10, 12, 13 and 16)

A study was made of the gut contents and diurnal feeding habits of lavnun in July 1996 (Fig 18) Fish were sampled at 11 stations using a commercial purse seine net Zooplankton samples were collected simultaneously at the same stations during day and night Two daytime net hauls one at dusk and 8 over the night at one hour intervals were made Fifty sardines were preserved from each catch and the gut contents from 25 of them were microscopically examined Lake zooplankton was counted as well The fat content of the fish was also determined (see Gophen and Landau, 1977, Landau *et al* 1991)

In the catches there were two fish size groups 1) 20-25 g body weight and 8-10 cm Total Length (TL) and 2) 30-40 g body weight and 13-16 cm TL Fish caught in the night are smaller than those caught in the day From the gut contents analysis, it was determined that all zooplankton except for *Bosmina* were consumed at significantly higher rates during the day than during the night Nevertheless all items were consumed in small quantites also at night *Bosmina* were consumed equally day and night, but many more *Bosmina* fragments were found in the guts of fishes sampled at night Copepods were eaten exclusively in the day Smaller fish have a higher fat content than large fish and eat per body weight more than larger fish Variability between fish with zooplankton in their guts and those without is greater at night Larger fish eat more per body weight copepods than smaller fish Larger fish showed a preference for copepods, *Diaphanosoma* *Moina* *Ceriodaphnia* and large rotifers Relative zooplankton gut content (consumption) during the night showed a significant drop in *Bosmina*, cyclopoids (adult and juvenile) and copepod fragments, in comparison with daytime (Fig 18)

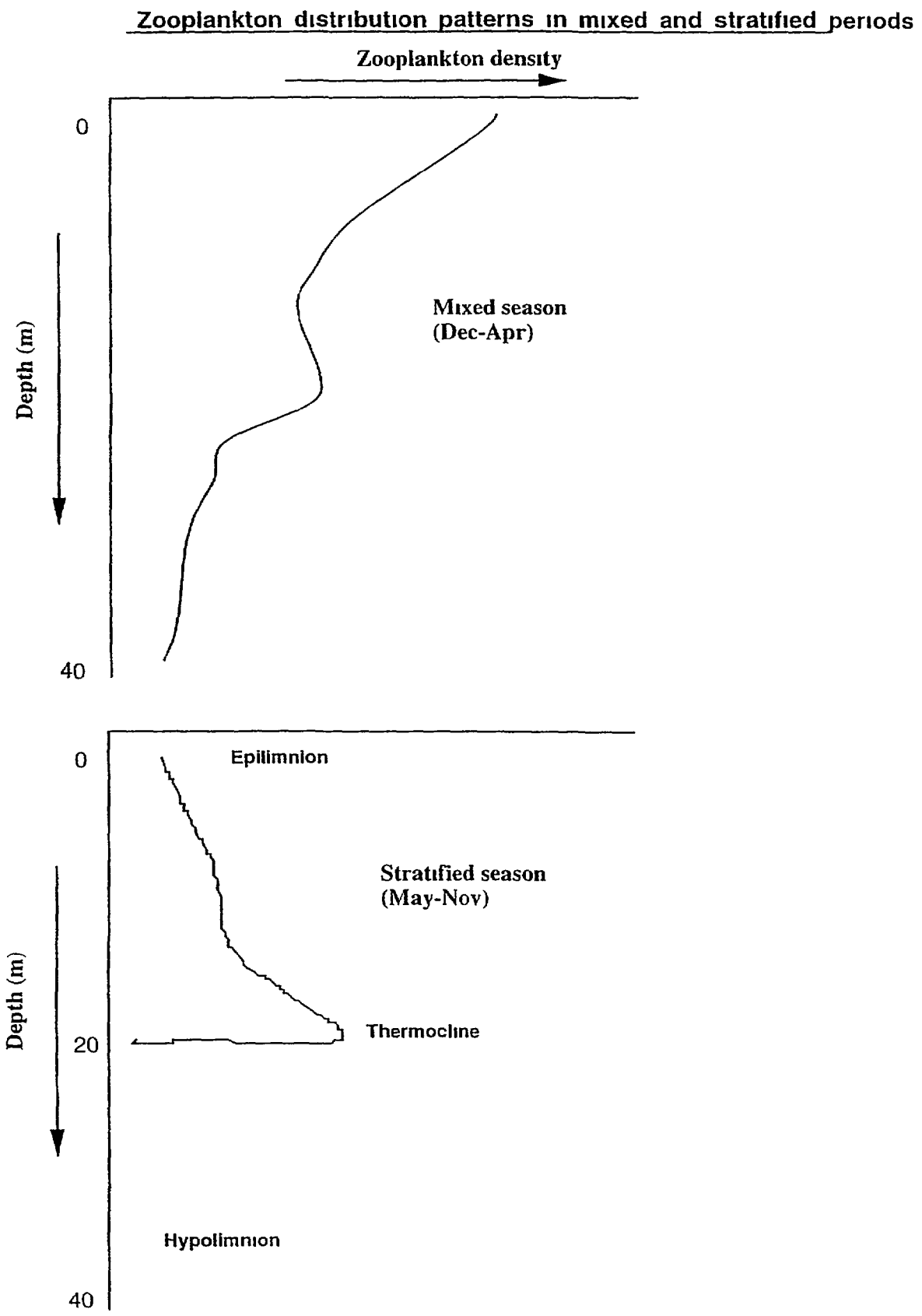


Fig 19 Schematic illustration of zooplankton distribution during the mixing period (Dec - Apr) and the stratified period (May-Nov)

A similar survey of lavnun gut contents and feeding habits was made during the winter The sampling plan included 6 stations with 6 purse-seine net hauls at two hours intervals and zooplankton sampling The analysis was the same as in the summer survey Results showed that as the night progressed, there was a significant drop in the relative numbers of large rotifers, *Bosmina* and Cladocera fragments in the guts of lavnun In parallel there was a significant increase in the number of adult copepods and copepod fragments, both relative to other zooplankton and in actual numbers/fish gut In some of the catches, it appeared that up to 25% of the lavnun were feeding on the bottom, as shown by the presence in the guts of large amounts of detritus and *Alona* (a benthic organism)

The effect of larval fish density on zooplankton mortality was studied in 20 L bottles The bottles were suspended in large (5 m^3) outdoor tanks filled with lake water The following fingerling densities were tested 1, 2, 3, 4 6 12 per 10 L The experiments continued 24 hours Zooplankton was counted at 0 and 24 hours, with a control (fishless) bottle and 3 replicates with fingerlings for each fish density Three trials were carried out one with 3, 6, 12, and 20 fish/L and two with 1, 2 4, and 20 fish/L

In the first trial there was no significant increase in mortality of zooplankton as fish densities increased There was, however, a significant mortality of cyclopoid and calanoid copepodites adult cyclopoids, *Bosmina*, *Ceriodaphnia*, large and small rotifers and total zooplankton during the 24 h experiment In the second trial mortality of copepodites and *Ceriodaphnia* increased as fish densities increased During the experiment mortality of *Bosmina* and total zooplankton was significant, but small rotifers increased in abundance In the third trial, zooplankton of <0 3 mm showed lower mortality as fish densities increased Large zooplankton >0 8 mm was positively selected and zooplankton size >1 3 mm negatively selected

VII The lavnun (sardine) crisis, 1993-1997 (Figs 20-29)

In May 1993 commercial fishery of sardines stopped in Lake Kinneret The lake was then inhabited by a dense population of sub-commercial sized lavnun (see Section VIII) At the same time zooplankton biomass was at the lowest level ever recorded (Figs 1 and 1a) Based on results of the AID Project we recommended to the Water-Fishery Authorities to dilute (remove) sub-commercial sized sardines by paying commercial fishermen to remove them Our recommendation was implemented during 3 seasons (1994-1997) Following this lavnun dilution program, zooplankton communities recovered and during winter-spring 1997, reached levels as high as those recorded in the early 1970's (Figs 20, 21 and 24)

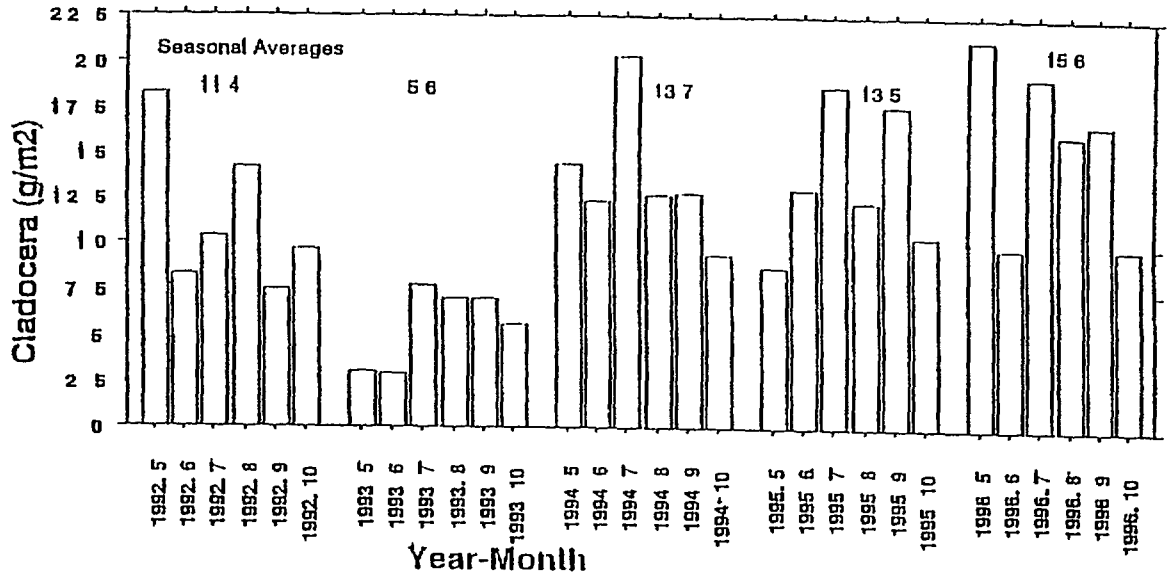


Fig 20 Monthly (May-Oct) distribution of cladocerans (g/m^2) during 1992-1996 Seasonal averages are given above the bars

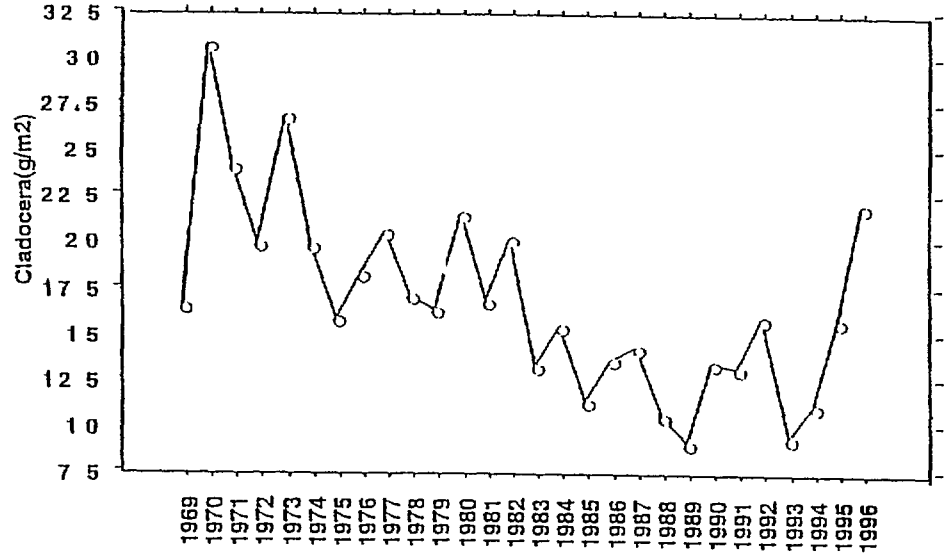


Fig 21 Annual averages of Cladocera biomass (g/m^2) in lake Kinneret during 1969-1996

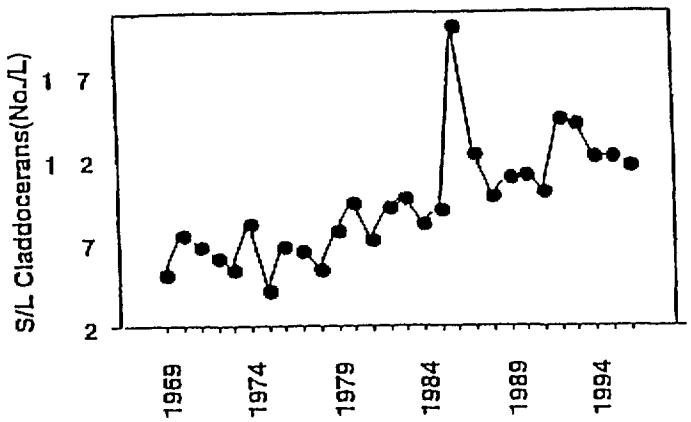


Fig 22 Annual averages of the ratio between small and large (S/L) cladocerans in Lake Kinneret

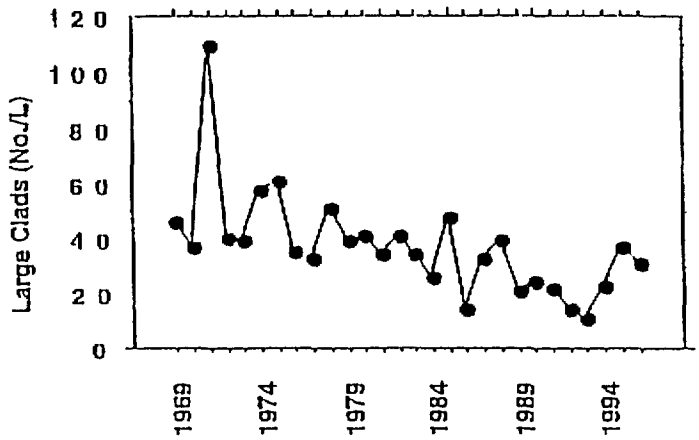


Fig 23 Annual averages of the densities (No /L) of large cladocerans in Lake Kinneret

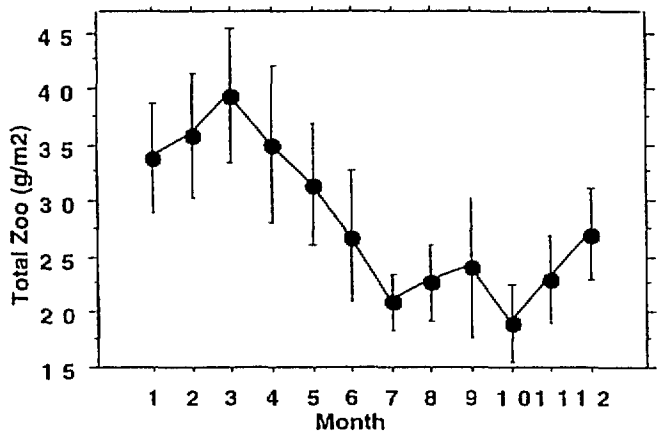


Fig 24 Monthly averages (1969-1997) of total zooplankton biomass (g/m^2) in Lake Kinneret (Error bars 95% confidence intervals)

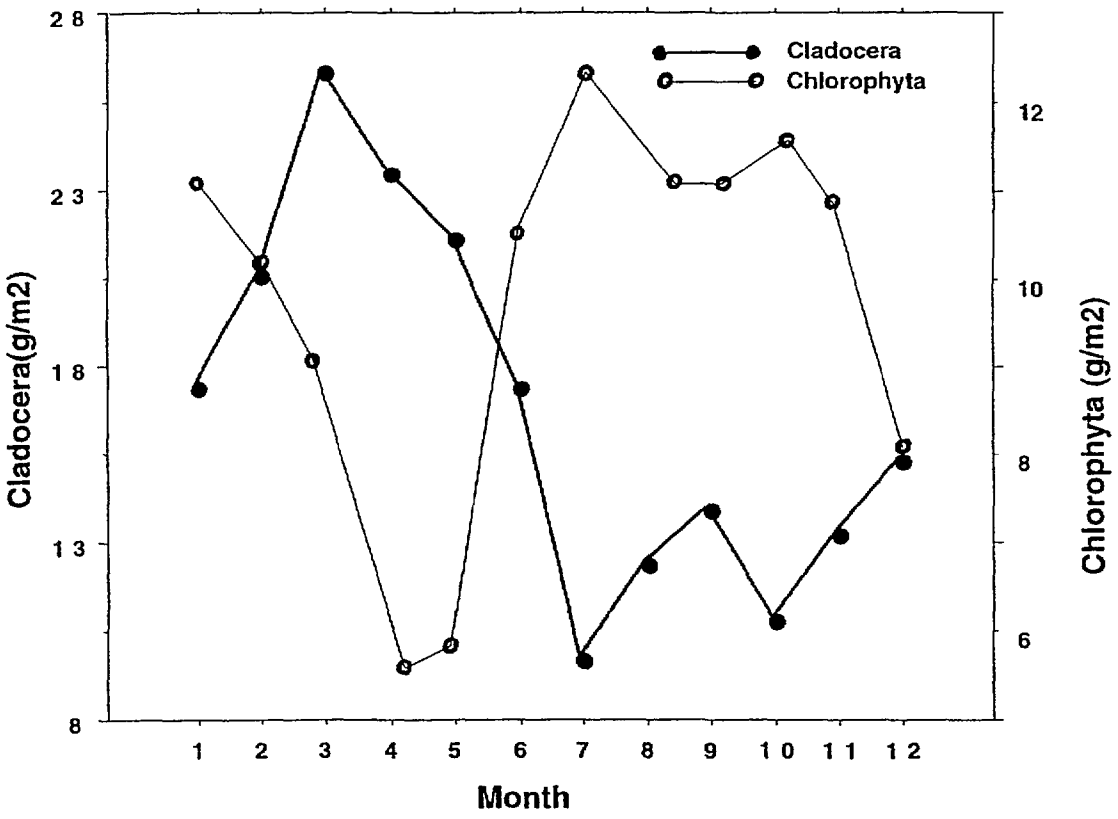


Fig 25 Monthly averages (1969-1996) of Cladoceran and Chlorophyta biomass (g/m^2) in Lake Kinneret

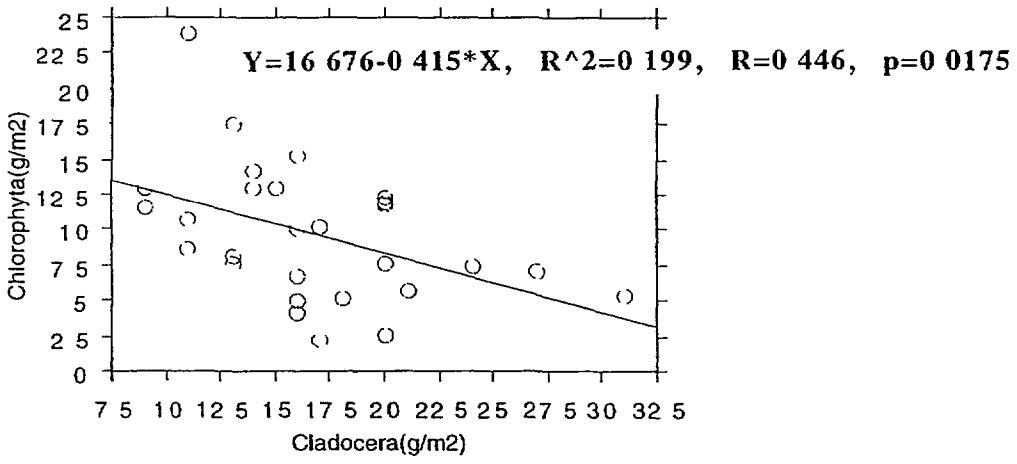


Fig 26 Regression plot of Chlorophyta (g/m^2) versus Cladocera (g/m^2) annual averages

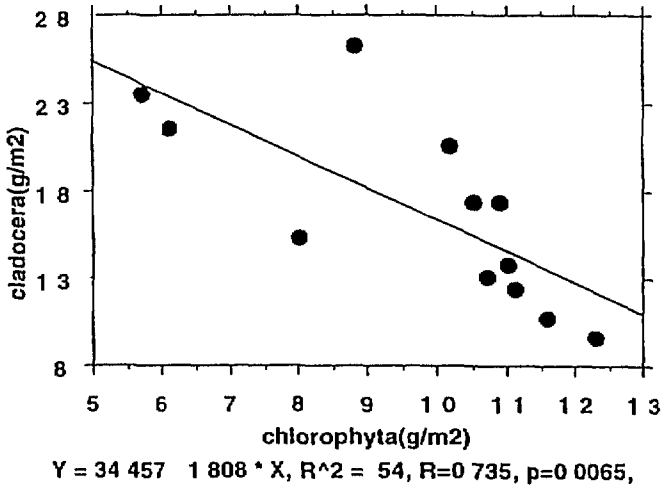


Fig 27 Regression plot of Chlorophyta (g/m^2) versus Cladocera (g/m^2) monthly averages (1969-1996)

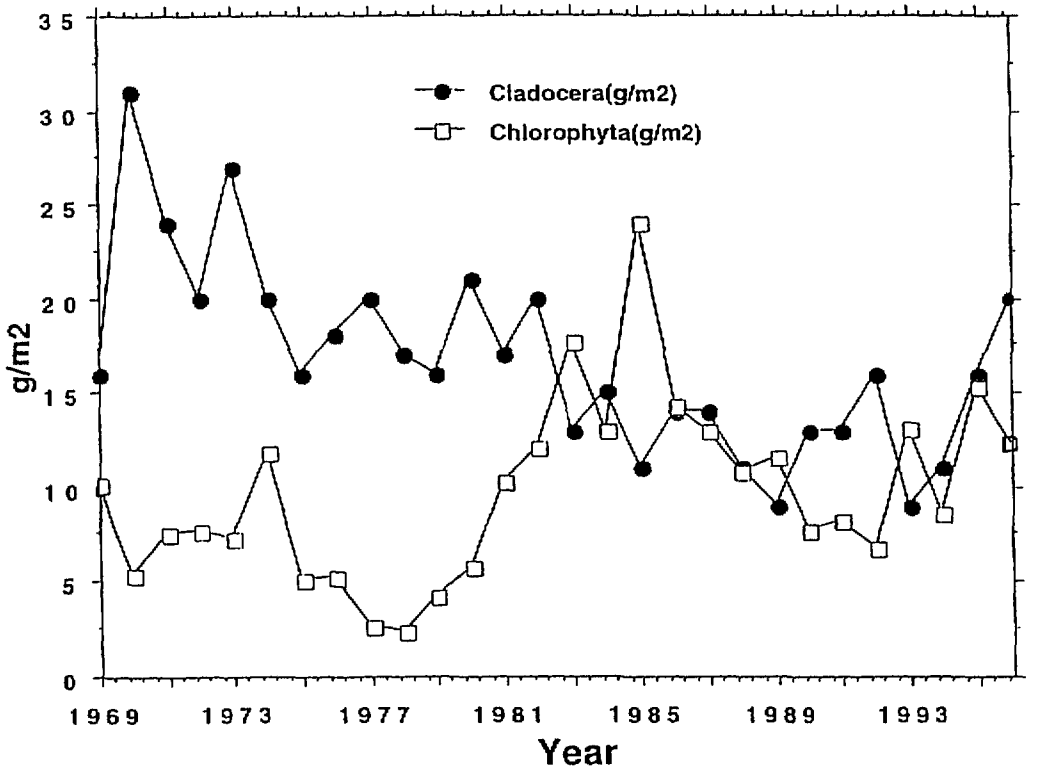


Fig 28 Annual averages (1969-1996) of Cladocera and Chlorophyta biomass (g/m^2) in lake Kinneret

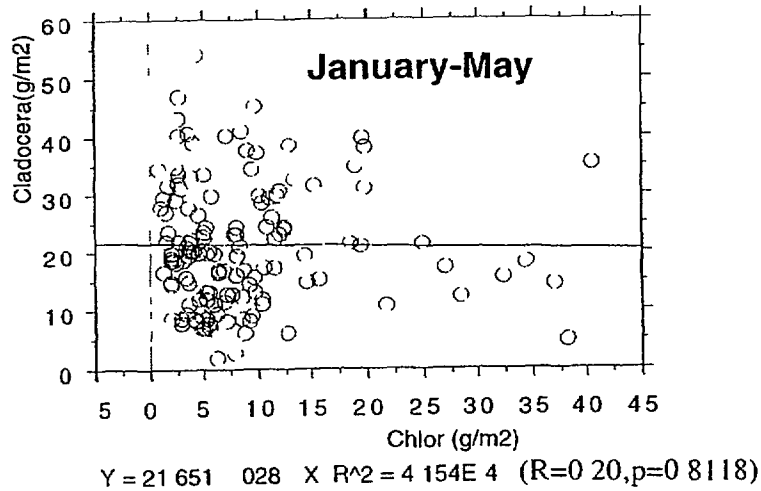


Fig 29 Regression plot of monthly averages of Chlorophyta (g/m^2) and Cladocera (g/m^2) for the winter-spring period (Jan -May)

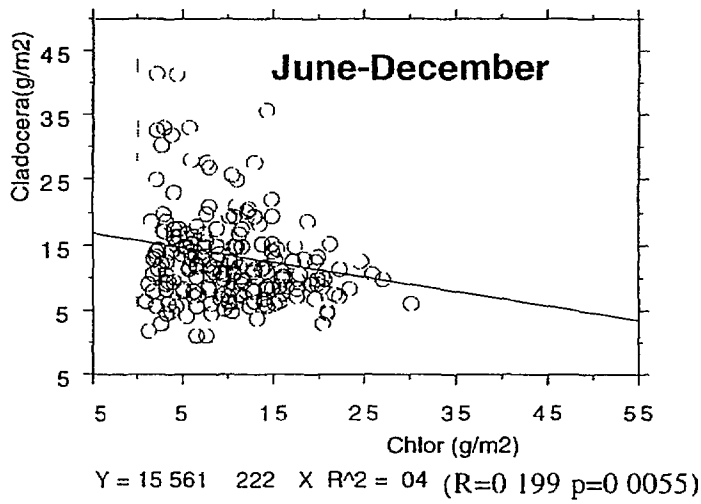


Fig 30 Regression plot of monthly averages of Chlorophyta (g/m^2) and Cladocera (g/m^2) for summer-fall period (June-December)

Nevertheless, the relative importance of reduced grazing pressure (dilution program) and the improved nanoplanktonic (algae) food resources, which also positively affected the zooplankton populations, have not been definitively determined Increase of zooplankton biomass can be attributed either to improvements of food resources (nanoplankton) or to suppression of fish predation If the former were the case, we would expect positive relations between grazers (Cladocera) and their food (Chlorophyta) Analysis of the long-term data record indicates the opposite, i e a significant inverse relationship (Figs 25, 26, 27 and 30) The inverse relation appears for monthly averages (Figs 25 and 27) as well as for annual averages (Fig 26) Annual averages clearly show the inverse relations during 1981-1997, when zooplankton biomass was low and chlorophyte biomass was high, and no relation during 1969-1980, when zooplankton biomass was high and chlorophyte biomass was low (Fig 28) When all monthly values of cladocerans and chlorophytes were analyzed no significant relation was observed in the winter-spring period and a significant inverse relationship was indicated for the summer-fall season (Figs 29 and 30) Thus, we suggest that grazers are not food limited, but controlled by fish predation Consequently, a higher biomass of Cladocera is followed by a decline of chlorophytes and vice versa

The enhanced grazing capacity of the recovered zooplankton stocks was illustrated by the fact that in spite of a high level of primary production in 1995-1996, the biomass of the predominant nanoplanktonic algae was low (Table 1)

	Biomass (g/m^2)		Chlorophyll (mg/m^2)		Primary production ($gc/m^2/d$)	
Period	I-XII	I-VI	I-XII	I-VI	I-XII	I-VI
1970-96	80	118	197	287	1732	1987
1996	44	48	132	143	2079	2506
1997	x	x		200		1591

Table 1 Phytoplankton biomass (g/m^2), chlorophyll (mg/m^2) and primary production ($mgC/m^2/d$) in Lake Kinneret Averages for 1970-1996, 1996, 1997 in winter-spring (I-VI) and annually (I-XII) (Lake Kinneret Database) x - No data available

To summarize, the following changes were documented after lavnun removal

1) The ratio between small and large cladocerans declined (Fig 22), i e large bodied grazers became more abundant This was a positive development in terms of water quality improvement, because large bodied cladocerans have a higher capacity for filtering and algal removal
2) The total zooplankton biomass, and especially the biomass of cladocerans, significantly increased (Figs 1, 1a, and 24)
3) The abundance (No /L) of large cladocerans increased (Fig 23)
4) Lavnun body size increased and in 1996, and the commercial fishery of lavnun was renewed
5) Although primary production was high, the biomass of phytoplankton remained relatively low

Future work will focus on a whole lake study of the long term (years) and seasonal effects of lavnun removal on water quality of Lake Kinneret

VIII Feeding mechanism of *Daphnia* high-speed camera analysis

Single *Daphnia* were placed in filtered lake water, glued to the tip of a plastic fiber, which was then fixed on a holder of a fine tipped micromanipulator A fine (~100 micron internal diameter) glass tube was placed close to the *Daphnia* and very small pulses (controlled by threaded injector) of India ink were injected The *Daphnia*'s activity (motion of body parts, especially the thoracic appendages) was taped by High-Speed-Camera through microscopical lenses The tapes were analyzed in slow motion with a motion-time-analyzer

The number of milliseconds per stroke of appendages at different levels of ink qualities is given below (number of observations are given in parentheses) (SD's were <30%)

	No Ink	Low Ink	High Ink
Young *D magna*	275 (41)	297 (53)	367 (8)
Adult *D magna*			447 (6)

Increasing ink quantity lowered number of strokes (filters activity) Older and larger daphnids are less active (lower number of strokes, i e filter movements, per second) than young specimens In our experiments young *D magna* (body length 1 9 mm) made 2 7-3 6 strokes per second, and adult *D magna* (body length 3 7 mm) made 2 2 strokes per second Nevertheless, it is

possible that larger daphnids have a higher rate of filtration because of the larger filtering surface of their "combs"

Two internal microflows inside the carapace space of the *Daphnia* were observed a lateral subcarapace flow (LSF) and a median filter flow (MFF)

The LSF starts from the water inlet zone above appendage 2 (P2) and continues along the internal surface of the carapace until being pushed away unfiltered to the exit zone at the distal body area The MFF microflow starts also from the inlet zone and continues downward between the two filter rows (P3 and P4) The flow is then split between the filters and tangentially passes through the combs towards the water outlet zone Approximately 50% of incoming water flows through as MFF and 50% as LSF This mechanism ensures a smooth and non-pulsated outflow of the water from the *Daphnia s* body We determined by volumetric image analysis that the filtering rate in our experiments was 1 02 ml per hour

Our results indicate that filtering capacities should be accounted as 50% of water inflow, since part of the water is channeled for regulating inside flows and prevention water pulses by smoothing outflows in order to reduce the ability of predators to detect the organism

IX Hydroacoustic surveys of the pelagic fish populations of Lake Kinneret

P Walline, Y Kalikhman, I Ostrovsky

Despite the unavailabilty of the dual-beam echosounder for many months during the project (installation of new hardware, repair after breakdown), 7 complete hydroacoustic surveys were made with the system The total number of fish in the lake for each survey was calculated (Figure 31) The results, when plotted together with results obtained with the Simrad system in years 1987-1993, indicate that total numbers of fish remain at the high level reached initially in 1993 In May 1996 total numbers reached the highest levels observed so far in the acoustic surveys (381 million)

In addition to the lake-wide surveys, 10 cruises were made in which acoustic data were obtained simultaneously with purse seine net hauls Fish length distribution from these catches was compared with acoustic sizes to obtain an equation relating acoustic size to fish length This equation together with length-weight measurements made on the same fish samples was used to obtain the biomass of fish along the transects surveyed These data were mapped and integrated to obtain total biomass of fish in the lake for the 7 lake-wide surveys made with the dual-beam system since July 1994 (Table 2) Results indicate that biomass ranged from a low of 1200 tons in March 1996 to a high of 4700 tons in September of 1996 There is a strong indication of seasonal variation in biomass, which is to be expected for a fast-growing, short-lived fish However, the number of samples is too low to allow very detailed comparisons between years In an attempt to reduce the grazing pressure on zooplankton, a sardine dilution program was instituted in 1994 to remove

sub-commercial sized sardines It was thought that by removing a substantial number of small sardines (1000 tons) during the winter, grazing pressure on zooplankton during the spring phytoplankton bloom would be reduced In addition, the size composition of the sardine population would be shifted to larger sizes by removal of small sardines and by the improvement of feeding conditions of the remaining sardines The program was monitored acoustically (and by sampling with a purse seine) About 450 tons were removed in winter 95-96 and 1000 tons were removed in winter 95-96 Surveys made before and after the 96 removal (10/95 and 3/96) detected a decrease in biomass from 2878 tons to 1200 tons, indicating that the 1000 tons removed constituted a significant fraction of the biomass

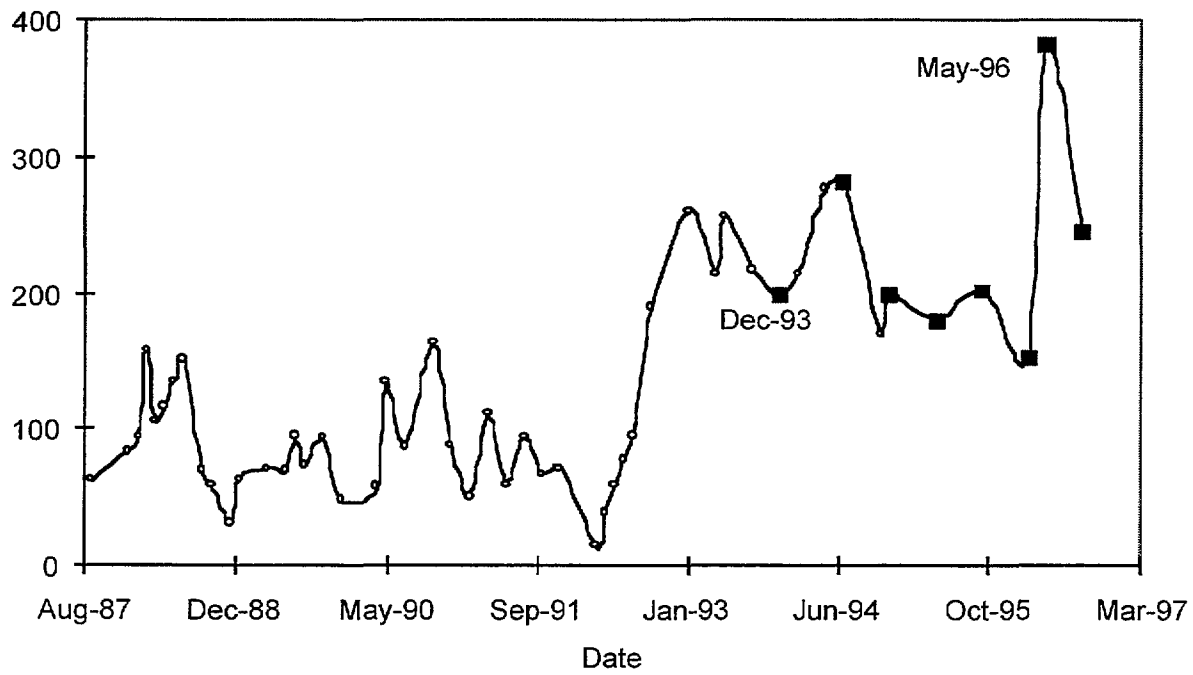


Figure 31 Total number of fish in L Kinneret over time The squares indicate surveys made with the dual-beam system, and the open circles indicate surveys made with the Simrad EY-M single beam system

Table 2 Biomass of fish in L Kinneret as obtained from acoustic surveys Average fish weight is calculated from biomass and total numbers

	Number	Biomass	Ave Fish Wt
Jul-94	281	1860	9 4
Dec-94	198	2435	12 3
May-95	180	1746	9 7
Oct-95	202	2878	14 2
Mar-96	153	1200	7 8
May-96	381	2568	6 7
Sep-96	244	4700	19 3
Average	234	2484	11

Date	TS	Length	Weight
June '94	-49 4	8 8	4 8
June '95	-46 8	11 2	11 0
June '96	-45 4	12 7	17 2

Table 3 Comparison of fish size obtained acoustically and averaged over 6 stations Numbers of targets observed were weighted by depth Weight is calculated from the length-weight relationship obtained from purse seine samples taken in May 1993

Identical surveys made in June 94, 95, and 96 show an increase in the average size of fish in L Kinneret following the two years of the dilution program (Table 3) In addition, large sardines (>100 g) were observed in our purse seine catches in June 96 for the first time since the collapse of the fishery in 1993 The commercial fishery has resumed for the first time since 1993 and around 300 tons were removed according to the Fisheries Dept The results of this project provide the scientific basis for our recommendation to continue to remove 1000 tons of lavnun from the Kinneret each year

X Ecopath 3 0 model of Lake Kinneret ecosystem

P Walline and M Gophen

Early in the project we concluded that it would be valuable to compare the Lake Kinneret and Lake Qarun (Egypt) ecosystems by constructing a steady-state model of the two systems Such a model had been constructed previously for the Kinneret ecosystem using the ECOPATH model (Christensen and Pauly 1993, Walline *et al* 1993), and the exercise proved useful from several

points of view The model provides a good framework to present in summary form the results of research on all aspects of the ecosystem, and especially information on fish stocks The model is very simple to build, and does not require programming expertise or modeling experience In addition, the process of gathering the data and discussing with the scientists who collected it stimulated fruitful discussions The results of the modelling exercise highlighted areas where data were insufficient (in the case of Lake Kinneret, the data on benthic production and biomass was considered inadequate) and led to various hypotheses concerning food web relations

Since the publication of the results of the Ecopath model for Lake Kinneret, there have been several developments in the ecosystem and with the model that made it worthwhile to update our previous work A new version of the Ecopath software has been released, and we have new data on the fish stocks obtained with the dual-beam acoustic system purchased for this project

As a starting point, we used the same ecosystem components as for the published version of the model (Fig 32) As mentioned above, Ecopath is a steady-state model, and therefore cannot account for changes over time in ecosystem components In the published version, we used estimated long-term average values for the biomasses and turnover rates of the main components For the present exercise, we have input updated values (the annual average for 1996 was used) for the fish stocks, zooplankton biomass, and phytoplankton biomass The results were not greatly different from the original model, in large part due to the fact that in order to balance the original model, we were forced to use higher zooplankton biomass than that measured in 1993 when the model was being developed As mentioned above in Section VI, zooplankton biomass has risen dramatically since then, and is now even higher than the values we were forced to use in 1993 From this result, it can be concluded that zooplankton biomass was too low in 1993 to support fish populations as large as those measured in the lake This is consistent with the observation that large lavnun disappeared in the lake sometime in 1993, and those few that were present were in poor condition

One unexpected result concerned cannibalism by zooplankton Because of the large increase in the biomass of zooplankton, the loss due to cannibalism was also greatly increased In order to balance the model, it was necessary to reduce the amount of zooplankton in the diet of zooplankton This once again emphasizes the importance of zooplankton as a consumer of zooplankton For this reason the model is very sensitive to the composition of the zooplankton populations

We are currently working with Prof Ezzat Ibrahim Awad and his students on a manuscript comparing the ecosystems of L Kinneret and L Qarun The models have been constructed and are being "tweaked", and we expect the work to be submitted for publication within a few months

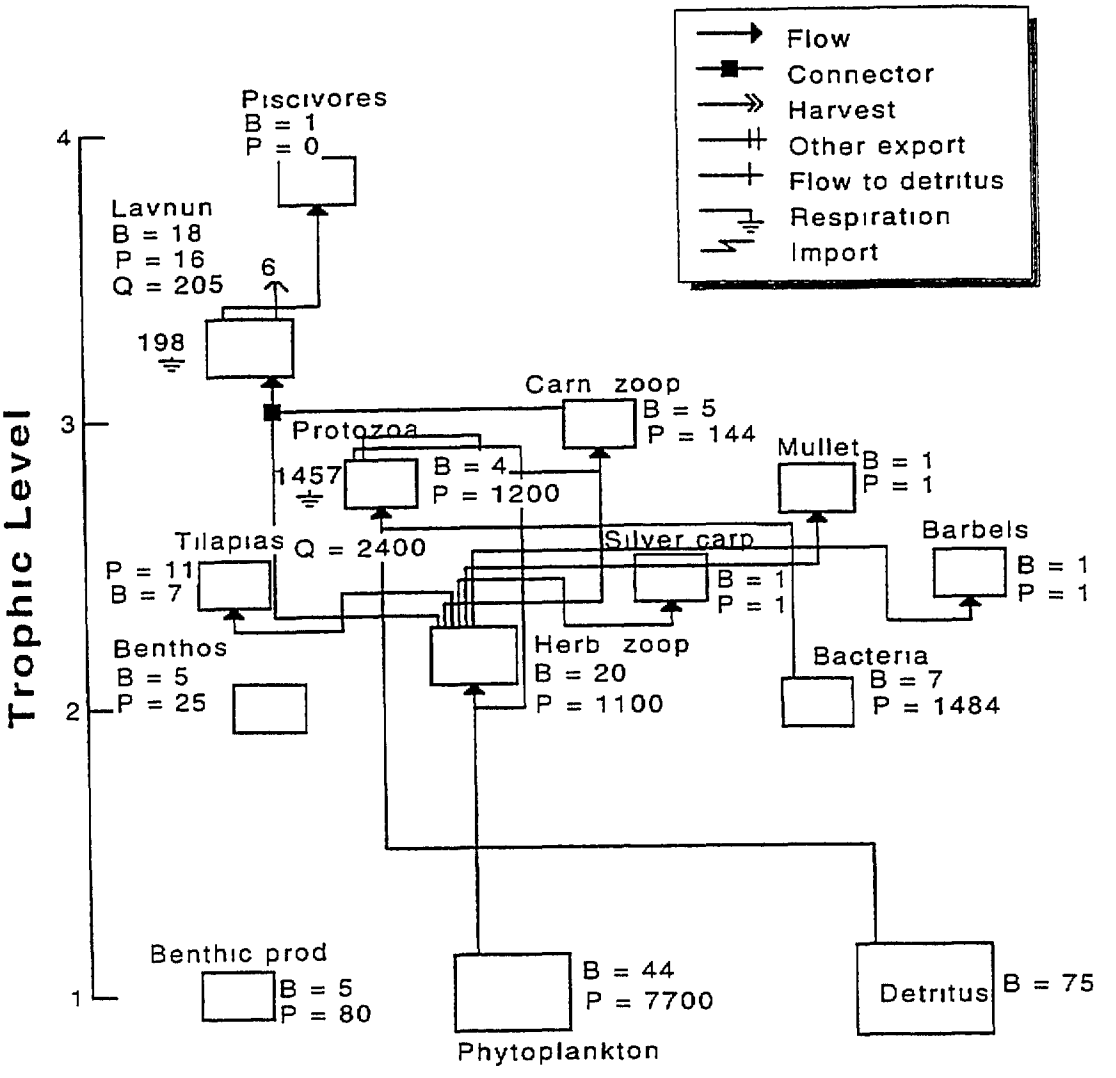


Figure 32 Diagram of the Lake Kinneret food web Each ecosystem component considered in the model is represented by a box with size proportional to the biomass of the component. The vertical position of the boxes corresponds to the trophic level of the component, according the scale to the left. The biomass (B), production (P), and consumption (Q) are presented in labels for some of the components Predator-prey connections (flows) for the lavnun, protozoa, and herbivorous zooplankton components are detailed Annual averages for 1996 were used for the biomass and production of zooplankton and phytoplankton

XI Summary

Results of studies on fish and zooplankton made during the AID project allowed improved management of the lake with regards to water quality During AID-Phase 1 (1980-82) investigation of the diets of two species of fish stocked in the lake led to recommending the cessation of stocking *Oreochromis aureus* and increased stocking of *Sarotherodon galilaeus* It was also proposed to protect the spawning grounds of *S galilaeus* The changes in stocking policy were implemented In Phase 2 (1984-86) pressure on zooplankton from fish was further documented The findings provided a scientific basis for recommending the elimination of the exotic silver carp from the lake Stocking was stopped It was also documented that L Kinneret sardines, the most common fish in the lake, are almost exclusively zooplanktivorous, and it was recommended to reduce the stock However, this was not implemented because of its very low commercial value Fishing restrictions designed to protect spawning *S galilaeus* in the Beteicha lagoons were passed into law During AID-Phase 3 (1992-present) interactions between sardines and *S galilaeus* were studied Intensive field investigations of the behavior of sardines in relation to their zooplankton food have strengthened arguments in favor of reducing the stock of sardines Detailed acoustic studies have revealed changes in the size of the sardine stock, which for the first time have been directly related to the size of the zooplankton stocks Changes in the lavnun biomass and size composition have led us to recommend a subsidy program for reducing the biomass of sardines in the lake, in an attempt to protect the water quality of the lake The program was implemented and monitoring showed that it was a success In summary, we feel that the AID program has made an important contribution to protecting the drinking water supply from our only freshwater lake

XII References

Ban, S 1992 Effects of photoperiod, temperature, and population density on dicution of diapause egg production in *Eurytemora affinis* (Copepoda Calanoida) in Lake Ohnuma, Hokkaido, Japan J Crust Biol 12 361-367

Berman T , Y Z Yacobi and U Pollingher 1992 Lake Kinneret phytoplankton Stability and variability during 20 years (1970-1989) Aquat Sci 52 104-127

Berman, T , L Stone, Y Z Yacobi, B Kaplan, M Schlichter, A Nishri and U Pollingher 1995 Primary production and phytoplankton in Lake Kinneret A long-term record (1972-1993) Limnol Oceanogr 40 1064-1076

Christensen V and D Pauly 1993 Trophic models of aquatic ecosystems ICLARM Conf Proc 26, 390 p

Demott W R , Zhang, Q and W Carmichael 1991 Effects of toxic cyanobacteria and purified toxins on the survival and feeding of a copepod and three species of *Daphnia* Limnol Oceanogr 36 1346-1357

Dimentman, Ch and F D Por 1985 Diaptomidae (Copepoda, Calanoida) of Israel and Northern Sinai Hydrobiol 127 89-95

Elser J J et al 1988 Zooplankton-mediated transitions between N and P limited algal growth Limnol Oceanogr 33 1-14

Gophen M 1976 Temperature effect on lifespan, metabolism and development time of *Mesocyclops leuckarti* (Claus) Oecologia (Berl) 25 271-277

Gophen M 1978 Zooplankton In Lake Kinneret, Monographiae Biologicae 33 pp 297-311 (C Serruya, Ed) Dr W Junk Pub The Hague

Gophen M 1979 Bathymetrical distribution and diurnal migration of zooplankton in Lake Kinneret (Israel) with particular emphasis on *Mesocyclops leuckarti* (claus) Hydrobiol 64 199-208

Gophen M 1979a Extinction of *Daphnia lumholtzi* (Sars) in Lake Kinneret (Israel) Aquaculture 16 67-71

Gophen M 1992 Long-term changes of plankton communities in Lake Kinneret Israel Asian Fish Sci 5 291-302

Gophen M 1994 Blue-green algae and Lake Kinneret Bull Amer Soc Limnol 3 5

Gophen M and R Landau 1977 Torphic interactions between zooplankton and sardine (*Micrograx terraesactae*) populations in Lake Kinneret, Israel Oikos 29 166-174

Gophen M S Serruya and S T Threlkeld 1990 Long term patterns in nutrients phytoplankton and zooplankton of Lake Kinneret and future predictions for ecosystem structure Archiv F Hydrobiol 118 449-460

Hairston Jr N G and W R Munns 1986 The timing of copepod diapause as an evolutionarily stable strategy Am Nat 123 733-751

Hambright, K D and S Friedman 1994 A computer-assisted plankton analysis system for the Macintosh Fisheries 19 6-8

Landau R , M Gophen and P Walline 1988 Larval *Mirogrex terraesanctae* (Cyprinidae) of Lake Kinneret (Israel) Growth rate, plankton selectivities, consumption rates and interactions with rotifers Hydrobiol 169 91-106

National River Authority 1990 Toxic blue green algae The report of the National River Authority, Water Quality Series No 2 London England

205

Santer, B 1994 Influences of food type and concentration on the development of Eudiaptomus gracilis and implications for interactions between calanoid and cyclopoid copepods Arch Hydrolol 131 141-159
Schindler, D W 1977 Evolution of phosphorus limitation in lakes Science 195 260-262
Serruya, C (Ed) Lake Kinneret, Monographiae Biologicae 32 Dr Junk Pub The Hague pp 502
Smith, V H 1983 Low nitrogen to phosphorus ratios favor dominance of cyanobacteria in lake phytoplankton Science 221 669-671
Vitousek, P M 1990 Biological invasion and ecosystem processes toward an integration of population biology and ecosystem studies Oikos 57 7-13
Walline P D , S Pisanty, M Gophen and T Berman 1993 The ecosystem of Lake Kinneret, Israel, p 103-109 *In* V Christensen and D Pauly (eds) Trophic models of aquatic ecosystems ICLARM Conf Proc 26, 390 p

XIII International Cooperation

Prof M Gophen and Dr P Walline began the planning for the current project during the first Annual Project Meeting held in Cairo, Egypt 29-31 December 1992 They met with their counterpart Dr E A Ibrahim After the planning and business meeting, Gophen and Walline went to visit Dr Ibrahim at his laboratory in Cairo There they met with Dr Ibrahim's students and discussed scientific issues concerning the research program to be carried out Dr Ibrahim's students made presentations of the work they planned for the project and Dr Gophen and Dr Walline provided feedback After the meeting in Cairo, Drs Walline and Gophen visited L Qarun and checked out the facilities there, which were to be used as a base for sampling the lake The project PI's also visited Wadi El-Rayan south of Cairo and concluded that the methods and information developed during the current project could be put to good use in the future in developing a management plan for Wadi El-Rayan, which has potential for fish production

Dr Paul Walline represented the Israeli side of the project at the second Annual Project meeting held in Sharm El Sheik in December 1993 Dr El Gammal and Dr Ibrahim presented results of the first year of sampling in L Qarun, and Dr Walline presented the results of the work in L Kinneret

Dr Ezzat A Ibrahim and Dr Fahmi Ibrahim El-Gammal visited the Kinneret Laboratory 16-18 October 1994 The visit was taken up with reviewing research results obtained during the project and planning future research based on the work done during the Lakes Management Project It was decided that 2-3 colleagues of Dr Ibrahim would attend a mini-workshop at the lab on Lake Kinneret

Three Egyptian scientists (Mr Osama Khalifa Sayed, Mr Gamal M El-Shabrawy, and Mr Adel H Konsoaa) from the Egyptian National Institute of Fisheries and Oceanography (NIOF) visited Prof Moshe Gophen and Dr Paul Walline at the Kinneret Limnological Laboratory of IOLR

204

during the period of 22 May to 1 June 1995 The visit was planned as an informal "workshop" covering a wide variety of subjects currently of interest in the AID-funded Lakes Management Project During the visit all three scientists participated in an acoustic survey of Lake Kinneret and helped plan and execute a tank experiment designed to investigate feeding relationships of zooplankton and fish Mr Sayed worked closely with Dr Walline in gaining familiarity with the Ecopath program and developing a preliminary model of the L Qarun ecosystem He also participated in the analysis of the survey data from the acoustic cruise Mr Konsoaa had the opportunity to consult with Prof Utsa Pollingher on identification of phytoplankton in samples from L Qarun, which he brought with him for this purpose Mr El-Shabrawy worked with the video camera system to measure zooplankton from L Qarun All three took advantage of the library at the Institute in Haifa to collect literature important for their respective research subjects The group toured the Upper Galilee and the Lake Kinneret watershed

Prof Moshe Gophen and Dr Paul Walline visited Dr E Ibrahim in Cairo from 25-29 June 1995 During the visit trips were made to L Qarun, Wadi Raiyan, and several other facilities managed by the NIOF At the L Qarun facility a short cruise was made together with scientists from the laboratory Discussions (started at KLL, see above) on zooplankton culture, data analysis, and other subjects of interest were held Prof Gophen and Dr Walline also visited the new laboratory of NIOF in Cairo Discussions with Dr Ibrahim were held on possible future research projects, such as planning the fishery development of Wadi Raiyan, and making a fishery and acoustic survey of Lake Nasser

XIV Publications and Presentations

Gophen, M 1995 Chapter 3 Food web alterations by physical changes, eutrophication and selective fisheries *In* R De Bernardi and G Giussani, eds , Guidelines of Lake Management, Vol 7, Biomanipulation in Lake and Reservoir Management, International Lake Environment Committee, United Nations Environment Program

Gophen, M 1995 Chapter 11 Long-term (1970-1990) whole lake biomanipulation experience-case study Lake Kinneret (Israel) *In* R De Bernardi and G Giussani, eds , Guidelines of Lake Management, Vol 7, Biomanipulation in Lake and Reservoir Management, International Lake Environment Committee, United Nations Environment Program

Kalikhman, I , I Ostrovsky, P Walline, M Gophen and Y Z Yacobi 1995 Distribution fields for aquatic ecosystem components method of identification of correlation zones Freshwater Biology 34 317-328

Kalikhman, I , P Walline and M Gophen 1992 Simultaneous patterns of temperature, oxygen, zooplankton and fish distribution in Lake Kinneret, Israel Freshwater Biology, 28 337-347 (Also cover picture in the same issue)

Ostrovsky, I and P Walline Manuscript prepared for submission Spatial inhomogeneities in the population structure of a pelagic fish in a small subtropical lake

"Feeding habits of larval bleaks in Lake Kinneret (Israel) an overview", M Gophen, B Azoulay, J Easton and P Walline, oral presentation (Gophen), Conference on Trophic Interactions of Age-0 Fish and Zooplankton in Temperate Waters, Plankton Ecology Group (PEG), 5-8 February 1966, Dresden, Germany

"Identification of correlation zones for aquatic ecosystem component distributions", I Kalikhman, I Ostrovsky, P Walline, M Gophen and Y Z Yacobi, oral presentation (Kalikhman), ICES International Symposium on Fisheries and Plankton Acoustics, Aberdeen, June 12-16, 1995

"A pelagic fish in a small subtropical lake aspects of spatial inhomogeneities", I Ostrovsky and P Walline, oral presentation (Ostrovsky), American Society of Limnology and Oceanography 1996 Annual Meeting, University of Wisconsin-Milwaukee, June 16-20, 1996

"Fish distribution as an indicator of temperature seiche activity in Lake Kinneret, Israel", P Walline and I Ostrovsky, Poster Session III Observation and Behavior, ICES International Symposium on Fisheries and Plankton Acoustics, Aberdeen, June 12-16, 1995

"Lavnun dilution can the effects on the population be detected acoustically?", P Walline, oral presentation, Kinneret Sardine Discussion Meeting, Kinneret Limnological Laboratory, 29 October 1996

"Relations between Kinneret sardine (*Acanthobrama terraesanctae*) and zooplankton in Lake Kinneret", Ph D Thesis of James Easton, supervised by M Gophen and D Hambright, 1994-present

"The biology of new Lake Kinneret invader, the calanoid copepod *Eudiaptomus dreischi*", Ph D Thesis of Bonnie Azoulay, supervised by M Gophen and D Por, 1995-present

"Diurnal vertical migrations and trophic relations of zooplankton and Kinneret sardines", J Easton, oral presentation, Annual Meeting of the Israeli Environmental Society, Haifa, July 1997 (Abstract submitted and accepted)

"Vertical and temporal distribution of *Eudiaptomus dreischi* in Lake Kinneret", B Azoulay, departmental seminar, KLL, September 1966

"Background, rationale, implementation and success of sardine dilution program in L Kinneret, 1994-1996", M Gophen and P Walline, memorandum submitted to Minister of Agriculture, Treasury, and Kinneret Authority, 1996 (In Hebrew)

XV List of Participants

Prof Moshe Gophen, PI
Dr Paul Walline, PI
Dr Yigal Kalikhman
Dr Ilia Ostrovsky
Dr David Hambright
Dr Tamar Zohary
Dr Ora Hadas
James Easton, Ph D student
Bonnie Azoulay, Ms student, technician
Ofra Ohion, student from ORT Technical College, Carmiel
Dr Jim Dawson, BioSonics, Seattle, Washington (visited in May 1994)

XVI Acknowledgements

IV-3 TROPHODYNAMICS OF THE SOUTHEASTERN MEDITERRANEAN WITH SPECIAL REFERENCE TO COMMERCIALLY IMPORTANT FISHES

FINAL REPORT *

Principal Investigator Dr Ali I Beltagi
National Institute of Oceanography and Fisheries
Alexandria, Egypt

[*Editors note Report has not reached us by the time the consolidated Final Report was compiled, it will be forwarded to the sponsor at a later date]

INVESTIGATIONS OF LAKE ECOSYSTEMS IN ISRAEL AND EGYPT WITH IMPLICATIONS FOR FISHERIES AND WATER QUALITY MANAGEMENT

V-2 Lake Qarun (Egypt)

FINAL REPORT

Principal Investigator Ezzat I Awad

Ministry of Scientific Research
National Institute of Oceanography and Fisheries
Inland Waters & Aquaculture Branch

21

Table of Contents

I	Acknowledgments	91
II	Research Team/Contributors to Final Report	92
III	Abstract	93
IV	Summary of Project Accomplishments	95
V	Introduction	96
VI	Materials and Methods	102
VII	Results	119
VIII	Environmental Conditions	119
	A Meteorological parameters	119
	B Physico-chemical parameters	122
VIIII	Sediments	140
X	Pollutants	147
	A Organo-chlorine	147
	B Heavy Metals	147
XI	Biological Paramers	150
	A Phytoplankton	150
	B Zooplankton	165
XII	Bottom Fauna	176
XIII	Fish Pathology	184
	A Bacteriology	184
	B Bacterial diseases	184
	C Parasitology	187
XIV	Fisheries	197
	A Fisheries Statistics	197
	B Bilogical studies	205
	C Reproduction	225
	D Management	229
XV	Discussion	254
XVI	Acknowledgements	267

Acknowledgments

Grateful acknowledgment is expressed to the US Agency for International Development (AID) for the financial support of this project (under contract No L 300042) The Principal Investigator and the research team of the Lake Qarun Project wish to thank the AID personnel for their interest and support of the project

Thanks are also extended to all members of the Steering Committee of Marine Technology Program for the Middle East and in particular, Dr Robert B Abel, Program Manager, for his valuable help and encouragement

Special thanks are extended to Professor Sayed Z El-Sayed, Chief Scientist, and his staff at Texas A&M University for their valuable assistance in procuring the equipment and instruments used in carrying out the research Gratitude is expressed to Professor El-Sayed for editing the Annual and Final Reports

ABSTRACT

Investigation of Lake Qarun ecosystem was carried out over 48 successive months starting from January 1993 to December 1996 This comprehensive survey was aimed at providing complete information on the physical, chemical and biological conditions of this enclosed saline environment, and determining the factors responsible for the severe decline in fish production Most of these factors were found to be related to the lack of proper management plan rather than ecological problems

Several new data, for instance meteorological parameters, were acquired during this study The previous meteorological data were collected from the weather station at Fayoum City (35 Km south of Lake Qarun), while the present meteorological information were collected from the weather station (purchased through the project) installed at the lake

The chemical data revealed high levels of all major nutrient salts (N, P & Si), as well as the essential trace metals Due to shallowness of the lake (average depth 4 m) there is no thermal and oxygen stratification The primary and secondary productions are sufficiently high to account for the essential requirements of the higher trophic levels Further the present investigation provided detailed information on the natural food, limiting nutrients, grazing pressure and feeding behavior of mullet fry in the lake The primary aim of good management of Lake Qarun is to ensure utilization of the natural food reserves by the indigenous and transplanted fish species in order to obtain high production rates

No evidence for external source of heavy metal pollution in the lake was found For pesticides, since 1991, their levels were obviously low due to the application of biological techniques for controlling agriculture pest Raw sewage is the main source of pollution in the lake and is responsible for the increase in bacterial diseases and parasites among indigenous and transplanted fish species These diseases have direct effect on survival of fish and are causing mass mortality of *Solea aegyptiaca* in addition to their adverse effect on the growth rate and reproduction of the infected fishes One of the most important achievements of this project was the discovery of pathological condition of transplanted mullet fry from El-Gerbee near Domietta (northern Delta) where the fry were highly infected with trematodes Our recommendation in this respect was approved, and has already been implemented, by the General Authority for Fish Resources Development As a result the fry are now collected from Ashtom El-Gameel near Port Said (Mediterranean Sea), where the fry are less infected This step will have a significant impact on mullet production in the lake

The availability of healthy mullet fry at reasonable price is a major constraint for fisheries development in Lake Qarun This problem underscores the importance of a construction of hatchery for mullet fry production near the lake This hatchery will also feed Wadi El-Rayian Lakes (18,000 hectares) that lie at the same area and which will depend on mullet fry for annual stocking

The feeding behavior experiments proved the capability of mullet fry to feed on fertilized eggs of *Solea aegyptiaca* and this will adversely affect production of *S aegyptiaca*

Fish biological studies revealed the difference in growth in length and weight between males and females of the different fish species inhabiting the lake On the other hand, shrimp

(*Metapenaeus stebbingi*) and soles (*S aegyptiaca)* are characterized by high mortality rate, while the reverse is true for *O niloticus* In general, all fish stocks in Lake Qarun are over-exploited and the exploitation rate should be decreased to achieve the maximum yield per recruit All fish stocks in the lake are bottom-feeders especially on Crustacea Thus, in order to improve the lake ecosystem, filter feeder fish species that can tolerate the lake condition should be transplanted

The present study revealed overexploitation of both indigenous and transplanted fish In order to obtain the maximum sustainable yield (^{f}MSY), the fishing effort, as represented by the number of fishing boats, should be reduced from 394 to 165, for indigenous species, and from its present 394 to 182, for the transplanted species The total expected ^{f}MSY after reducing the fishing efforts, will be around 1100 tons

Summary of Project Accomplishments

Infra structure Development

Advanced Laboratories were constructed at the Barrage Research Station through governmental funds and were equipped through the project's budget ($162,000) By these facilities the institute signed several research contracts with national and international authorities Through these new activities the available fund covered continuation of the project activities, maintenance and upgrading the equipments

Manpower Development

- 10 Ph D students have obtained their degrees while working on this project or have utilized its facilities
- 2 Ph D and 1 M Sc student finished their field work within the project objectives, and expected to submit their theses/dissertations by the end of the year (1997)
- 3 Ph D students spent 12 days training in the fields of fisheries, zooplankton and pigment analysis (using HPLC technique) at the Kinneret Labs (in Israel) under the supervision of Prof M Gophen and Dr P Walline

Collaboration

National

- A contract was signed between the National Institute of Oceanography and Fisheries and the Fish Farmers Society at Shakshouk (the Project site) according to which fish farming activities were technically spuervised by the Project sicentists
- A contract was signed between the National Institue of Oceanography and Fisheries and El-America Petrochemical Company for water quality evaluation of the feed water, as well as the environmental impact assessment of its wates
- A contract was signed with the Academy of Scientific Research and Technology for the investigation of the ecological status of Wadi El-Raiyan Lakes

International

- Profs Ezzat A Ibrahim and Fahmy El-Gamal visited Kinneret Labs (15-18 Sept 1994) to discuss and review the Project results with Prof M Gophen and Dr P Walline (the Israeli Co-Principal Investigatiors)
- New research activities began in Jan 1996 to study phytoplankton of the Gulf of Aqaba in Collaboration with Israeli and German Scientists Through this program, Prof E Z Ibrahim visited Israel in July 1997 and met with Profs Aftalion and Kimor and discussed with them ways to collaborate in the mass production of genetically pure Oreochromis niloticus fry, as well as in the productio of a catalogue for plankton in Aqaba Gulf

INTRODUCTION

At early 1993 the research team of Inland Water and Aquaculture Branch of National Institute of Oceanography and Fisheries began the implementation plan for the Investigation of Lake Qarun Ecosystem The main objectives of this investigation were

1 To determine the variability in lake water quality and soil-condition, and how this impacts the biological productivity in the lake
2 To obtain information on parasites and diseases that may cause fish kills directly or reduce fish productivity by adversely affecting growth rates and reproductive capacity
3 To provide information on growth rates of the endemic and introduced fish and prawn species and their feeding habits at different growth stages
4 To assess the stock and the success of introduced fish in terms of growth and survival, and to estimate the catch efficiency of different fishing gears
5 To formulate a stocking policy by assessing the stocking potential of the lake and selecting a scheme for adjusting the stocking rate

The investigations carried out by the research groups included physical and chemical water analysis, pollutants (heavy metals & pesticides), sediment (chemical and mechanical analysis), phytoplankton analysis (standing crop, species composition, and primary productivity) zooplankton, bottom fauna, fish populations and their pathological status The physical, chemical and biological analyse were carried out at monthly intervals during 4 years (from January 1993 - December 1996) The sediment and pollutants analyse were carried out at quarterly intervals

The present report covers the investigation which was conducted in Lake Qarun within the framework of the above mentioned objectives

Lake Qarun, the project site, between 29° 25 & 29° 34 N and 30° 24 & 30° 49 E occupies the lowest part in the Fayoum Depression It is an isolated saline basin, used as reservoir for agriculture drainage water, and is situated in the Western Desert, about 83 km from Cairo It has a rectangular shape and covers an area of about 228 km^2 (about 40 km length and 5 7 km mean width) The lake lies at about 45 m below the sea level Its water level is compensated by inflowing drainage water, evaporation seepage through the bottom and banks

The northern side of the lake is bordered by the sandy dunes of the Western Desert, and the southern side by fertile and cultivated Fayoum Oasis The cultivated lands of Fayoum Governorate are naturally irrigated by Nile water through Bahr Youssef Canal The drainage water flow to the lake via two main drains, namely El-Bats (at the east) and El-Wadi (at the middle) as shown in Fig 1

The salinity of the lake ranges from 14 to 35‰, the lowest salinity values are found in front of the drains The rates of inflow and evaporation of water almost equal, this leads to annual accumulation of salt contents of the agriculture drainage water

Several authors investigated the different environmental aspects of lake Qarun The geological characters of the lake were studied by Gardner (1932), Caton-Thompson and Gardner (1929),

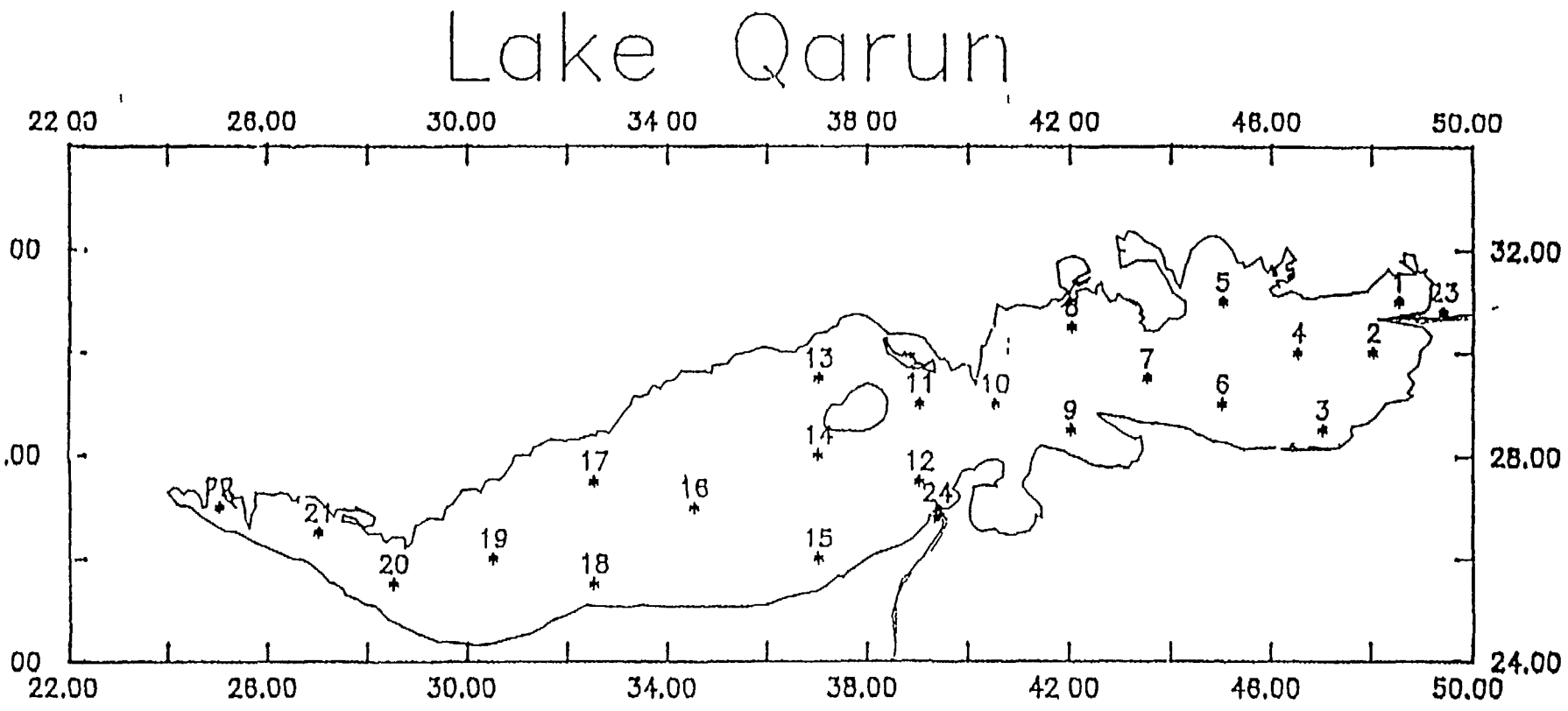


Fig 1 Position of Stations Occupied in Lake Qarun

Ball (1939), Said (1962), and Coque (1975) Dietrich and Kalle (1957) studied the chemical characteristics of the lake water in relation to the Mediterranean Sea Recently, El-Sayed (1986) provided detailed information on some environmental aspects of the lake

On the other hand, studies of the species composition and biomass of phytoplankton, zooplankton and benthic organisms in the lake are scarce (Wimpenny, 1936, Naguib, 1961, El-Maghraby and Dowidar, 1969, Abdel-Malek, 1978, and Abdel-Malek and Ishak, 1980, Abdel-Monem 1991, Fishar, 1993 and Ahmed 1994)

The gradual increase in salinity in the lake water had an adverse effect on the freshwater plankton species Girgis (1959) examined some plankton samples collected from the lake in 1959 and found that *Diaptomus salinus* and *Moina salinarum* disappeared, whereas, the neritic copepod *Acartia latisetosa* Kriczageum was found in large numbers The presence of *Acartia latisetosa* and *Balanus sp* in the lake was also confirmed by Naguib (1961) The composition of zooplankton, at present, shows that the marine species include not only *Acartia latisetosa* and *Cirripedia* nauplii, but also other species such as l polychaet larvae

Since the lake was freshwater, its fisheries production contained most of Nile fishes The lake has been noted during the beginning of 20th century for the great quantities of *Lates niloticus* Linn, and *Tilapia nilotica* Linn (Faouzi, 1936)

Since then, the salinity of the lake has progressively increased which made the condition became unfavorable for most of the freshwater fish fauna originally inhabiting the lake Thus all freshwater species gradually disappeared from the lake with the exception of *Tilapia* and *Anguilla* Faouzi (1938) indicated that remnant of the original freshwater *Tilapia zillii* was the only species that had not suffered from the salinity increase In this connection, El-Zarka (1961) stated that *Tilapia nilotica* can still be found in small numbers at the discharging points of the drains into the lake

As a result of disappearance of original fish fauna, the commercial catch dropped from 4000 tons during 1920 to an average of 1000 to 2000 tons in subsequent years (Faouzi, 1938) This situation had a negative impact on the economy of the communities of fishermen around the lake In order to compensate for the decline in freshwater fish production, the lake was stocked with fish species which can tolerate high salinity Wimpenny, the head of Egyptian Fisheries Research Department from 1928 to 1931, thought to stock Lake Qarun with grey mullet (*Mugil cephalus*) Thus for the first time in 1928, grey mullet fry were collected from El- Mex Station, near Alexandria, and transplanted to the lake During the period from 1971 to 1978, about 55 million mullet fry were introduced to the lake In recent years 1991/92, 92/93 and 93/94 about 106 million mullet fry were transplanted to Lake Qarun *Anguilla vulgaris* and *Atherina mochon* were accidentally introduced as fry mixed together with mullet

As a result of mullet fry transplantation, mullets appeared in the commercial catch ifor the first time in 1929 and 1930 In subsequent years, especially after 1934, the production of mullets constituted a major part in the commercial catch During 1961/62 fishing season, when the statistics of mullet fisheries production for the different species were compiled separately, it was found that *M saliens* constituted about 13 6% of the total fish production of

the lake, while *M capito* and *M cephalus* constituted 4 7 % of the total yield (El-Zarka, 1964)

Wimpenny and Faouzi (1935) and Faouzi (1936) found eggs and larvae of *M saliens* in the plankton hauls collected from the lake This was a strong evidence for the natural spawning of *M saliens* in Lake Qarun El-Zarka (1965) attributed the low percentage of *M capito* and *M cephalus* in the fish catch to their inability to spawn in the lake Meanwhile, he ascribed the high production of *M saliens* to its ability to spawn in the lake Till now, the issue of mullet spawning in the lake is shrouded in controversy

Solea vulgaris, is another marine species which was successfully transplanted and acclimatized in Lake Qarun The fish was first introduced into the lake in 1938 and was stocked in the lake in 1943, 1945 and 1948 A total of 1,603 sole fish ranging from 7 to 10 cm in length have been collected from Maadia District at the Mediterranean Sea (about 32 kilometers to the east of Alexandria) The transplanted soles to Lake Qarun during different periods were 103, in 1938, 700, in 1943, 428, in 1945 and finally 377, in 1948 The first record of soles appearing in the commercial catch was reported in 1938, total catch of 38 kg In 1942, 87 kg of soles were caught accidentally in trammel nets used for tilapias The sole catch increased to 1,555 kg during 1943 This indicated that soles were successfully spawned and established itself in Lake Qarun (El-Zarka, 1965a) In subsequent years, the increase of the annual catch of soles was probably due, in part, to natural spawning in the lake and, in part, to the improved skill of the local fishermen From 1961 to 1966, the sole fishery in the lake constituted about 33 2% of the total yield (El-Zarka, 1968) During 1970's, their production ranked at the top of the other species, where it contributed more than 50% of the lake production (Bishai and Kirollus, 1987)

From 1977 to 1979, about 2 million sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) fry have been transplanted in the lake

During the period from December 1977 to May 1978, about 3 million shrimp larvae have been transplanted to the lake Shrimp larvae included *Panaeus japonicus*, *P semisulcatus*, *P latisulcatus*, *Metapenaeus stebbingi* and *Metapenaeopsis philipii* As A result, the production of shrimps increased and comprised a major part in lake fisheries Again, this indicates that shrimp was successfully acclimatized and established in the lake ecosystem Shrimp prolific and the profitable returns, encouraged the lake fishermen intensify shrimp fishing, and this, has led to increase shrimp production to 500 tons during 1987/88, constituting about 45% of total fish yield Unfortunately, the intensive shrimp fishing had a destructive effect on the fish stocks in the lake as the shrimp nets caught other fish fry and fingerlings

Since the beginning of 20th century, several investigations have been carried out on Lake Qarun fisheries During 1920's and early 30's, the main focus of the research was to investigate means to compensate the loss of freshwater fishes in the lake Faouzi (1936) reported the successful transplantation of mullet fry from the Mediterranean Sea to the lake Wimpenny and Faouzi (1935) and Wimpenny (1936), recorded eggs and larvae of *M saliens* in the plankton samples collected and it was concluded that *M saliens hass* naturally spawned in the lake

El-Zarka (1960, 1961 & 1962) reported the results and conclusions of research program started in 1957 to survey the fisheries of *Tilapia zillii* Gev , in the lake He studied the annulus formation on scales and its validity in age and growth He investigated the length frequency distribution, age composition, length-weight relation and growth rate Also, he studied maturity, spawning and sex ratio El-Zarka (1963 a & b) conducted an investigation of the acclimatization of both of *Solea vulgaris* and *Mugil saliens* in Lake Qarun He studied monthly variations of their catch composition and length frequency El-Zarka and Kamel (1965) discussed the mullet fry transplantation and its contribution to the fisheries of the inland and brackish lakes in Egypt The same authors examined the sources of fry, and described methods of collection, seasonal abundance and the appearance of mullet fry Finally, they discussed the economic significance of mullet transplantation with special reference to Lake Qarun El-Zarka (1968) gave a brief account on the fisheries status in Lake Qarun during the period from 1961 to 1966 El-Zarka and El-Sedafy (1970) studied age, growth and reproduction of *M saliens* in the lake

Sporadic investigations were carried out on some biological aspects of Lake Qarun fisheries Abdel-Malek (1972 a,b) investigated the food and feeding of *T zillii* in the lake according to different length groups and different sexes, while Al-Kholy and Abdel-Malek (1972) studied, in detail, the variation of food consumption of *T zillii* in the different localities of the lake Boulos and Ashour (1973) studied the histology and seasonal cycle of the ovary of *Solea vulgaris* collected from the lake They concluded that the spawning period of the soles was long and extended from November to early March Boraey (1974) studied age, growth, length-weight relation and condition coefficient of 4 mugilidae species in Lake Qarun, namely *M cephalus*, *Liza ramada*, *L saliens* and *Chelon labrous* Kirollus (1977) was interested in studying the biology of *S vulgaris* in the lake Ezzat *et al* (1979) studied the morphological variations in *S vulgaris* as a result of adaptation to its new environment

From 1974 to 1980, National Institute of Oceanography and Fisheries carried out a five year research project, funded by Academy of Scientific Research and Technology The project aimed at increasing fish yield in Lake Qarun by increasing the number of transplanted mullet fry as well as introducing a new fish species and shrimps to the lake (Anonymous, 1981)

Ishak *et al* (1982) gave a brief account of the mullet fisheries production in Lake Qarun They studied length and age composition of different mullet species in the lake Bishai and Kirollus (1988) carried out net selectivity experiments for *S vulgaris* using five sets of both cotton and nylon trammel nets They concluded that the net of 29 4 mm mesh size is the most suitable for catching 23 to 32 cm long soles Mosaad (1990) studied the length-weight relation and condition factor is the most common fish in the lake, *M capito*, *M cephalus*, *M saliens*, *S vulgaris* and *T zillii* He compared his result with that of the previous investigators on the same species but from other localities

Shafik (1991) investigated the biological parameters of *M cephalus* and *L ramada* in Lake Qarun with emphasis on the possibilities of inducing breeding of *M cephalus* This was in an effort to restock the lake which has been suffering from the decrease in the number of mullet fry collected from natural resources Recently, Kamel and Fathalla (1995) studied the histology of gills, liver and gonads of the most common economic fish in the lake

Although extensive investigations were carried out on the limnology, fisheries and pollution of Lake Qarun (Abu-Samra, 1936, Aleem, 1958, Naguib, 1958, Hussein *et al*, 1964, El-Maghraby and Dowidar, 1969, Meshal, 1973, Abu El- Keir, 1987, Abdel -Malek, 1980, Ibrahim, 1981, El- Sayed, 1986, Abdel-Malek and Ishak, 1980, Abdel Malek, 1990 and Abdel-Monem, 1991), additional information was needed to provide a data base for optimal fisheries and water quality management of the lake

MATERIALS AND METHODS

Sampling Stations

In 1993, twenty-two stations were selected, these were distributed all over the lake, beside the two drains (El-Bats and El-Wadi), see Fig 1 During the period from 1994 to 1996, sampling was limited to 9 stations in addition to the two drains Of these, three stations representing the eastern, middle and western regions were selected for measuring chl *a* of different phytoplankton size compositions (net > 20 µm, nano, < 20 µm and pico > 2 µm), and primary productivity at different depths on the basis of light attenuation

Sampling Program

- ***Environmental parameters***
  Physical, chemical and biological data were collected at monthly intervals Samples for sediments and pollutants (heavy metals and pesticides studies), were collected at quarterly intervals

Analytical Techniques
Environmental Parameters

Meteorological Conditions

In January 1996, AANDERAA, Automatic Weather Station Model 2700 was installed on the lake at the project site at Shakshouk Research Station The following meteorological parameters were recorded air & water temperature, wind speed & direction, relative humidity, sunshine duration, air pressure and rain fall

Physical and Chemical Characteristics

- Air water temperatures

At the time of sampling, air temperature was measured (in the shade) using a dry mercury thermometer graduated to 0 01°C , while water temperature was measured by a mercury thermometer installed in the sampler

- Evaporation (E)

The evaporation rate was calculated by using the equation

$$E = Au (eo - ea)$$

Where	E	rate of evaporation
	A	coefficient of wind speed
	eo	saturated vapor pressure (mb)
	ea	vapor pressure (mb)

- Water Depth

The water depth at each station was measured by a portable echosounder Model (Lowrance X 25)

- ***Turbidity***

Water turbidity was measured by the standard Nephelometric method (APHA, 1992) The results were expressed as Nephelometric Unit (NTU) by Orbico-Halling Instrument

- ***Transparency***

Water transparency was measured by standard Secchi disc of 25 cm diameter with black and white surface

- ***pH***

The water pH was measured *in-situ*, using portable pH meter Genway equipped with microprocessor Model 3405

- ***Salinity (S‰)***

Total dissolved solids were determined by filtration of water samples through Millipore filter (0 45 *um* pore diameter) Known volumes of filtered waters were poured into dishes (made of aluminum foil) and dried in oven at 105°C (for 24 hours) The TDS values were calculated by subtracting the weight of the dish from the total weight of the dish and the sample Salinity was calculated from the following equation

S‰ = TDS / Density

- ***Electrical conductivity (E C)***

Electrical conductivity of water was measured using conductivity meter YSI (Yellow Spring Instrument) Model 32

- ***Dissolved Oxygen (DO)***

DO was determined by modified Winkler method according to the standard method (APHA, 1992), values of dissolved oxygen were expressed in mg $O_2 L^{1}$

- ***Chemical Oxygen Demand (COD)***

COD was measured by the oxidation of known volume of sample using $KMnO_4$ (Strickland and Parson, 1968), and the results were expressed as mg $O_2 L^{1}$

- ***Alkalinity***

CO_3 & HCO_3 were determined according to standard methods APHA (1992) using ph ph and Methyl Orange as indicators and standard H_2SO_4

Nutrient

- ***Nitrogen***

• ***Ammonia (NH_4-N)***

NH_4-N was determined spectrophotometrically using phenate method as reported by Booth and Labring (1973) The results were presented as *u*g NH_4-N L^{1}

• ***Nitrite (NO_2-N)***

NO_2-N was measured by diazotizing with suphanilamide and measured by coupling with N-(1- naphthyl ethelyne diamine) to form highly colored azo-dye phenate NO_2-N was measured according to the method of Barnes and Folkard (1951)

• ***Nitrate (NO_3-N)***

NO_3-N was determined using cadmium reduction technique as described by Nydahl (1976) The results were expressed in µg NO_3-N L^{1}

• ***Organic Nitrogen***

Total nitrogen (TN) and Total Dissolved Nitrogen (TDN) were measured using Kjeldahl method as described by McKenzie and Wallence (1954) Total Organic Nitrogen (TON) and Total Dissolved Nitrogen (DON) were calculated by subtracting the NH_4-N value from the total Kjeldahl nitrogen and total dissolved nitrogen

- ***Phosphorus***

• ***Orthophosphate (PO_4-P)***

PO_4-P was determined by the ascorbic acid and potassium antimonyl tartarate method according to Strickland and Parsons (1965) The results are expressed in µg PO_4-P L^{1}

• ***Organic Phosphorus***

The total phosphorus was measured using digestion method as described by Gales *et al* (1966) The organic phosphorus was calculated by subtracting the values of orthophosphate from total phosphorus

- ***Silicate***

Reactive silicate concentration was measured by molybdosilicate method according to Chow & Robinson (1953)

- ***Sulfate***

SO_4^{2} was determined by turbidimetric method as reported by Rossum and Villarruz (1961)

- ***Hardness (Ca^{+2} & Mg^{+2})***

Ca^{+2} & Mg^{+2} were determined by EDTA titrimetric method as reported by Katz and Navone (1964)

- ***Sodium and Potassium***

Na and K were measured by a Digital Flame Photometer Corning Model 410

SEDIMENTS

Soil samples were collected at each station as well as at the two drains on a quarterly basis during 1993 The samples were air dried, ground and passed through a standard sieve 2 mm mesh diameter The mechanical and chemical properties of the samples were determined

The mechanical analysis was carried out using the pipette method in the presence of hexametaphosphate as dispersing agent (Kilmer and Alexander, 1949) The soil organic matters were determined using diphenylamine as indicator (Jackson, 1967) Soil pH was determined in 1 2 5 soil water suspension using portable pH meter Soil conductivity was measured by a conductivity meter in 1 5 soil water extract Soluble cations (Ca & Mg) were determined in the soil extract by titration against EDTA disodium salt using merioxide and Eriochrom Black T as indicators (Jackson, 1967) Soluble chlorides were determined according to Mohr's method using silver nitrate (Standard Method, 1992) Carbonate and bicarbonate alkalinity were determined by titrating the soil extract against known normal H_2SO_4 in the presence of ph ph and methyl orange as indicators (Jackson, 1967) Sulfate was measured by titrating the soil extract against Na-EDTA and barium chloride The sediment samples were size- fractionated as follows clay fraction was separated by sedimentation procedure using sodium chloride as dispersion Carbonates were dissolved using 1 N NA Oak-Hooch at pH 5 and the samples were treated with 20% H_2O_2 followed by the citric dithonite for the removal of free ion oxides The mineralogical analysis was conducted using magnesium saturated, glycerol solvated and K heated to 550 °C for 4 hr X-ray difraction patterns were obtained using PW 1050 Philips X-ray diffractometer with Ni-filtered and Cu-X-radiation at 36 Kv and 16 MA potential, (Jackson, 1969)

Sediment samples were collected from the eastern, middle and western Lake regions as well as the drains The samples were dried and prepared for mechanical and chemical analyses The percentage composition of different particle sizes were determined after sieving the dried sediment using standard sieves with mesh diameter of > 4 mm, > 2mm, > 1mm, > 0 5 mm, >0 25 mm, > 0 152 mm, > 0 063 mm, > 0 138 mm and > 0 38 mm The moisture content of the samples was measured and its percent was calculated

The chemical analyses performed on the samples were carried out as mentioned above and included the following parameters total phosphorus (TP), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), total carbon (TC) and percentage of total organic matter (% TOM)

POLLUTANTS

- Pesticides

Sample preparation

Sediment samples were collected from Lake Qarun and the two drains The samples were gently homogenized in a beaker with 3 times their weight of anhydrous sodium sulfate [10 g sediment samples, 30 g anhydrous Na_2SO_4 and extracted with 220 ml Hexane (HPLC Grade) for 12 hours] A blank was made by adding 30 gm anhydrous $Na_2S_2O_4$ After extraction the sample was quantitatively transferred to rotary evaporator (30-40°°C) until the extract was

reduced to 15 ml Sodium anhydrous sulfate was added to remove residue of water The sample was then brought to 10 ml by Hexane Metallic mercury was added to the extracted samples to remove sulfur compounds

Column chromatography

Preparation

Florisil was pre-cleaned by soxhlet extraction with methanol for 8 hours and with hexane for 8 hours, dried in oven at 60°C for 4 hours, then stored in a dark bottle The florisil was activated at 200 °C for 4 hours and partially deactivated by adding deionized water

Sample fractionation

Organochlorine pesticides were separated by florisil chromatography column (20 mm IDK 300 mm) The column was filled with 16 g of 60/80 florisil and washed with hexane The extract (I ml) was added to the column and eluted with 70 ml of the first elutant hexane The first elutant contained Aroclor , Hexachlorobenzene (HCB), Heptachlor and Aldrine The eluted sample was concentrated to 15 ml by using rotary evaporator and reduced to 1 ml using N_2 gas Fifty ml of mixture of Hexane and Dichloromethane (7 3 v/v) were added, and poured into another beaker (second fraction contained HcHs isomers and cyclodienes compounds) The elutant volumes were concentrated to 15 ml by using rotary evaporator to 15 ml then reduced to 1 ml by using a stream of nitrogen gas The remainder was kept in a 1 ml vials with a teflon cover The extracts were analyzed by gas chromatography

Chromatographic Conditions

Organochlorine pesticides were analyzed using Hewlett-Packard Model 5890 Series II Gas Chromatograph equipped with a split -splitless injector and an Electron Capture Detector A25 m X 0 25 mm ID X 0 32 µm film thickness Fused-Silica, Capillary Column with SE-54 (HP Ultra-2) was used for analysis The GC conditions were as follows Carrier gas nitrogen at flow-rate of 1 5 ml/min, temperature program 60°°C for 1 min 60 °C to 150°C at 30 °C /min, 150 °C° to 225 °C° at 2 C°/min, 225°C° to final temperature 275 °C° at 10 °C°/min, injector temperature 200 °C° and detector temperature 300 °C Carrier gas (He) 250 Kpa, makeup gas nitrogen 300 Kpa Aliquots of 1 µl were injected in the splitless mode using the micro-syringe needle technique

The spiked samples were subjected to the above mentioned treatments Residual organochlorine pesticides were corrected and calculated by using HP-CHEM Program provided with the GC System

- HEAVY METALS

The total heavy metals were measured in the water and sediments samples taken in the lake and the two drains The samples were collected, digested and analyzed according to the standard techniques as reported in Messiha-Hanna (1992) and APHA (1992) The results are expressed in $\mu g\ L^{1}$, for water and mg Kg^{1} for sediment

BIOLOGICAL CONDITIONS

- Phytoplankton

- ***Standing crop and species composition***

Integrated water samples for quantitative estimates (i e standing crop) and species composition of phytoplankton communities were collected at the different stations by the Ruttner sampler and preserved immediately in 4% neutralized formalin In the laboratory, the samples were poured into glass cylinders and Lugol's solution (I_2 + KI) was added until the samples changed to faint tea color The phytoplankton organisms were allowed to settle (by gravity), for 5 days About 90% of the supernatant was then siphoned off Drop technique was applied for counting and identification of the phytoplankton species using a counting chamber and an inverted microscope The species composition and the number of phytoplankton cells were determined at high magnification (40 x & 100 x) The number of phytoplankton cells per liter was then calculated

- Chlorophyll a and phaeophytin

A known volume of the lake water was filtered *in-situ* using syringe filtration unit (Sartorious) and glass micro-fiber filter GF/F This unit is equipped with a plastic holder (13 mm diameter) Chlorophyll *a* was extracted by grinding the filters with the samples in 90% acetone The extracts were clarified by centrifugation at 2000 rpm using T 24 centrifuge The samples were measured by fluorometry using Turner III automatic fluorometer The apparatus was calibrated using standard *Chl a* (Sigma product) The extract was acidified by adding two drops of 0 1 N HCl and measured again

The value of chlorophyll *a* and phaeophytins were calculated according to the standard methods (APHA,1992)

In January 1996, a new fluorometer (Turner Series 10-AU) was acquired The fluorometer is equipped with a kit for direct measurements of chl *a* without any interference from phaeophytin and chl *b* The *chl a* measurement by the new equipment began in January 1996 The extraction of *Chl a* was carried out in 90% acetone for 24 h at - 20 °C The *Chl a* of net, nano-and pico-phytoplankton was determined by applying the same technique for filtration and measurements, the only variable was the size fractionation of the samples as follow

For nano-plankton, the samples were filtered through a plankton net 20 µm mesh diameter

For pico-plankton, the samples were first filtered through a plankton net 10 µm mesh diameter, and then through an iso-pore filter 2 µm pore diameter

- BENTHIC ALGAE

The biomass of the benthic algae (estimated by *Chl a,)* was determined at quarterly intervals One cm^2 of surface sediment, as well as a known weight of mixed sediment were collected from the sampling stations *Chl a* was extracted in 90% at -20 °C for 24 hr The Chl *a* was measured spectrophotometry according to the standard methods (APHA,1995)

- Nutrient limitation of phytoplankton biomass in Lake Qarun

Up to 20 L of lake water were taken from the euphotic zone of the middle region of the lake Immediately after collection the water was filtered through a gauze of 250 µm mesh diameter to remove the macro-zooplankton Preparation of water for bioassays began within 2 hr after collection The nitrogen was added either as NO_3 or NH_4 at concentrations of 0 075 (N1), 0 225 (N2) and 0 75 (N3) mg L^{-1}, while PO_4-P concentrations were 0 005 (P1), 0 0225 (P2) and 0 15 (P3) mg L^{-1} The combined effect of different P N ratios (1 15, 1 10 and 1 5) on phytoplankton biomass as represented by *Chl a* was investigated Phytoplankton communities were subjected to 4 days assay under the following conditions temperature of 26°C (average air temperature of the Lake area), light intensity, 4000 lux from overhead cool-white fluorescent tubes and light cycle of 14 h alternating with 10 hr darkness Daily measurements of *Chl a* was carried out from the start (time 0) to the end of experiment (96 hr)

- Zooplankton

For quantitative analysis, standing crop and species composition, zooplankton samples were collected by vertical net hauls from near the bottom to the surface using a plankton net 55 µm mesh diameter The samples were fixed in 4% neutral formalin and examined under binocular microscope The number of zooplankton organisms per m^3 was calculated from the data of the counting tray (3 ml) , and the zooplankton species composition made The results presented in this report are those of monthly average value and include the standing crop of different zooplankton groups, percentage composition of the groups depending on the annual average values and the main dominant zooplankton species

- Grazing experiments of zooplankton on phytoplankton in Lake Qarun

In situ grazing experiments were conducted in the lake Two sets of transparent plastic bottles (20 L) each were used in these experiments The first set, representing ungrazed bottles, the lake water was filtered with screen of 45 µm mesh diameter The second set of bottles, containing lake water represented the grazed condition The bottles (both grazed and un-grazed) were incubated in the euphotic zone (75 cm below the surface water) The standing crop and species composition of both phyto- and zooplankton were monitored every 2 days In the meantime, phytoplankton biomass, represented by *Chl a* was measured as mentioned before

- Feeding Behavior of Mullet Fry in Lake Qarun

In late summer 1995, one phase of research focused on the feeding selectivity of mullet fry and their impact on zooplankton community in Lake Qarun Preliminary feeding trial of mullet fry was conducted in 30 L glass aquaria under laboratory conditions and 20 L transparent plastic bottle *in situ* (received as a gift from Kinneret Limnological Laboratory) The standard length (ST) of the test fry ranged from 46 to 64 mm and their weight varied from 1 68 to 3 86 g Three sets of either glass aquaria or plastic bottles were used in these experiments The first set served as control (i e zooplankton without fry), the second and

221

third sets were stocked with 4 and 9 fry each Feeding procedure consisted of adding freshly caught zooplankton collected from Lake Qarun by plankton net (55 µm mesh diameter)

Fish feeding selectivity was investigated by monitoring zooplankton densities in aquaria and plastic bottles as well as in gut contents of the fry before feeding and after 24 h Another experiment was conducted in the glass aquaria and the feeding behavior of mullet fry was followed before feeding and after 30, 60 minutes

- BOTTOM FAUNA

The benthic organisms were collected from the selected sampling stations using Ekman Grab (opening area is 250 cm^2) The sampling techniques depend on collection of more than one grab at each station

The bottom samples were washed *in situ* and filtered through a small hand net of 500 µm mesh diameter to remove the suspended particles The samples were fixed in 7% neutral formalin and sorted in plastic jars The benthic species were counted and weighted after drying on filter papers for five minutes to remove excessive water The results were given as the total numbers of bottom fauna per square meter as well as their biomass in gram fresh weight per square meter (g f w m^2)

The data include the standing crop and fresh weight of the main dominant benthic species, photographic pictures of these species were also taken

Fish Pathology

- Bacteria

Sampling

Water samples were collected from the selected stations, using sterilized 500 ml glass bottles and transferred immediately (in an ice-box) to the laboratory The samples were analyzed within 6-8 hrs of collection

Bacterial count using spread-plate method.

The method involved the spreading of 0 03 ml from diluted sample over the surface of a solidified agar plate Spreading was usually carried out with a wet glass rod shaped almost like a hockey stick The excess liquid was allowed to get absorbed and evaporated at room temperature, before the plates were inverted inside the incubator Three replicate inoculated plates were incubated at 22 °C and 3 others at 37 °C Counting of the bacterial colonies was carried out after 24 hr for the plates incubated at 37 °C and after 48 hr for those incubated at 22° (Clark, 1971)

Most probable number (MPN) of coliform bacteria

- Presumptive test

The determination of MPN-index of coliforms as determined by the multiple fermentation technique was carried out using 3 decimal dilution (10, 1 0 and 0,1 ml) for each sample Five replicate tubes containing Macconkey Broth were used for each sample Double and single strengths media were used for the 10, 1 and 0 1 ml, dilation, respectively All tubes were incubated at 37 °C for 48 hr and their the readings were taken A positive reaction was indicated by acid and production The corresponding MPN-index was computed from Swaroop's Table (Swaroop 1951 and APHA,1975)

- Confirmatory and differential coliform tests

Plates of Eosin-Methylene Blue (EMB) agar (Levin's medium) were inoculated from the Macconkey - Positive tubes (producing acid and gas) and incubated at 37 °C for 24 hr Coliform growth usually showed a metallic sheen on that medium

- Most probable number (MPN) index of fecal coliform

Two loops were transferred using sterilized tube (4 mm diameter) from all positive presumptive tubes in the total coliform MPN test to fresh single strength Macconkey's medium in tubes provided with the Durham tubes The inoculated tubes were incubated at 44 5 °C for 24 hr Gas production in a fermentation table within 24 hr or less was considered as positive reaction indicating fecal origin of the coliform bacteria (APHA, 1975) The MPN index per 100 ml of water was determined from Swaroop (1951)

- Bacterial Diseases

This work was carried out to investigate bacterial diseases in the native fish species or those transplanted to the lake

Random fresh samples of *Tilapia* spp , *Solea aegyptiaca* and mullets were taken on monthly basis by experimental fishing and from landing sites May 1993 and 1996 The **fish were** examined for clinical symptoms and P M according to the technique reported by Amlach (1970)

For isolation and identification of bacteria, samples were taken from different organs (skin, gills, fins, liver, kidney, spleen, gonads and intestines) and cultivated on nutrient agar, nutrient broth, Mac Conky agar, Mac Conky broth, blood agar, alkaline peptone water, TCBS agar SSA, Rimmlar shots media (RSM) and sub-craud dextrose agar (oxide) according to the method of Munn (1978)

Plates including samples and different media were incubated at 25 °C for 24 and 48 hr Microbial colonies were subjected to gram-stain, microscopic examination and biochemical tests according to the techniques reported by Macfaddin (1980) and Popoff (1984) Bacterial isolates were confirmed by the API system (Bio Merieux, France)

- Paracytological Investigation

Live or freshly-caught fish samples were obtained monthly (on three consecutive days) from fishermen and different landing sites in the lake During the annual closing period of the lake, fish samples were collected by experimental fishing by local fishermen The paracytological

investigation of the lake fishes covered two consecutive years (May 1993-May 1995) Some sporadic sampling were done during 1996

Fresh and live fishes were immediately transported to the laboratory for examination During this study a total of 572 fish of different species, weights and sexes were obtained In order of their abundance in the lake, they can be arranged as follows *Tilapia spp, Liza saliens L ramada, Solea aegyptiaca, L auratus* and *Mugil cephalus*

Fish Examination

The specimens were examined for the detection of any visible lesions, ecto-parasites, macroscopic metacercariae, myxosporean pseudocysts and microsporean xenomas Skin and fin smears were made, in searchfor external protozoa Internal organs such as gills, stomach, intestine, liver, kidney, spleen, urinary and gall bladder were examined for the detection of any parasites

Examination of parasites was carried out in fresh as well as stained preparations and photomicrographed by a Zeiss research microscope All measurements were taken using an ocular micrometer Measurements of protozoan parasites are expressed in (μm), whereas those of the other parasites are given in (mm) unless otherwise stated

- Detection of Ectoparasites

Smears were taken from skin, fins, and gills in order to search for any ectoparasite Gills were also examined under dissecting microscope to look for any microscopic parasite

Smears containing trichodinids were air-dried, then impregnated with $AgNO_3$ (Lom and Dykova, 1992) Terminology and method of measurement of the components of the adhesive disc followed the uniform specific characteristic system proposed by Lom (1958), Wellborn (1967) and Arthur & Lom (1984) Body diameter is measured as the adhesive disc blue border membrane (Basson *et al*, 1983) Denticle description was done according to Van As & Basson (1989)

Other ectoparasites like *Scyphidia* spp were fixed after drying in absolute methanol, then stained with Giemsa or Hematoxylin to study the nuclear apparatus

- Detection of intestinal parasites

The alimentary canal of each fish was removed, divided into three segments and placed in petri-dishes The intestine was cut longitudinally and examined for the presence of any worms Intestinal scrapings from each segment were then examined for the detection of any parasite

Detection of encysted metacercariae

Small snips of the muscles were taken from different regions of the body especially the head, trunk and the caudal regions Each snip was compressed between two slides and examined under a stereo-dissecting microscope The metacercariae were then isolated by tissue dissection and withdrawn by a fine pipette into 0 5% saline Some metacercariae were ex-cysted by a dissecting needles then either stained with acetic acid alum carmine or stained with 1% neutral red and then examined microscopically

- Detection of trematodes

The worms were collected from fish specimens by washing and sedimenting several times until they were more or less clear The sediment was examined and the flukes collected The trematodes were washed in 0 5% saline then flattened between a slide and a cover, fixed in 10% formalin for 6-12 hours then stained with acetic acid alum carmine for 12-24 hours

- Experimental infection of animals

White mice and rats were used as experimental animals Encysted metacercariae aspirated in 0 5% saline were introduced carefully into the esophagus of the animal with a plastic syringe (its needle is replaced with a rubber tube) About 50 encysted metacercariae were fed singularly to the laboratory animals The feces of these animals were examined from the 3rd day on to look for the trematode ova

Fisheries Statistics

Catch statistics for 25 successive fishing seasons extending from 1970/71 to 1995/96 were compiled The annual catch by species and group of species for the period from 1970 to 1992 was collected from two main sources, the General Authority for Fish Resources Development (GAFRD) and the General Agency for Public Mobilization and Statistics (CANPS) The monthly catch records of the last four years, i e from 1992/93 to 1995/96, have been collected from the Fishermen's Cooperative Society of Lake Qarun and from GAFRD, Nile Valley Sector, El Fayoum

Catch effort data, i e the number of fishing day and number of fishing boats were compiled from the data collected Another catch effort index i e numberof landings has been calculated As an index of relative abundance, catch per landing was estimated

- ***Biological Studies***

Monthly samples of the common fish species either from the commercial landings or by means of experimental fishing (during closed seasons) were collected The collected samples were carefully identified and the following parameters were measured for each specimen

* Total length, to the nearest mm
* Standard length, to the nearest mm
* Forked length, to the nearest mm
* Total weight, to the nearest 0 1 g
* Sex and maturity stage
* Gonad weight, to the nearest 0 01 g
* Degree of stomach fullness

* Gutted weight, to the nearest 0 1 g

Fish Stomachs were collected for determination of food and feeding behaviors of the different fish species For age and growth studies, both scales and otoliths were collected from each specimen and preserved in paper envelopes, on which serial number, date of capture, species and location were recorded

Monthly samples of shrimp were obtained from the local market, these were identified and the different species were separated From the external examination, different sexes were separated and the following measurements were determined

* Total length, to the nearest mm
* Carapace length, to the nearest mm
* Total weight, to the nearest 0 1 g

A few stomachs were also collected to study contents and feeding habits

- ***Age and Growth***

Otoliths were chosen for age determination of the different fish species in Lake Qarun, since they are more reliable than any other method The advantage of using the otoliths for going is due to their formation during the embryonic stages, so they reflect all life history events In addition, each fish has otoliths similar in shape and this avoids the confusion in the different shape and size of the fish scales However, it shall be stated that otolith collection requires more skill and is time-consuming compared to collecting fish scales (Khalifa, 1995)

Before age determination, otoliths were cleaned by immersing them in 2% hydrochloric acid and immediately cleaning with tap water and carefully washing them with distilled water Otoliths were cleared in clove oil and examined using Nikon Zoom Stereo-microscope

The relationship between the otolith radius and the total body length is represented by the linear relation,

$$L = a + b R$$

where,	L	is the total fish length (cm)
	R	is the total otolith radius (mm)
	a & b	are constants, whose values were determined by the least-squares methods

- ***Back-calculation***

The back-calculated lengths at the end of different years were determined using Fraser (1916) and Lee (1920) formula as shown below

$$l_n - a = \left(\frac{r_n}{R}\right) \times (L - a)$$

or

$$l_n = a + (L - a)\left(\frac{r_n}{R}\right)$$

where,

ln	is the body length at the time when the nth annulus was formed
L	is the length of fish at capture
R	is the radius of the hard part containing the annuli
a	is the correction factor which represent the value of intercept of body length/otolith radius relationship

- ***Length-weight relationship***

The general power equation was used to described this relation

$$W = a L^b$$

where,

W	the total fish weight (gm)
L	the total fish length (cm)
a & b	are constants

The parameters a and b were estimated by the least-squares method After a logarithmic transformation the above equation, can be expressed as follows

$$\log W = \log a + b \log$$

- ***Condition factors***

Two measures of Indices of 'well-being' or 'Pendoral indices' were estimated for each specimen The first is the Fulton's condition factor (K_c)

$$K_c = \frac{W \times 100}{L^3}$$

the second is the Relative condition factor (K_n)

$$K_n = \frac{W \times 100}{a L^b}$$

where,	W	the weight of fish (gm)
	L	the length of fish (cm)
	100	is a scaling factor
	a & b	are the constants of length-weight relationship

- ***Theoretical model of growth***

The most widely used Von Bertalanffy growth function (VBGF) (1938) was applied to describe the growth pattern of Lake Qarun fishes VBGF is in the form

$$l_t = L_\infty (1 - e^{k(t\ t_0)}) \qquad \text{for leng}$$

$$w_t = W_\infty (1 - e^{k(t\ t_0)})^b \qquad \text{for wei}$$

where,

l_t and w_t	are the length and weight at time t
L_∞ & W_∞	are the asymptotic length and weight
K	is the Body growth coefficient
t	is the hypothetical age at which the fish has zero length
b	is the exponent of length weight relationship

The three methods used for determination of VBGE parameters are Ford (1933) – Walford's (1946) method, Gulland and Holt's method (1959) and Chapman's method (1961)

The length frequency distribution analysis was applied for shrimp, and the Modal class progression analysis technique was applied using FISAT computer program (Gayanilo *et al*, 1996)

- ***Food and feeding habits***

Stomach fullness degree was visually classified by using five digit scale, 0 for empty, 1 for 25% full, 2 for 50% full, 3 for 75% full and 4 for distended stomach

Selected full stomachs were labeled and preserved individually in 10% formalin solution Later, the content of each gut was flushed in a petri-dish and examined microscopically Various food items were sorted and identified to the lowest possible taxonomic level, sometimes to the species level Point method has been applied in stomach content analysis

- ***Reproductive Biology***

Data concerning gonad weight and total weight were used to determine the gonado-somatic index The latter is calculated as a percentage of the gonad weight ratui to the total fish weight, as follows

$$GSI = \left(\frac{G\ wt}{T\ wt}\right) * 100$$

where,

GSI gonado-somatic index

G wt gonad weight (0 01 g)

T wt total fish weight (0 1 g)

Length and age at first sexual maturity was determined graphically as the length at which 50% of the fish reach sexual maturity (L_{50}%)

- ***Management***
- ***Population structure***

Length frequency distribution for the different sexes were used in determining sex ratio, age length key and age composition

Total mortality coefficient "Z" was estimated by means of the following methods

For the different fish species, analysis of catch curve based on age composition data (Chapman and Robson, 1960 and Richard, 1975) which is mainly applied for determining survival rate as shown in the following equation

$$S = \frac{T}{[\Sigma N + T - 1]}$$

where, $T = N_1 + 2n_2 + 3N_3 + \quad + xN_x$

and $\Sigma N = N + N_1 + N_2 + \quad + N_x$

Denoted that, the successive age groups coded from 0 to X, where zero is attributed to the first fully recruited age group

As,

$$S = e^z$$

where, S the survival rate

Z total mortality coefficient

then,

$$Z = - \ln S$$

For shrimp, analysis of linear catch curve based on length composition data was applied (Pauly, 1983)

Natural mortality coefficient (M) was determined using the equation proposed by Ursin (1967) In this method the natural mortality coefficient can be calculated as a decreasing function of body weight,

$$M = W^{\frac{1}{3}}$$

where, W is the mean total observed weight in gram

Fishing mortality coefficient (F) was simple subtraction of the value of M from that of Z, since,

$$Z = F + M$$

The exploitation ratio (E) is estimated from the equation

$$E = \frac{F}{F + M} \qquad \text{(Gulland, 1971)}$$

- ***Yield per recruit***

Beverton and Holt (1957) yield per recruit model was applied to calculate yield per recruit for the different fish species in Lake Qarun, as a function of natural mortality coefficient and age at first capture The formula suggested by Gulland (1983) as a simplified form of Beverton and Holt model was used The formula was

$$Y/R = F e^{M(t_c - t_r)} W_\infty \left[\frac{1}{Z} - \frac{3S^2}{Z + 2k} - \frac{S^3}{Z + 3k} \right]$$

where,

F Fishing mortality coefficient

M Natural mortality coefficient

Z Total mortality coefficient

t_c age at first capture

t_r age at recruitment

K, L_∞ and t_o Von Bertalanffy growth parameters

Length at first capture (l_c) is determined from the length frequency distribution using the method of Caddy (1982) Then, the length converted to age using the following rearrangement of VBGF,

$$t_c = \frac{1}{k} \ln\left[\frac{L_\infty}{L_\infty - l_c}\right] + t$$

The length at recruitment (l_r) was chosen as the smallest fish length appeared in the catch Then, age at recruitment (t_r) was determined by the above equation

Relative yield per recruit (Y'/R) as well as Relative biomass per recruit (B'/R), were estimated on the basis of Beverton and Holt's Model of 1966, modified by Pauly and Soriano (1986) for the different fish species The following forms were used,

$$Y'/R = E\,U^{M/k}\left\{1 - \frac{3\,U}{1 + m} + \frac{3\,U^2}{1 + 2m} - \frac{U^3}{1 + 3m}\right\}$$

where,

$$U = 1 - \left(l_c/L_\infty\right)$$

$$m = (1 - E)\left(M/k\right) = k/Z$$

$$E = F/Z$$

The computed form of relative biomass per recruit is $B'/R = \dfrac{\left(Y'/R\right)}{F}$

239

RESULTS

Environmental Conditions

* *Meteorological parameters*

- *Net solar radiation*

The monthly variations of net solar radiation in the study area are given in Fig (2) Net radiation showed a gradual increase from January 1996, reaching the maximum value of 241 9 W m^2 in June 1996, its minimum being 53 05 W m^2 in December 1996 The annual average radiation of Lake Qarun area in 1996 amounted to 148 3 W m^2

- *Air pressure*

The air pressure of the lake area is inversely proportional to air temperature Therefore, its values fluctuated between a maximum of 1,022 19 mb in December and a minimum of 1,011 81 mb in July (Fig 3)

- *Wind condition*

- ***Wind Speed***

As shown in Fig (4), there is a general decrease during winter months (January & December) when its values were 2 6 and 2 11 m sec^{1}, respectively The maximum wind speed 5 4 m sec ^{1} was recorded in

- ***Wind gust and direction***

The results of wind gust and direction are shown in Fig (5) The continuous records of these parameters began in January 1996 after installation the weather station The most dominant wind direction in the lake region is northwest (NW), except in winter (January and December) when its direction is northeast (NE) The wind gust showed a gradual increase from January, reaching the maximum of 8 89 m sec^{1}, in June Obvious gradual decrease started in July and reached its minimum of 3 7 m sec^{1}, in December

- *Relative humidity*

Lake Qarun lies in hyper arid area, the relative humidity reaches its maximum value of 58 76% in December (Fig 6), its average value is 48 8% The relative humidity in the lake area is directly proportional to air pressure and inversely related to wind speed

Fig (2) Net Radiation

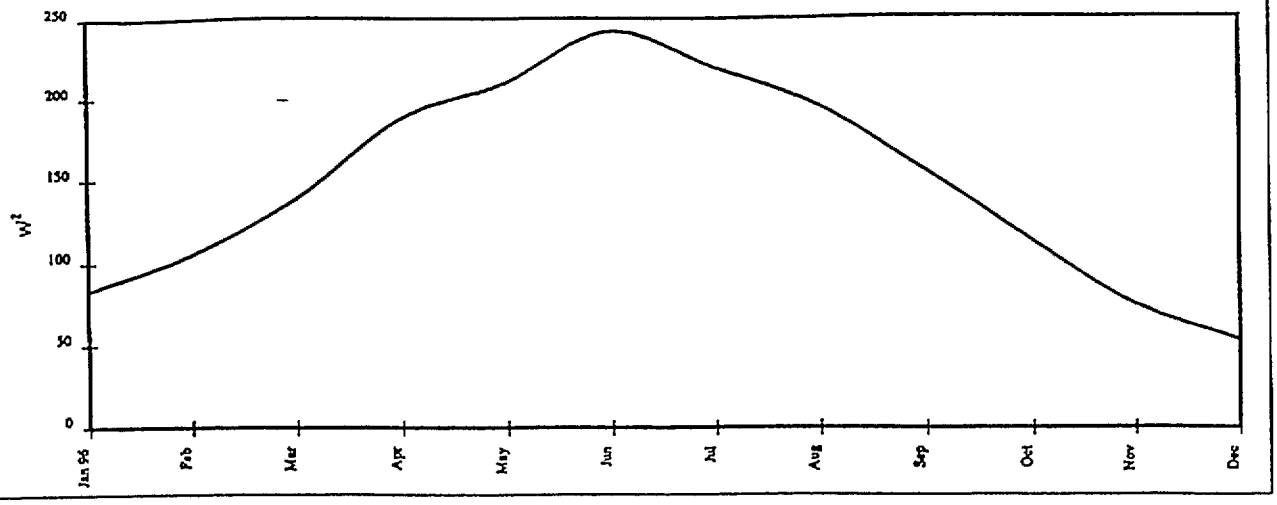


Fig. (3) Air pressure

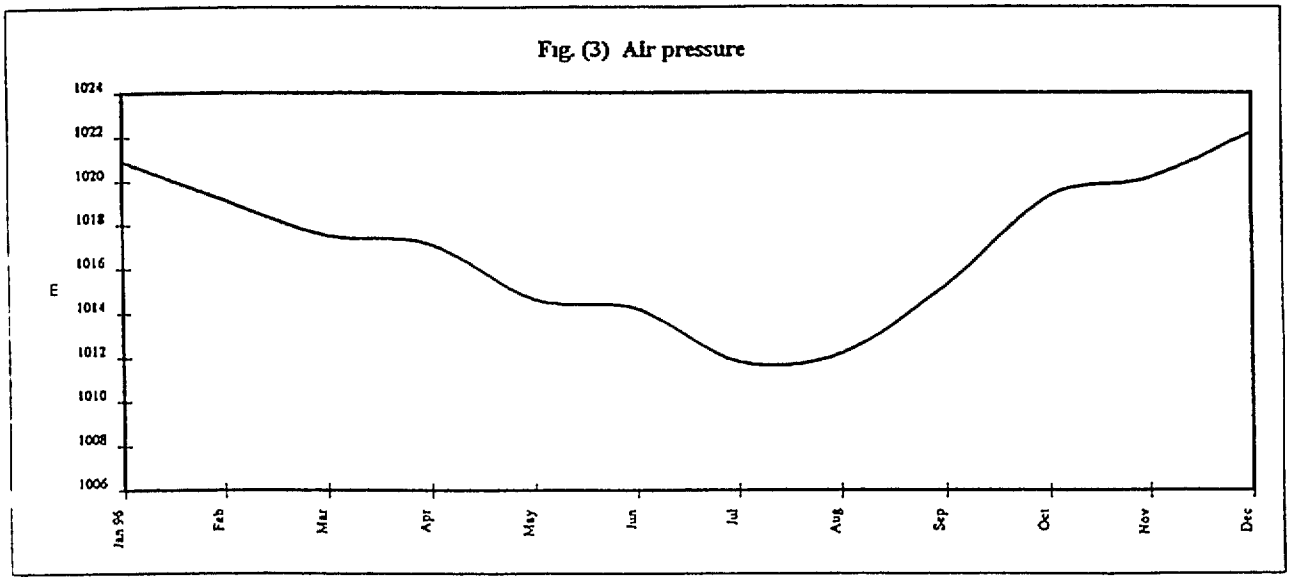


Fig (4) Wind speed

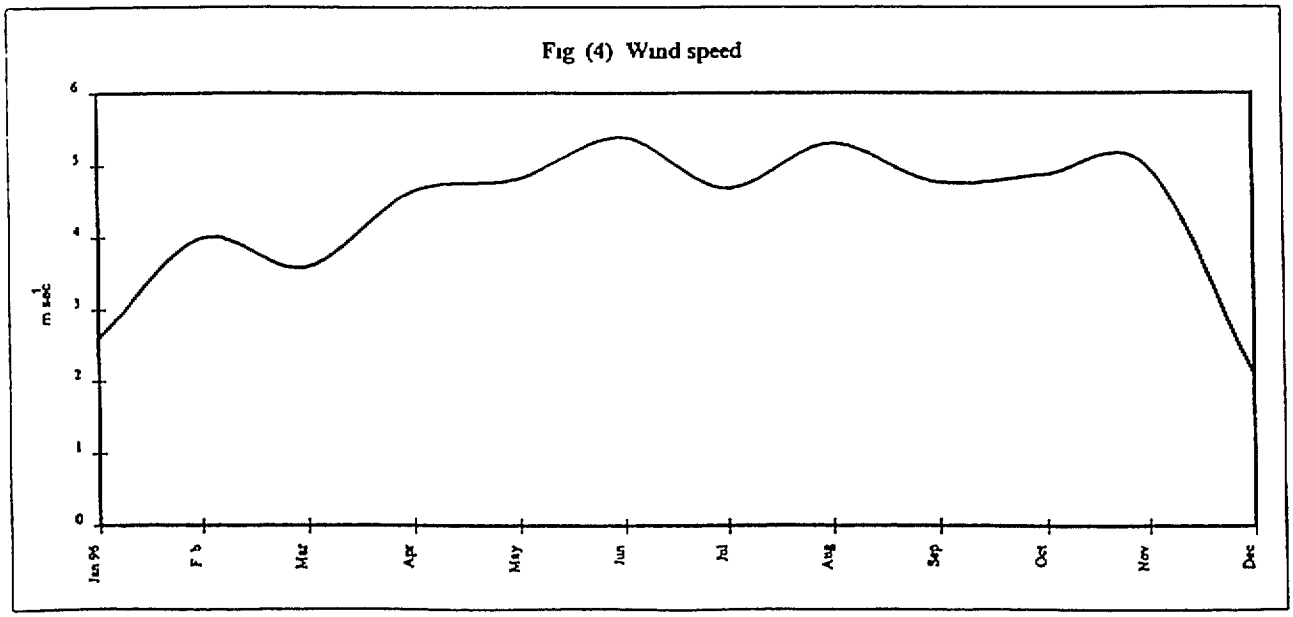
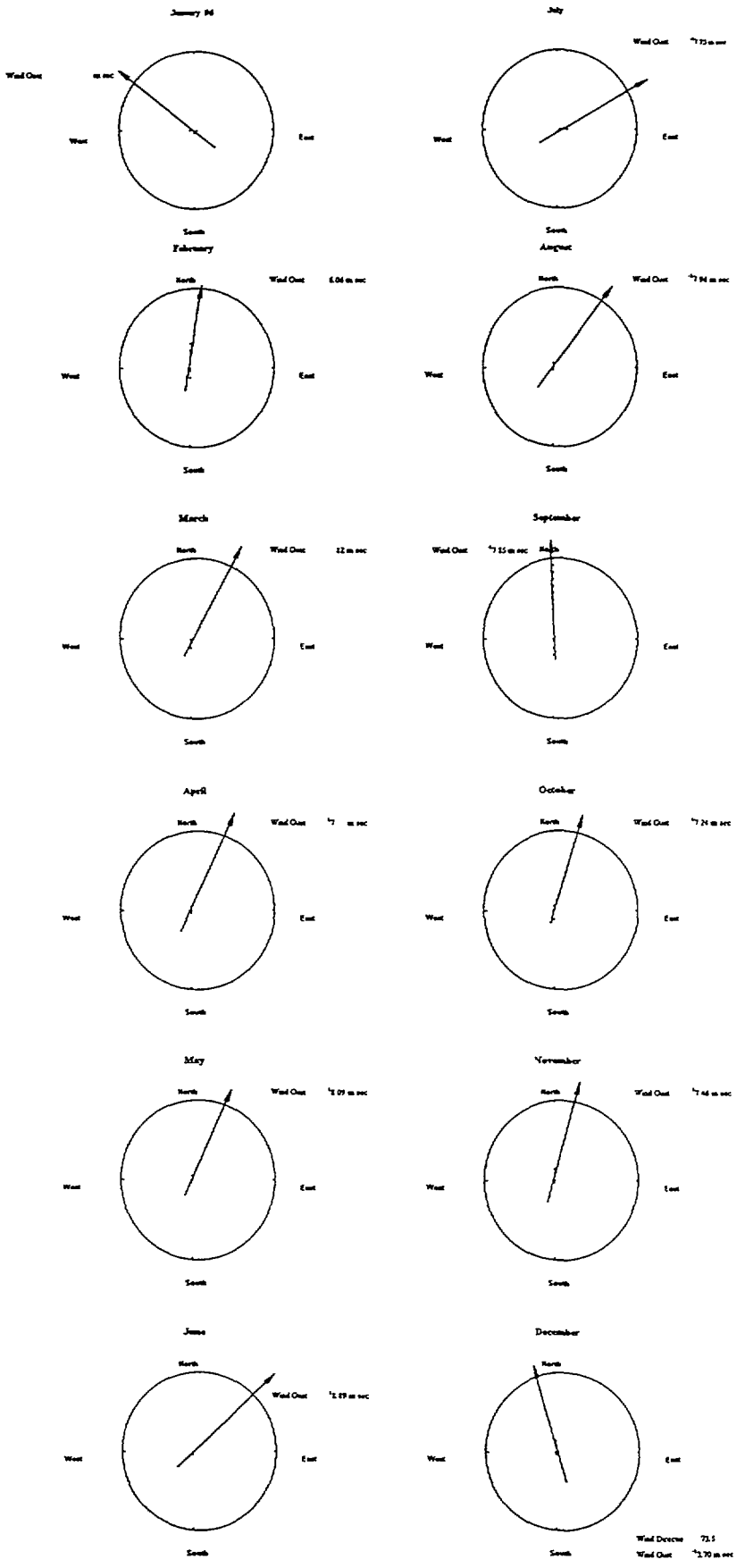


Fig (5) Wind Direction & Gust in Lake Qarun



- Evaporation rate

The evaporation rate is directly proportional to air temperature Its values fluctuated from a maximum of 28 4 cm month^{1}, in August to a minimum of 4 1 cm month^{1}, in December, with an annual overage value of 16 78 cm month^{1} (Fig 7)

- Rain Fall

The precipitation pattern within the lake area is shown in Fig (8) This parameter was recorded in 1996, after installation the weather station in January 1996 The precipitation in the lake was recorded in March, April and May 1996, its values were 0 28, 0 01 and 1 8 mm, respectively

Physico-chemical parameters

- Air & Water temperature

The monthly mean variations of air & water temperature for the sampling stations for three successive years (1993 - 1995) are shown in Fig (9) In 1996, air & water temperature were recorded by the weather station which was installed on the lake in January

The highest absolute water temperatures recorded in the lake occurred in June 1993, in August 1994 & 1996 and in July 1995 The lowest absolute temperatures were all recorded in January, except one record in December 1995 In general, water temperatures followed the corresponding air temperatures

- Depths and Secchi disc

The monthly average depths of the lake are shown in Fig (10) The greatest depths were recorded in winter, except in 1995 & 1996 when the maximum depth occurred in late autumn and summer, respectively Depending on the annual average depths, the minimum value of 4 02 m was recorded in 1994 and the maximum of 4 33 occurred in 1996

The Secchi disc readings displayed their maximum values of 0 68 and 0 97 m in autumn 1993 & 1994, respectively In 1995 & 1996, the maximum Secchi disc values of 0 83 & 0 8 m were recorded in summer In general, the Secchi disc did not reach the bottom, this reflects the high turbidity of the lake water Since the depth of euphotic zone is calculated by multiplying the Secchi disc value by a factor 5 4 at most stations, the data indicated that the euphotic zone does not extend to the bottom. This is true when the calculations are made using the monthly average Secchi disc values, while the actual situation in the lake is the existence of euophotic and aphotic zones at the deep stations only i e > 4m

- Turbidity (NTU)

The turbidity data are presented in Fig (11) The results indicate that the turbidity of the lake water had significantly increased in 1996, while its least values were recorded during 1994 The range and annual average turbidity values recorded during the four successive years of the project are summarized as follows

Fig. (6) Relative Humidity (%)

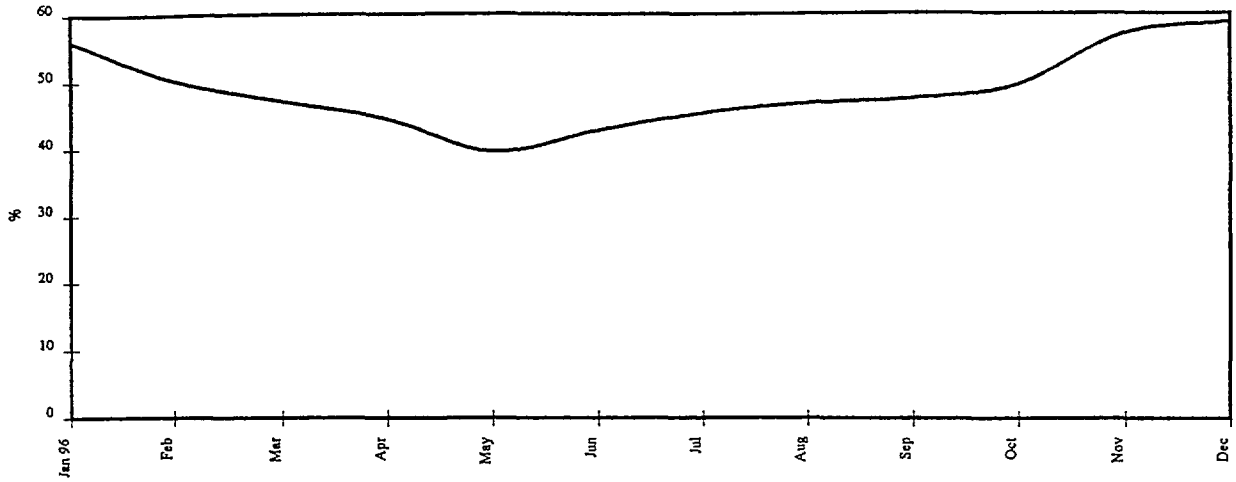


Fig. (7) Evaporation Rate

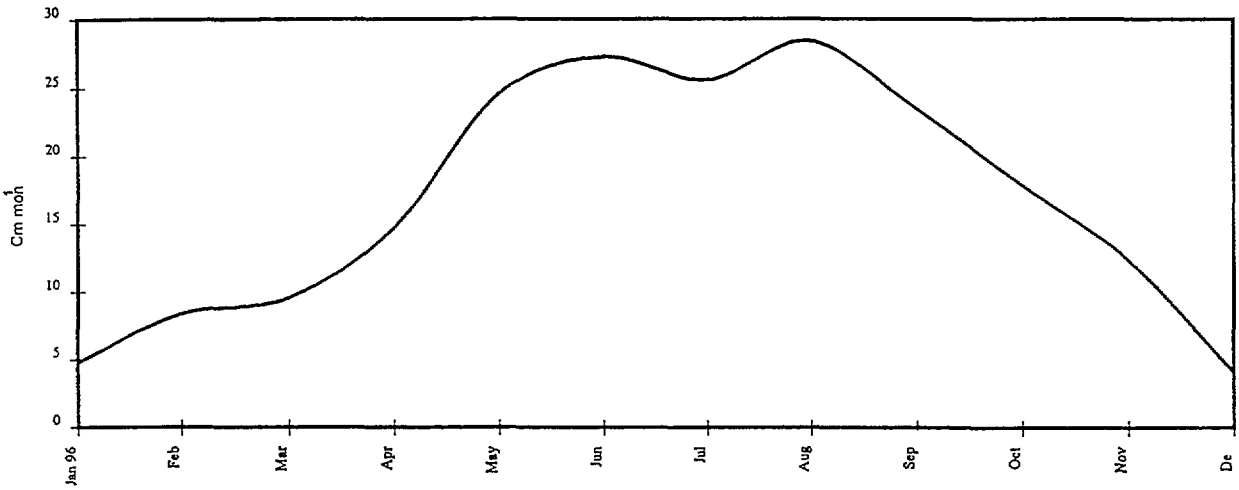


Fig. (8) Rainfall

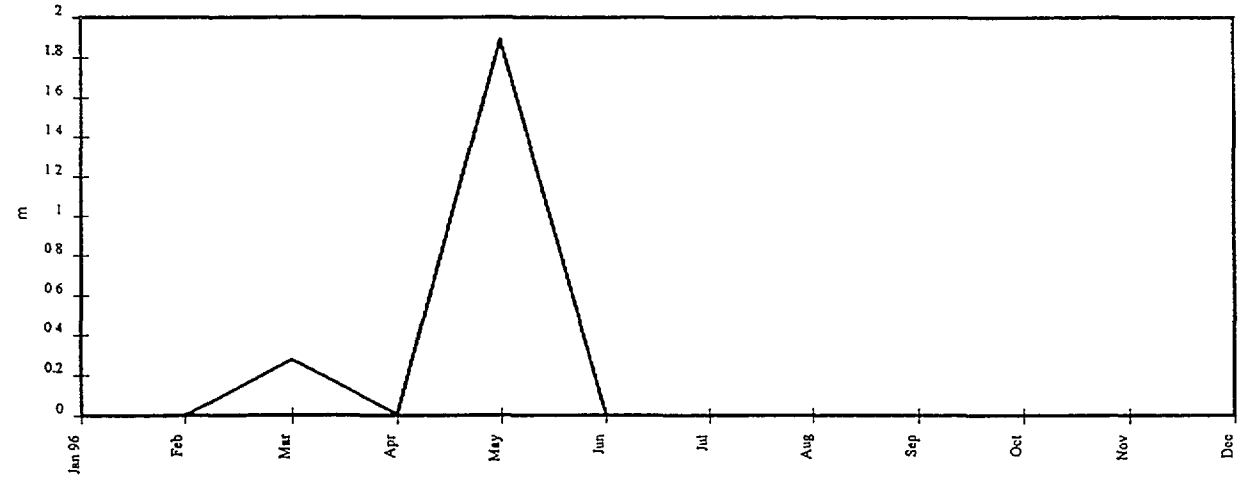


Fig (9) Air & Water temperature

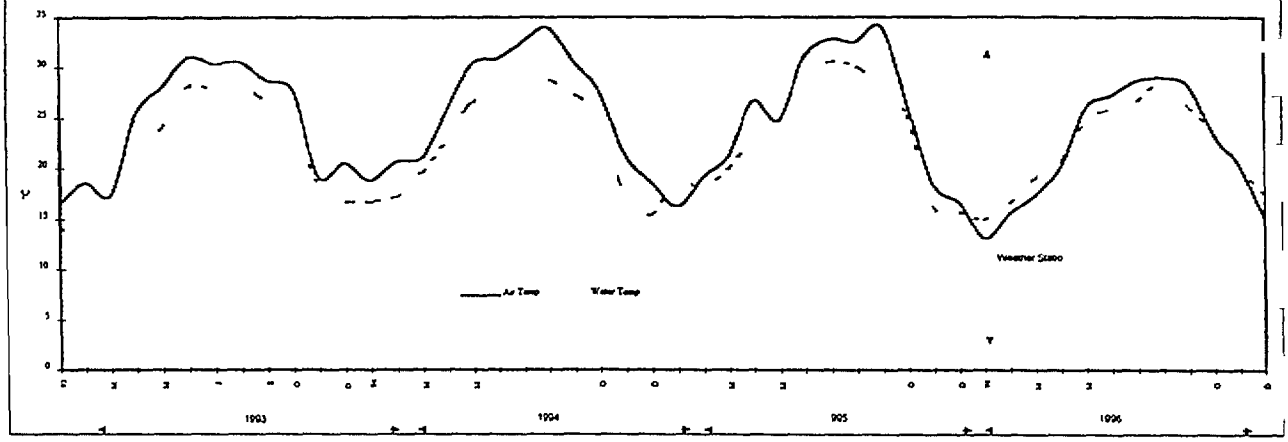
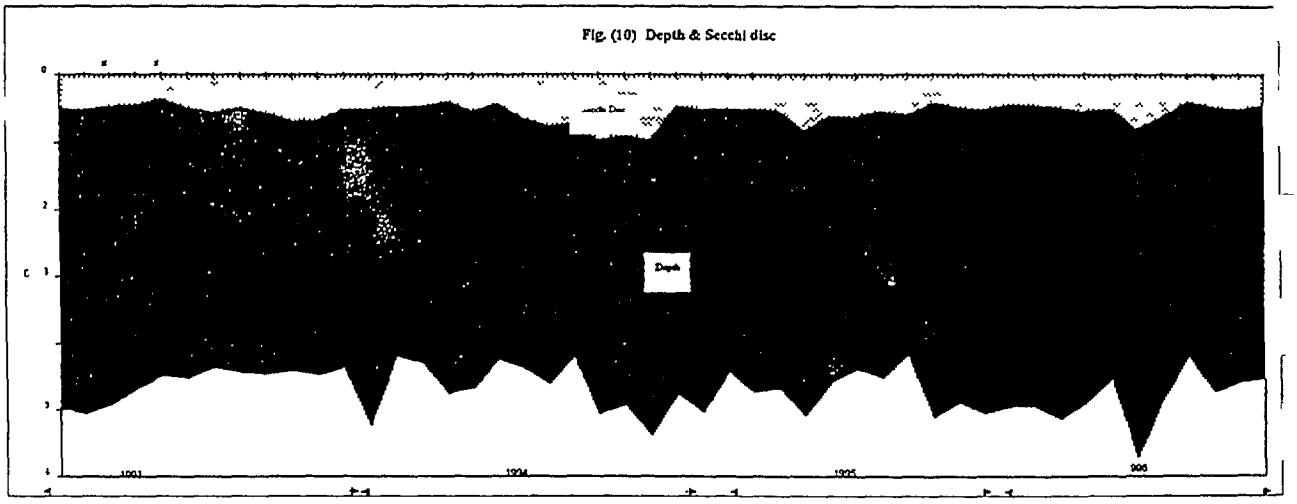


Fig. (10) Depth & Secchi disc



245

Fig (11) Turbidity

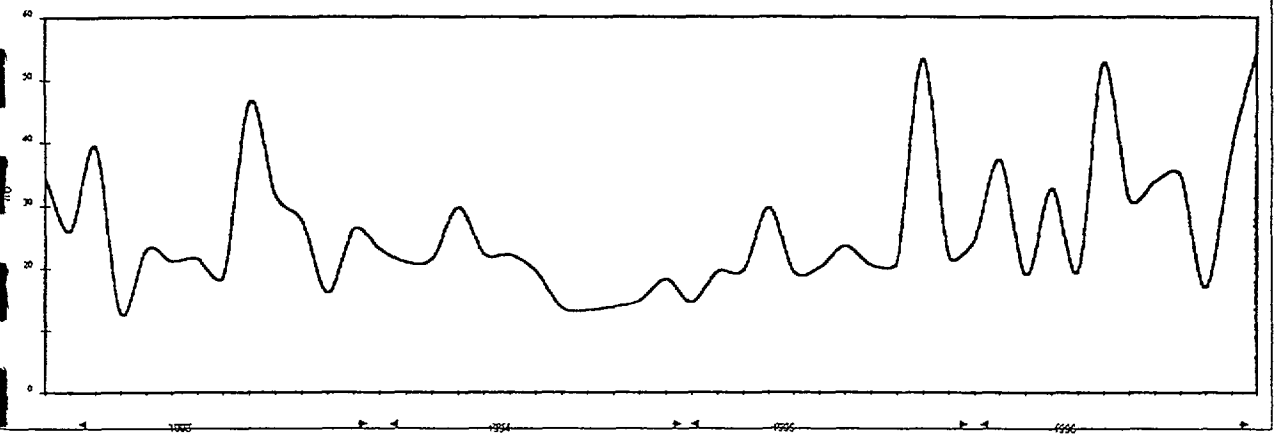
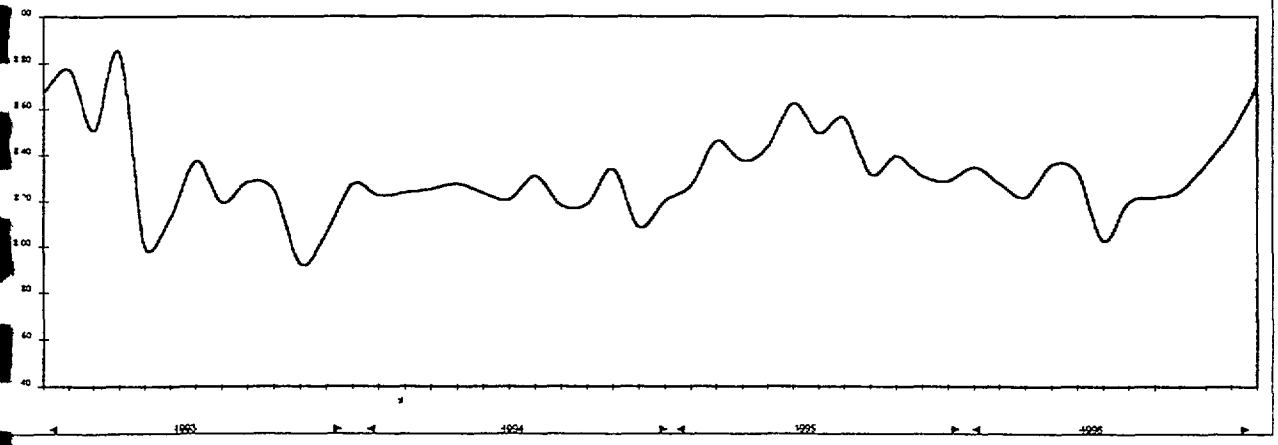


Fig (12) pH



246

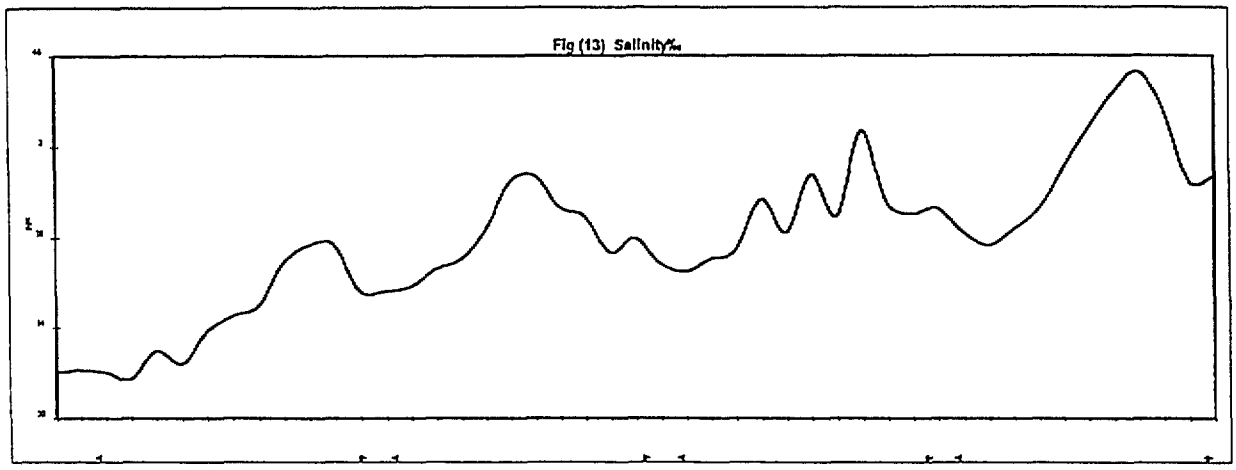


Fig (13) Salinity‰

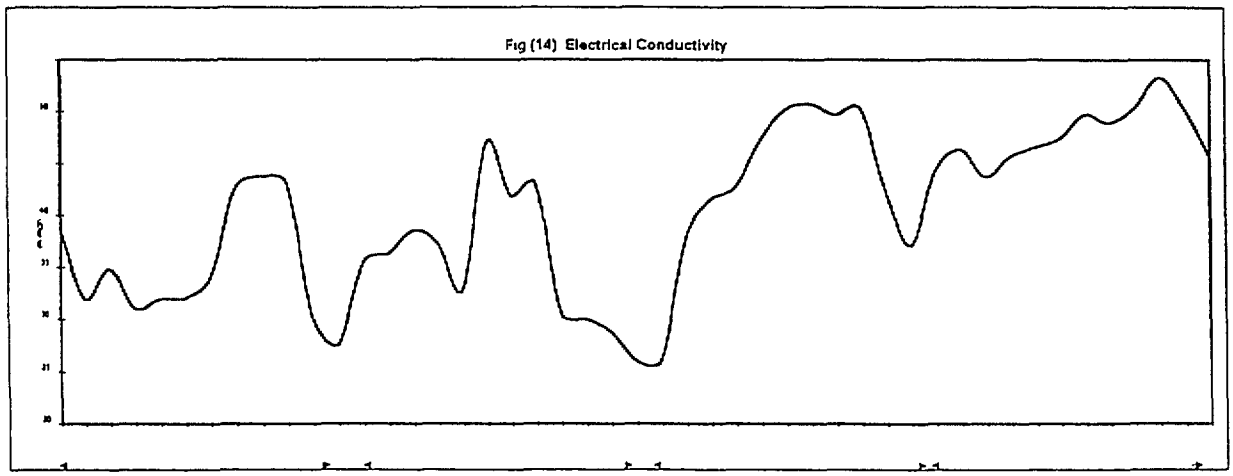


Fig (14) Electrical Conductivity

In 1993, its values ranged from 12 75 NTU in April to 46 25 NTU in September, the annual average value was 26 54 NTU In 1994, a severe drop in turbidity was observed, its values fluctuated from a maximum of 29 64 NTU in May to a minimum of 13 21 NTU in October , with an average value of 20 05 NTU In 1995, a slight increase in turbidity was recorded, its values ranged between 53 22 NTU in November and 14 53 NTU, in February, with an annual average value of 23 45 NTU In 1996, the highest turbidity values were recorded, they varied from 54 6 NTU in December to 16 96 NTU in October, with an annual average value of 33 NTU

- Hydrogen Ion Concentration (pH)

The pH values of Lake Qarun water during the four successive years (of this project) are shown in Fig (12)

The results indicated a small variation in the pH values In 1993, these values ranged between a minimum of 7 93 in November, and 8 84, in April, with an annual average value of 8 33 A slight decrease in pH was observed in 1994 when its values varied from 8 09, in December to 8 34 in November, with an annual average value of 8 23 In 1995, maximum pH values were observed their levels changed from 8 2, in January to 8 63 in June, while its annual average value was 8 4 In 1996, the pH values fluctuated from 8 03 in June to 8 7, in December, with an annual average value of 8 32

- Salinity (S‰)

The monthly variations of water salinity in Lake Qarun are presented in Fig (13) The highest salinity was recorded in autumn and late summer, while the lowest values occurred in spring and late winter The data showed a clear increase in water salinity during the project's period In 1993, salinity values varied from a maximum of 37 67‰ in December to a minimum of 31 74‰ in April , with an annual average value of 34 06‰ In 1994, obvious increase in salinity was observed and its values ranged between 40 7‰, in August and 35 6‰, in January & February, with an annual average value of 37 79‰ In 1995, more increase in salinity was recorded its levels fluctuated from 42 7‰, in October to a minimum of 36 49‰ , in March, with an annual average value of 38 72‰ In 1996, the highest salinity was recorded in the lake compared to the data of the preceding years, in that year its values ranged between 45 31‰, in September and 37 64‰, in March, with annual average value of 40 93‰

- Electrical conductivity (EC)

The EC values of the lake are shown in Fig (14) The readings were relatively high in summer and spring seasons In 1993, the electrical conductivity ranged between a maximum of 43 76 m mhos in September and a minimum of 27 61 m mhos Cm^{1} in December In 1994, EC values ranged between a maximum of 47 1 m mhos Cm^{1} in June and a maximum value of 28 84 m mhos Cm^{-1} in December During 1995, the EC levels varied from 50 79 m mhos Cm^{1}, in August to 25 99 m mhos Cm^{1} in January In 1996, substantial increase in EC-values was observed, with values fluctuating between 53 3 m mhos Cm^{1} October and 43 75 m mhos Cm^{1} The results revealed a significant gradual increase in EC during the project's period, its annual average values were 35 12 m mhos Cm^{1} in 1993, 36 59 m mhos Cm^{1} in 1994, 41 85 m mhos Cm^{1} in 1995, and 47 69 m mhos Cm^{1} in 1996

- Dissolved Oxygen (DO)

Dissolved Oxygen in the lake water originates from the atmosphere and through the process of photosynthesis The results of DO are presented in and Fig (15) The data reveal that the DO in the surface water was always higher than the values in the bottom layer

In 1993, the DO values varied from 5 87 to 11 01 mg L^{1} at the surface, and from 4 93 to 8 76 mg L^{1}, in the bottom water The annual average values were 7 88 and 6 38 mg L^{1} for the surface and bottom layers, respectively

In 1994, a slight decrease in DO was observed in both surface and bottom waters The DO values ranged between 8 83-6 19 mg L^{1} and 6 79-4 57 mg L^{1} for surface and bottom layers, respectively The annual average values for the two layers amounted to 7 12 and 5 59 mg L^{1}

In 1995, DO showed a slight decrease compared to its level in the preceding year The values fluctuated from 8 39 to 4 25 mg L^{1} and 7 72-2 69 mg L^{1} for surface and bottom waters, respectively Its annual average values for the two layers were 6 89 and 5 81 mg L^{1}

In 1996, the highest DO values were recorded and its concentrations varied from 10 88 - 6 1 mg L^{1} , in the surface and from 7 77-4 29 mg L^{1} , in the bottom layer Its annual average concentrations amounted to 8 5 and 6 29 mg L^{1} for surface and bottom layer, respectively

- Chemical Oxygen Demand (COD)

The results of COD, shown in Fig (16), indicate that there was a narrow fluctuation range, except in 1994 when noticeable drop concentration was observed Its variations during the investigation period can be given as follows

In 1993, COD concentrations varied from a maximum of 25 04 mg L^{1} in January to a minimum of 8 44 mg L^{1} in October, with an annual average value of 15 78 mg L^{1}

In 1994, a severe drop in COD was observed, its values ranged between 15 79 mg L^{1} in October and 6 46 mg L^{1} in December, its annual average level was 11 85 mg L^{1}

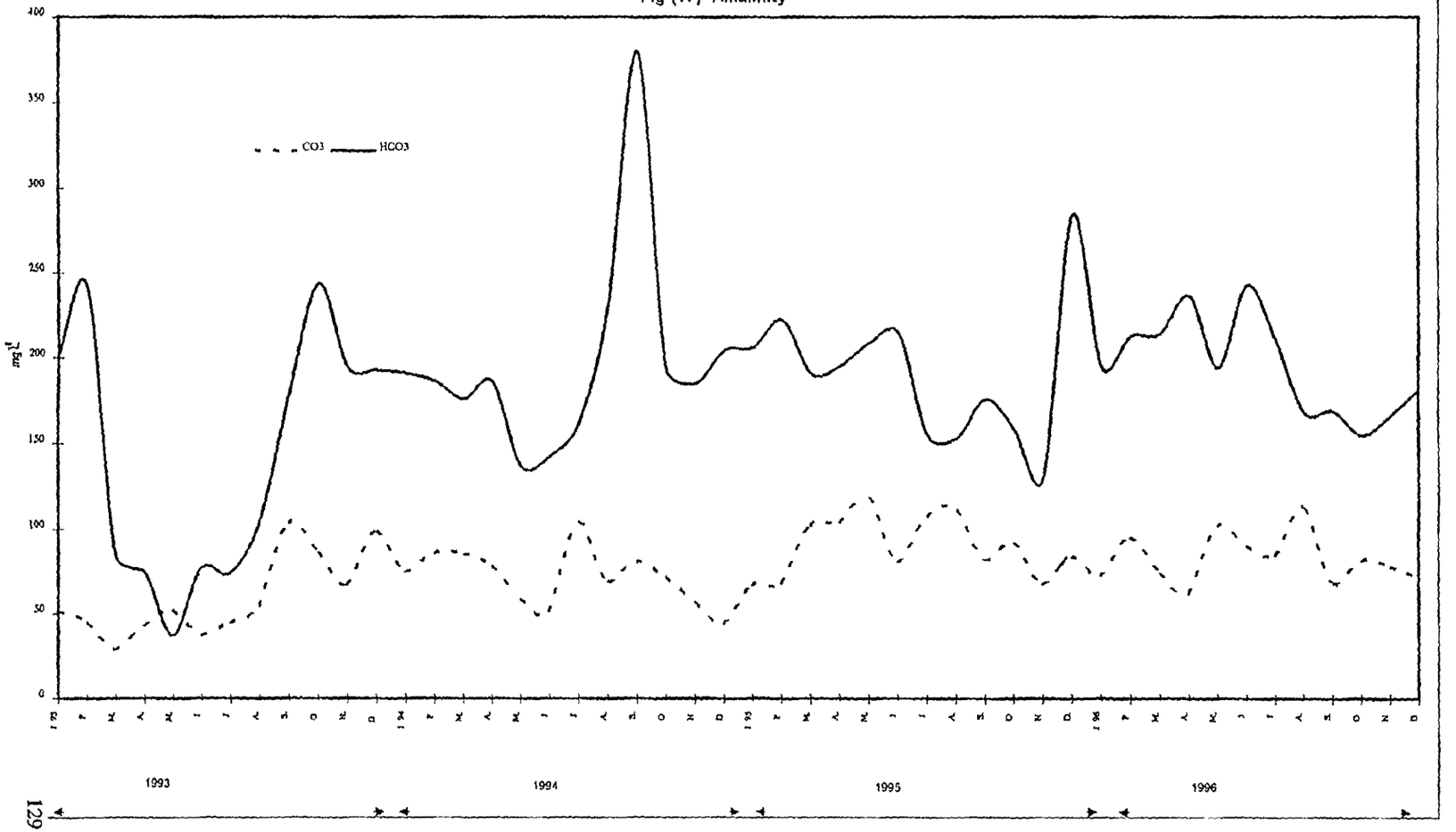
In 1995, COD levels had increased and varied from 21 09 mg L^{1} in November to 6 16 mg L^{1} in January, with annual average value of 14 98 mg L^{1}

In 1996, the highest COD values were recorded, its concentrations ranged between 21 86 mg L^{1} in May and 9 73 mg L^{1} in June Its annual average concentration was 17 04 mg L^{1}

- Alkalinity (CO_3^{2} & HCO_3)

Alkalinity (CO_3^{2} & HCO_3^{1}) data are shown in Fig (17) Bicarbonate concentrations were always much higher than the corresponding CO_3^{2} values In the first year (1993), a severe drop in both CO_3^{2} and HCO_3 was observed compared to the data recorded in subsequent years

Fig (17) Alkalinity



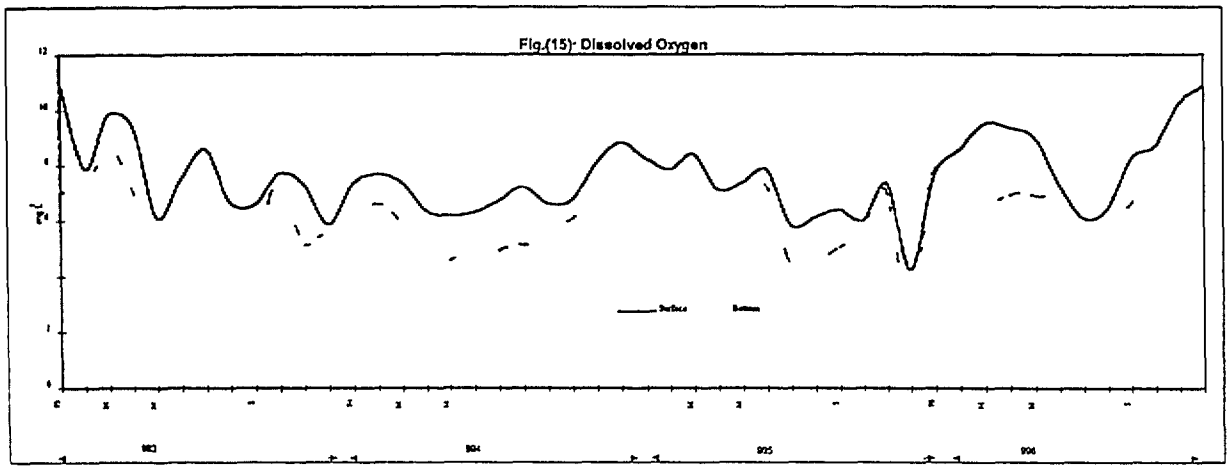


Fig.(15)- Dissolved Oxygen

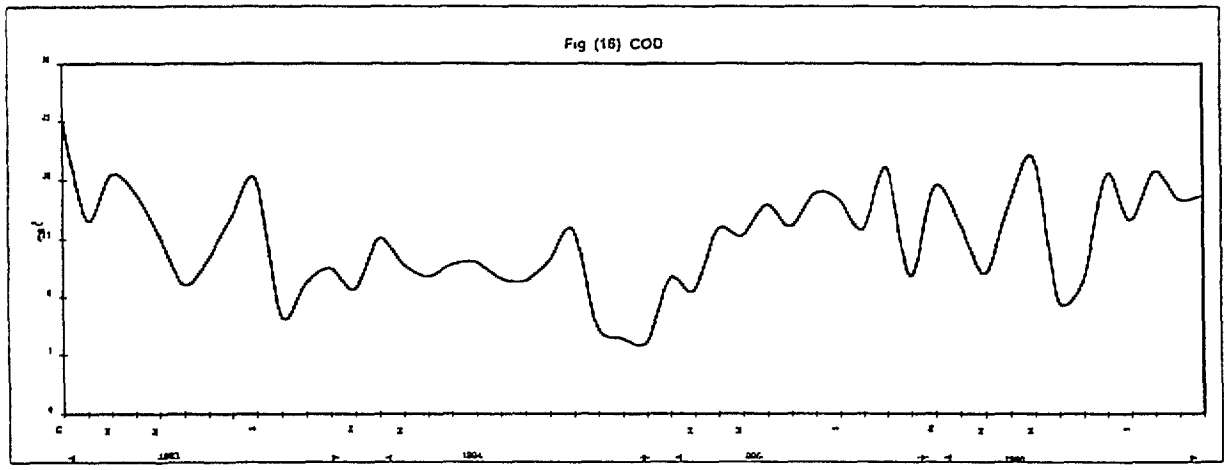


Fig (16) COD

In 1993, alkalinity values varied from 243 5 to 37 35 mg L^{1}, for HCO_3 and from 102 97 to 28 63 mg L^{1}, for CO_3^{2} The annual average HCO_3 & CO_3^{2} concentrations were 142 07 & 58 93 mg L^{1}

In 1994, a sharp increase in alkalinity was observed and its values varied from 379 62 to 137 19 mg L^{1}, for HCO_3^{1} and from 103 56 to 43 56 mg L^{1}, for CO_3^{2} The annual average HCO_3 & CO_3^{2} concentrations were 197 92 & 71 36 mg L^{1}

In 1995, HCO_3 decreased, however, the phenomenon was reversed for CO_3^{2} Their levels fluctuated between 284 and 129 44 mg L^{1} for HCO_3 and between 118 67 and 65 78 mg L^{1}, for CO_3^{2} Their annual average concentrations were 191 18 and 89 59 mg L^{1}

In 1996, a slight increase in HCO_3 associated with a decrease in CO_3^{2} was observed Their levels varied from 242 4 to 145 78 mg L^{1}, for HCO_3 and from 112 to 60 8 mg L^{1}, for CO_3^{2}

Nutrients

- Nitrogen

- ***Ammonia - N (NH_4-N)***

Ammonia nitrogen (ammonia NH_3 + ammonium NH_4) is the soluble product in the anaerobic decomposition of nitrogenous organic matter It is also formed when nitrites and nitrates are reduced either biologically or chemically The proportion of NH_3 and NH_4 depends on the pH and temperature Since the maximum pH did not exceed 8 8, NH_4 is the dominant component (Fig 18)

For NH_4 its concentration in the first year was significantly higher than the corresponding values in the following years On the other hand, the NH_4-N values seem to have stabilized in the last two years The most interesting finding was the increase in NH_4-N concentration during summer, when it reached its maximum in all years, except in 1994 when the highest NH_4-N was recorded in winter The annual average NH_4-N concentrations were, 119 59 µg L^{1} in 1993, 71 61 µg L^{1} in 1994, 54 27 µg L^{1} in 1995 and 57 74 µg L^{-1} in 1996

- ***Nitrite (NO_2-N)***

Nitrite is an intermediate product of ammonia and also an intermediate form in the denitrification process from nitrite to nitrogen gas The nitrate data revealed a sharp decrease during the project's period Their values were much lower than corresponding NH_4-N and NH_3-N (Fig 18)

In 1993, NO_2- N levels varied from 14 71 - 1 32 µg L^{1}, with an annual average value of 7 38 *ug* L^{1}

In 1994, a slight decrease in NO_2-N was observed, its concentration ranged between 27 73 and 1 74 μg L^{1}, with an annual average level of 6 78 μg L^{-1}

Fig (18) Inorganic Nitrogen

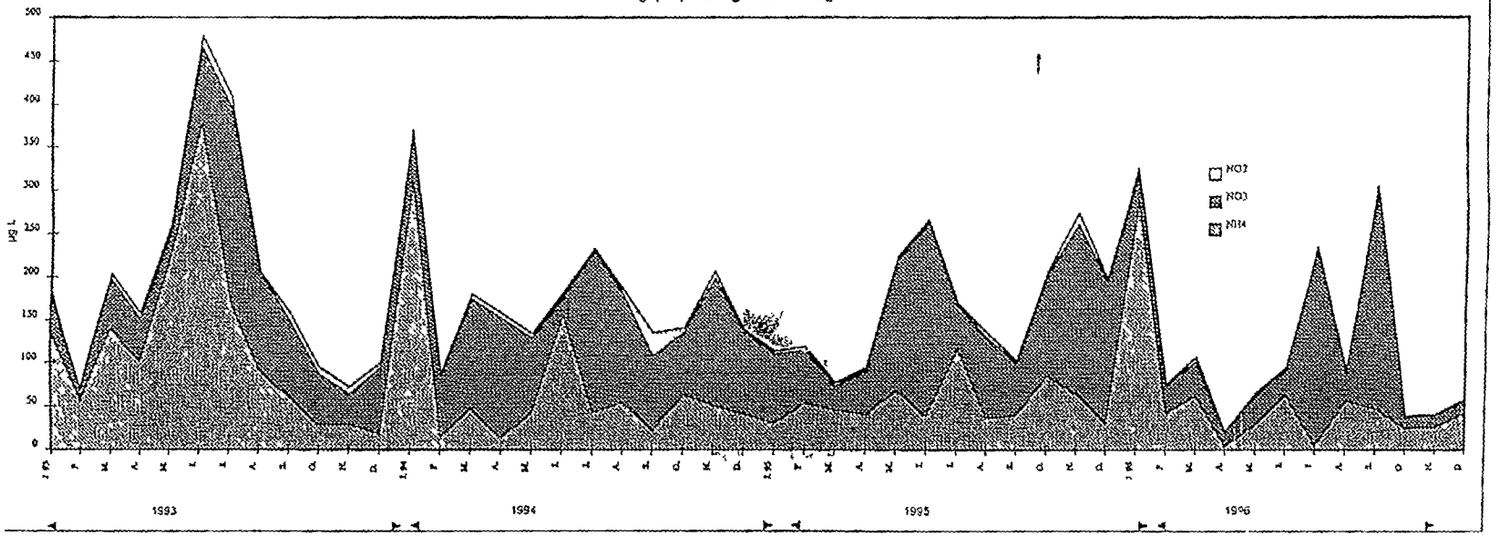
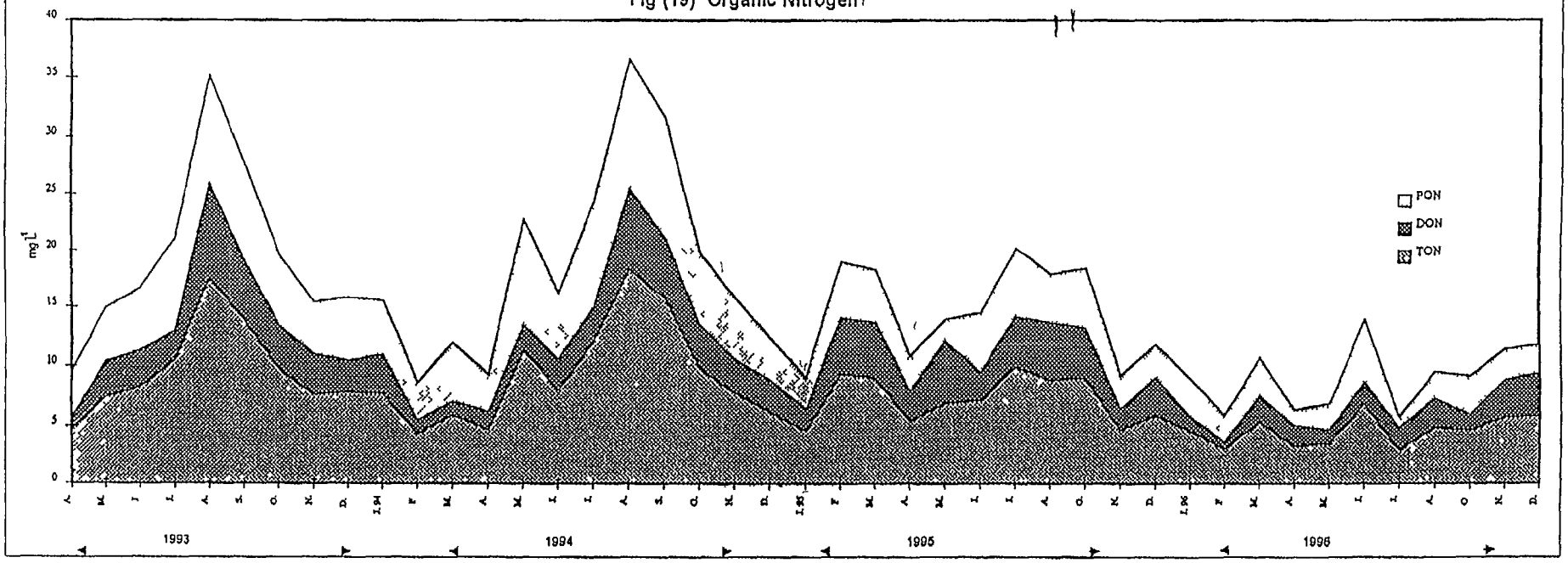


Fig (19) Organic Nitrogen



In 1995, NO_2-N had significantly decreased, its values reached a concentration of 13 2-2 61 $\mu g\ L^{-1}$, with an annual average concentration of 4 46 $\mu g\ L^{-1}$

In 1996, a severe drop in NO_2-N concentration was recorded Its values changed from 8 18 - 0 7 $\mu g\ L^{-1}$, with annual average concentration of 2 6 $\mu g\ L^{-1}$

- *Nitrate (NO_3-N)*

Nitrate is the end product of the stabilization of the organic nitrogen which occurs through aerobic biochemical processes Nitrate concentrations showed a gradual increase during the first three years The highest concentrations were always recorded in summer, except in 1996, when the maximum value occurred in early autumn (Fig 18) The range and average NO_3-N values recorded during the four years can be summarized as follow

In 1993 NO_3-N values fluctuated between 225 54 and 11 57 $\mu g\ L^{-1}$ with an annual average value of 72 72 $\mu g\ L^{-1}$

In 1994 considerable increase in NO_3-N was observed, its levels ranged from 187 7 to 21 3 $\mu g\ L^{-1}$, with an annual average value of 100 36 $\mu g\ L^{-1}$

In 1995 a slight increase in NO_3-N was recorded, its values varied between 222 74 and 27 37 $\mu g\ L^{-1}$, the annual average value was 105 85 $\mu g\ L^{-1}$

In 1996, a substantial decrease in NO_3-N was observed, its concentration varied between 253 39 and 13 45 $\mu g\ L^{-1}$, the annual average value was 61 21 $\mu g\ L^{-1}$

- *Organic - N*

Organic nitrogen compounds are usually found in natural waters in two forms, namely dissolved organic nitrogen (DON) and particulate organic nitrogen (PON) In Lake Qarun, PON concentrations are much higher than the corresponding DON (Fig 19) Both PON and DON were clearly high during the first two years and sharply decreased in the last year Their range and annual average values are given below

In 1993 their concentrations varied between 8 28 and 1 03 mg L^{-1} for DON, and from 9 3 to 3 79 mg L^{-1} for PON, with annual average values of 3 57 & 6 02 mg L^{-1}, respectively

In 1994 their values fluctuated from 7 13 to 1 13 mg L^{-1} for DON, and from 11 18 to 2 64 mg L^{-1} for PON, their annual average levels were 2 9 & 6 22 mg L^{-1}, respectively

In 1995 a slight increase in DON and a marked decrease in PON were observed Their concentrations ranged from 5 22 to 1 31 mg L^{-1} for DON and from 5 87 to 1 79 mg L^{-1} for PON, with annual average values of 3 53 & 3 91 mg L^{-1}, respectively

In 1996 significant decrease in the two organic nitrogen fractions was observed, their levels ranged from 3 63 to 0 58 mg L^{-1}, for DON and from 5 18 to 0 94 mg L^{-1} for PON The annual average values were 2 05 & 2 57 mg L^{-1}, respectively

- Phosphorus

During this investigation the phosphorus compounds were orthophosphate (PO_4-P) and organic phosphorus (OP) (Fig 20) In general, the concentration of organic phosphorus was much higher than the corresponding PO_4-P values The range and annual average PO_4-P & OP values are given as follows

In 1993 the highest PO_4-P values and the least OP levels were recorded during this year Their concentrations changed from 192 8 to 13 51 $\mu g\ L^{-1}$ for PO_4-P, and from 159 29 to 19 16 $\mu g\ L^{1}$ for OP, with annual average values of 54 92 & 67 98 $\mu g\ L^{1}$, respectively

In 1994 a substantial decrease in PO_4-P and a slight increase in OP were observed, their values fluctuated between 55 83 and 6 98 $\mu g\ L^{1}$ for PO_4-P, and from 134 91 to 27 45 $\mu g\ L^{1}$ for OP, with annual average values of 24 73 & 74 61 $\mu g\ L^{1}$, respectively

In 1995 the level of PO_4-P was more or less similar to the preceding year, while the OP concentration had significantly increased Their concentrations varied between 63 56 and 12 29 $\mu g\ L^{1}$ for PO_4-P, and from 285 3 to 34 76 $\mu g\ L^{1}$ for OP, with annual average levels of 25 69 and 97 13 $\mu g\ L^{1}$, respectively

In 1996 a notable decrease in PO_4-P and OP values was observed, their values ranged from 34 99 to 5 14 $\mu g\ L^{1}$ for PO_4-P, and from 104 55 to 43 96 $\mu g\ L^{1}$, annual average values of 13 11 & 71 96 µg L^{1}, respectively

- Silicate (SiO_3 - Si)

Silicate concentrations showed narrow fluctuations especially the last two years (Fig 21)

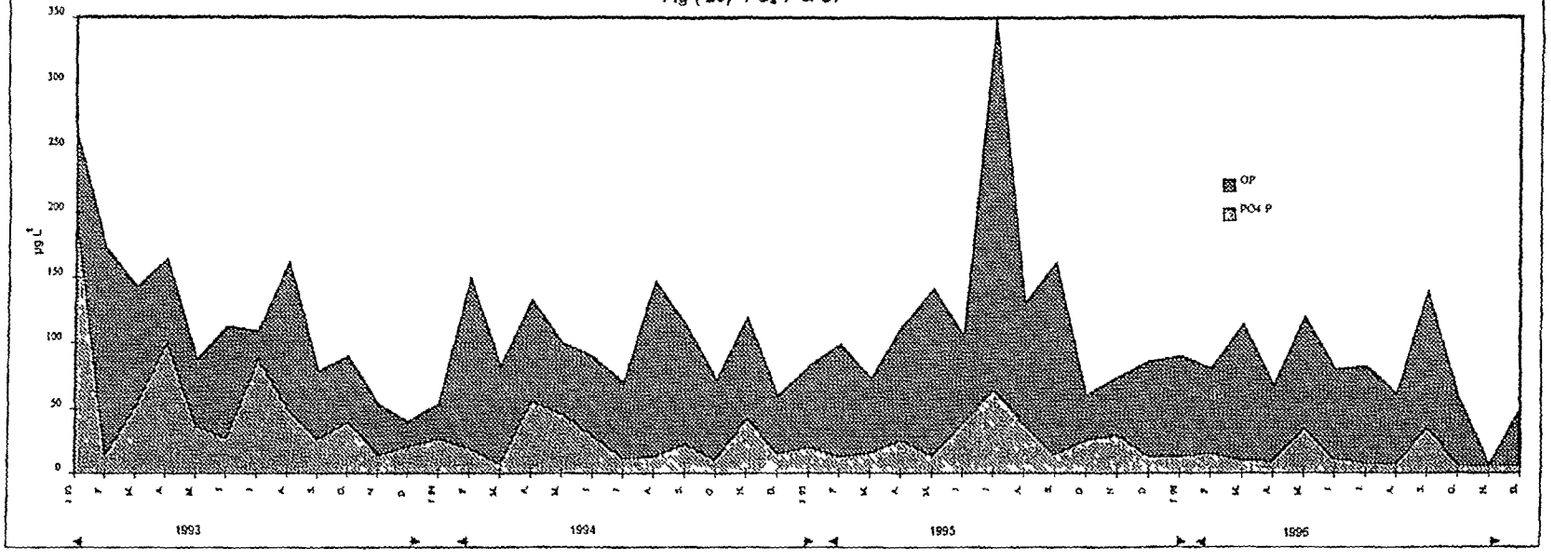
In 1993, its silicate values ranged between 11 63 and 3 63 mg L^{1} with an annual average level of 7 48 mg L^{1} A slight increase in its concentrations was observed in 1994 when it varied between 16 4 and 5 98 mg L^{1} with an average value of 8 67 mg L^{1} On the other hand, silicate concentration in the last two years (1995 & 1996) was more or less the same, the annual average concentrations for the two years were 6 73 and 6 95 mg L^{1}

- Sulfate (SO_4^{2})

The results presented in Fig (22) showed the monthly variations of SO_4^{2} in the lake during the four successive years of the project Sulfate concentrations were significantly high during 1993 & 1994 compared to the values recorded in 1995 & 1996

In 1993 SO_4^{2} concentrations varied between a minimum value of 299 34 mg L^{1} in January and a maximum of 1121 73 mg L^{1} in October, with an annual average level of 808 21 mg L^{1}

Fig (20) PO_4 P & OP



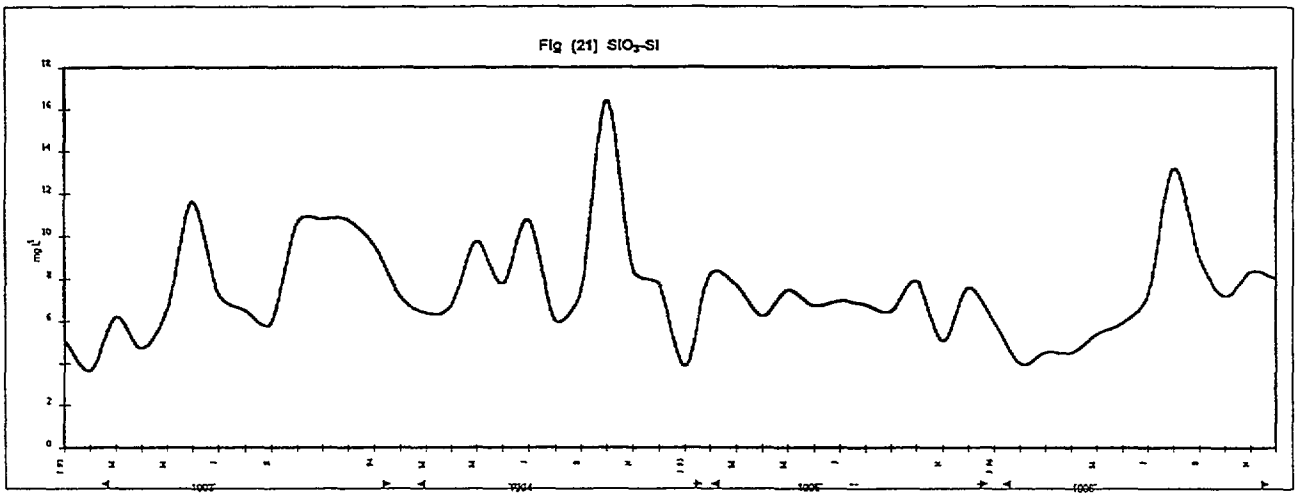


Fig (21) SiO_2-Si
mg/l
0
2
4
6
8
10
12
14
16
18
1993
1994
1995
1996

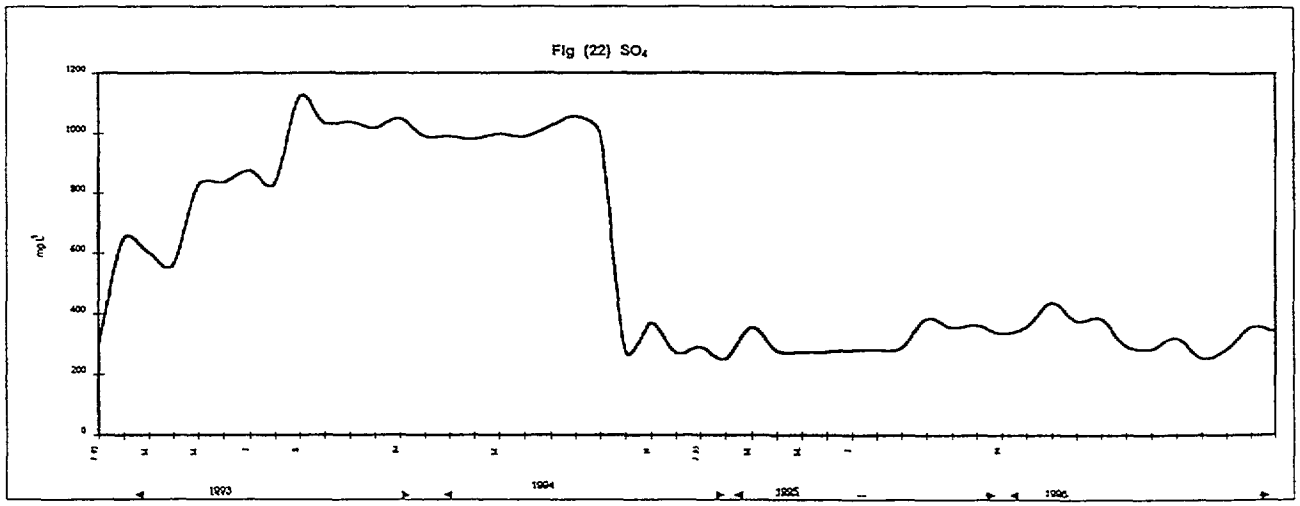


Fig (22) SO_4
mg/l
0
200
400
600
800
1000
1200
1993
1994
1995
1996

A slight increase in SO_4^{2} concentration was observed during 1994 when its concentration ranged between 272 22 and 1056 67 mg L^{1}, with an average value of 834 14 mg L^{1}

A marked decrease in SO_4^{2} concentration was recorded during 1995 & 1996 the average value were 307 7 and 336 99 mg L^{1}, respectively

- Hardness (Ca^{+2} & Mg^{+2})

The hardness of the lake water is mainly due to Mg rather than Ca (Fig 23) The results obtained during this study are summarized as follows

In 1993 Ca^{+2} & Mg^{+2} values varied between 4,803 68 and 781 60 mg L^{1} for Ca and between 5,686 5 and 4,191 03 mg L^{1} for Mg, with annual average values of 1,494 56 & 4,927 64 mg L^{1}, respectively

In 1994 their values were more or less similar to the preceding year, and their concentrations changed from 2,215 35 to 1,122 22 mg L^{1} for Ca and from 6,888 56 to 3,311 93 mg L^{1} for Mg, with annual average concentrations of 1492 85 & 4930 45 mg L^{1}, respectively

In 1995 Ca & Mg concentrations had significantly increased, their values ranged between 3,669 85 and 1,618 82 mg L^{1} for Ca, and between 5,983 07 and 4,718 11 mg L^{1} for Mg, with annual average values of 2,331 09 & 5,505 88 mg L^{1}

In 1996, a substantial decrease in Ca occurred, however the reverse was true for Mg Cavalues varied between 2,692 38 and 1,010 45 mg L^{1} for Ca and from 8,101 8 and 4,986 5 mg L^{1} for Mg, with annual average concentrations of Ca and Mg were 1,902 77 & 5,983 33 mg L^{1}, respectively

- Sodium and Potassium (Na & K)

Sodium concentrations in Lake Qarun were much higher than the corresponding K levels Their concentrations showed very narrow variations during the investigation period, except in 1993 when their values were slightly lower than in the following years (Fig 24)

The annual average values of Na in 1995 varied from 3 36 g L^{1} in 1993 to 3 88 g L^{1} and from 0 4 g L^{1} in 1993 to 0 44 g L^{1} in 1995 & 1996 for K

Fig.(23) Hardness (Ca & Mg)

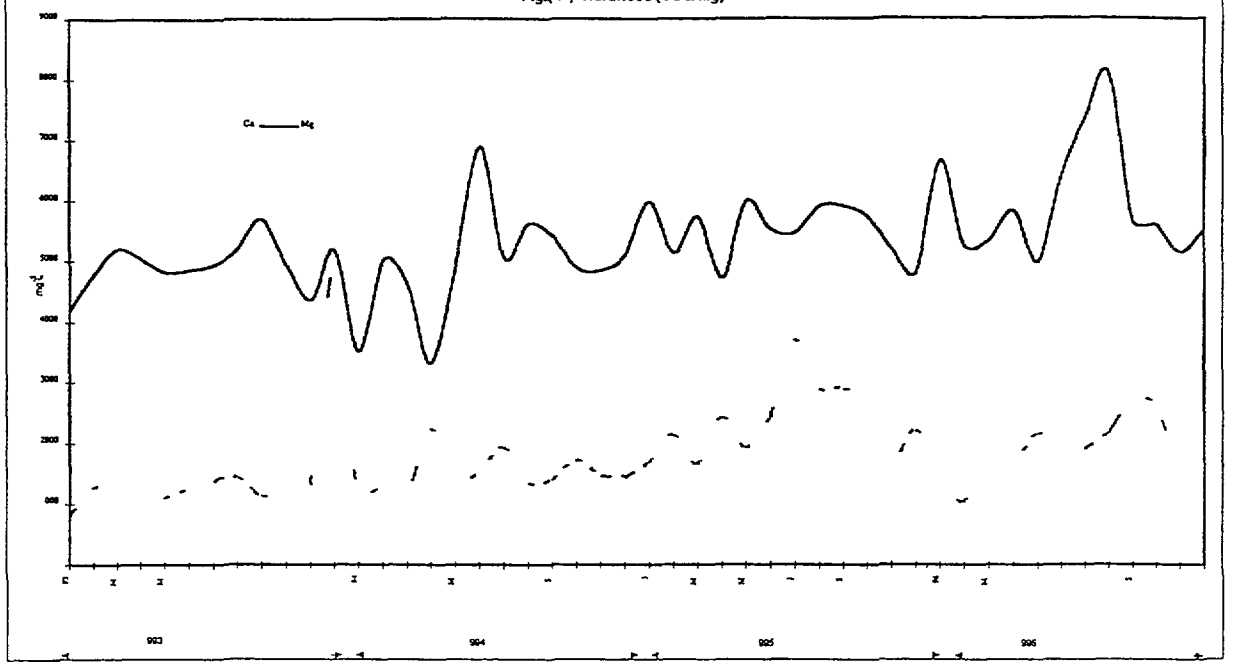
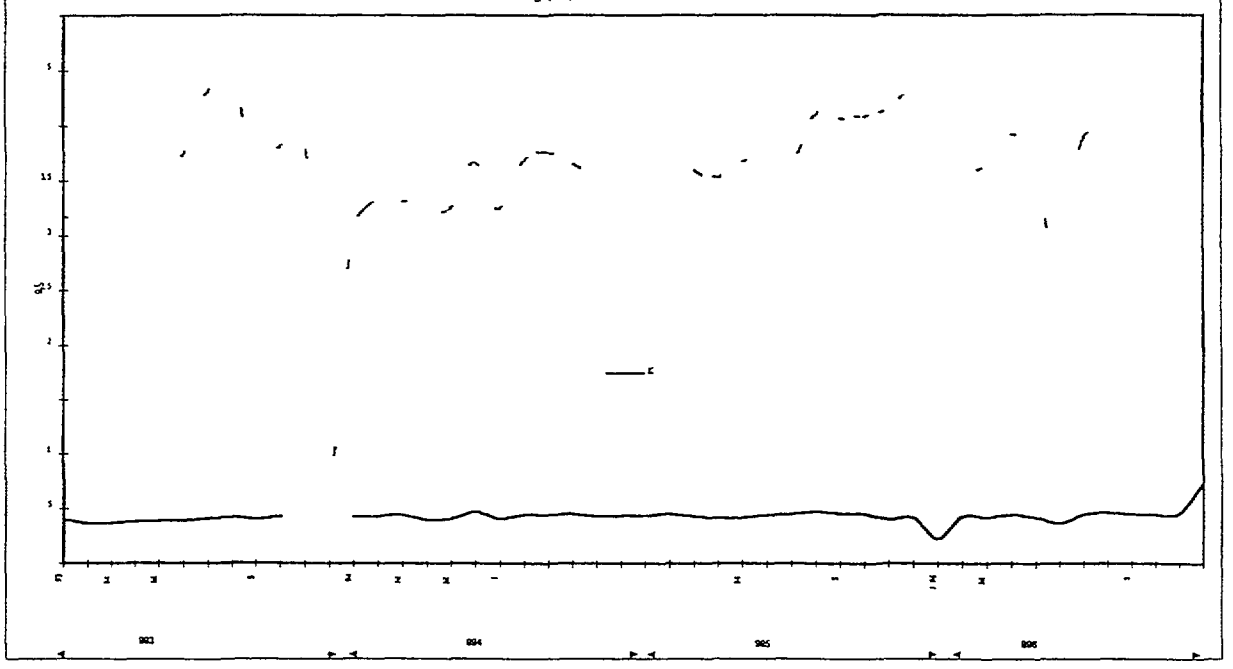


Fig (24) Sodium & Potassium



SEDIMENTS

- *Mechanical Analysis*

The results shown in Fig 25 indicate that Lake Qarun sediments consist of clay, silt, fine and coarse sand Their distribution reveal great variations between stations For instance, in the eastern region, the percentage of clay, silt and coarse sand were high, while the fine sand constituted minor fractions At the middle stations, coarse sand comprised the major fraction reaching a maximum of 55 91% at station 10 Moving from the middle region westward, fine sand significantly increased and reached the highest percentage of 49 56 at station 15 In the western region, clay silt and fine sand constituted the major fractions In general, the mechanical properties of the lake are mainly clay loam (40 9% of the stations), and sandy loam (40 9%), while the loam and sand were found to be 18 2% of the sampling stations, forming 24% & 23%, respectively The least particle size (> 0 5 mm) constituted 10 5%

In the eastern region of the lake that lies under the influence of El-Bats Drain, 0 063 mm particle constituted an important fraction, comprising > 41 9%, followed by particle size 0 138 mm that constituted 28 9% On the other hand, particle of > 0 5 mm size was the least fraction and formed 1 4% (Table 1)

In the middle region, the particle of > 0 138 mm size constituted the major fraction (33 2%) , followed by particle sizes > 0 068 and > 0 125 mm

In the western region, the coarse particle of > 1 mm size was recorded and formed 0 6%, while the major component was particle of > 0 138 mm size, constituting 28% On the other hand, particles of > 0 25, > 0 125, > 0 063 and > 0 38 mm sizes varied within a narrow range and comprised 16 3, 17 5, 15 1 and 14 5%, respectively

The drains sediment is characterized by the presence of coarse particles of > 2 and > 1 mm sizes, they constituted the least percentages of > 0 1 and 1 3% The particle of > 0 5 mm size constituted 13 1%, while particles of > 0 063 size were the dominant component, forming 20 1%

- *Chemical properties of the sediment*

The results are shown in Fig 26 and can be summarized as follows

- ***pH***

The quarterly variations in the pH of Lake Qarun sediments indicated that their readings were always on the alkaline side (i e > 7) pH values varied between a minimum of 7 96 in summer and a maximum of 9 22, in spring

261

Table (1) Chemical characteristics of Lake Qarun's sediments

Site	Moisture%	TOM%	TP	Bioavailable P	TKN	TON	TC
East	34 4	6 1	19 5	19 5	1247 8	1 037	2 801
Midlle	44 9	8 3	25 5	25 5	1536	1 0836	4 8581
West	44 7	9 4	52 5	52 5	2334 3	1 2925	6 1996
Drains	34	6 2	16 5	16 5	1084 1	0 6215	2 6974

TOM Total Organic Nitrogen

TP Total Phosphorus

TKN Total Kjekldahl Nitrogen

TOC Total Organic Carbon

TC Total Carbon (Organic & Inorganic)

Fig (25)· Percentage of size fractions

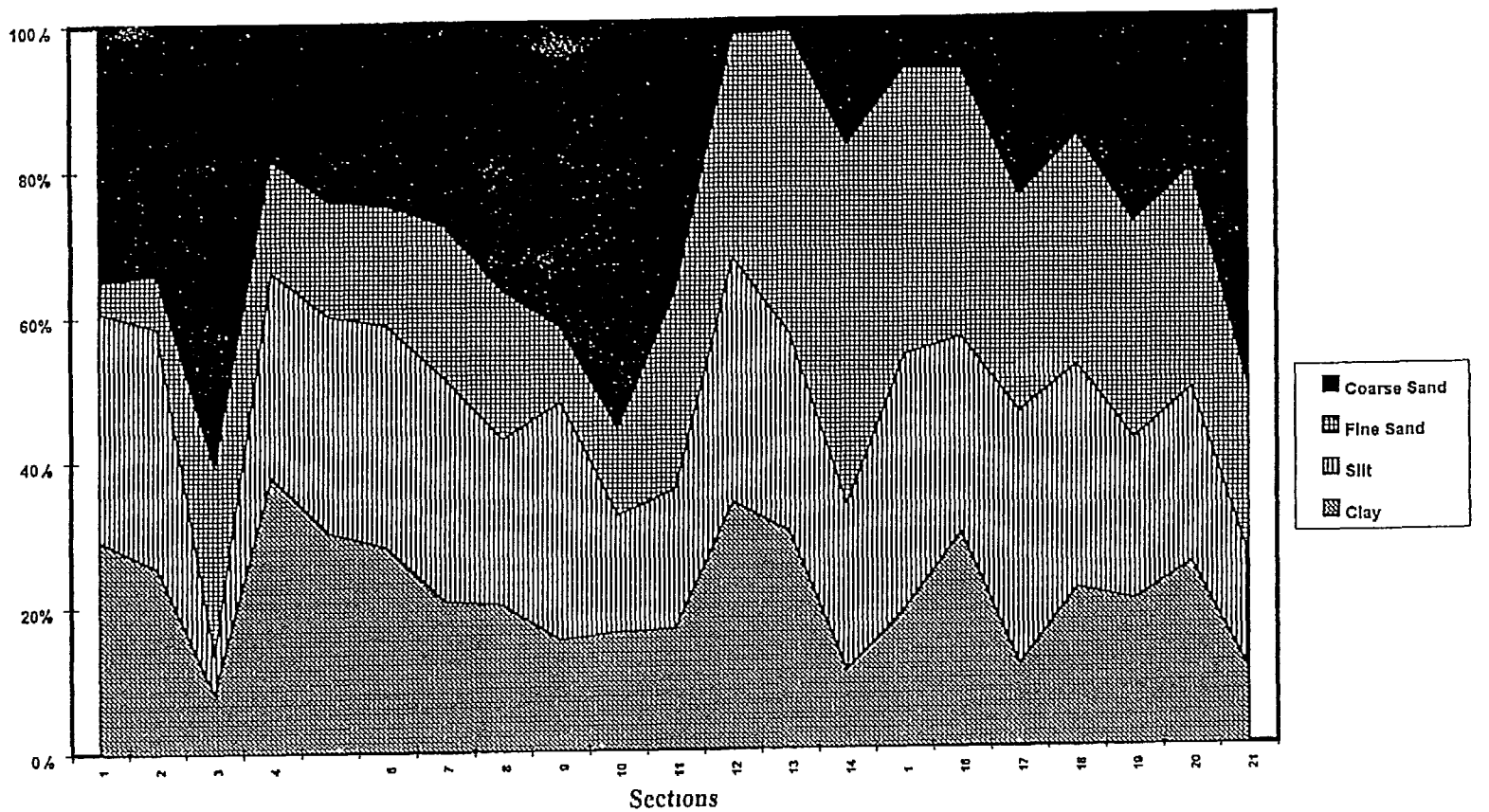
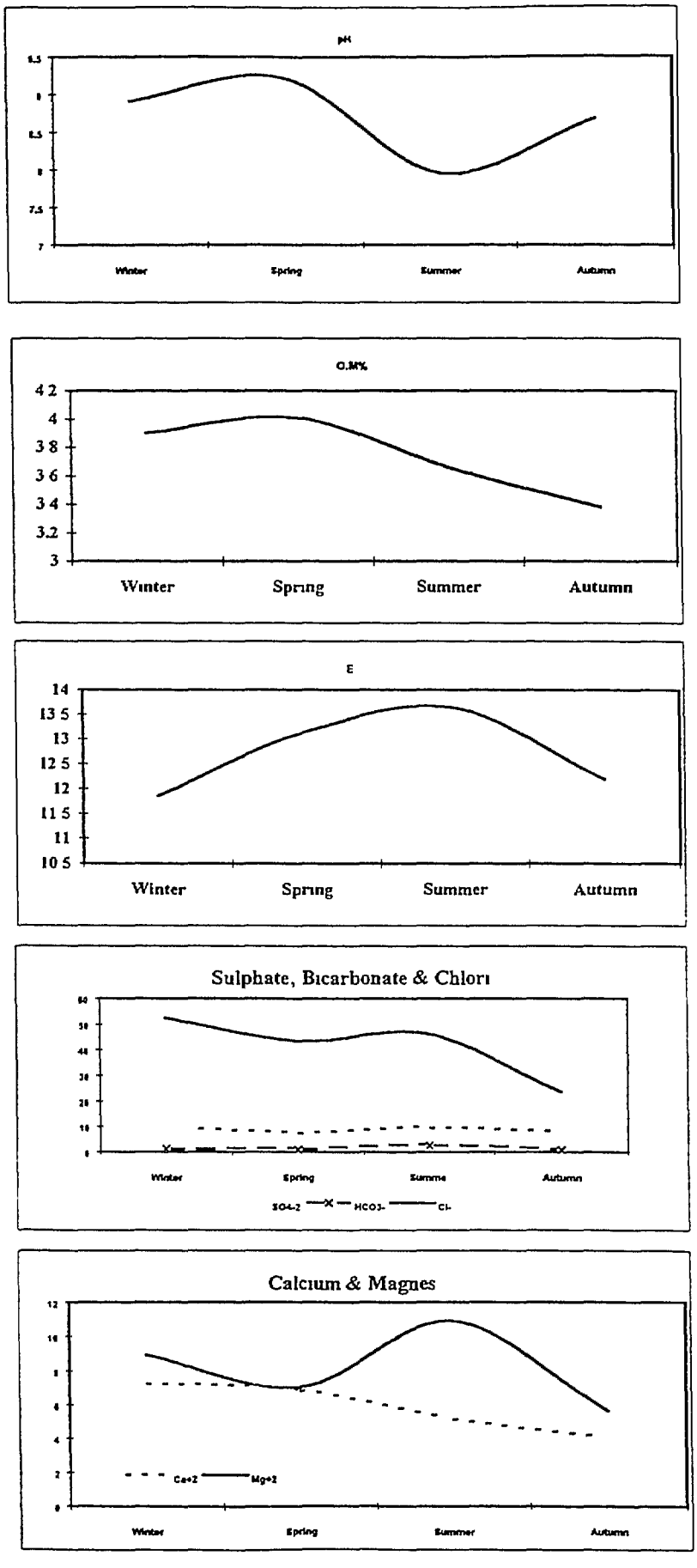


Table (2)· Grain size of different Lake region's sediments

Site	> 4 m%	> 2 m%	> 1 m%	> 0 5 m%	> 0 25 m%	> 0 125 m%	> 0 063 m%	> 0 138 m%	> 0 38 m%
East	0	0	0	1 40	9 50	10 00	41 90	28 90	8 30
Midlle	0	0	0	1 50	10 00	23 00	24 00	33 20	8 30
West	0	0	0 6	8 00	16 30	17 50	15 10	28 00	14 50
Drains	0	0 1	1 30	13 10	16 50	13 90	20 10	19 70	15 30

Fig (26) Seasonal variations of chemical properties of Lake Qarun bottom sediments



- ***Organic matters (OM)***

The organic matter percentage in the sediment showed narrow variations, its percentage values varied from a minimum of 3 38% in autumn to a maximum of 4 01%, in spring

- ***Electrical conductivity (EC)***

The EC values of the lake sediments increased during spring and summer seasons, their values ranged between 11 86 m mohs Cm^{1} in winter and 13 64 m mohs Cm^{1} in summer

- ***Anions***

The anions of Lake Qarun sediment were dominated by Cl^{1} followed by SO_4^{2}, while the least anion was HCO_3

- ***Sulfate (SO_4^{2})***

Noticeable increase in SO_4^{2} concentrations was observed during winter and summer seasons Their values varied between 7 46 m. equ /100 g soil in spring and 9 62 m. equ /100 g soil in winter

- ***Chloride (Cl^{1})***

The concentration of the major anion in the sediments varied from 27 62 m. equ /100 g soil in spring and 61 2 m. equ/100 g soil in winter

- ***Bicarbonate***

HCO_3^{1} exhibited narrow variations with abnormal increase in summer when HCO_3^{1} value of 2 47 m equ /100 g soil was reached Its least concentration of 0 95 m. equ /100 g soil occurred in autumn

The sediment data presented in Table (1) showed the chemical characteristics of the eastern, middle and western regions of the lake as well as the two main drains

- ***Moisture***

The moisture contents of sediment samples of the eastern region of the lake and drains were more or less similar being 34 4 and 34 0%, respectively In the meantime, the percentage moistures of the middle and western regions were 44 9 & 44 7%, respectively

- ***Total organic matters (TOM)***

The percentage organic matter in the sediment indicated that its value in the western region was 9 4%, which was much higher other regions The lowest levels of organic matters (6 1 & 6 2%) were found in the eastern region and drains, respectively

- ***Total carbon***

The total organic and inorganic carbon content in the different regions and in the drains varied from a minimum value of 2 6974 mg k^{1}, in the drains to a maximum of 6 1996 mg Kg^{1} found in the western region

- ***Total organic carbon (TOC)***

The total organic carbon in the western region of the lake (1 2925 mg kg^{1}) was higher than at any other region, the least value occurred in the drains (Table 1)

- ***Bio-available phosphorus***

The highest bio-available phosphorus value, 52 5 mg kg^{1}, occurred in the western region, while its lowest concentration of 16 5 mg kg^{1} was recorded in the drain's sediment (Table 1)

- ***Total Kjeldahl nitrogen***

TKN was significantly high in the western region (2334 3 mg kg^{1}) compared to the other investigated sites, the least concentration (1084 1 mg kg^{1}) occurred in the drains

L67

POLLUTANTS

- *Organo-chlorine*

The chlorinated pesticide residues were determined in the lake sediments as well as in the two drains Before presenting the residual measurements, it is important to discuss the reasons for analyzing these organo-chlorine pesticides The information and standards of commonly used chlorinated pesticides at Fayoum Governorate were received from the El-Giza Seed and Herbicide Subsidiary of Kato & Aromatic The company has all the information about the pesticides used in the different Egyptian Governorates It has a well-equipped laboratory established and operated in collaboration with German experts

The results presented in Fig (27) indicated that 17 organo-chlorine pesticides are widely used at the Fayoum Governorate Their seasonal variations in the lake sediment showed that of these pesticides 11 were found in relatively the high concentrations In summer 1995, heptachlor epiokide, methoxychlor, quintozine, ortho, para DDT and BHC-Beta were found in high concentrations of 24 94, 20 26, 16 92, 15 58 and 12 84 µg Kg^{1}, respectively The other pesticides were recorded in low concentrations

In autumn 1995, significant increase in pesticides was observed, their concentrations (in µg kg^{1}) were 90 89 Alpha-Endosulfan, 64 05 Ortho, Para DDT, 40 17 Alpha- chlordan, 42 05 Quantozine, 12 88 Heptachlor Epioxide and 11 86

In winter 1996, the main pesticide residues found in the sediments and their concentrations (in µg kg^{1}) were 78 16 BHC-Beta, 42 98 Alpha-Chlordan, 37 19 Heptachlor Epioxide, 23 33 Beta-Chlordan, 17 40 Quintozene, 18 06 Methoxychlor, 16 194,4-DDD and 14 80 Heptachlor

In spring, summer and autumn 1996, a sharp decline in the pesticide residues was observed in Lake Qarun's sediments This was mainly due to the application of biological control for agricultural pests not only in the Fayoum Governorate but also in other Governorates The main pesticides recorded during this period were Methoxychlor, 4,4 DDD, Ortho Para DDT, Endrin, Heptachlor Epioxide, and Quintozine

- *HEAVY METALS*

- ***In Lake Water***

Heavy metal analyses in lake water and sediment began in winter 1996, after purchasing the AA-Spectrophotometer (Perkin El-Mer 3110 equipped with Graphite Furnace Model HG600, as well as Hydride unit Hg-20), from the project's budget

The results of heavy metal analyses in the water and sediments are given in Fig (28)

The heavy metals measured in lake water were Hg, Cu, Ni, Co, Fe, Cd, Pb, Mn, Zn and Cr

In winter 1996, the most important metals in lake water and their concentrations (in µg L^{1}) were Fe, 430 75, Ni, 184, Co, 158 33 and Zn, 157 67 In spring 1996, obvious increase in Co

Fig (27) Residual Organochlorine Pesticide of Lake Qarun (Sediment µg mg $^{-1}$)

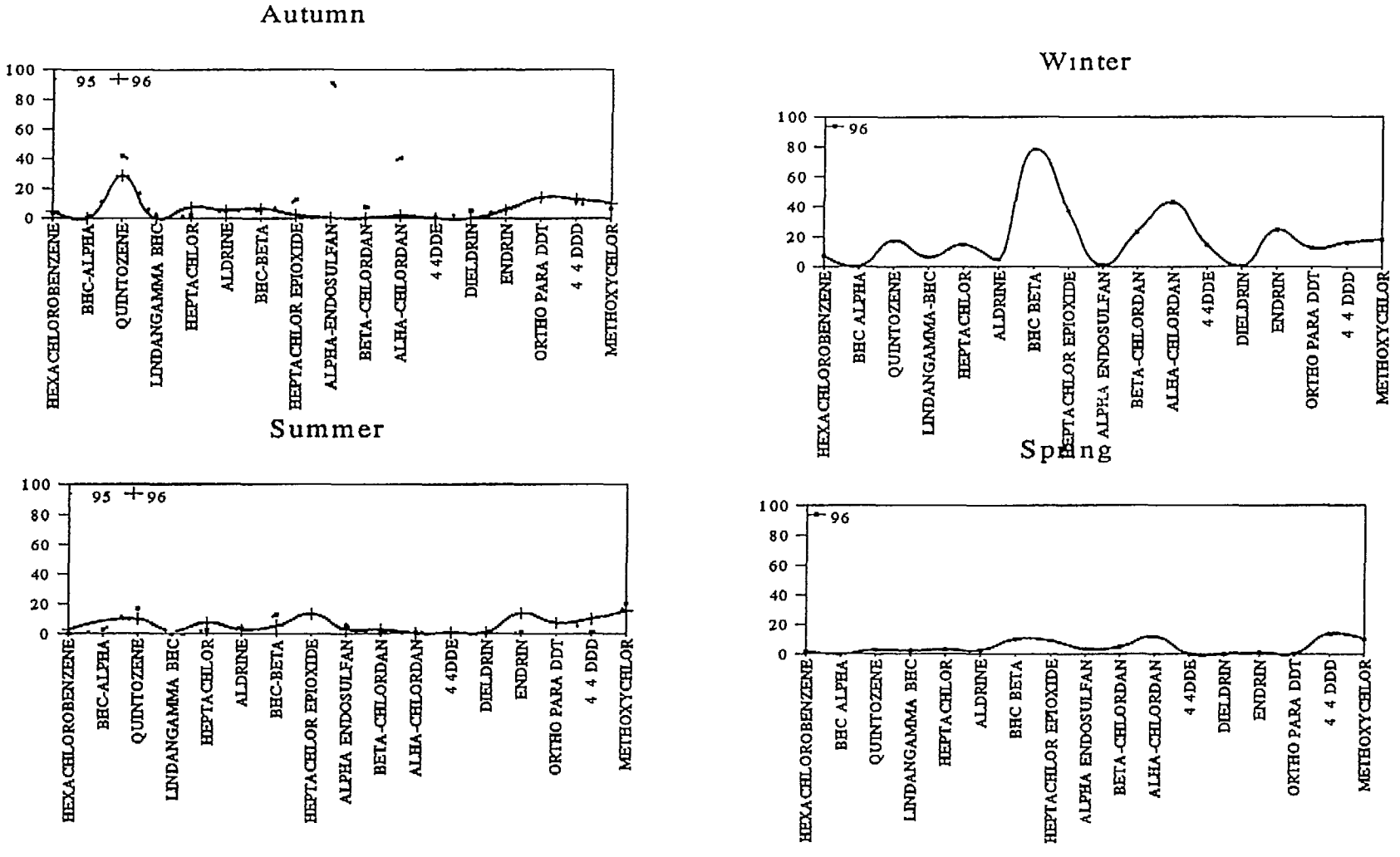
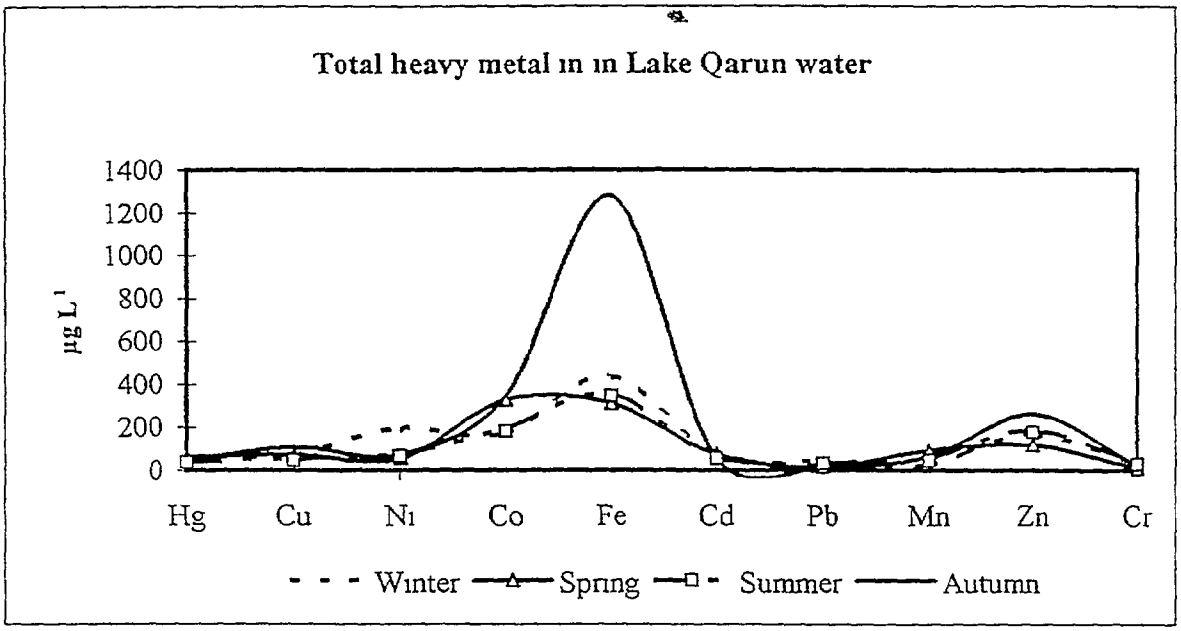
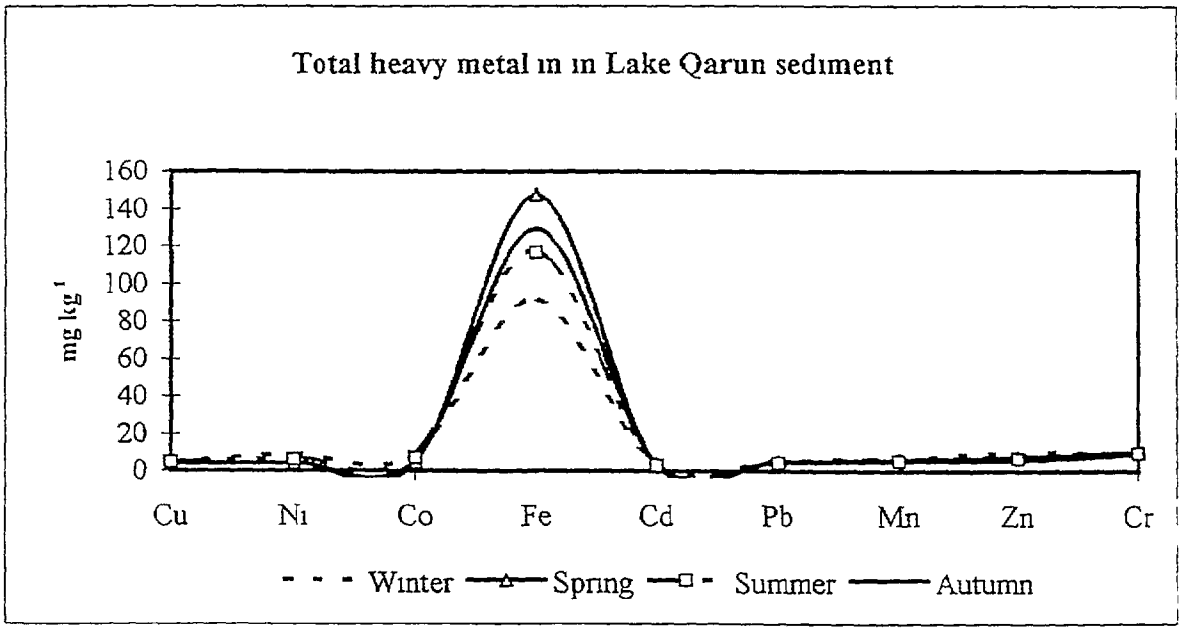


Fig (28) Total Heavy Metals in Lake Qarun





210

and Mn was observed, while the other metals had decreased In summer 1996, the heavy metal concentrations had significantly decreased, except Zn and Fe when their concentrations increased In autumn 1996, obvious increase in Fe, Co, Zn and Cu concentration was observed

- ***Heavy metals in sediments***

The heavy metals in lake sediment are characterized by the dominance of Fe Its concentrations fluctuated between a minimum of 90 27 mg kg^{1} in winter and a maximum of 147 57 mg kg^{1}, in spring The less important metals, based on their maximum concentrations in mg kg^{1}, were Cr, 10 14, Zn, 8 43, Ni,7 83, Co,7 27, and Mn, 6 07 mg kg^{1} It is noteworthy that the industrial activities in the Fayoum Governorate are very limited, there is no other significant source of industrial effluents discharged into the lake either directly or through the drains

BIOLOGICAL PARAMETERS

- Phytoplankton

- ***Standing Crop***

The phytoplankton communities in Lake Qarun are represented by six classes, namely, Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, Euglenophyceae and Cryptophyceae

The standing crop of the total phytoplankton as well as the population density of each class and their monthly variations are presented in Fig (29)

The results clearly showed substantial decrease in the phytoplankton standing crops during the investigated period The highest standing crop of 2,663 73 X 10^3 cells m^3, was recorded in 1993, whereas the least value was 1,106 75 X 10^3 cells m^3 These figures depend on the annual average values

Conspicuous phytoplankton peaks were observed spring 1994 & 1996 and in summer 1993 & 1995 On the other hand, the minor peaks were recorded in winter 1993, summer of 1994 & 1996, and spring 1995 The major phytoplankton peaks are mainly due to outburst of diatoms, except in summer 1993 when the dinoflagellates were the main dominant class In general, the flourishing of dinoflagellates was always observed in summer seasons, except in 1994 when their highest density occurred in early autumn

The percentage abundance of different phytoplankton classes during the investigation period is shown in Fig (30) The results revealed a significant gradual decrease in percentage abundance of Bacillariophyceae during the 4 successive years Its percentage abundance varied from 66 32%, in 1993 to a minimum of 53 1% in 1996 In contrast, the abundance of

Dinophyceae has increased from 34 1% in 1993 to a maximum of 46 46% in 1996 Cyanophyceae, has also increased from 0 45% in 1993 to a maximum of 1 27% in 1996 Chlorophyceae, which were less represented, their abundance has also increased from a minimum of 0 13% in 1993 to a maximum of 0 18% in 1996 Green algae were usually found at the discharging points of the two main drains into the lake

Fig (29) Total Phytoplankton

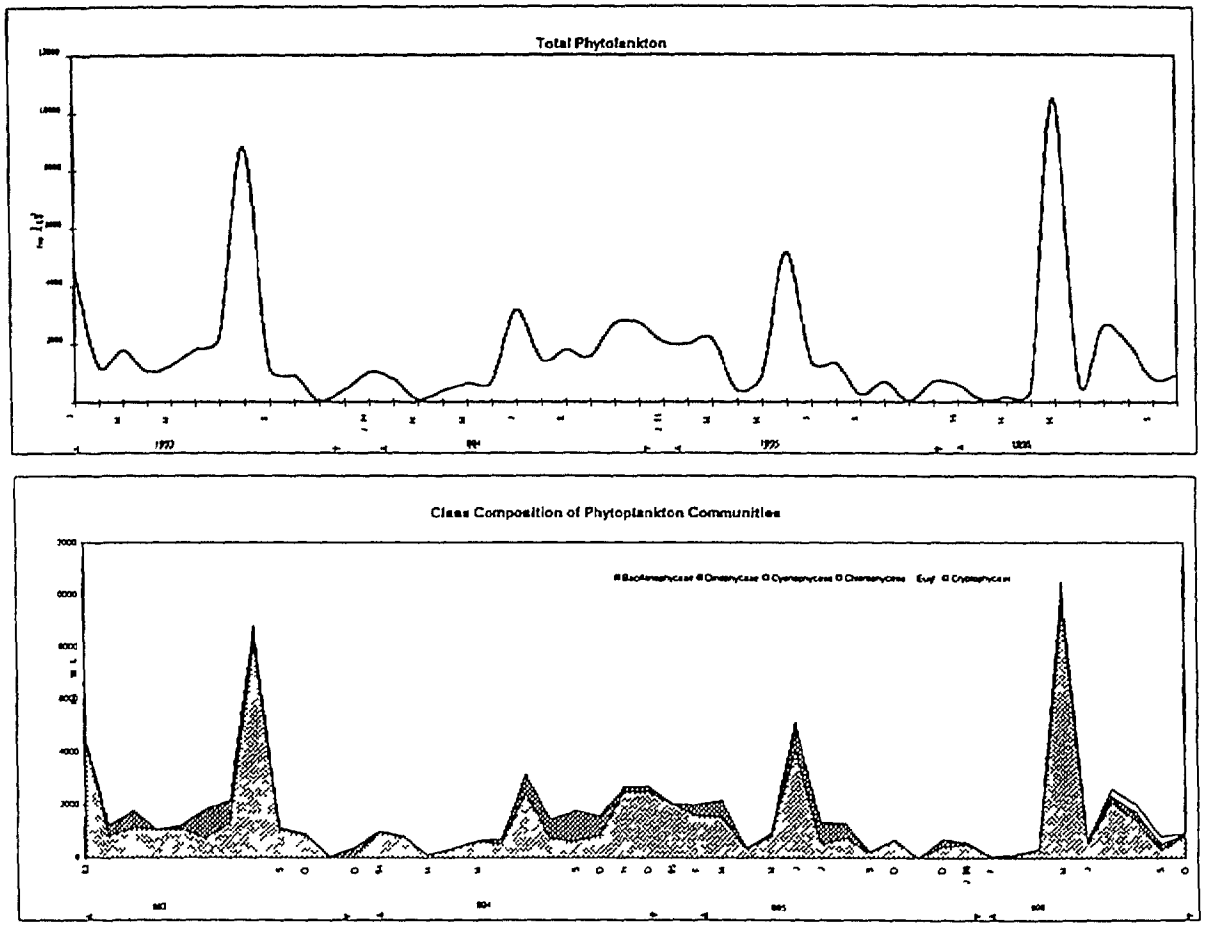


Fig (31) The vertical & temporal variations of *Chl a* at the 3 hydro-stations

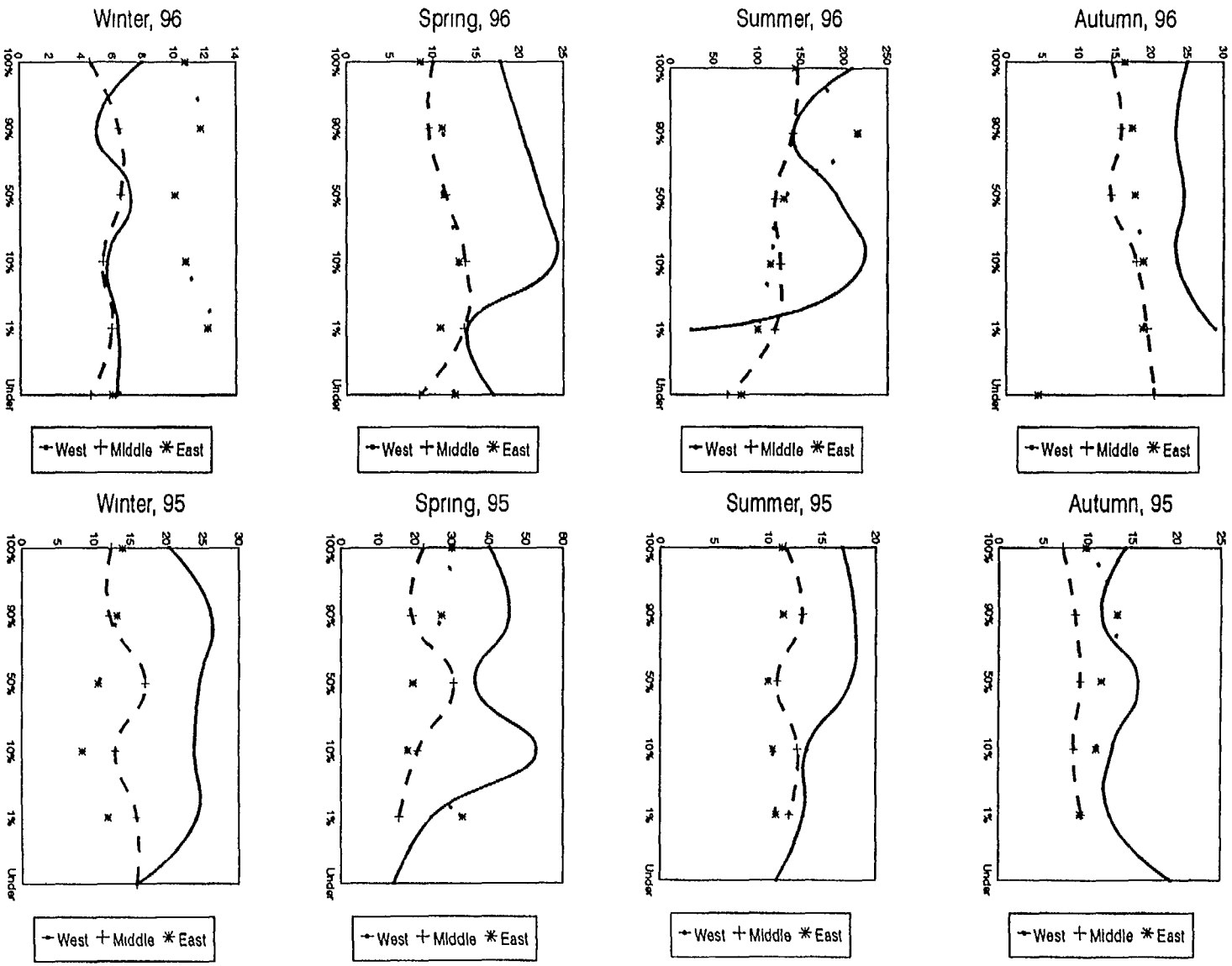
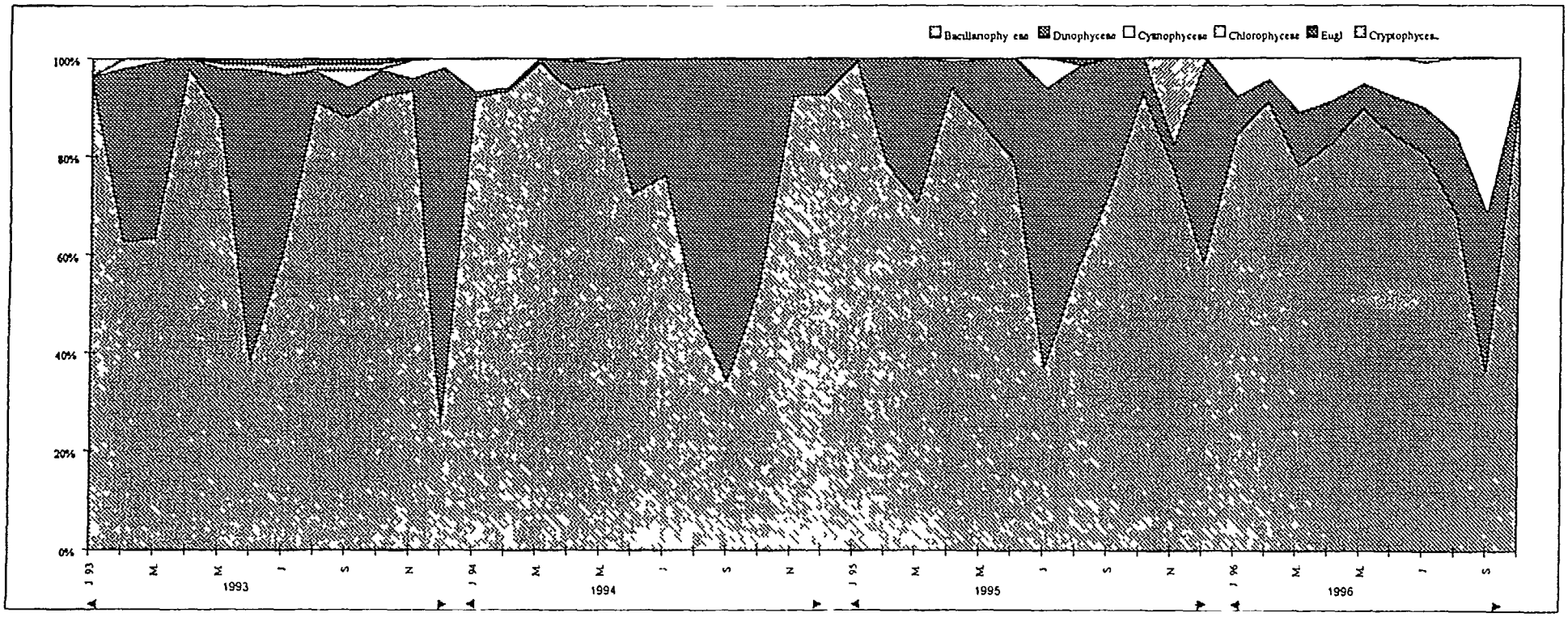


Fig (30) Percentage abundance of different phytoplankton class



The list of phytoplankton species recorded in Lake Qarun during the period from 1993 - 1996 is presented as follows

1 Bacillariophyceae

Achnanthes kolbei
A lanccolata var rostorata
A lanceolata
A longibes
Amphiprora paludosa
Amphora coffeoformis
A ovalis
Asterionella japonica
Bacillaria paradoxa
Biddulphia rhombus
B sp
Campylodiscus echeneis
C sp
Chaectoceros sp
Climacosphenia moniligera
Cocconeis lineatus
Cocconeis placentula
C scutellun
Coscinodiscus excentrics
C lineatus
C granuii
Crammatophora marina
Cyclotella glomerata
C Kutizingiana
C menghiniana
C ocellata
Cymbella helvatica
C lanceolata
Nitzchia recta
N angularis
N apiculata
N closterium
N fonticola
N frustulum
N frustulum var perpusilla
N kutizingiana
N linearis
N microcephala
N palea
N sigma
Nitzschia sp
N thermalis
N thermalis var minor
N trybionella
Opeophora martyi
Plagiogramma vanheurcki
Pleurosigma delecatulum
P salinarum
Stephanodiscus aegyptiacus
S asteria
Surirella ovata
Syndera ulna
S fulgen
S ulna var longissma
Thalassionema nitzschiodes
T fraunfeldii

Cymbella sp

Diploneis interrupta

Fragillaria construens

Gomphonema olivacium

Gonialax monocaanpha

Grammatophra marina

Naviaula cryptocephalus

Naviaula sp

N alpina

N cancellata

N capitata

N lyra

Triceratium untediluvianum

Gyrosigma accuminatum

Hanzschia amphioxys

Lichmophora abbreviata

L flabellata

Mastoglia brunii

Melosira granulata

M momiliformis

2- Dinophyceae

Diplopsalis lenticulata

Exuviella apora

Goniaulax monocantha

Goniaulax sp

Gymnodinium smile

Gymnodinium sp

Hermecium adriaticum

Monas sp

Peridinium sp

Prorocentrum micans

3- Cyanophyceae

Lyngbya sp

Merismopedia punctata

Ocillatoria bonnemaisonii

O agardhii

O carollinae

O formosa

O margaritifera

Oscillatoria sp

Phormedium retzii

Spirulina sp

Synchocystis salina

4- Euglenophyceae

Euglena sp

5- Chlorophyceae

Scenedesmus quadricauda

S dimorphus

Staurastrum sp

6- Cryptophyceae

Chroomonas salina

Rhodomonas minima

Monas affinis

The most important phytoplankton species are shown in Plates (1-3)

- **Photosynthetic Active Radiation (PAR) and *Chl. a***

Starting in January 1995, PAR and *Chl a* were measured at three hydrostations, representing the eastern, middle and western regions of the lake A maximum of five depths was chosen on the basis of light attenuation (90, 50, 10, 1 and < 1% of the surface PAR)

- ***PAR***

The monthly average surface of PAR over the investigated period varied between a minimum of 158 4 μ mole m^2 S^1 in January and a maximum of 675 7 μ mole m^2 S^1 in July The euphotoic zone (as approximated by 1% of surface light level) extended to the bottom of the three regions, in August, while in May, June and July, the photic zone extended only to the middle and western regions

- ***Chl a***

The data presented in Fig (31) whow the vertical and temporal distribution of chl *a* at the three hydrostations In 1995, two peaks were observed and showed a wide variation In most cases, highest chlorophyll values were recorded at 50% PAR, however in a few cases it was found at 100 & 90% PAR

The major peak was observed in spring, a less prominent peak occurred in winter The *chl a* maxima were 52 89 mg m^3 in the east, 30 5 mg m^3 in the middle, and 32 89 mg m^3 in the western region These maxima were recorded at 10, 50 and 1% PAR, respectively The *chl a* values at the minor peaks of the three regions were 26 13, 17 07 and 13 9 mg m^3 These were observed at 90, 50 and 100 PAR for the eastern, middle and western regions of the lake, respectively

In 1996, the highest *chl a* values were observed in autumn, while the minor peak occurred in spring In the major peak, the *chl a* maximum of 28 8, 20 4 and 18 95 mg m^3 were found at 1, < 1 and 10% PAR in the eastern, middle and western regions For the minor peak, the *Chl a* maximum of 23 98, 13 75 and 13 mg m^3 were recorded at 10% PAR for the three regions

- ***Size fractionation of phytoplankton Chl a***

The results of *chl a* of different phytoplankton size components (i e net > 20 μm, nano < 20 μm and picoplankton < 2 μm) are presented in Fig 32 The monthly average *chl a* values of

Fig (32) Size Fractionation of Chlorophyll *a*

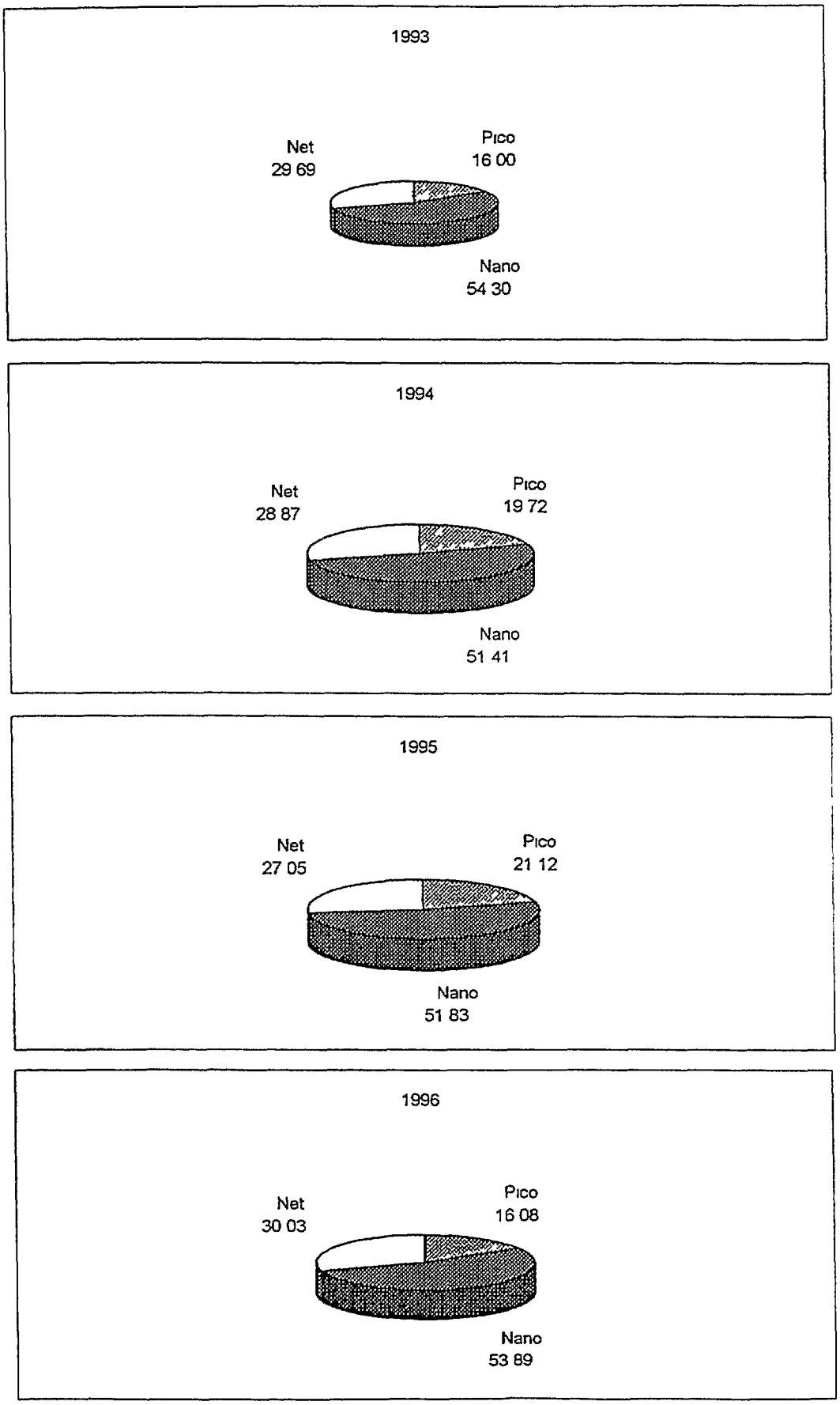
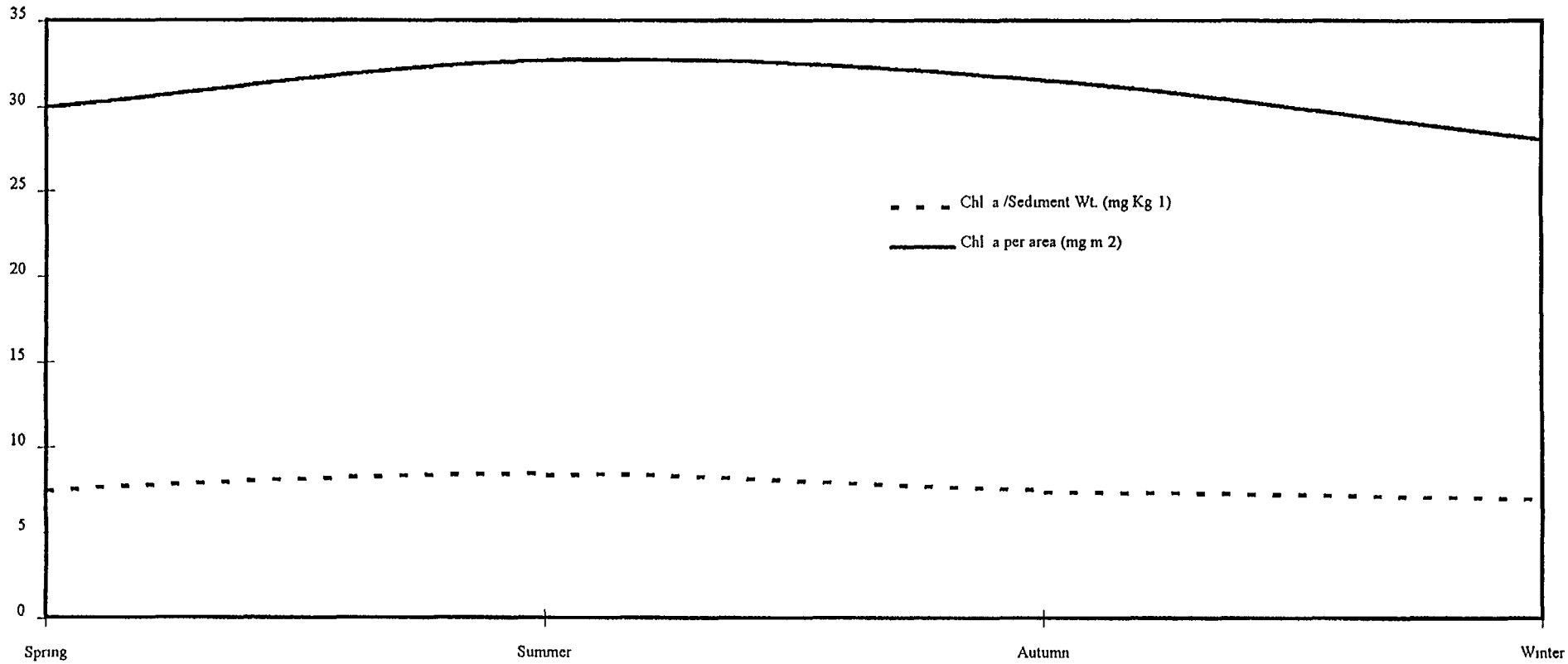


Fig (33) Quarterly variations in Chl *a* of benthic algae



the different phytoplankton size fractions indicate that the highest concentrations were observed in spring, except in 1993 when the major peak occurred in mid summer

The *chl a* values recorded in 1993 were much higher than in the following years The highest *chl a* concentrations were observed in July, 1993 when their values were 7 5 mg m^3, for picoplankton, 31 44 mg m^3, for nanoplankton, and 15 96 mg m^3, for netplankton Depending on the annual average values, nanoplankton was the dominant fraction, its values varied from a maximum of 18 23 mg m^3 in 1994 to a minimum of 17 81 mg m^3 in 1996, constituting 51 41 & 51 83% of the total *chl a*, respectively Net plankton was second in abundance, their contribution varied between a maximum of 10 24 mg m^3 in 1994 and a minimum of 9 64 mg m^3 in 1995, comprising 28 87 and 27 05% of the total *chl a*, respectively Picoplankton was the least abundant component, their contribuion varied between 7 52 mg m^3 in 1995 and 5 29 mg m^3 in 1993, constituting 21 12 and 16 08% of the total *chl a*

- ***BENTHIC ALGAE***

The seasonal variation of benthic algal biomass (in terms of *chl a)* is shown in Fig 33 The data revealed very small changes in benthic algae in the lake sediments with a value of 32 66 mg m^2 recorded in summer,and a concentration 27 99 mg m^2 in winter These results correspond to the data calculated based on the weith of the sediment Here again the highest *chl a* value of 8 338 was found in summer, while its minimum concentration (6 85 mg kg^1) was observed in winter The annual average *chl a* values of benthic algae in the lake were 30 519 mg kg^2 & 7 51 mg kg^1

- ***Nutrient limitation of phytoplankton***

The results, presented in Fig 34, show the dual limitations of NO_3 and PO_4 (N P = 1 5) during the May and July experiments Nitrogen and phosphorus ratio 1 10 stimulated the phytoplankton growth in June The results revealed that NO_3-N is the primary limiting nutrient in Lake Qarun If NO_3-N or either NO_3+PO_4 were to enter the lake from some external sources, increased phytoplankton growth would occur NH4-N seems to have little effect on phytoplankton growth either when added alone or in combination with P

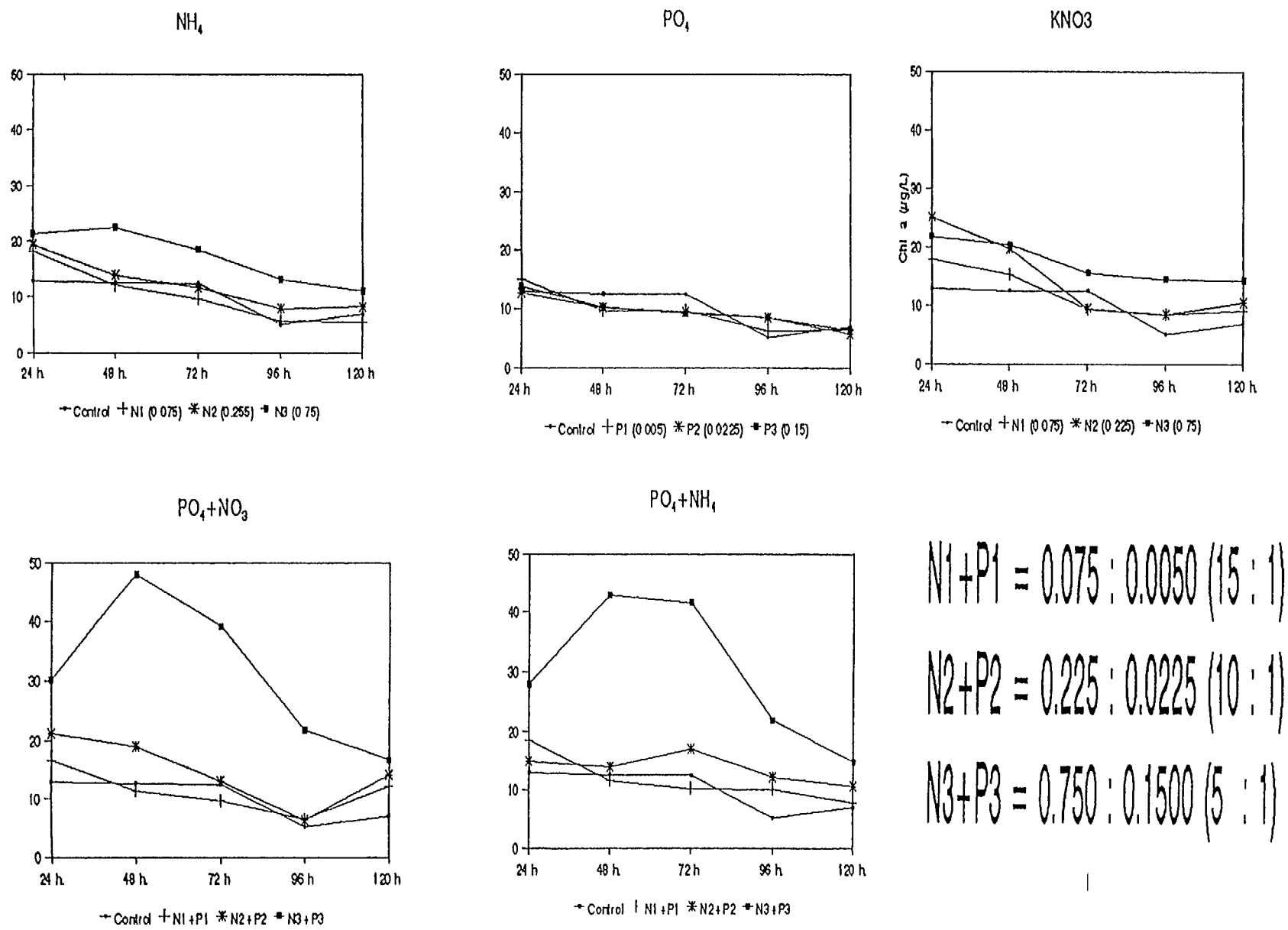
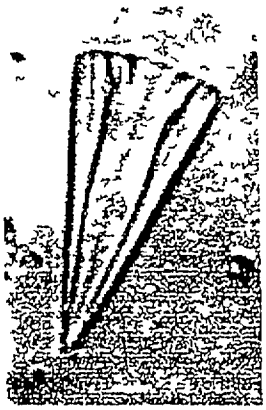


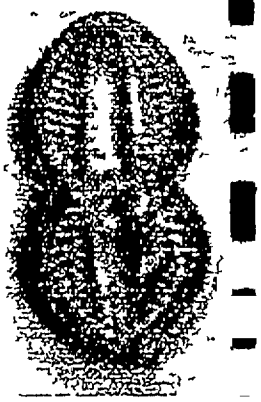
Fig . (34): Nutrient Limitation of phytoplankton

Surirella striatula

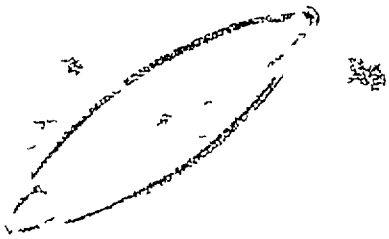
Achnanthes sp



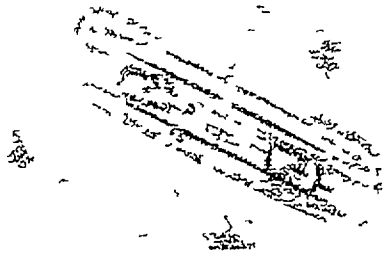
Lichmophora abriviata



Diploneis interrup

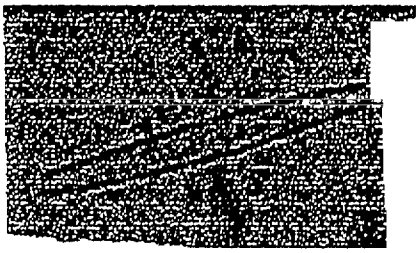


girdle view

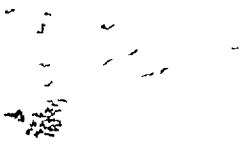


Mastoglia braunii

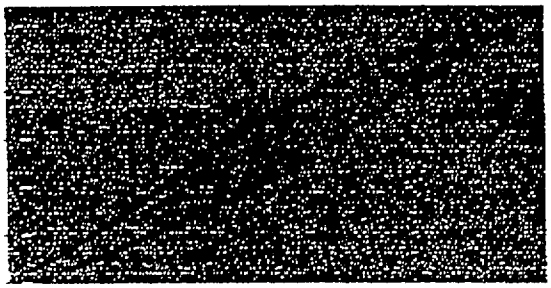
valve view



Thalassionema nitzchio

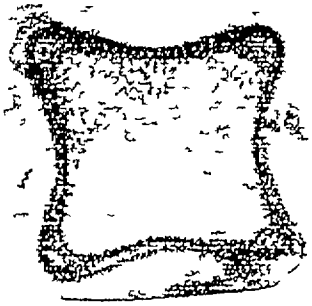


Thalassiothrix fraunfedii

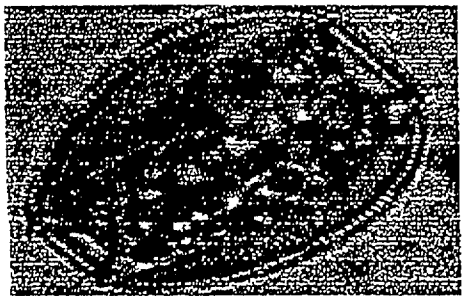


Pleurosigma salinarum

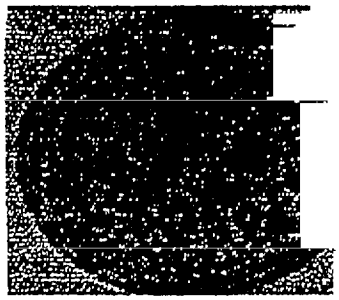
Cosinodiscus lineatu



Triceratium antidiluviana

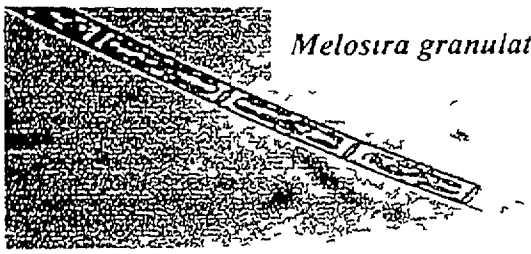


girdle view



valve view

Cosinodiscus granii



Melosira granulata

Bacillariophyceae
Plate I

Peridinium sp

Prorocentrum micans

Hermecium adriaticum

Diplopsalis denticula

Exuviaella apora

Phormidium retzii

Spirolina

Cyanophyceae

Euglena sp

Phacus sp

Euglenophyceae

28

ZOOPLANKTON

Zooplankton communities in Lake Qarun are represented by three main classes, namely, protozoa, rotifers and copepoda (Fig 35) Other zooplankters of lessor importance were also recorded The results of the monthly variations of the zooplankton standing crop during the investigation period can be summarized as follows

The data collected indicate that the major zooplankton peaks were always recorded in summer seasons, except in 1995 when the maximum standing crop was observed in early autumn (September)

The annual average zooplankton standing crops showed considerable variation with substantial increase during 1994 (1344 org L^{1}), while the lowest standing crop of 150 org L^{1} occurred in 1993 Rotifers were always the most important and dominant group from early summer (June) to mid-autumn (September or October), although they also were dominate in late spring 1995 Copepoda, on the other hand, were the second domineant group, except in 1995 when the protozoa occupied that place Copepoda usually flourished in winter and spring seasons, with the exceptions in 1995 & 1996 when the protozoa occurred in substantial numbers

The percentage abundance of zooplankton classes is shown in Figs 36 & 37 and the results are presented as follows

The rotifers were always the most dominant group, their percentage abundance varied between a minimum of 41 56% in 1993 and a maximum of 44 04% in 1994

As mentioned before, Copepoda occupied the second predominance place, except in 1995 when protozoa had increased higher than Copepoda The percentage abundance of Copepoda reached a maximum of 36 54% in 1996 and a minimum of 24 62% in 1995

Protozoa was the third predominant group except in 1995, when it occupied the second place Its percentage abundance was high in 1995 being 29 49%, its minimum abundance was recorded in 1993, when it formed 14 06% of the total zooplankton standing crop

- Dominant zooplankton species

The leading zooplankton species in the lake were *Brachionus plicatilis, Paracartia latisetosac,* and *Helicostomella subulata,* representing the three main groups, i e Rotifera, Copepoda and Protozoa, respectively

Brachionus plicatils was the dominant species and constituted the major part of zooplankton densities, especially during the period from late spring (May) to mid-autumn (October) Its highest population densities were always found in summer months

Paracartia latisetosa was the most important species among copepoda, its population densities showed wide fluctuations during the investigation period This species usually flourished in winter months and early spring

Fig.(35): Total Zooplankton

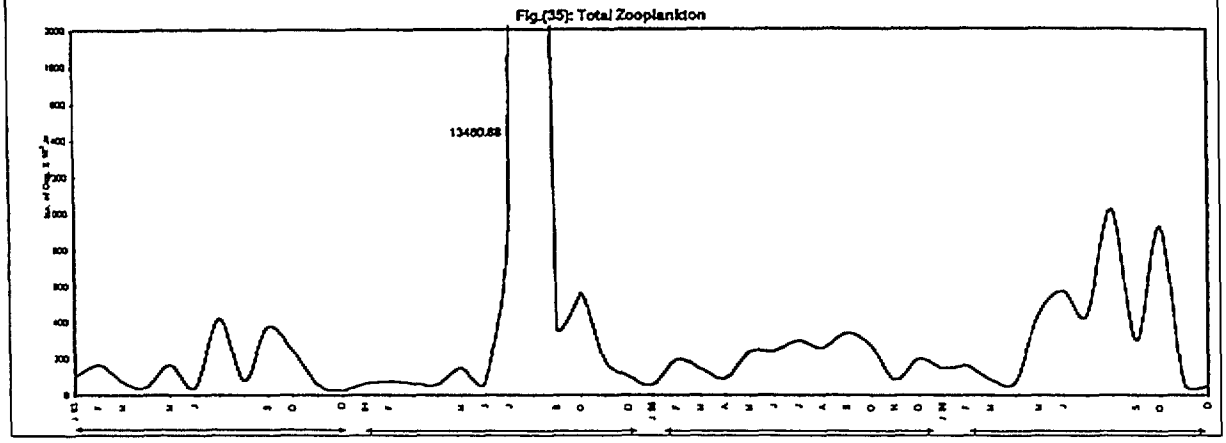


Fig (36)- Class composition of zooplankton

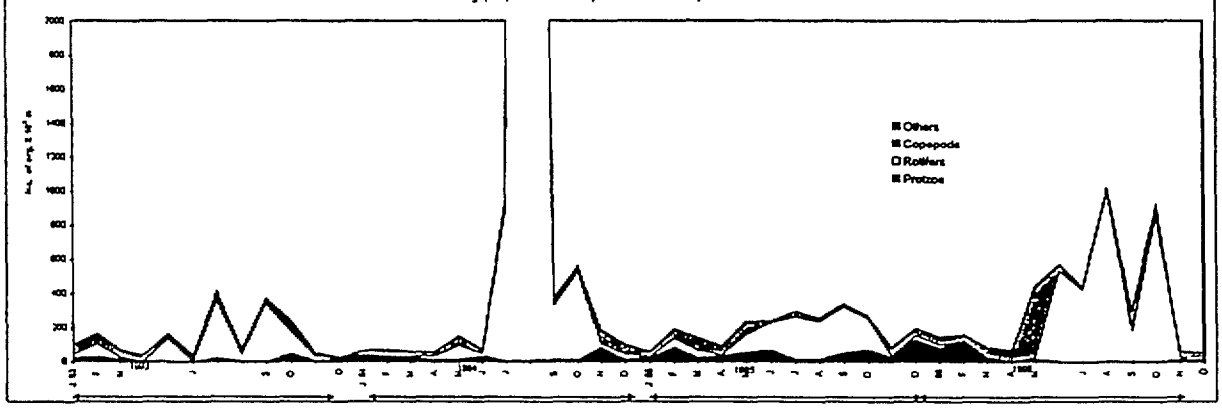


Fig (36) Class composition of zooplankton

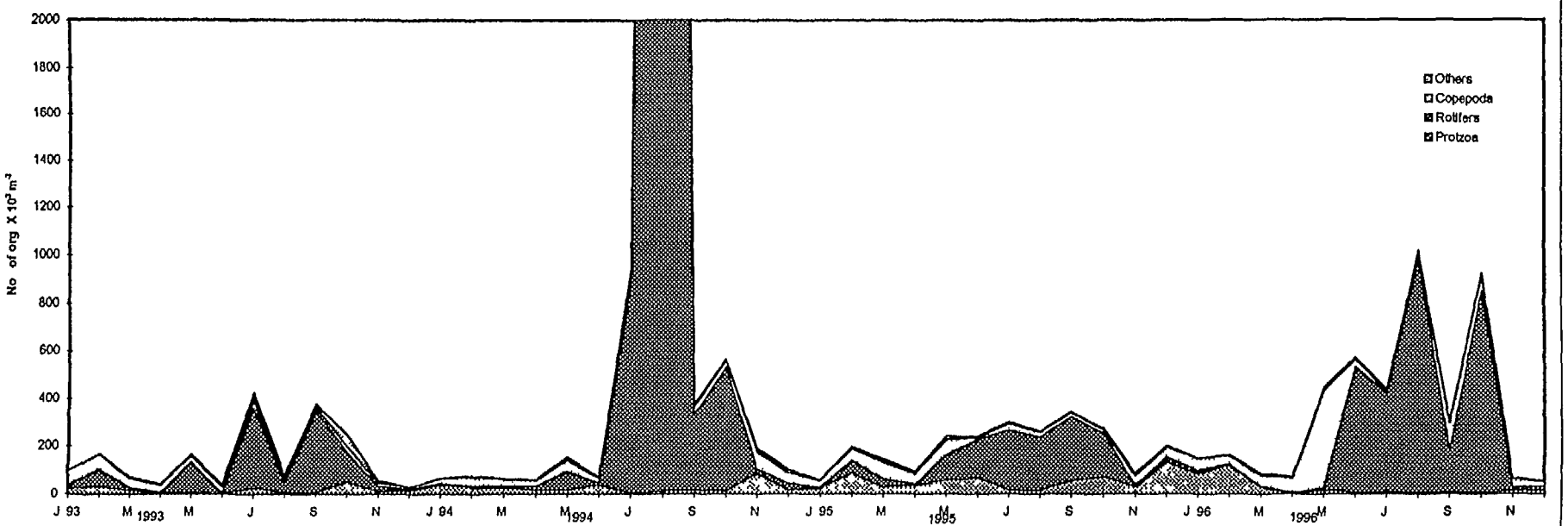
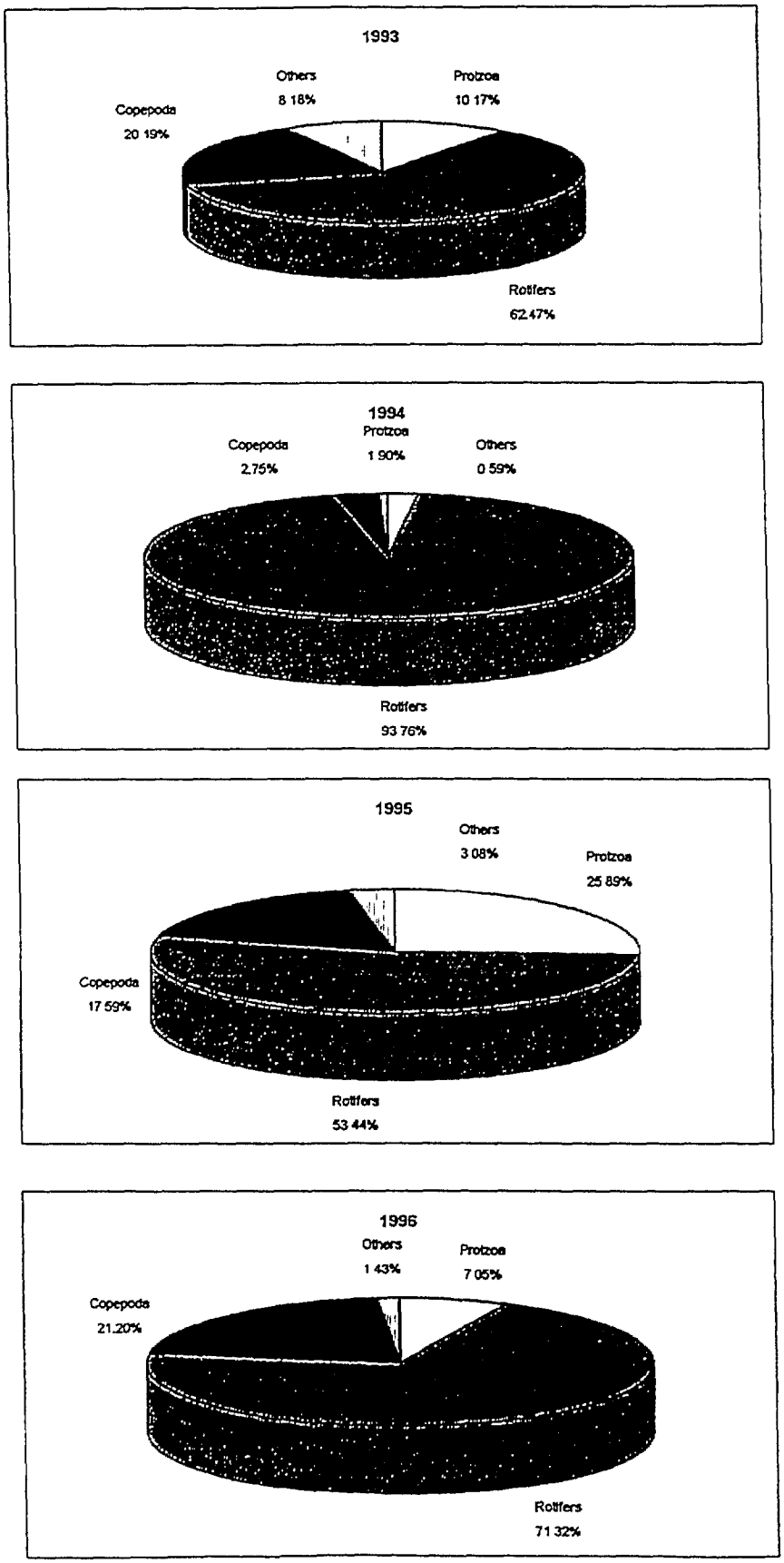


Fig (37) Percentage of class composition of zooplankton



289

Helicostomella subulata is the most abundant species among protozoa, its densities had obviously increased during winter months, especially January and February The most important zooplankton species in Qarun Lake are shown Plate 4

The main zooplankton species recorded in Lake Qarun during the period 1993 - 1996 are the following

Protozoa

Tintinnids

Tintinnopsis strigosa

T amphora

T kofoidi

T beroidea

Helicostomella subulata

Leprotintinnus botnicus

Euplotes vannus

Favella panamensis

F adriatica

F chrenbergi

F taraikensis

F serrata

F sp

Foraminefera

Globigerina sp

Textularia sp

Rotifera

Brachionus plicatilis

Keratella tropica

Notholca salinus

Synchaeta spectinata

Testudinella patina

Copepoda

Paracartia latisetosa

Mesachrd holdt

Apocyclops panamensis

Ostracoda

Cypridies torosa

Other forms

Polychaet larvae **Veliger larvae**

Cirriped larvae **Zoea larvae**

Insect larvae and Free-living Nematoda

- Grazing pressure of zooplankton on phytoplankton communities in Lake Qarun

Two grazing experiments were conducted in the lake during July and August 1994

In the first experiment (from July 21to August 2), the phytoplankton organisms in un-grazed aspirators (containing filtered lake water with 45 µm mesh diameter screen) had significantly increased with time, reaching a maximum of 110,600 X 10^3 cells L^{-1} on the 8th day They began to decrease, reaching a minimum of 51,500 X 10^3 cells L^{-1} at the end of the experiment (12 days) The zooplankton population had also increased with time, reaching a maximum of 2,062 org L^{-1} at the end of the incubation period Phytoplankton communities were mainly represented by *Nitzschia sigma* (61-79% of the total phytoplankton crop), while *N frustulum* var *perpusilla*, *N closterium* and *Cyclotella spp* were less abundant *Brachionus pelicatilis* was the most dominant species among the zooplankton organisms Its percentage abundance ranged from 84-100% of the total zooplankton crop

In the grazed aspirators (containing unfiltered lake water), a significant decrease in the population density of *Nitzschia sigma* and *N frustulum* var *perpusilla* was observed This decrease was enhanced with time till the end of the experiment On the other hand, growth of *N closterium* and *Cyclotella spp* showed a gradual increase, reaching a maximum on the 8th day, then began to decrease

The results of this experiment indicated that the grazing pressure of *Brachionus pelicatilis* was mainly centered on *N sigma* and *N frustulum* var *perpusilla*

The second experiment ran for 8 days (from 21-29 August 1994) The initial zooplankton standing crop (3450 org L^{-1}) was much higher than the corresponding value of the first experiment (694 org L^{-1}) The screen removed more than 99% of the total zooplankton *Brachionus pelicatilis* was also the leading species among the zooplankton organisms In contrast, the phytoplankton standing crop was low (76 X 10^3 cells L^{-1}) compared with the value of the first experiment The dominant species was *Nitzschia sigma*, while *N frustulum* var *perpusilla*, *N closterium* and *Peridinium sp* were less represented

In the un-grazed aspirators, a marked increase in phytoplankton standing crop was observed, this increase was enhanced with time reaching the maximum of 122,950 X 10^3 cells L^{-1} on the 8th day Zooplankton standing crop showed a gradual increase with time, reaching the highest value of 358 org L^{-1} at the end of experiment

In the grazed aspirators, phytoplankton had significantly decreased on the 2nd day followed by a slight increase from the 4th day until the end of the incubation period On the other hand, zooplankton had significantly increased on the 2nd day, followed by sharp decrease from the 4th day until the end of the experiment

Here again, the grazing pressure of zooplankton was mainly on *N sigma* and *N frustulum*, while the population densities of the phytoplankton species showed a gradual increase with time The data are presented in Fig 38

- Feeding Behavior of Mullet Fry

The results of the feeding behavior experiments are presented in Fig (39) The main zooplankton species during the experiments were *Brachionus pelicatilis, Syncheata pectinata,* nauplis larvae, polychaete and calanoid copepodites In plastic bottles, the total zooplankton densities at the beginning of the experiment in different bottles were 1,380 organisms L^{1} in the bottle without fish, 1,520 organisms L^{1} in the bottle with 4 fry, and 1,440 organisms L^{1} in the bottle with 9 fry *Brachionus pelicatilis* was the dominant species in the three bottles, comprising 71 7, 67 1 and 64 6% of the total zooplankton Nauplis larvae occupied the second dominant place, their percentage abundance in the three bottles were 23 9, 27 and 25% of the total zooplankton After 24 hr *in situ* incubation, a slight decrease (1 2%) in zooplankton density was observed in control bottle (i.e without fish)

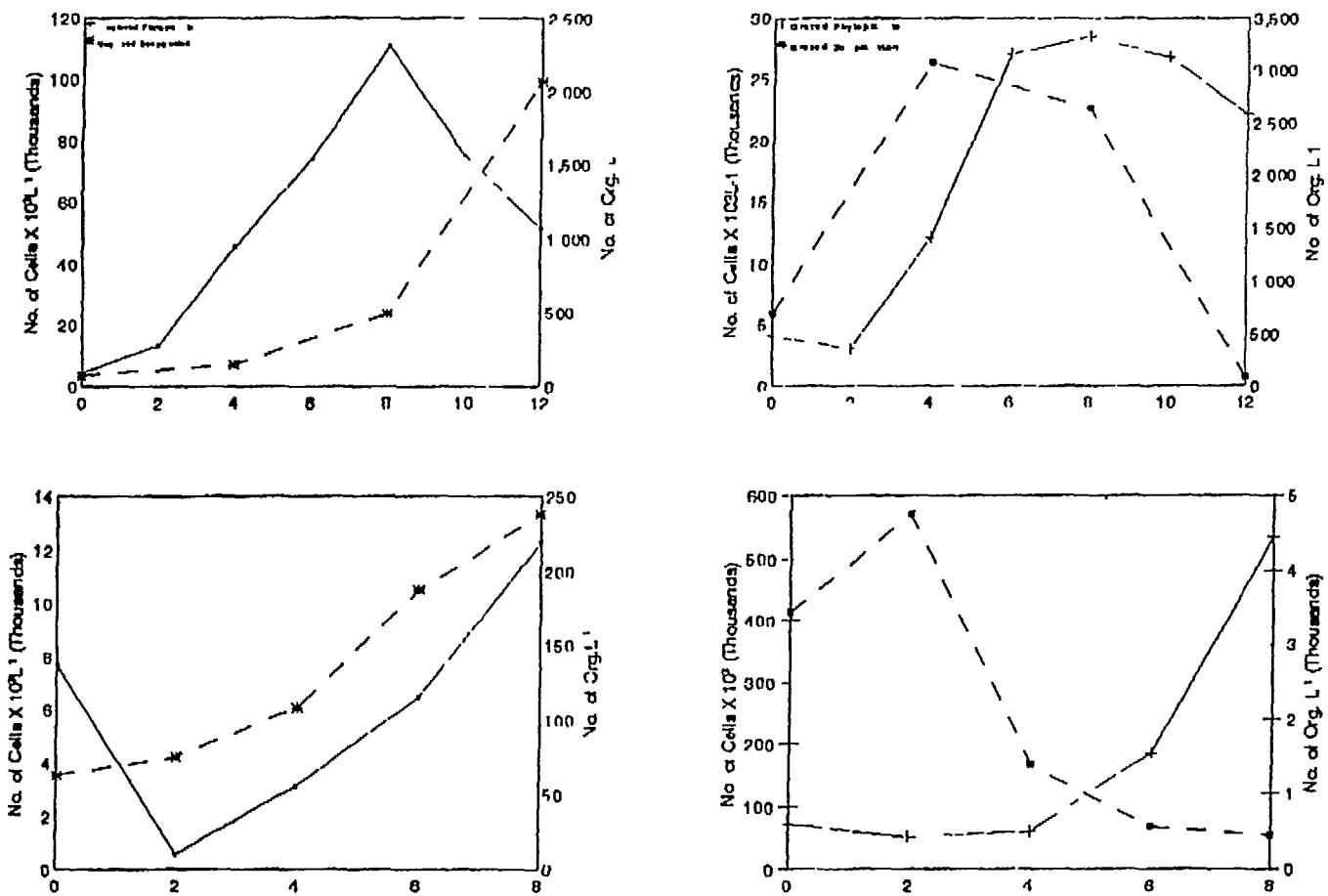
In the bottles with 4 & 9 fry, sharp decreases were recorded, constituting 77 3 and 93% of the initial zooplankton standing crops, respectively

In glass aquaria experiment, the initial zooplankton densities were 1,276 organisms L^{1} (control), 1,226 organisms L^{1} in aquarium with 4 fry, and 1,513 organisms L^{1} in aquarium with 9 fry After 24 hr a marked decrease in zooplankton densities was recorded in the aquarium with fry compared to the control (i e without fry) The percentage density decrease were 10 7%, for the control, 63 2% in the aquarium with 4 fry, and 94 8% in the aquarium with 9 fry

The results demonstrated the feeding rates of 9 mullet fry after half hour, one hour and 24 hrs in the glass aquarium. The data revealed a clear decrease in the zooplankton densities in the presence of mullet fry The percentage decrease of the zooplankton standing crops were 44 4, 60 6 and 86 6% of the corresponding controls after 1/2, 1 and 24 hr , respectively

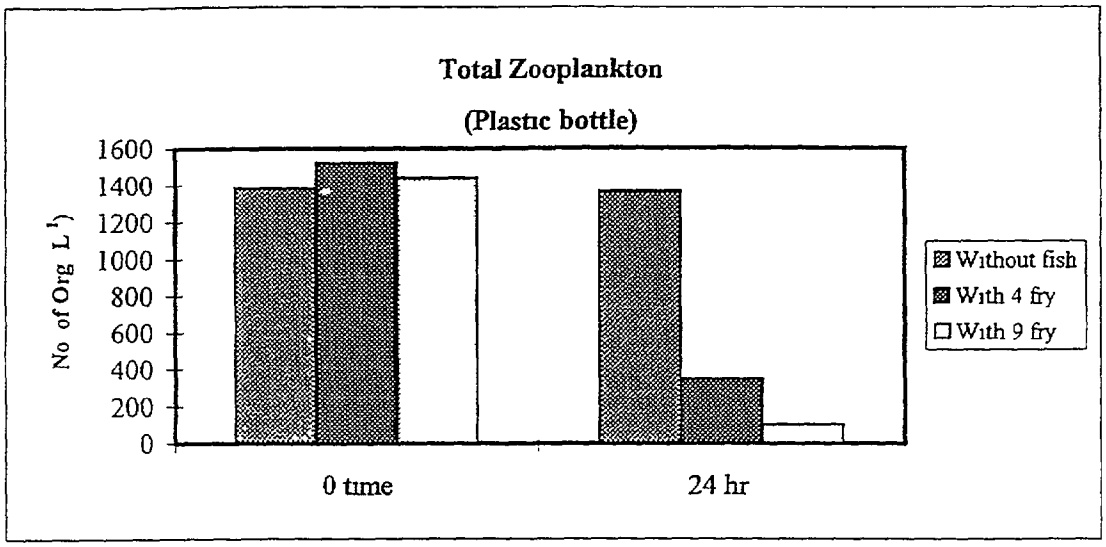
The gut analyses of the fry collected from the lake indicated the presence of eggs with developing embryo of *Solea aegyptiaca* (Plate 5)

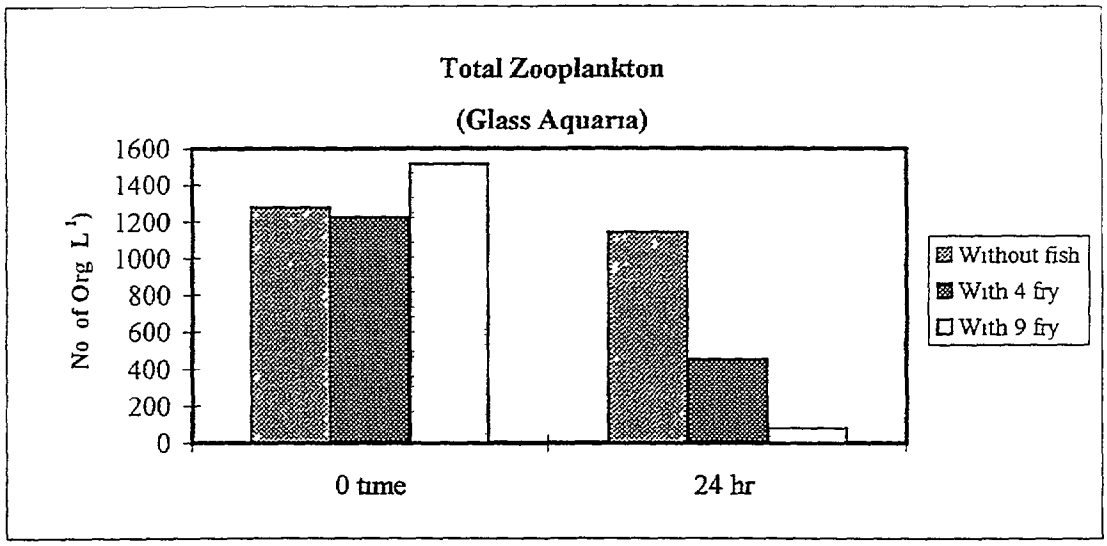
Fig (38): Grazing pressure of zooplankton on phytoplankton

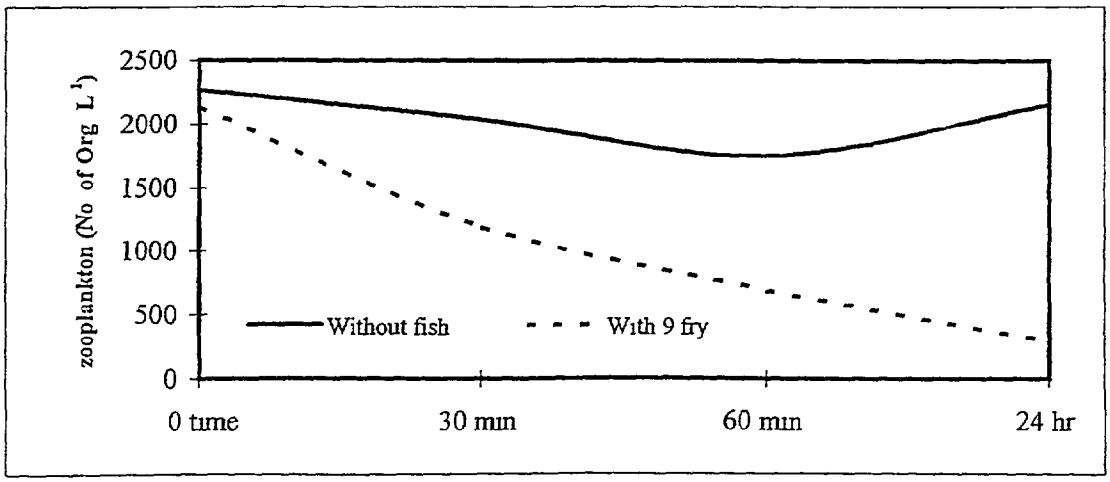


293

Fig (39) Feeding behavior of mullet fry in Lake Qarun



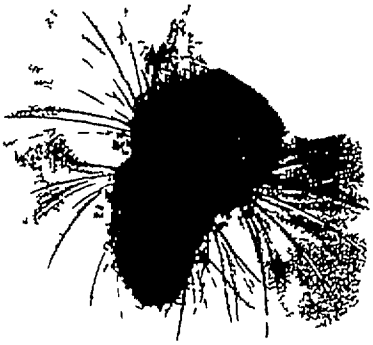




Tintinnids

Brachionous pelicatis

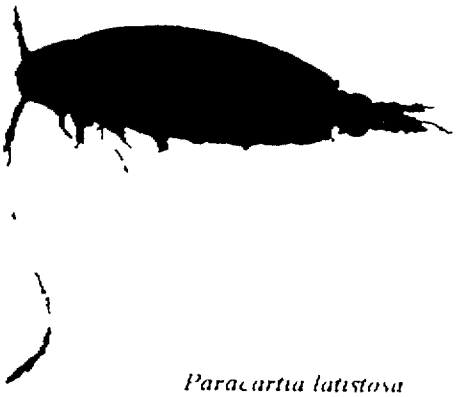
Cirripedae larvae



Polychaeta aspenoid

Nauplis larvae

Copepodid instar

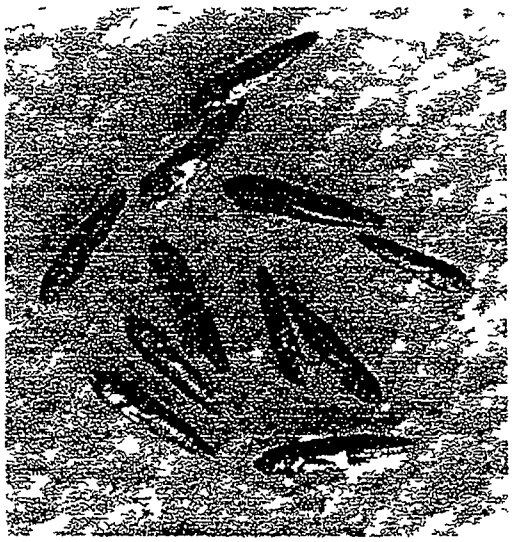


Paracartia latistosa

Cirriped larvae

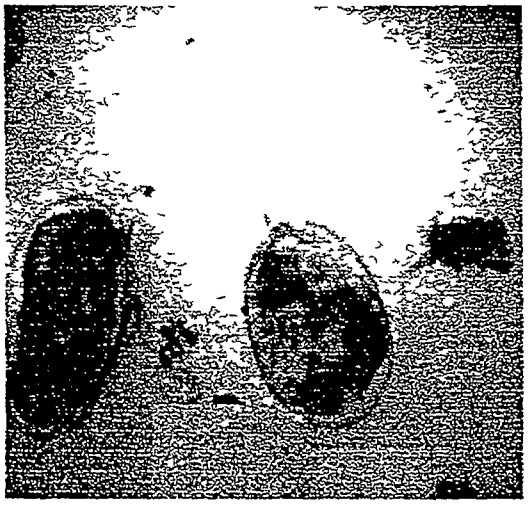
Cypridae torosa

PLATE 5



Mullet fry

Zooplankton



Egg of Solea aegyptiaca

Gut Content of mullet fry in Qarun Lake

BOTTOM FAUNA

- Annual and monthly variations of total benthos

During the study period (1993 - 1996), the annual average standing crop of total bottom fauna in Lake Qarun varied from year to year As shown in Fig 40, the lowest population of 2,282 organisms m^3 was recorded in the first year (1993), followed by a sharp increase in 1994 when the population reached 17,104 07 organisms m^3 This is mainly attributed to increasing number of ostracod species (*Cypridies torosa*) During 1995 and 1996, the total population densities of the benthos were more or less similar being 11,531 and 11,686 organisms m^3

With regard to the biomass of the benthic organisms, the results were presented in g fresh weight m^2 as shown in Fig 41 The values showed a wide variation with a highest value of 117 6133 g m^2 in 1995, and lowest value of 48 2 g m^2 in 1996 Mollusca constituted the major component of the benthic biomass, their percentage abundance varied from a highest value of 65% in 1995 to the lowest value of 43%, in 1993 Arthropoda occupied the second position, their abundance varied from 38%, in 1994 to 30%, in 1995 Next in abundance was the annelida, their density fluctuated between 17% in 1996 and 4% in 1995 Coelentrata comprised the least biomass, their abundance varied between 6% in 1993 to 1% in 1995

The total number and biomass of the benthos displayed monthly variations (Fig 42) During 1993, a peak of 6,083 organism m^2 was recorded in January, whereas, the highest biomass value of 129 25 g m^2 was observed in May On the other hand, the lowest population density and biomass were recorded in June and September, respectively

During 1994, the highest population density and biomass were recorded in the winter months, while the lowest values occurred in the summer months

During 1995, the picture was changed and the highest population density and biomass of 14,413 organisms m^2 and 178 78 g m^2 were recorded in August and May

In 1996, two peaks of 16,448 and 16,120 organisms m^2 were recorded in April and May while the highest biomass value was observed in March On the other hand, the lowest biomass of 5 23 g m^2 was found in April

- Community Composition

The benthic organisms in Lake Qarun are represented by four main phyla, namely arthropoda, annelida, mollusca and coelentrata (Fig 43) Arthropoda were always the most abundant phylum, constituting 87 03% of the total benthos population during the investigation period The phylum was also abundant in all years, it contributed 71 09%, 94 95%, 91 44% and 89 95% of the total benthic organisms during 1993, 1994, 1995 & 1996, respectively On the other hand, mollusca and coelentrata were less abundant constituting 1 59% and 2 17% of the total population density, respectively

With regard to the biomass, mollusca were the dominant group They constituted 51 91% of the total biomass, followed by the annelids which contributed 34 59% to the total biomass during the investigation period On the other hand, coelenterate was less comprised 3 3% of

Fig (40) Monthly variations of standing crop of bottom fauna

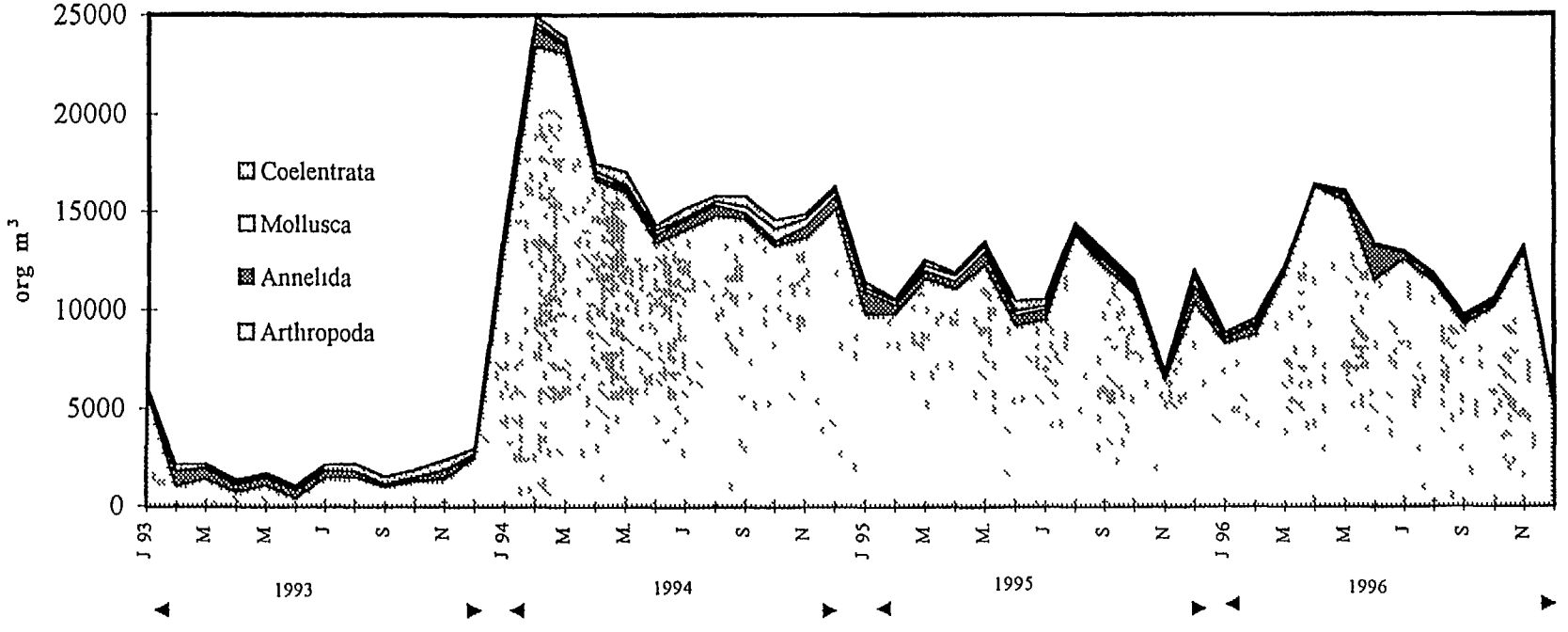
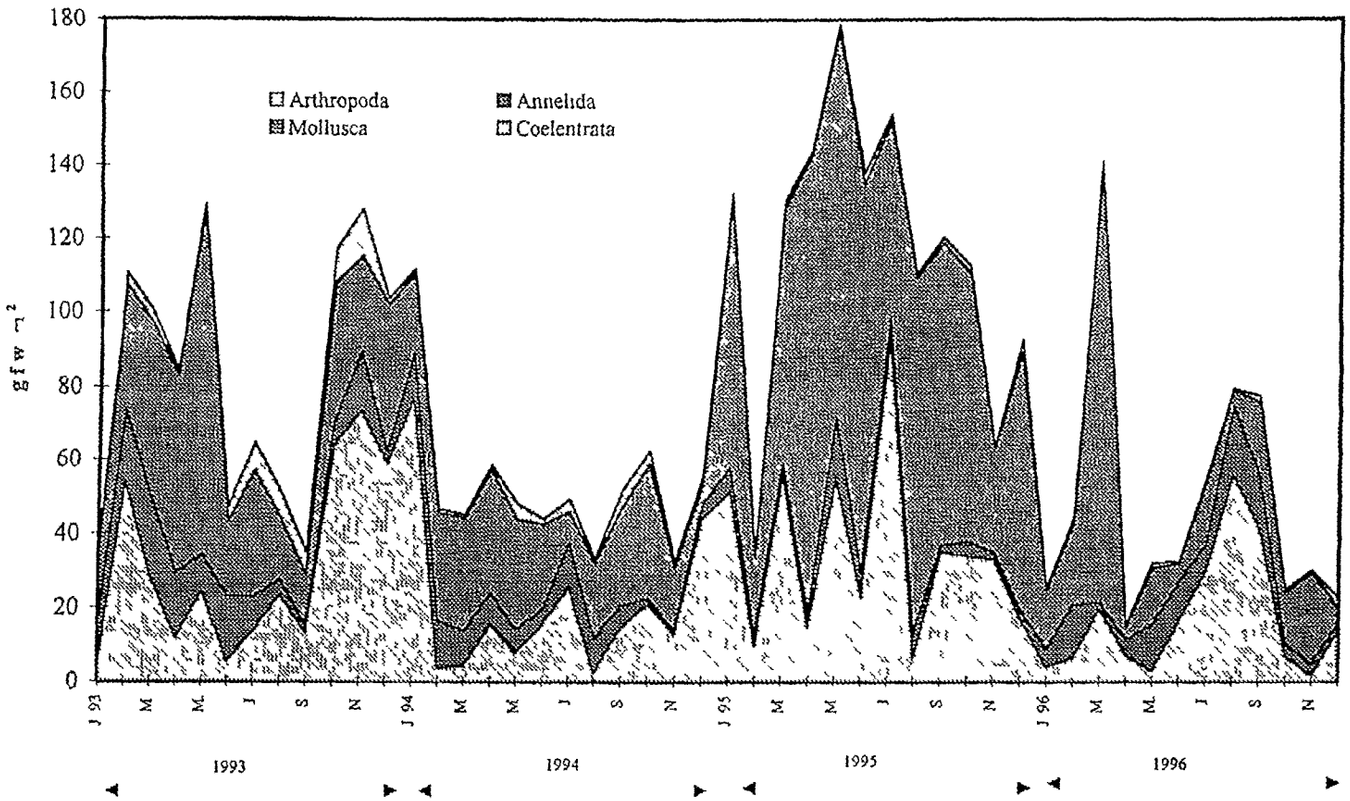


Fig (41) Monthly variations of biomass of bottom fauna



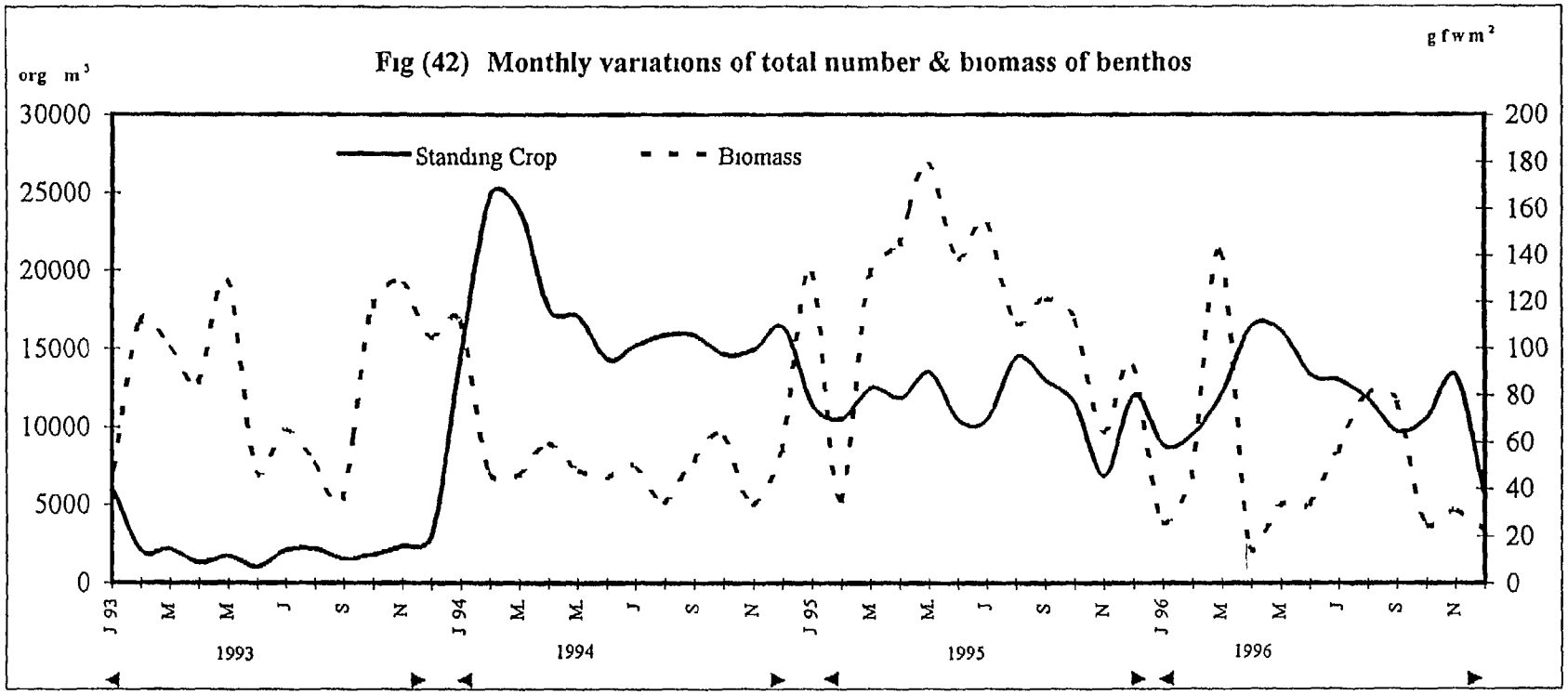


Fig (42) Monthly variations of total number & biomass of benthos
org m⁻³
g f w m⁻²
Standing Crop
Biomass
30000
25000
20000
15000
10000
5000
0
200
180
160
140
120
100
80
60
40
20
0
J 93
M
M
J
S
N
J 94
M
M
J
S
N
J 95
M
M
J
S
N
J 96
M
M
J
S
N
1993
1994
1995
1996

the total biomass of the benthic organisms On the other hand, benthos in El-Bats and El-Wadi Drains were represented by only three phyla, namely arthropoda, annelida and mollusca It shall be noted that the list of species recorded in Lake Qarun (Fig 42-43) was greatly different from that recorded in the drains This is because the freshwater fauna observed in the drains were not able to tolerate the high salinity of the lake, except the euryhaline amphipods *Gammarus aeqicauda* and *Corophium ascherusicum* and the polychaete *Neris diversicolor* which survive in freshwater as well as in waters of variable salinity

The monthly and annual variations of benthic phyla are summarized as follows

- **Arthropoda**

Arthropoda were the most numerically abundant of the benthic phyla The phylum was represented by 8 species belonging to three classes, namely crustaceae, ostracoda and insecta

The annual average population density of arthropoda ranged between 1,621 and 16,224 organisms m^2 This great year-to-year variation was due to the increase in the number of ostracod *Cypridies torosa* in 1994 As to the biomass, their values ranged from 17 113 to 35 597 g m^2 Most of the biomass values of the arthropoda were attributed to the presence of barnacle *Balanus pallidus*

The monthly variation of arthropods showed that their population density increased during winter and early spring, except in 1995 This flourishing in population density was associated with decreasing in their biomass values

- **Annelida**

The Phylum annelida was numerically the second most important component of the total fauna in Lake Qarun The phylum was represented by two species belonging to the class polychaeta

The annual average standing crop of annelids varied slightly from year to year The lowest population density of 342 org m^2 was recorded during 1993 This value increased gradually in 1994 and 1995 when its densities reached to 471 & 492 organisms m^2 In 1996, its density decreased and reached a low of 360 organisms m^2 The reverse was true for the biomass where the highest weight of 11 535 g m^2 was recorded in 1993 This value decreased in 1994 & 1995 but increased in 1996 when its value reached 8 111 g m^2

The monthly variation of annelid showed their highest population density and biomass in winter and spring On the other hand, the lowest values were observed in late summer and autumn This may be attributed to the fact that the life cycle of these organisms occurred in summer (with increasing temperature), when the early stages of worms were recorded during that time

- **Mollusca**

Mollusca occupied the first position in benthic biomass in Lake Qarun It was represented by 5 species, 2 bivalves and 3 gastropods In addition, empty shells and shell fragments of different species were also observed

The annual average population density of mollusca showed that its lowest value occurred in 1993 when 51 organisms m^2 were recorded This value has sharply increased in 1995 to about 6 fold the number observed in 1993 (303 org mthe density reached 101 organisms m^2 As to biomass, the annual average values ranged bet ^{2}) In 1996, ween 22 004 g m^2 in 1996 to 75 289 g m^2, in 1995

With regard to monthly variations of mollusca, the population density showed their highest counts in autumn, except in 1993 when the maximum density occurred in spring At the same time, the biomass showed its highest value during spring, except in 1994 when the maximum biomass was reached in autumn

- **Coelentrata**

Coelentrata were less represented in the lake compared to the other benthic phyla This phylum was represented by one species of sea anemone, namely *Aiptasiogeton* c f *comatus*

The annual average population density of this species was 242 organisms m^2 weighing 2 447 g m^2 Its density varied between 356 and 106 organisms m^2

The monthly variations of this species varied from year to year, with two peaks observed, the major one (578 organisms m^2) occurred in September 1994, whereas the minor peak (498 org m^2) was reached in June, 1995

- *Dominant Species*

The monthly variations of the dominant benthic species are shown in Fig 43

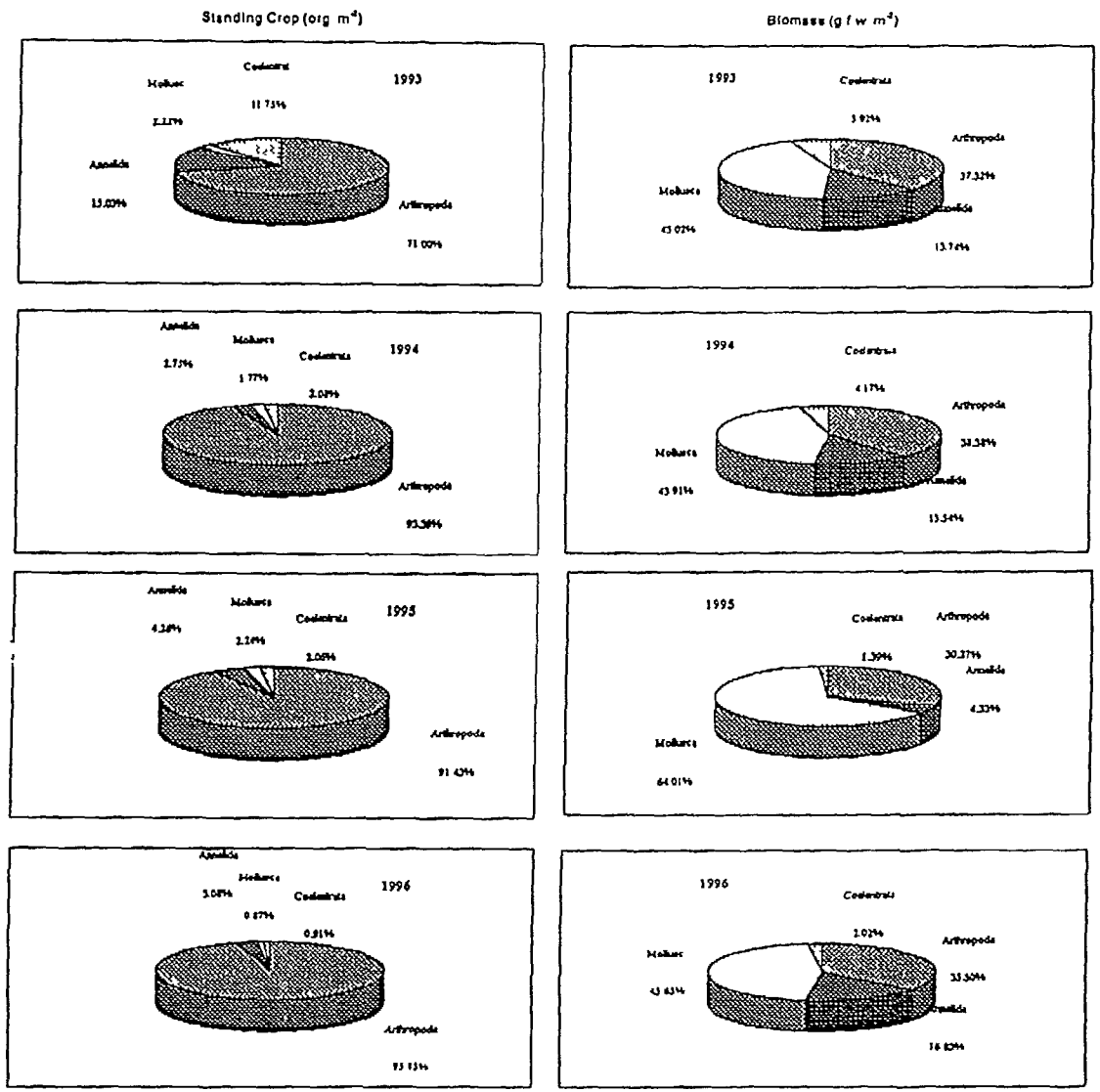
- *Corophium ascherusicum*

This species is one of the most important and dominant species found in Lake Qarun The results of the present investigation showed a wide variation in the timing of outburst of standing crop and biomass of this species The major peak of its standing crop (2209 organisms m^2) was recorded in December 1993, while its highest biomass (1 826 g m^2) occurred in March, 1993 In 1994 the highest density of 1,476 organisms m^2 was observed in July, while the maximum biomass of 1 32 g m^2 was found in June Contrariwise, the highest population densities of this species were associated with maximum biomass in 1995 and 1996

- *Nereis diverscolor*

The polychaete *Nereis diverscolor* represents one of the most important organisms inhabiting Lake Qarun Its highest population densities and biomass were always recorded in February

Fig (43) Percentage of class composition



303

Their values were 571 org m^2 & 26 094 g m^2, in 1993, 324 org m^2 & 11 66 g m^2 in 1994, 413 org m^2 & 16 39 g m^2, in 1995 and 248 org m^2 & 18 928 g m^2, in 1996

- ***Ceratoderma glaucum***

The bivalve *Ceratoderma glaucum* is a common edible species abundant in all Egyptian coastal shore The data collected showed that the population density and biomass of this species reached their maximum during late winter and spring

The most important benthic organisms in Qarun Lake are shown in Plate (6)

List of benthic species recorded in Lake Qarun and the drains during the investigation period

Phylum	Class	Species	Location	
			Lake	Drain
Arthropoda	Crustacea	*Balanus pallidus*	+	-
		Sphaeroma pulchellum	+	-
		Gammarus aeqicouda	+	+
		Corophium ascherusicum	+	+
		Brachynotus sexdentatus	+	-
	Insecta	Chironomus larvae	+	+
	Ostracoda	*Cypridies torosa*	+	+
Annelida	Polychaeta	*Neris diversicolor*	+	+
		Polydora ligni	+	-
	Oligochaeta	*Tubificida sp*	-	+
Mollusca	Bivalvia	*Ceratoderma glaucum*	+	-
		Venerupis aurea	+	-
		Corbicula consbrina	-	+
	Gastropoda	*Theodoxus niloticus*	-	+
		Cleopatra bulimoides	-	+
		Physa acuta	-	+

FISH PATHOLOGY

- Bacteriology

Total Bacterial Counts (TBCs)

The results of TBCs at 22°C and 37°C in Lake Qarun as well as in the two main drains are presented in Fig 44 Their monthly variations can be briefly explained as follows

The TBCs in the lake showed a wide variation, their maximum numbers were recorded in August when their numbers reached to 44 66 & 56 8 X 10^{11} ml^{1} at 22 & 37°C, respectively

In the drains the maximum bacterial counts 94 15 & 56 5 X 10^{11} ml^{1} were recorded at 22°C & 37°C, respectively

The least TBCs in the lake were observed in late spring (May), their values at the two above-mention temperatures were 0 74 & 0 7 10^{11} ml^{1} The lowest TBCs in the drains showed a great variation, the minimum TBC (at 22°C) of 5 4 X 10^{11} ml^{1} occurred in October, the corresponding count at 37°C reached 12 2 X 10^{11} ml^{1} in July

The seasonal averages of most probable numbers (MPN) of total and fecal coliformis are shown in Fig 45 It is clear from this figure that both total and fecal coliformis had significantly increased in number during summer when their maximum counts of 255 6 & 176 / 100 ml were recorded

Their least numbers of 56 2 & 24 9 / 100 ml were observed in autumn In general, fecal coliformis were usually found near the discharging point of El-Bats Drain at the easternmost region of the lake

The total and fecal coliformis in the drains were much higher than their corresponding numbers in the lake Their numbers recorded in summer were comparatively higher than the corresponding counts in the other seasons The highest count of total coliformis of 1,450,000 / 100 ml was observed in August, while the maximum number of fecal coliformis of 575,000 / 100 ml occurred in June

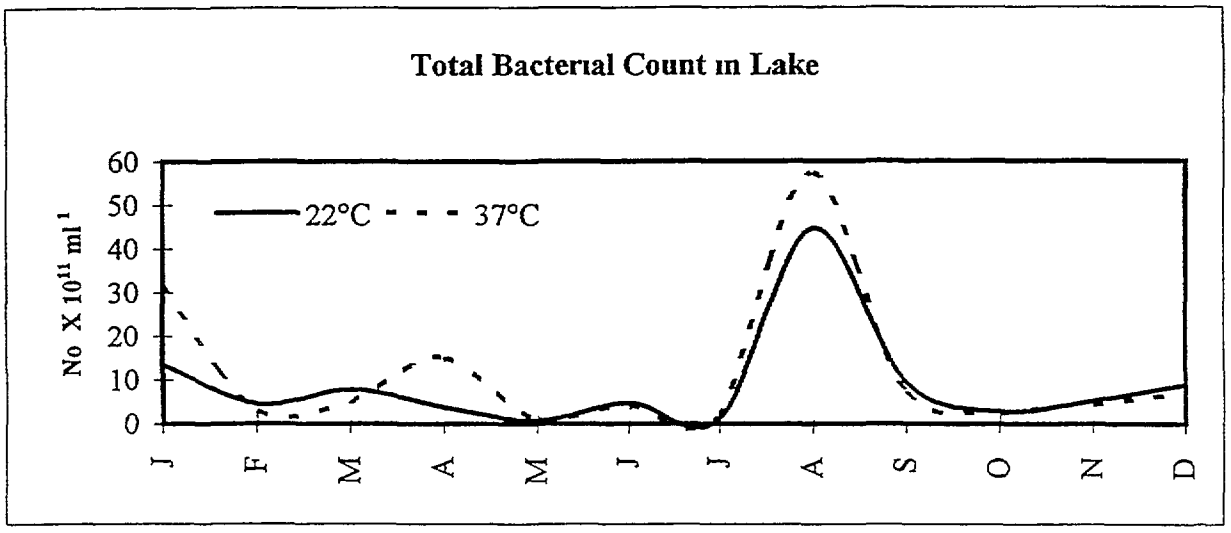
- Bacterial diseases

The external examination of infected fishes revealed petechial haemorrhages of the skin Congested base of fins and opercula, nerosis of fins, lip erosion, darkness of skin especially in the ventral view, ulceration of the skin exophthalmia, eye cataract and abdominal distention (Ascitis) were also observed

Post mortum examination showed general congestion of visceral organs and muscles, bloody fluid, enlargement of liver, kidney, spleen, gonad and distended gall bladder These lesion are shown in the attached photographs

The bacterial examination revealed that the isolated bacterial pathogens were mostly Gram-negative and little Gram-positive infections Streptococcus B-haemolytic which was highly

Fig (44) Total Bacterial Counts (TBCs) in Lake Qarun



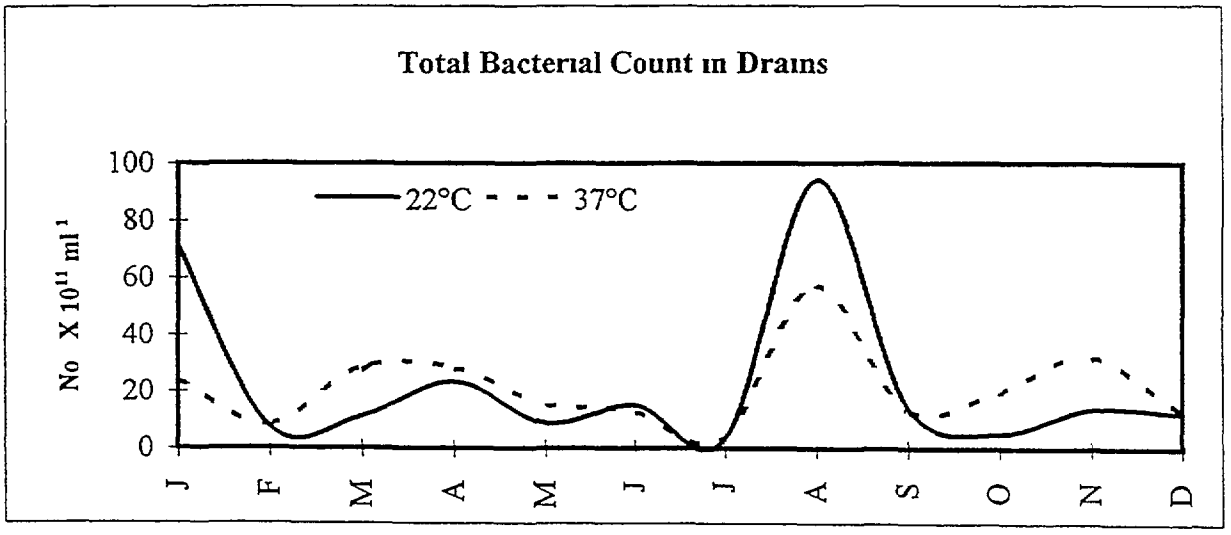
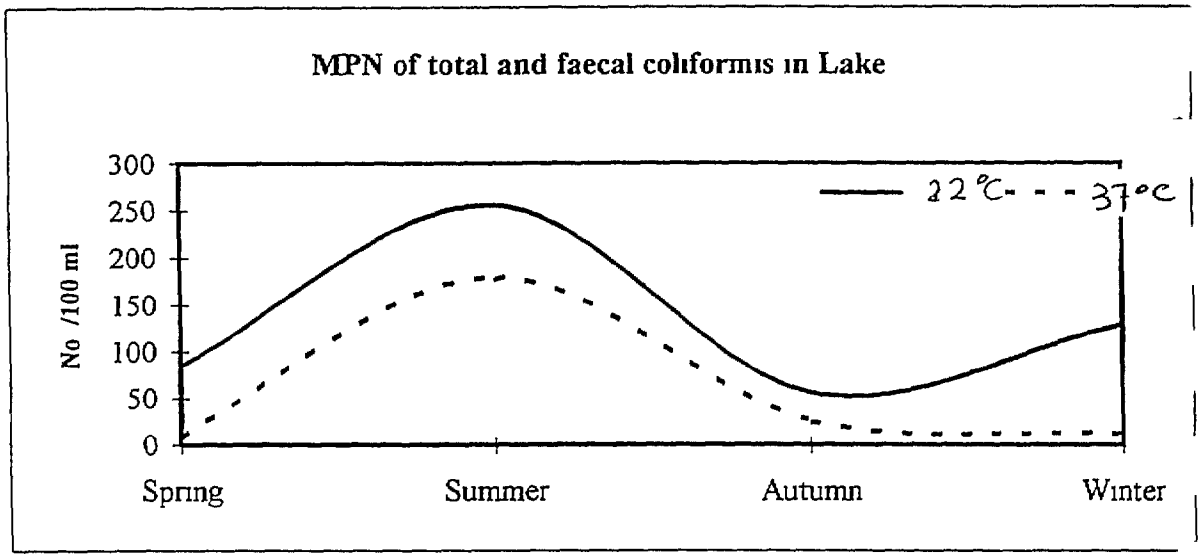
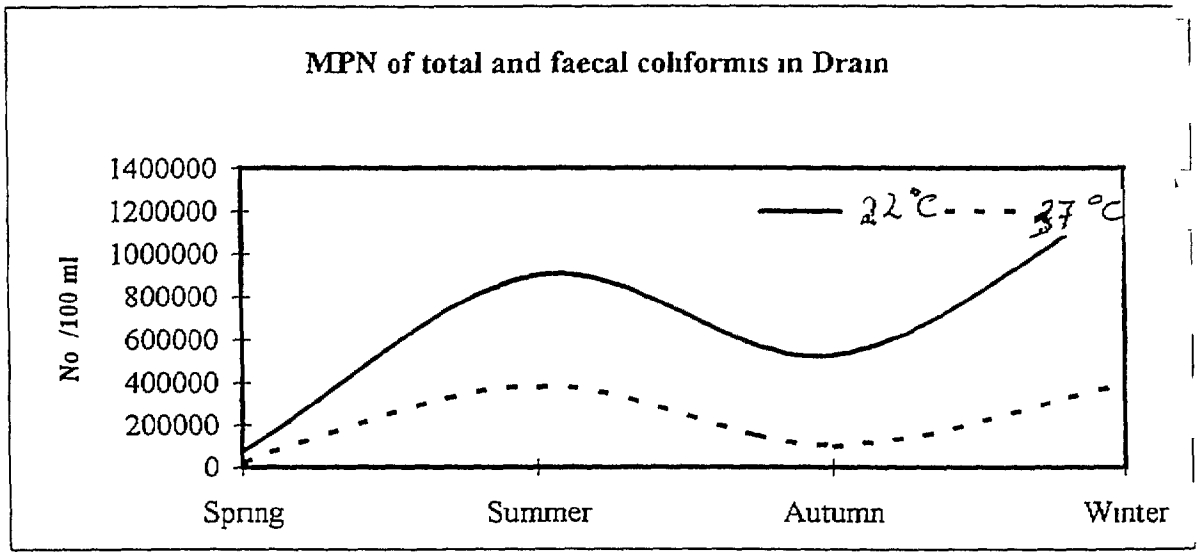


Fig (45) The Most Probable numbers (MPN) of total & faecal coliformis





prevalent among infected fishes *Salmonella typhimurium, Aeromonas sp , Ps aerugenosa, E coli, Yersenia entcrocolitica* were highly infectious among fishes (Tables 3 & 4)

In May 1996, vibriosis caused high mortality rates of Solea sp (50%) while the incidence *Yersinia* and *streptococcus* in the naturally infected fishes were 30% in Mullets and *Tilapia zilli*

Parasitology

- Protozoa

During the present study 7 trichodind species belonging to two genera were observed in Lake Qarun fishes The systematic position of these parasites is given below

- ***Trichodina lepsii* Lom, 1962 (Plate 7, Photo 1).**

Hosts & site of Infection *Mugil cephalus, Liza ramada, L saliens* and *Solea aegyptiaca* (gills)

The trichodinid has a relatively small body It is always found in large numbers in the infected gills The trichodinid also shows some variability in shape in the different hosts *Mugil cephalus* was the most preferable host in terms of the intensity of infection

- ***Trichodina puytoraci* Lom, 1962. (Plate 7, Photo 2)**

Hosts & site of infection *Liza saliens, Mugil cephalus* and *Solea aegyptiaca* (gills)

A relatively large trichodinid found in mixed infection with *T lepsii* and *T cf jadrnica Liza saliens* was the most susceptible fish to this parasite, while *Solea aegyptiaca* recorded the lowest infections The tricodinid shows very characteristics central circle composed grain-like granules

- ***Trichodina cf jadranica* (Plate,7 Photos 3 & 4)**

Hosts & site of infection *Liza saliens, Solea aegyptiaca* (gill)

A medium-sized trichodinid found in low numbers on the gills of the infected host always mixed with other trichodinids Two slightly different populations were observed on the hosts

- ***Trichodina batala* n sp. (Plate, 7, Photo 5)**

Hosts & site of infection *Mugil cephalus* (gill)

This trichodinid was found in moderate numbers in gills of *Mugil cephalus*

- ***Trichodina sp* (Plate, 7, Photo 6)**

Hosts & site of infection *Gobius sp* (gill)

3 OK

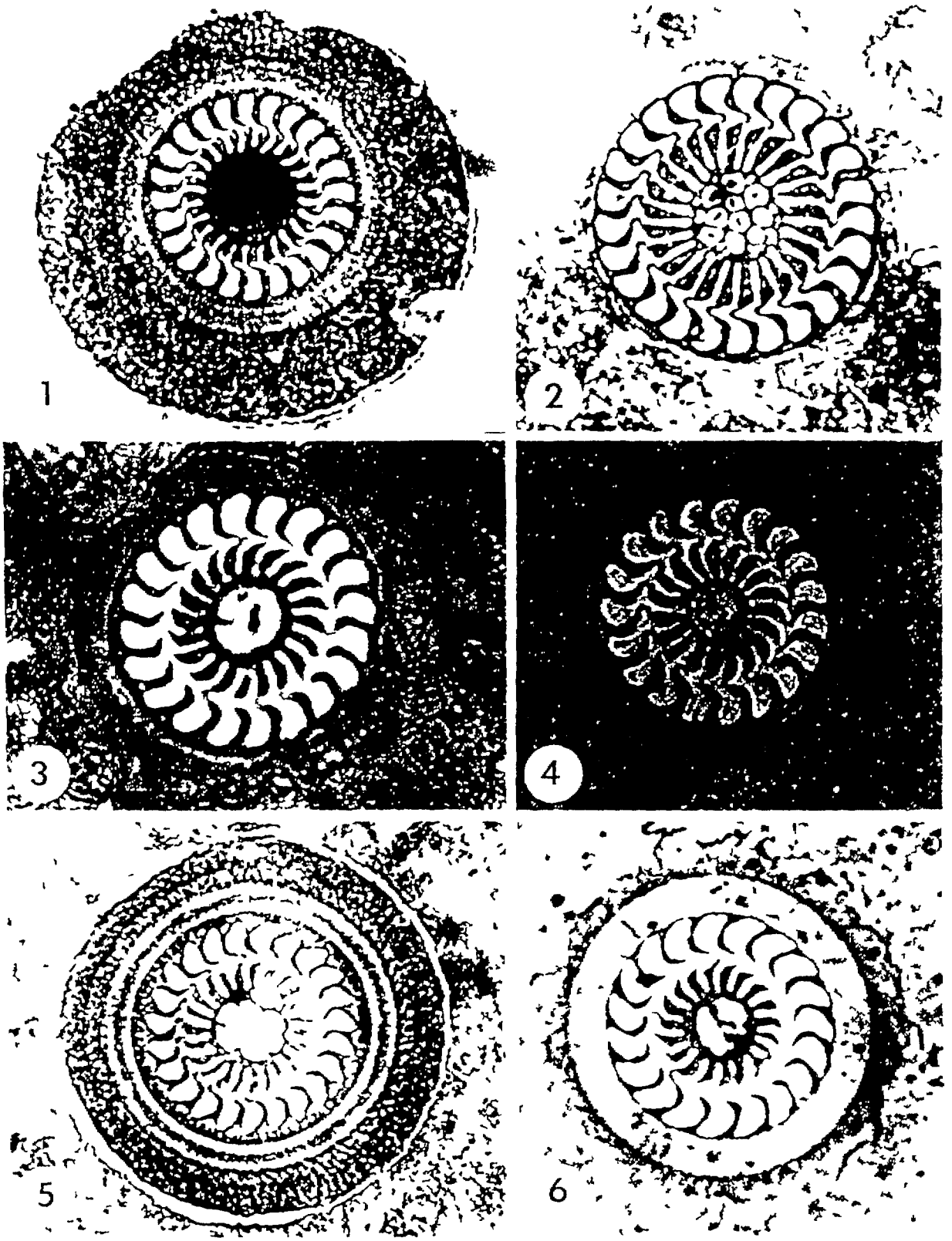
Table(3) Bacterial sp isolated in Spring

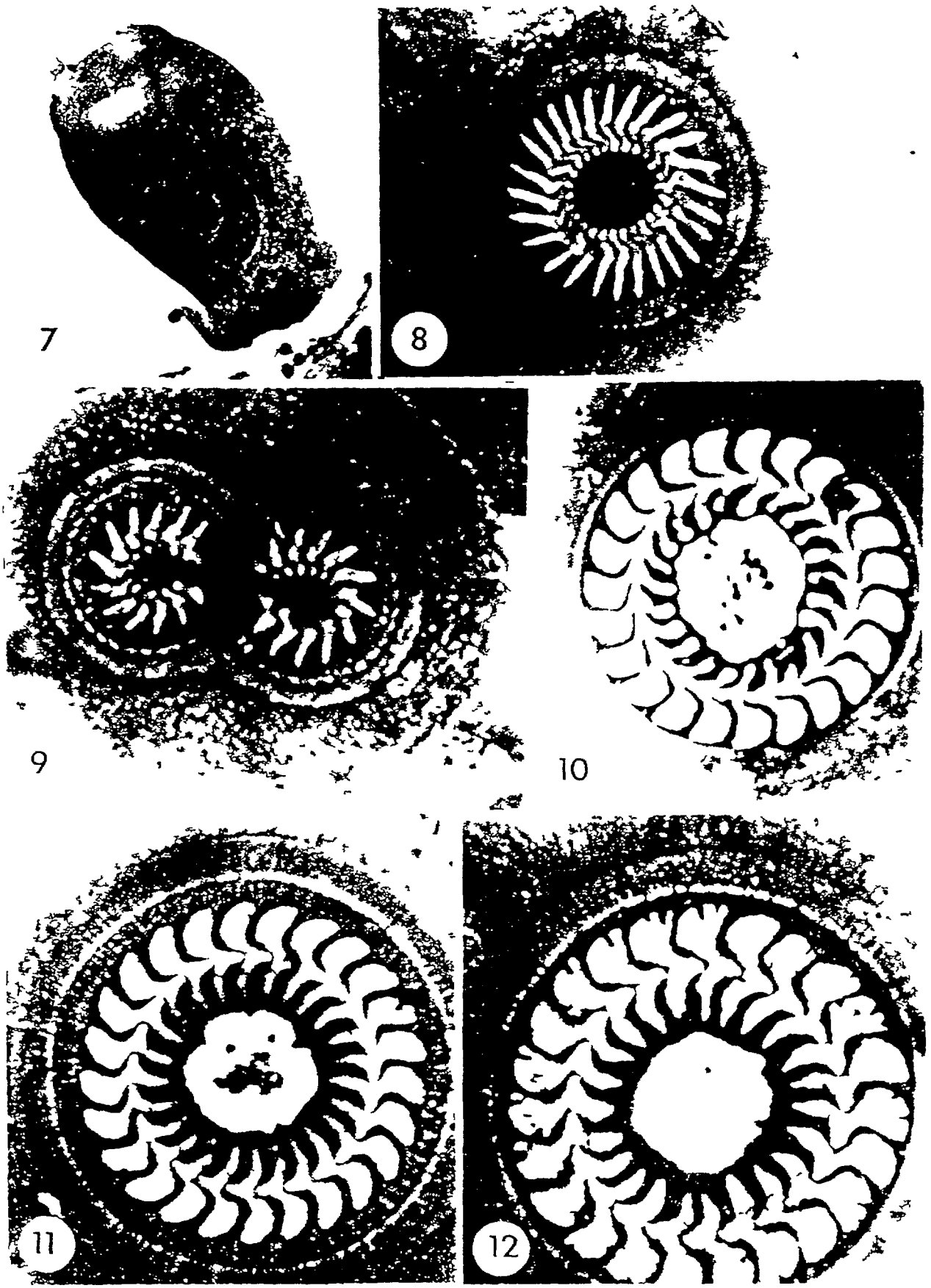
Bacterial sp	Fish species					
	Tilapia sp		Mullets		Solea sp	
	of diseased Fish %	(Total colony (Count/g	of diseased of Tlalpia Fish %	(Total colony (Count/g	of diseased Fish %	(Total colony (Count/g
Aeromonas hydrophila	23 50	100610	21 50	22000	15 84	150100
Ps aeurogenosa	11 10	400	5 00	3000	8 34	15000
Ps flourecnces					16 67	400
Yersenia ruchini						
Yersenia enterocolitica	2 78	500	15 00	4000000		
Streptococcus B haeno	34 45	1000030000	17 50	1000000	25 00	1500000
Staph- non haemolytic			5 00	100000		
Staph- haemolytic	4 00	1500000	10 00	2015000	6 00	1000000
Salmonella typhimunum	36 12	450000000	37 50	3000000000	8 34	4000000
Shigella simonis	16 67	10000	15 00	3000000		
E coli	19 45	200000	15 00	15000000		
Vibno angullarum	15 00	100000			25 00	1500000
Micococci	11 12	250000	5 00	15000		
Corynebactenum sp	4 00	1000000				

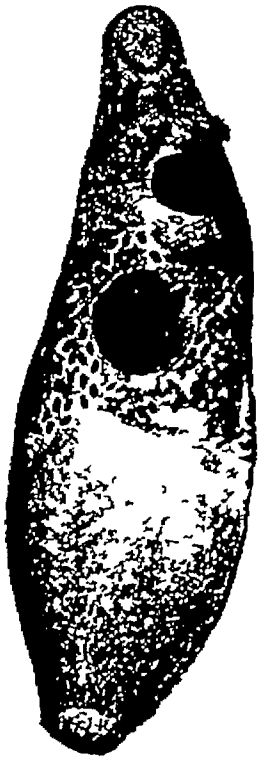
Table (4) Bacterial sp isolated in Summer

Bacterial sp	Fish species					
	Tilapia sp		Mullets		Solea sp	
	of diseased Fish %	(Total colony (Count/g	of diseased of Tialpia Fish %	(Total colony (Count/g	of diseased Fish %	(Total colony (Count/g
Aeromonas hydrophila	17 73	7000 00	25 79	23000 00	8 33	100 00
Ps aeurogenosa	19 32	3333 33	22 82	16900 00	5 56	1000 00
Ps flourecnces	2 93	6666 67	0 00	0 00	17 00	2316 67
Yersenia ruchirii	7 41	1666 67	0 00	0 00	0 00	0 00
Yersenia enterocolitica	20 78	4000 00	9 00	3500 00	0 00	0 00
Streptococcus B haeno	19 47	166933 33	38 29	396666 67	0 00	0 00
Staph- non haemolytic	1 96	26666 67	8 80	33333 33	0 00	0 00
Staph- haemolytic	28 43	200000 00	4 17	13333 33	0 00	0 00
Salmonella typhimurium	43 17	2886666666 67	63 72	1100000000 00	30 56	20233333 33
Shigella simonis	22 38	1333 33	21 53	1676666 67	0 00	0 00
E coli	34 73	150000 00	31 45	1370000 00	5 56	66666 67
Vibrio angullarum	0 00	0 00	7 41	666 67	0 00	0 00
Micococci	23 19	246666 67	10 32	66800 00	0 00	0 00
Corynebacterium sp	0 00	0 00	0 00	0 00	0 00	0 00

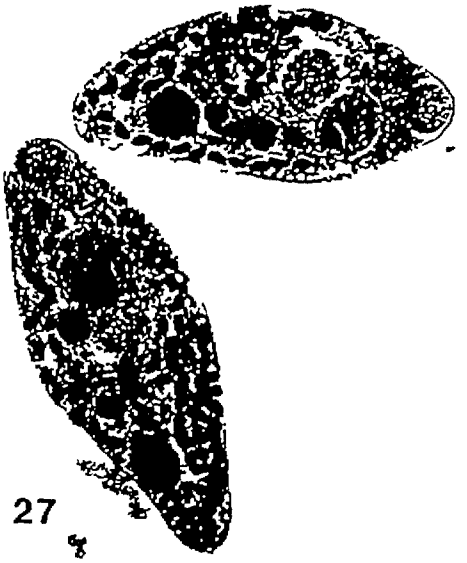
Plate 7




7
8
9
10
11
12



25



27

28

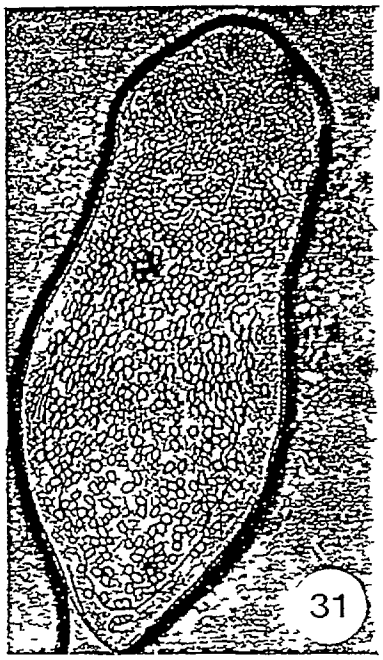
26

29

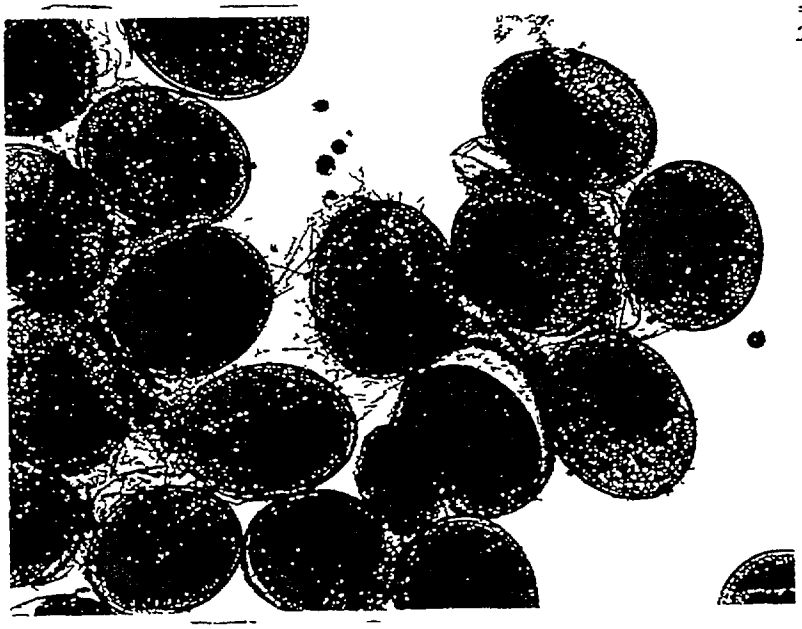
313

PLATE 10

30



31



32

Moderate infections of this small trichodinid were found on the gills of *Gobius* species, and one specimen was found on *Mugil cephalus*

- ***Trichodina* species of *Oreochromis aureus***

On the gills of some emaciated *Oreochromis aureus* some different trichodinids were observed in a mixed infestation with *Paratrichodina oblique*

- ***Ambiphria sp* (Plate, 8, Photo 7)**

At least one species of *Ambiphrya* is found in most of *Solea aegyptiaca* and to a lesser extent in tilapia fishes

- Myxosporidia

During the study period, two myxosporeans belonging to two genera were identified as follows

- ***Myxobolous exiguus* Thélophan, 1895**

Prevalence (%)	22 9%
Host	*Liza ramada*
Size of infection	*Intestine*

- ***Paratrichodina obliqua* Lom, 1963 (Plate, 8, Photo 8)**

Hosts & site of infection Mullet fry, *Oreochromis aureus* (gills)

During winter (January, 1995) an epizootic, among tilapia fishes was reported in Lake Qarun

On examination of the diseased fishes it was observed that the outbreak was confined to *Oreochromis aureus* The fishes suffered from debilitation and severe emaciation associated with minute scattered hemorrhages on the body surface Some ulcers on the trunk and bleeding from the tail peduncle were also noticed Microscopical examination revealed the presence of massive invasion of different trichodinid and sessile ciliates on the skin and gills Large numbers of the present trichodinid were found on gills and contributed to the main infestation This trichodinid, characterized by its small size, did not interfere with the impregnation as is usually the case with such small trichodinids

Stocks of the mullet fry were examined before releasing them into the lake These fry were collected from the coast of the Mediterranean Sea near the discharging point of Damietta Branch at El-Gerbee The fry harbored the same trichodinid but in " normal " numbers

***Ambiphria* sp (Plate 8, Photo 7)**

At least one species of Ambiphria is found in most of *S aegyptiaca* and to a lesser extent in tilapia fishes This sessile peritrich has a barrel or vase-shaped body of 48 9 μm (41 1-61 5)

315

long and 37 9 μm (31 5-46 0) width The characteristic macro-nucleus is ribbon-shaped and occupies most of the power body space

b. Myxosporidia·

During the course of this study, two myxosporeans belonging to two genera were identified, these are

(a) *Myxobolus exiguus* Thelohan, 1895

Prevalence 22 9% (22/96%),

Host *Liza ramada*

Site of infection Intestine

The plasmodia of this parasite were observed as pearly white cysts attached to the wall of intestine through the mesenteries and adipose tissue These cysts were rarely observed on the gizzard and -in two cases only - inside the wall of the intestine The cysts had various shapes and contained huge number of spores (polysporic) They were usually large and spherical but some times narrow and long Their sizes ranged from 0 58 - 9 9 mm in length Some fishes were infected with about 50 small cysts in a massive form. The infection was also observed in the mullet fry collected from a nursery in Lake Qarun (the fry was 5 cm long), infection started in autumn (October), peaked during winter, and vanished by spring

(b) *Zschokkella mugilis* Sitja-Bodadilla & Alvarez-Pellitero,1993

Prevalence 4 2% (4/96)

Host *Liza ramada*

Site of infection Gall bladder

The coelozoic forms of this parasite were observed as small, ellipsoid or round, di-sporic trophozoites measuring 13 6-15 0 μm in diameter The color of bile fluid of the infected gall bladder was blue-green

Histopathology
Some sizeeable amounts of sloughed cells and debris of epithelial cells were found in the bile together with the trophozoites

- ***Helminths***

a Encysted metacercaria

- ***Pygidiopsis genata***

Hosts *Tilapia spp , L ramada,L saliens* (viscera, muscles)

These metacercariae are found mainly infecting tilapia fishes and less frequently mullets The site of infection is usually the intestinal wall, the spleen and kidney and rarely in the muscles

31·

The viable metacercaria move inside the cyst wall It is spherical or subspherical in shape with a diameter of 0 2-0 3 mm. On excystation, the body of the larva is pear-shaped and shows an active peristaltic movement, the segment is covered with spinules up to the posterior part of the body The metacercaria is characterized by the presence of a Y-shaped vaculated matrix at the posterior end of the body This matrix flows upon rupturing the cyst wall to reveal two oval testis

- ***Lecithobotrys putrescens* Looss, 1902 (Plate 9, Photo 25)**

  Hosts & site of infection Liza ramada - Mugil cephalus (intestine)

- ***Saccocoelium tensum* Looss, 1902 (Plate 9, Photo 26)**

  Hosts & site of infection M cephalus, L ramada and L saliens (intestine)

- ***Dicrogaster contractus* Looss, 1902 (Plate 9, Photo 27)**

  Hosts & site of infection L ramada-L saliens (intestine)

- ***Haplosplanchnus pachysomus* (Eysenhardt, 1829) Looss, 1902 (Plate 9, Photo 28)**

  Hosts & site of infection M *cephalus, L ramada* and *L saliens* (Intestine)

- ***Haplosplanchnus sp* (Plate 9, Photo 29)**

  Hosts *L ramada & L saliens* (intestine)

  - Parasites of Stocked Fry in Lake Qarun

    The stocks of mullet fry were examined and the results showed the following

    Fry stocks were collected from El-Gerbee, near Damietta Branch, at the Nile discharge into the Mediterranean Sea (Plate 10, Photo 30) The examined fry were infected with the following parasites

- **Ectoparasitic ciliates 31% in gills &skin**
- **Trematodes 100% in intestine (Plate 10, Photo 31)**

  The mullet fry collected from Bogas Ashtoom El-Gameel near Port Said at the Mediterranean Sea The examination of these fry indicated the following parasites

  - Encysted metacercarea 9% in the viscera (Plate 10, Photo 32)
  - Normal numbers of ecto-parasitic ciliates on gills (40%)
  - A relatively high infection of a Myxosporean (Myxobolus exiguus) in intestinal wall

    Number of cysts found in the fry represented 30%
  - Cysts were localized in the muscular layer of the mucosa The growing cyst has greatly stretched this layer, and ultimately will lead to its rupture to release the spores This mechanism might cause serious complications to the fry (e g causing peritonitis)

- Encysted Metacercariae (EM) recorded in muscles, intestinal wall and liver

  It was represented by low numbers of *Pygidiopsis geatata* and infected about 60% of the Fry examined

- Trematodes only one trematode sp (*Licithobotrices sp*) was found in the intestine of about 10% of the examined fry

FISHERIES

Fisheries Statistics

The fishery in Lake Qarun is operated by 550 wooden, non-mechanized boats and about 4000 fishermen Fish harvest is landed in 11 landing sites lie along the southern coast of the lake The landing sites are from east to west are namely Sanoures, Abo-Neima, Shakshouk, Abo-Shanab, Allokanda, El-Saida, El-Horia, Kahk, El-Roshdia, Ayoub and Qarun Fishing is prohibited in June and July each year, as a regulatory measure to maintain tilapias, however during the last few years, the closing season was irregular

The main fishing gear used in the lake is the trammel gill nets Their height and construction depend on the target species For mullets, the net depth ranges between 8 to 10 meters The mesh of the inner layer is 17 (17 mesh openings in 50 cm, i e about 2 9 cm stretched mesh opening), while that of the outer layers is wider being 14 mesh size For tilapias and soles the nets are identical in shape but differ in the number of sinkers and floaters The inner layer with a mesh number of about 17 to 20, while meshes of the outer layers are much wider For catching soles, the net used is about 75 cm in depth and about 600 to 1500 cm long There is a few number of floaters on the head of the rope, and the sinkers are close to each other to keep the net on the bottom. For tilapias, the number of sinkers is moderate and the space between floaters on the head rope is less than that used for catching soles The depth of the net is about 65 cm, its lengths varies from 200 to 500 meters Beach seines are used for catching shrimp, their dimensions are 5 4 m in depth and about 25 m in length, with a small mesh size of 90, i e 0 55 cm stretched mesh opening and is operated by 2 or 3 fishermen Also, there are some traps and hooks used for catching *Tilapia zillii*

Annual fisheries production of Lake Qarun during the period from 1970 to 1996 are shown in Fig 46 Throughout this period, the total catch varied considerably between 2,023 tons, during 1970/71, and 473 tons, during 1989/90 From 1970 to 1978, soles production constituted about 50% of the total catch The catch of soles significantly decreased and reached its minimum of about 11 4 tons in 1989/90, i e about 2% of the total fish production during this season

Since 1978, tilapias fisheries contributed the major part of Lake Qarun fisheries Their production reached to about 73 % of the total catch during the 1980/81 fishing season Throughout this period mullets occupied the second position after tilapias, except from 1987/88 to 1991/92 fishing seasons, when shrimp fisheries production came in the second after tilapias and comprised 30% of the total fishery production

Table (6) - Age composition of the different fish species collected from Lake Qarun

Species	Sex	Age groups					
		0	I	II	III	IV	V
Solea aegyptiaca	Males	39 53	50 35	9 88	0 24		
	Females	34 02	45 75	18 18	0 88	0 59	0 59
	Combined	37 8	48 30	13 58	0 52	0 26	0 26
Liza salienS	Males	9 13	75 80	13 24	1 37	0 46	
	Females	2 83	62 39	32 39	1 52	0 65	0 22
	Combined	4 86	66 72	26 22	1 47	0 59	0 15
Tilapia zillii	Males	28 57	49 15	20 34	1 45	0 48	
	Females	42 68	39 49	16 56	1 27		
	Combined	32 46	46 49	19 03	1 40	0 35	
Oreochromis aureus	Males	46 69	47 12	5 79	0 41		
	Females	27 78	36 32	30 34	5 56		
	Combined	37 39	41 81	17 86	2 94		
Oreochromis niloticus	Males	65 91	25 00	6 82		2 27	
	Females	67 65	26 47	2 94	2 94		
	Combined	66 67	25 64	5 13	1 28	1 28	

Table (7) Natural mortality (M), Fishing mortality (F), Instanteneous total mortality (Z), Survival rate (S) and Annual mortlity rate (A) for the species collected from Lake Qarun .

Species	M	F	Z	S	A
Solea aegyptiaca	0 2322	1 3337	1 5659	20 89%	79 11%
Liza saliens	0 2605	1 0125	1 2730	28 00%	72 00%
Tilapia zillii	0 1730	1 1811	1 3541	30 90%	74 18%
Oreochromis aureus	0 2192	1 0677	1 2869	27 62%	72 38%
Oreochromis niloticus	0 2393	0 9348	1 1741	30 91%	69 09%
Metapenaeus stebbingi	0 6613	4 229	4 890	0 75%	99 25%

Table (8) **Exploitation rate (E), relative yield per recruit (Y'/R) and Relative biomass per recruit (B'/R) for the species collected from Lake Qarun**

Species	Present situation			At maximum Y/R		
	E	Y'/R	B'/R	E	Y'/R	B'/R
Solea aegyptiaca	0 852	0 119	0 089	0 702	0 128	0 234
Liza saliens	0 832	0 110	0 085	0 726	0 115	0 167
Tilapia zillii	0 872	0 105	0 089	0 623	0 139	0 486
Oreochromis aureus	0 813	0 077	0 081	0 576	0 108	0 363
Oreochromis niloticus	0 872	0 081	0 050	0 584	0 124	0 369
Metapenaeus stebbingi	0 865	0 177	0 042	0 640	0 248	0 210

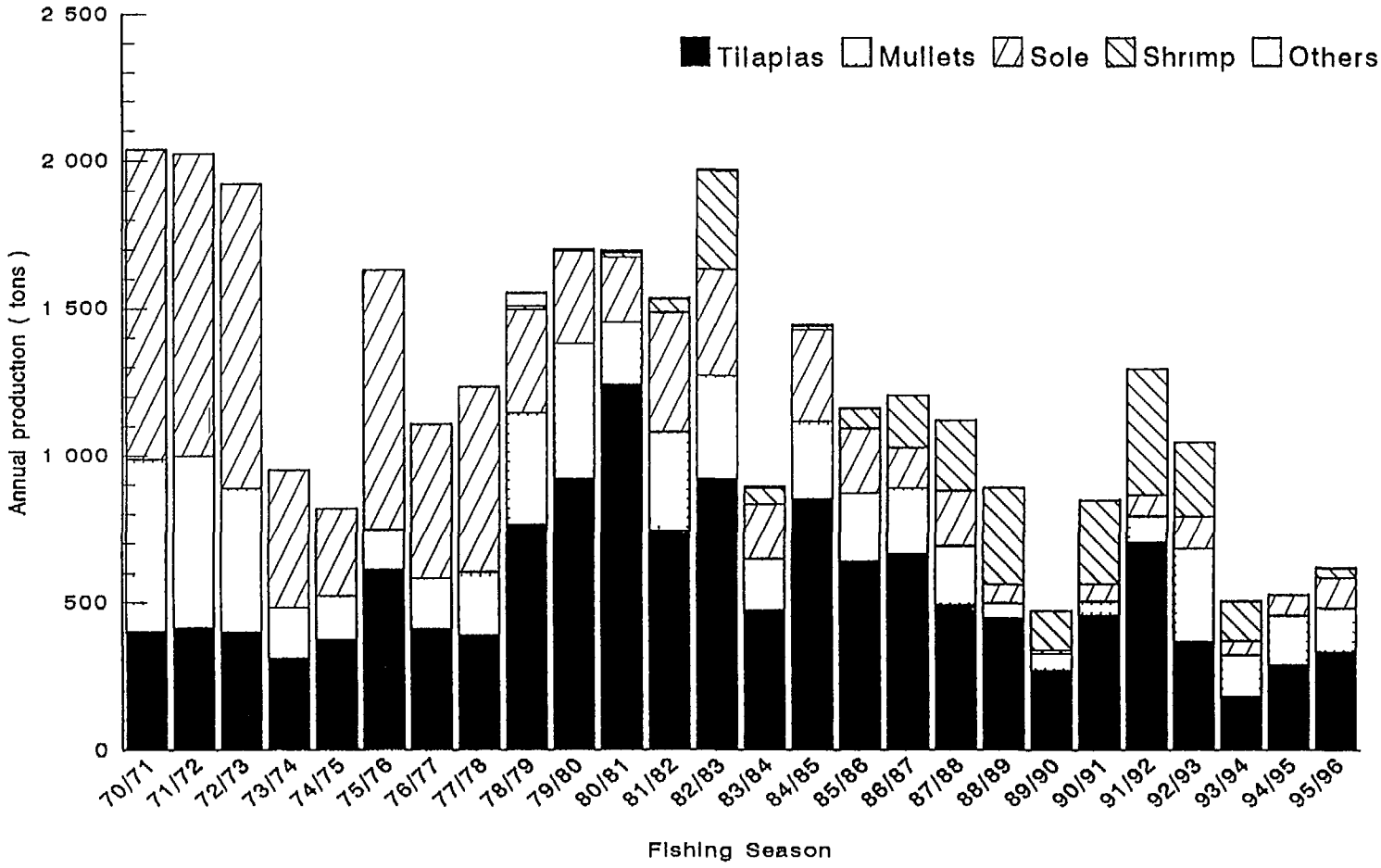


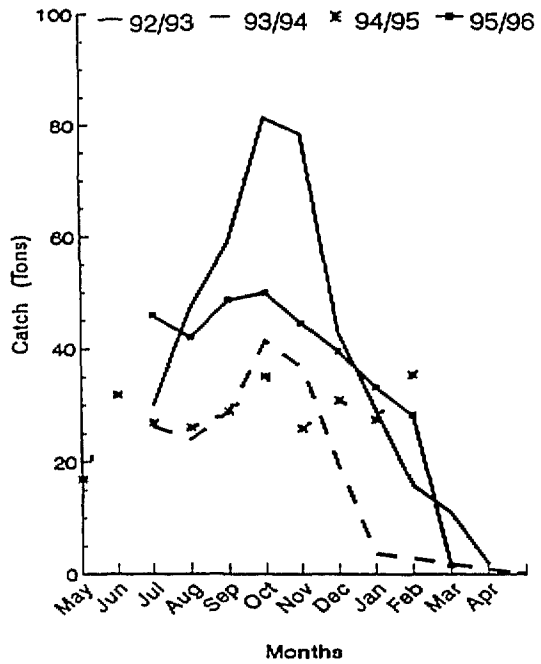
Fig (46) Total Annual fisheries production of Lake Qarun during the period from *1770 to 1996*

It was obvious that the depletion in the catch of soles was concomitant with the expansion of shrimp fisheries in the lake In 1982/83, the shrimp production increased to 334 tons when the total fisheries production was 1969 tons During the following season the total catch declined to 892 tons, i e a descrease of about 55%

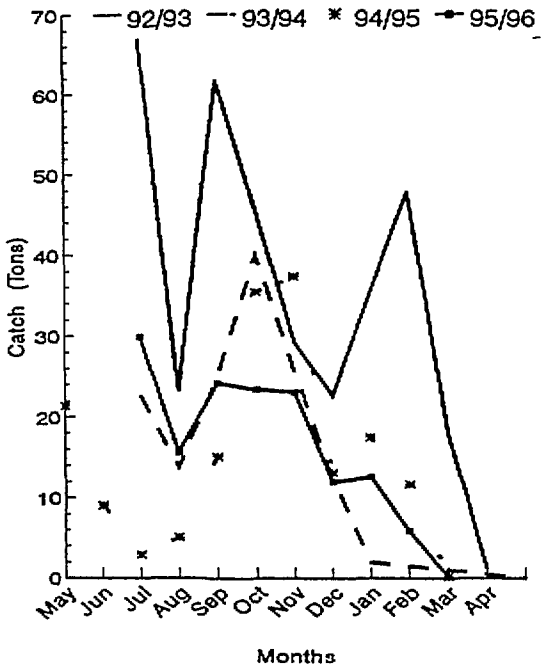
Catch and effort statistics for the fishing seasons from 1992/93 to 1995/96 were studied For fishing season 1992/93, the season extended from July 1992 till April 1993, with one month closed season during January 1993, i e a total of 170 days fishing season The total fishery production during this season was 1,045 tons Tilapias represented 35% of the total catch, while mullets, shrimp and soles contributed 30, 24, and 10%, respectively The maximum monthly catch was in July, amounting to 20% of the total annual catch The catch composition was mainly mullet and shrimp, forming 21 and 41% of the total population, respectively On the other hand, the maximum catch of soles and tilapias was observed during October comprising 19 and 22% of the total annual catch, respectively The number of landing, as an index of fishing effort, was 83,780 during the season The monthly landings varied between 6,250 during March 1993 and 13,260, during October 1992 Catch per landing (as an index of relative abundance), varied between 3 113 kg, during April 1993, and 20,189 kg during February 1993 In general, during this fishing season, the average catch per landing was 12 471 kg

During 1993/94, fishing activities began in July 1993 and terminated at the end of January 1994, a total of 170 days only The total fishery production during this year was 505 tons Tilapias and mullet constituted 36 and 28% of the total catch, respectively Whereas, shrimp fishery contributed 26% of the total yield, and the soles represented about 10% The maximum monthly production took place in July, when about 30% of the total catch was landed Highest landings (12,190 tons) were also recorded and comprised 19% of the total annual landings The highest monthly catch of shrimp was in July contributing about 70% of the total yield (Fig 47) The maximum landing of tilapias was recorded in October, forming 22% of the total tilapias production The highest monthly production of mullets was in October, forming 28% of the total mullet yield During this season, the fishing effort, in terms of number of landings, was 65,530 Catch per landing showed a decreasing trend, from 12 262 kg in July 1993 to 2 135 kg in January 1994 (Fig 48)

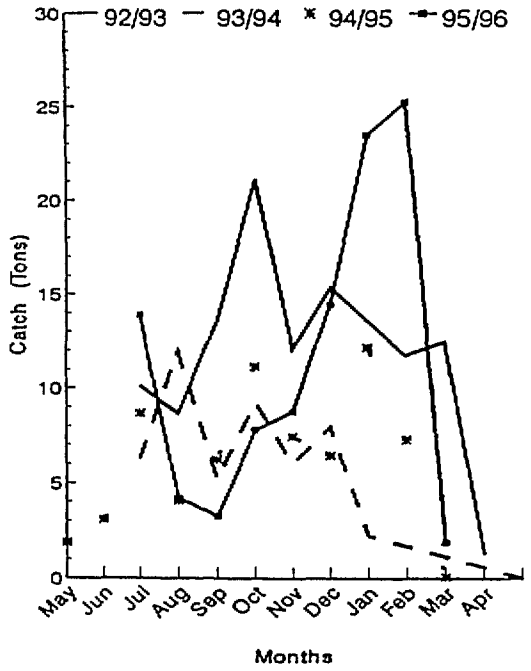
During the next fishing season of 1994/95, fishing activities began four days at the end of May 1994 and ended on 9th of March 1994, a total of 227 fishing days The total fishery production was 528 tons, of which 54% were tilapias, 32% mullets, 13% soles and 0 6% shrimp The monthly catch varied from 36 tons, in August, to 82 tons, in October As usual, the highest monthly catch of both of shrimps and tilapias was in July and October, respectively, when 58% and 18% of the total catch were landed in these months, respectively (Fig 47) On the other hand, the highest monthly catch of mullet and soles was recorded in November 1994 and January 1995 The number of landings during this season was 100,225 In June 1993, about 13% of the total landings were made The catch per landing varied from 2 137 kg during March 95 to 19 354 kg during May 1994, with an average value of 5 27 kg It is noteworthy that at the beginning of this fishing season, and in four days in May, 40 tons, constituting about 7 5% of the total catch, were fished with only 2,080 landings



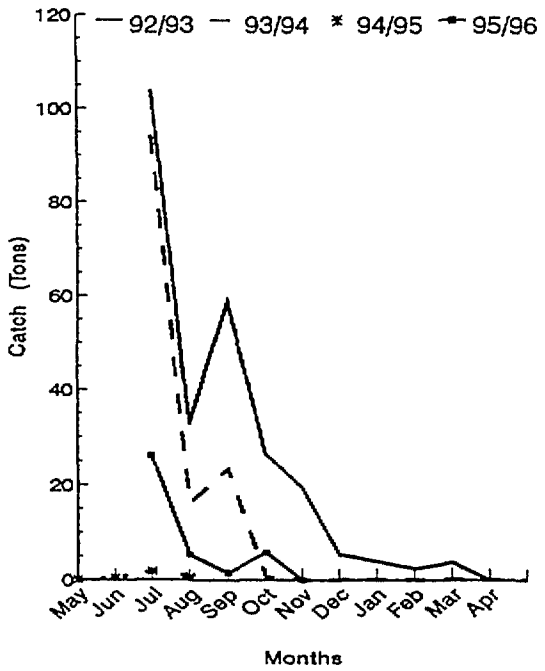
Tilapias



Mullets



Soles



Shrimps

Fig (47) Monthly catch of the important group of species in Lake Qarun during the fishing seasons from 1992/93 to 1995/96

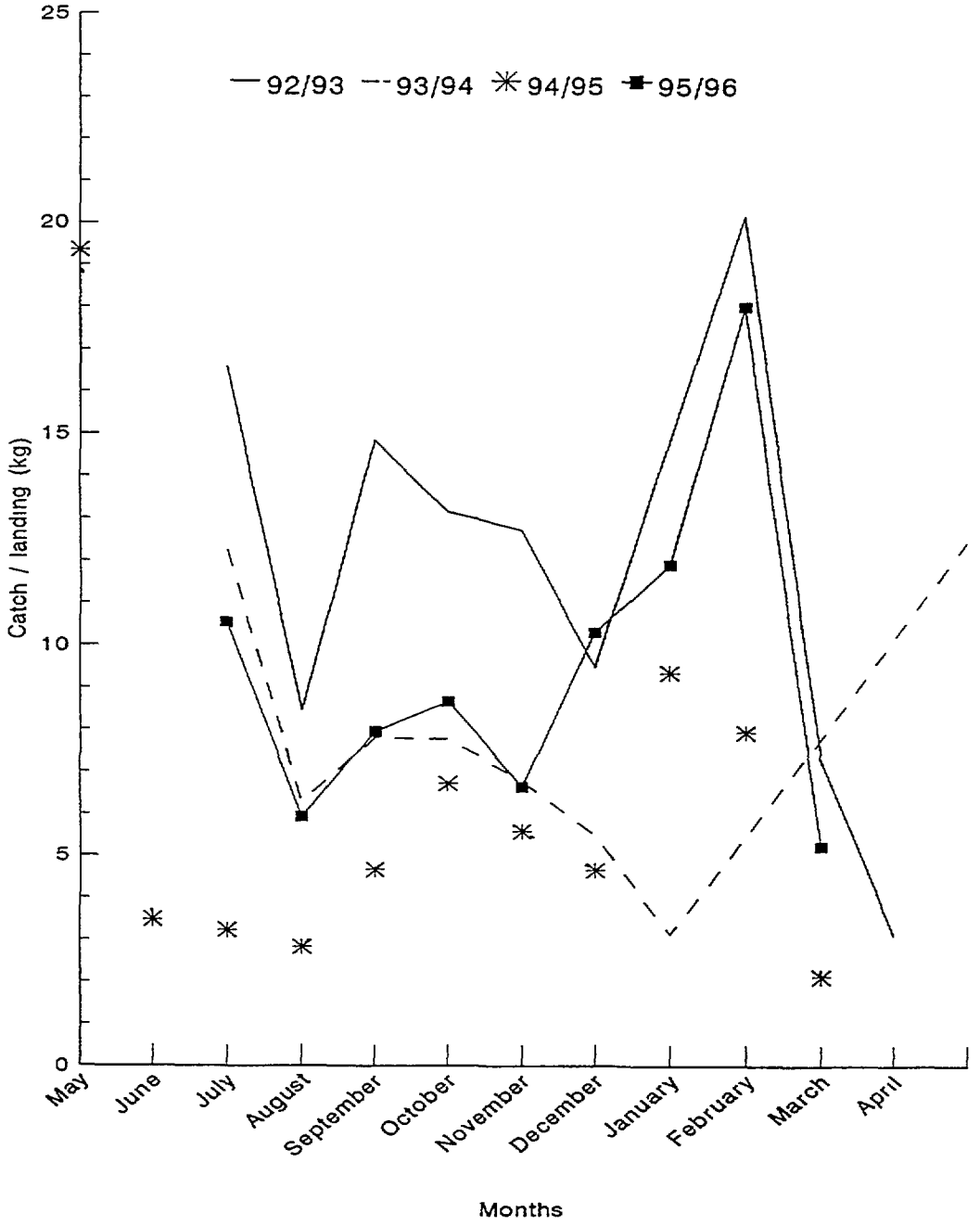


Fig (48). Monthly catch per landing of lake Qarun fisheries during the fishing seasons from 1992/93 to 1995/96

In 1995/96, the fishing season extended from July 1995 to March 1996, with 262 fishing days The total catch was 620 tons, of which 54% tilapias, 24% mullets, 17% soles and 5 % shrimps The highest production was recorded during July, when about 19% of the total fish production have been landed The highest monthly production of shrimp and tilapias was in July and October, when 78 and 21% of their total yield has been landed On the other hand, the highest monthly yield of mullet and soles occurred in July and February, when 20 and 25% of the total yield have been caught The number of landings, as a measure of fishing effort varied from 700 during March to 11,492 during November with an average value of 69,427 Catch per landing showed a gradual increase during the period from November to February, when it reached its maximum of 18 015 kg In general, catch per landing in the fishing season, 1995/96 was higher than that of the two preceding fishing seasons its value was 8 928 kg

- **Biological Studies**

Analysis of the fish samples collected either from the landing sites, or by experimental fishing showed that Lake Qarun fisheries consisted of the following fish species

1. Mullets were represented by 6 species, namely *Mugil cephalus*, *Liza ramada*, *Liza saliens*, *Liza aurata*, *Chelon labrousus* and *Liza craniata*) *L saliens* is the most dominant species and constituted about 80% of the mullets *L ramada* ranked second, it contributed about 10% of the mullet production *M cephalus* represented about 5% of the mullet production The rest of mullet species were rare and constituted about 5% of the total mullet catch
2. Soles, since the transplantation of this genus to the lake in1928, it was identified as *Solea vulgaris*

During January 1993, samples were collected through experimental fishing and the number of soles in the sample was very low Examination of the external features revealed that this species is *S aegyptiaca* One of the important criteria for identification of this species is the number of vertebra shown by X-ray examination (Plate 11) All the sole samples underwent to careful examinations, and the result confirmed that the species inhabiting Qarun Lake is *Solea aegyptiaca*

Tilapias in Qarun Lake include *Tilapia zillii*, *Oreochromis aureus* and *Oreochromis niloticus* *T zillii* constitutes the major bulk of the tilapia production, about 80% of the total yield *O aureus* represents about 15 % of the yield, while *O niloticus* comprises only about 5% of the yield

It is worth mentioning that, *Oreochromis aureus* was recorded for the first time in Lake Qarun This species was either wrongly identified as *O niloticus*, or was introduced while mixed with the transplanted mullet fry This was one of the important findings of the present study

Three species of shrimp were identified in the catch, namely *Metapenaeus stebbingi*, *Palaemon elegans* and *Penaeus semisulcatus* *Penaeus semisulcatus* was very rare, only 4 specimens were collected throughout the study *M stebbingi* contributed more than 99 5% of the shrimp catch in the lake

Biological studies were also carried out on the important fish species inhabiting the lake, these include *Tilapia zillii*, *Liza saliens*, *Solea aegyptiaca*, *Oreochromis aureus*, *O niloticus* and *Metapenaeus stebbingi*

- **Age and growth**

◊ **Length-Otolith radius (L/S) relationship**

The length-otolith radius relationship for the different species studied by sex and for the combined sex were determined as follows

- **For *Solea aegyptiaca***

Males	L = 7 296 + 6 128 S	r = 0 732
Females	L = 5 148 + 7 711 S	r = 0 760
Sexes combined	L = 4 351 + 7 858 S	r = 0 798

- **For *Liza saliens***

Males	L = 2 982 + 5 114 S	r = 0 738
Females	L = -0 045 + 6 578 S	r = 0 815
Sexes combined	L = -2 644 + 7 288 S	r = 0 849

- **For *Tilapia zillii***

Males	L = -0 559 + 6 166 S	r = 0 927
Females	L = -2 052 + 6 573	r = 0 959
Sexes combined	L = -1 224 + 6 386S	r = 0 936

- **For *Oreochromis aureus***

Males	L = -3 472 + 6 839 S	r = 0 947
Females	L = -3 724 + 6 758 S	r = 0 964
Sexes combined	L = -3 079 + 6 627 S	r = 0 961

- **For *Oreochromis niloticus***

Males	L = -4 266 + 7 406 S	r = 0 921
Females	L = -3 946 + 7 233 S	r = 0 932
Sexes combined	L = -3 946 + 7 233 S	r = 0 932

The above data show that, the value of the intercept was either positive with soles and mullets, or negative with all tilapias species

◊ **Length-weight relationship**

Length and weight data provide vital statistics that are cornerstones of the foundation of fishery research and management

The relation between total length (cm) and total weight (in gram) for the different fish species collected in Lake Qarun are represented in Figs 49 through 54 Constants of the power relation were calculated by least-squares method The relations were as follows

- **For *Solea aegyptiaca*:**

Males	$W = 0\ 0097\ L^{2\ 9544}$
Females	$W = 0\ 0124\ L^{2\ 917}$
Combined Sexes	$W = 0\ 0059\ L^{3\ 139}$

- **For *Liza saliens***

Males	$W = 0\ 0136\ L^{2\ 802}$
Females	$W = 0\ 0086\ L^{2\ 9773}$
Combined Sexes	$W = 0\ 0068\ L^{3\ 0499}$

- **For *Tilapia zillii***

Males	$W = 0\ 0177\ L^{3\ 0122}$
Females	$W = 0\ 0158\ L^{3\ 0639}$
Combined Sexes	$W = 0\ 0173\ L^{3\ 0217}$

- **For *Oreochromis aureus*:**

Males	$W = 0\ 0143\ L^{3\ 0469}$
Females	$W = 0\ 0168\ L^{2\ 9814}$
Combined Sexes	$W = 0\ 0167\ L^{2\ 976}$

- **For *Oreochromis niloticus*:**

Males	$W = 0\ 0115\ L^{3\ 1526}$
Females	$W = 0\ 0136\ L^{3\ 0899}$
Combined Sexes	$W = 0\ 0121\ L^{3\ 1344}$

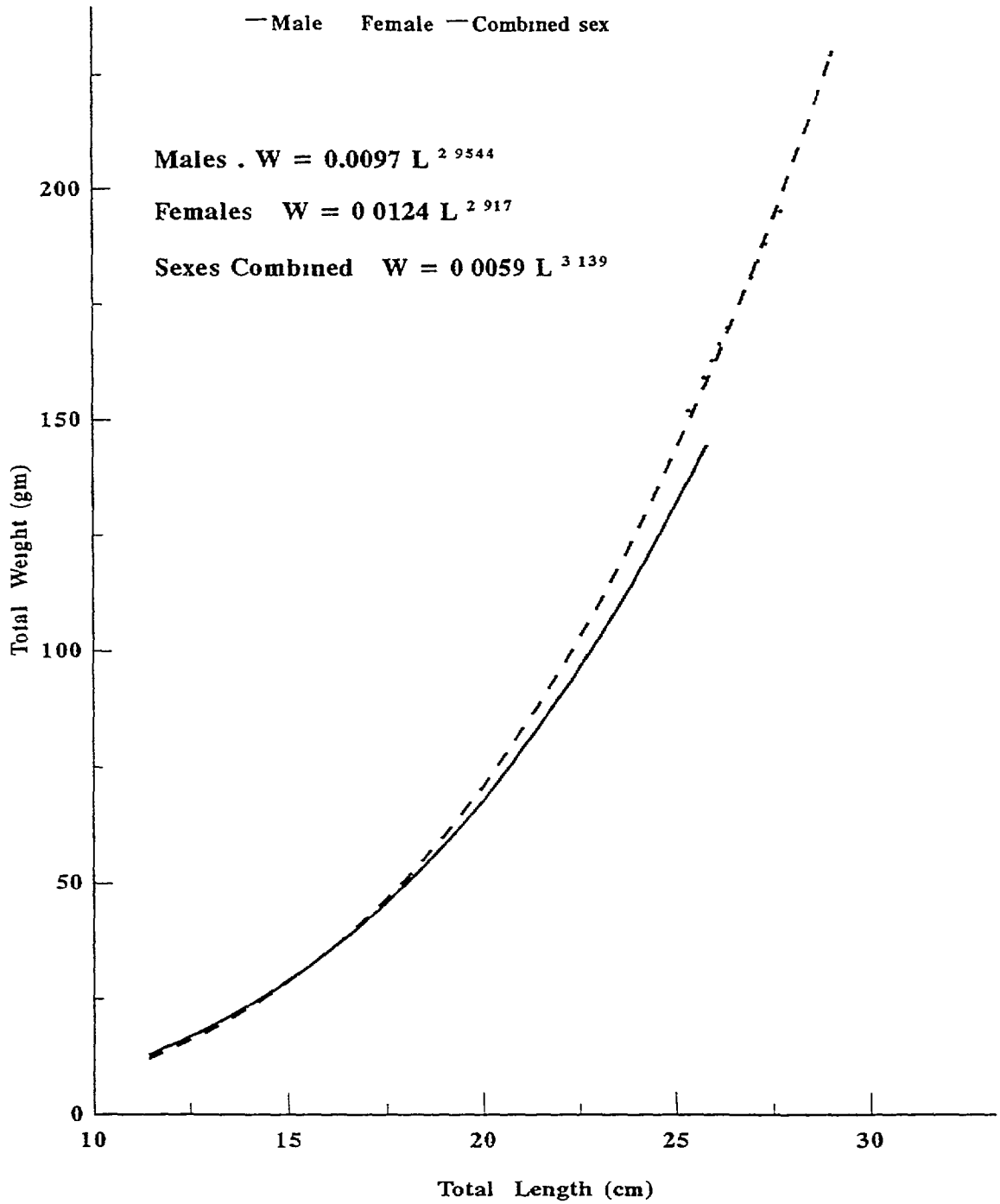


Fig. (49): Length-weight relationship of *Solea aegyptiaca* collected feom lake Qarun

329

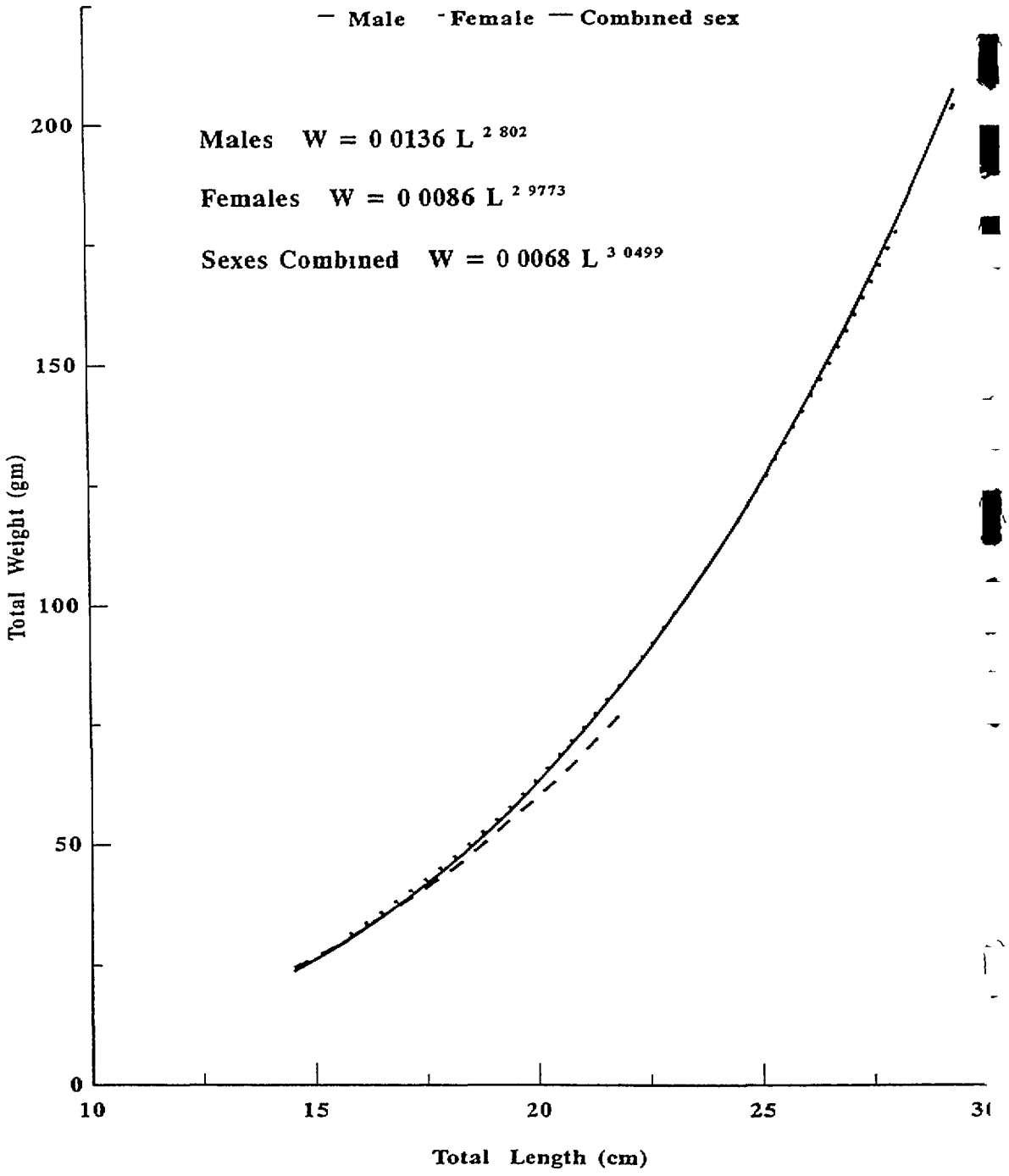


Fig.(50): Length-weight relationship of *Liza saliens* collected from Lake Qarun.

330

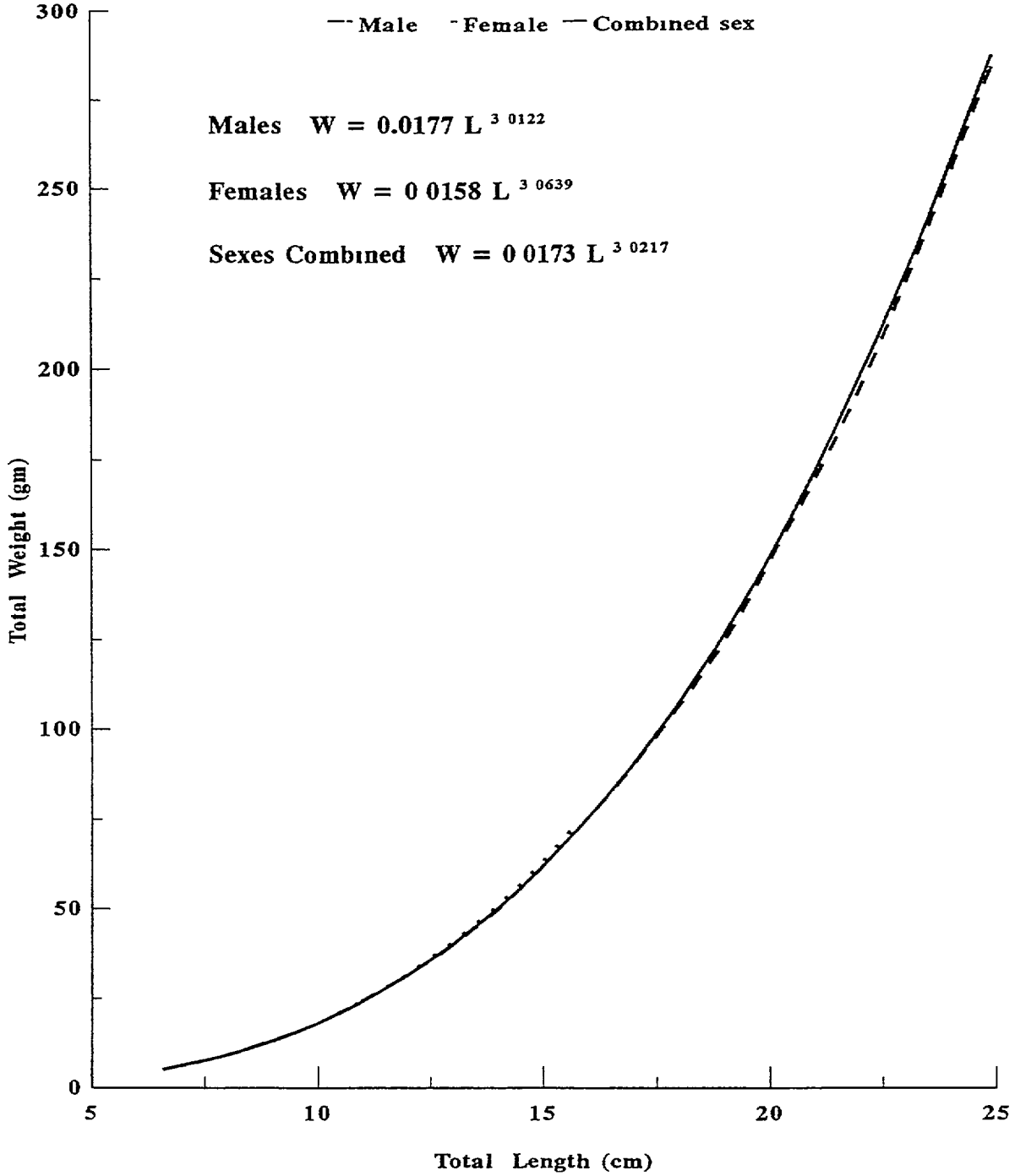


Fig.(51):Length-weight relationship of *Tilapia zillii* collected from Lake Qarun.

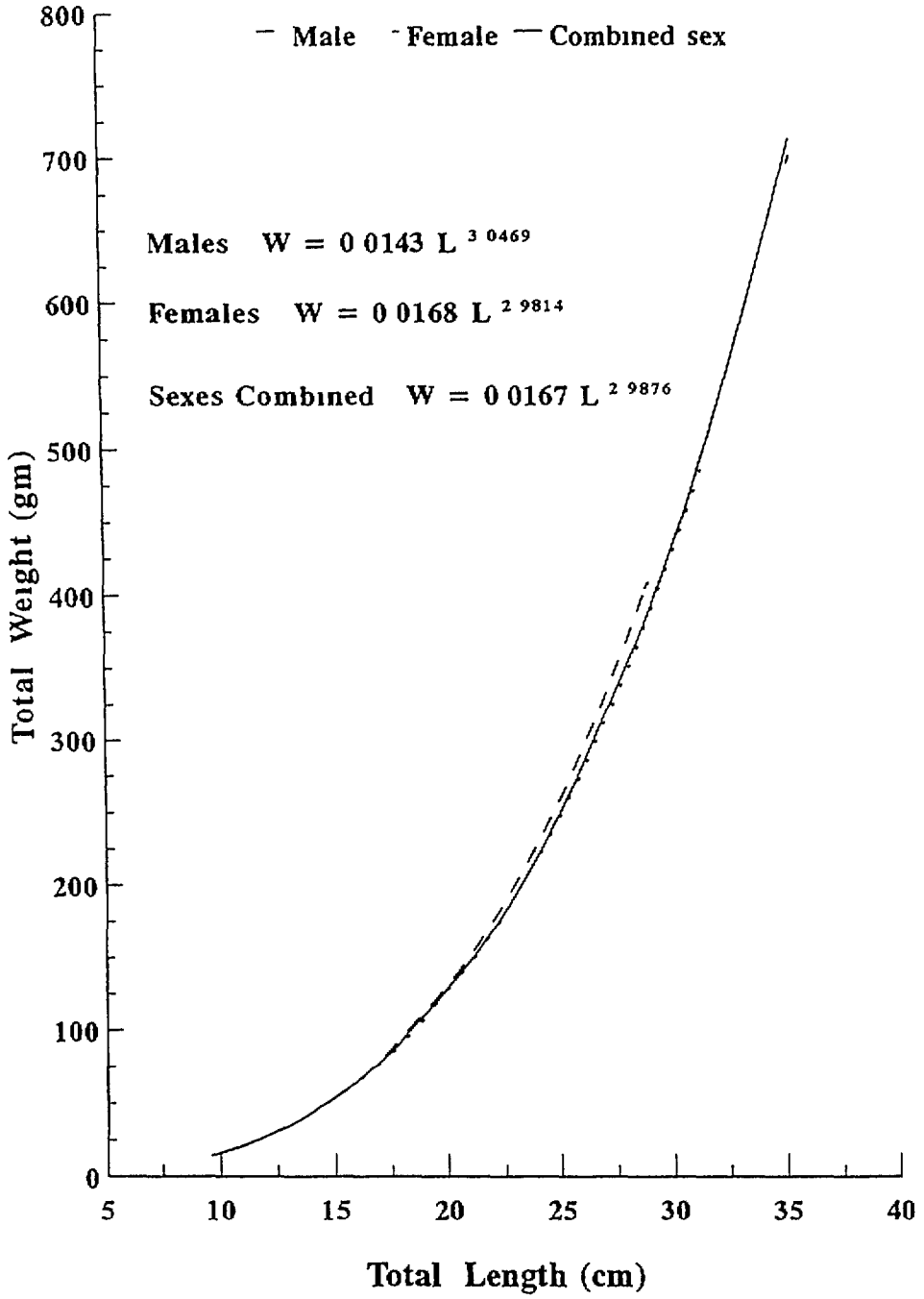


Fig.(52): Length-weight relationship of *Oreochromis aureus* collected from Lake Qarun.

332

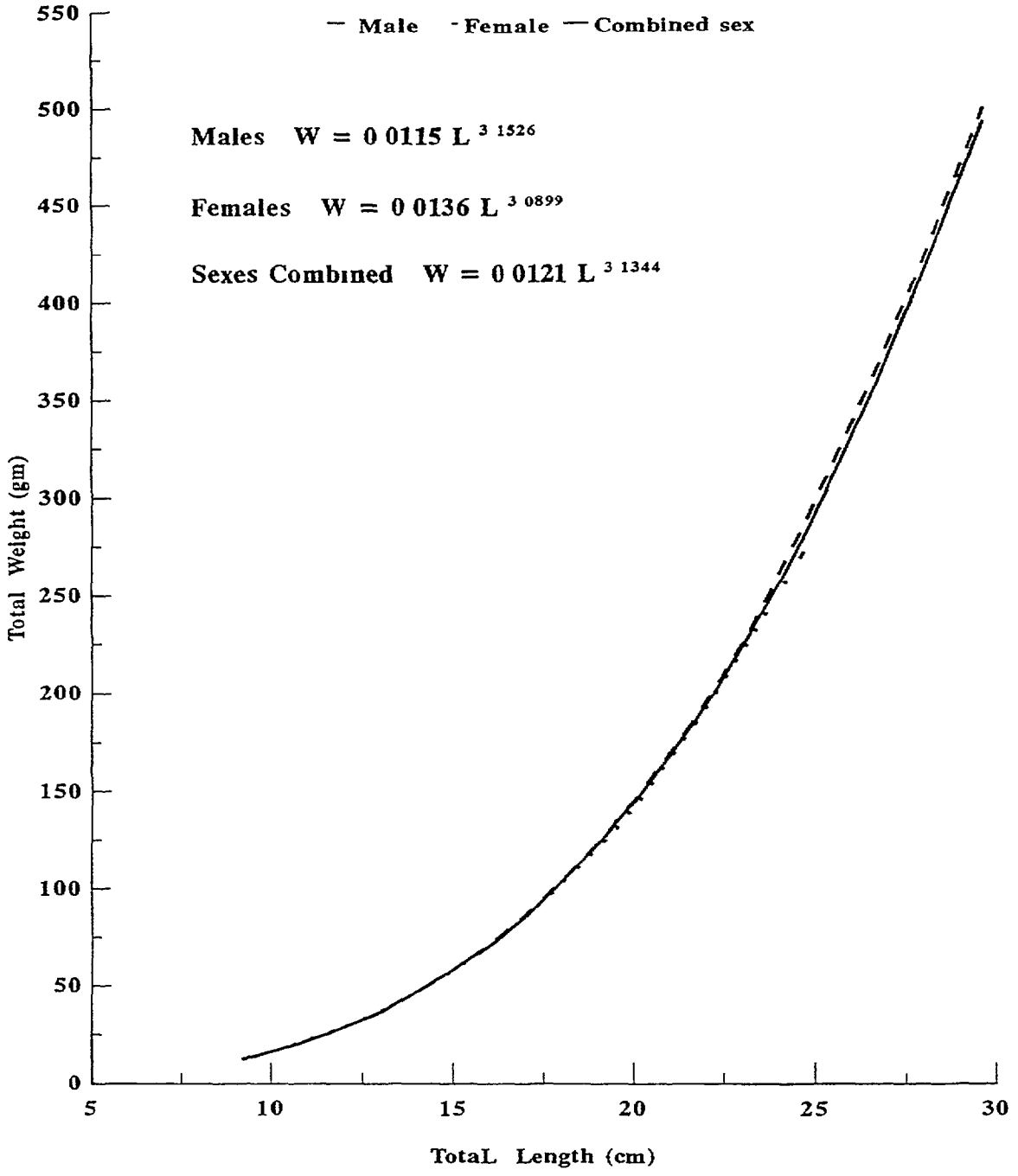


Fig.(53): Length-weight relationship of *Oreochromis niloticus* collected from Lake Qarun.

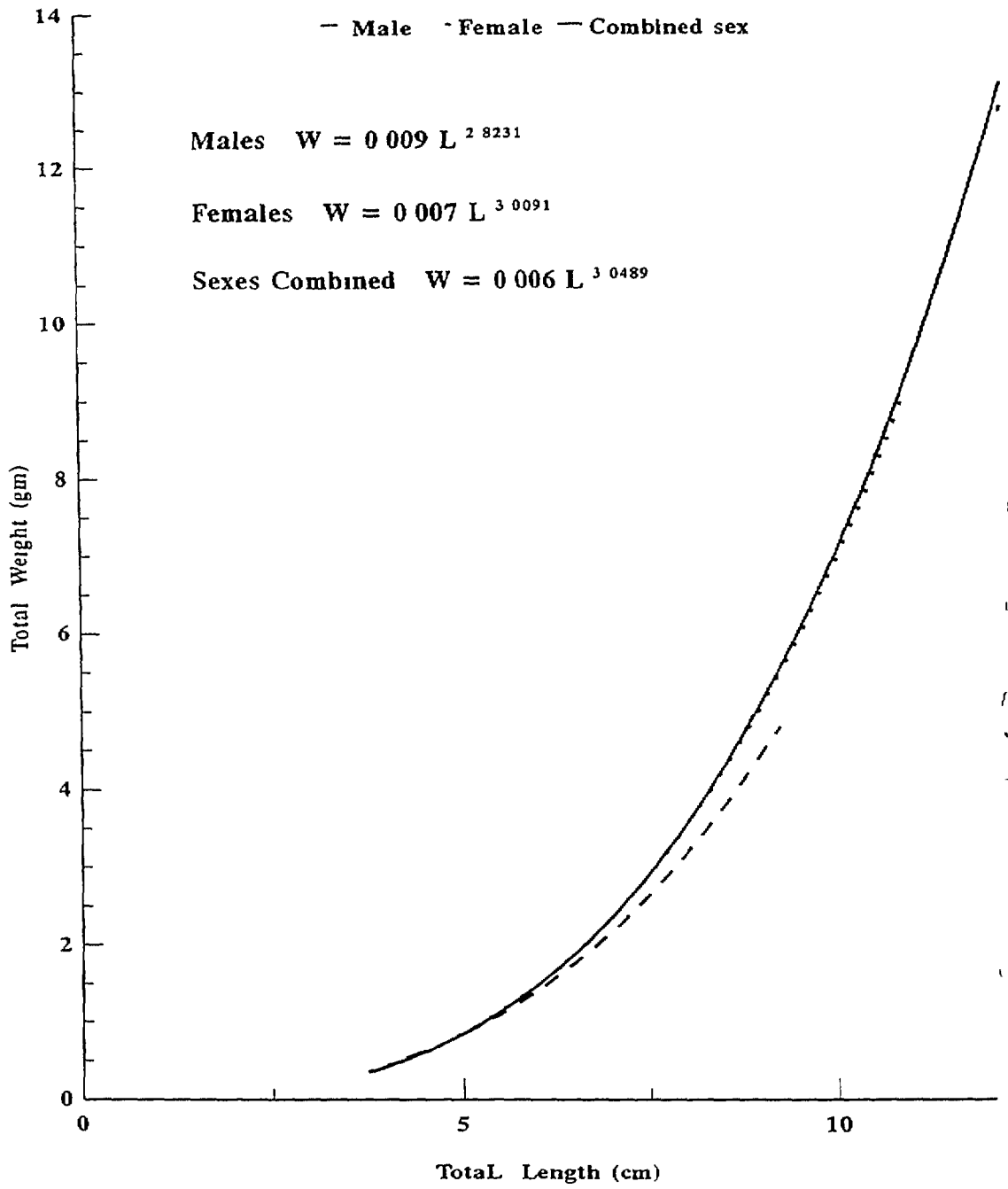


Fig.(54): Length-weight relationship of *Metapenaeus stebbingi* collected from Lake Qarun.

- **For *Metapenaeus stebbingi***

Males	$W = 0\ 009\ L^{2\ 8231}$
Females	$W = 0\ 007\ L^{3\ 0091}$
Combined Sexes	$W = 0\ 006\ L^{3\ 0489}$

The results showed that the value of the exponent (b) falls between 2 8 and 3 1 This indicates that the growth of these species may be isometric, i e the shape does not change as the fish grows

◊ **Condition factors**

Both Fulton (K_c) and Relative condition (K_n) factors were calculated for the different fish species, the results showed no significant monthly variations In general, relative condition factor (K_n) was less than that of Fulton (K_c), except for *S aegyptiaca* and *L saliens*

◊ **Growth in length and in weight**

Growth curves of the different fish species in Lake Qarun are shown in Figs (55 - 66) The average back-calculated lengths revealed that there was a clear difference in growth in length between males and females For *S aegyptiaca* and *L saliens*, the average calculated lengths at the end of the years of life for females were higher than those of males Further, the females attained older ages, their maximum age was 5 years For the soles and mullet, the maximum ages for the moles were 3 and 4 years, respectively

For *T zillii* and *O niloticus*, the males surpass the females in back-calculated lengths at the end of the different years of life, they attained older ages For *O aureus*, the maximum age both of males and females was 3 years, however the back-calculated lengths for the males were slightly higher than that of females

In general, for all species, the maximum incremental length was attained at the end of first year The average calculated weights of soles and mullet indicated that the maximum increment in weight was recorded at the end of first year, while for tilapias it was during the second year

For *M stebbingi*, FISAT, 4 modes and VBGA growth model was applied, and the calculated length was determined at the end of each quarter year of life for the males, females asa well as for combined sexes (Figs 65 & 66)

◊ **Theoretical growth.**

For management purposes, data concerning lengths and weights at different ages are not sufficient The available information should be reduced and expressed by means of a single equation This equation could be easily and readily incorporated into stock assessment models

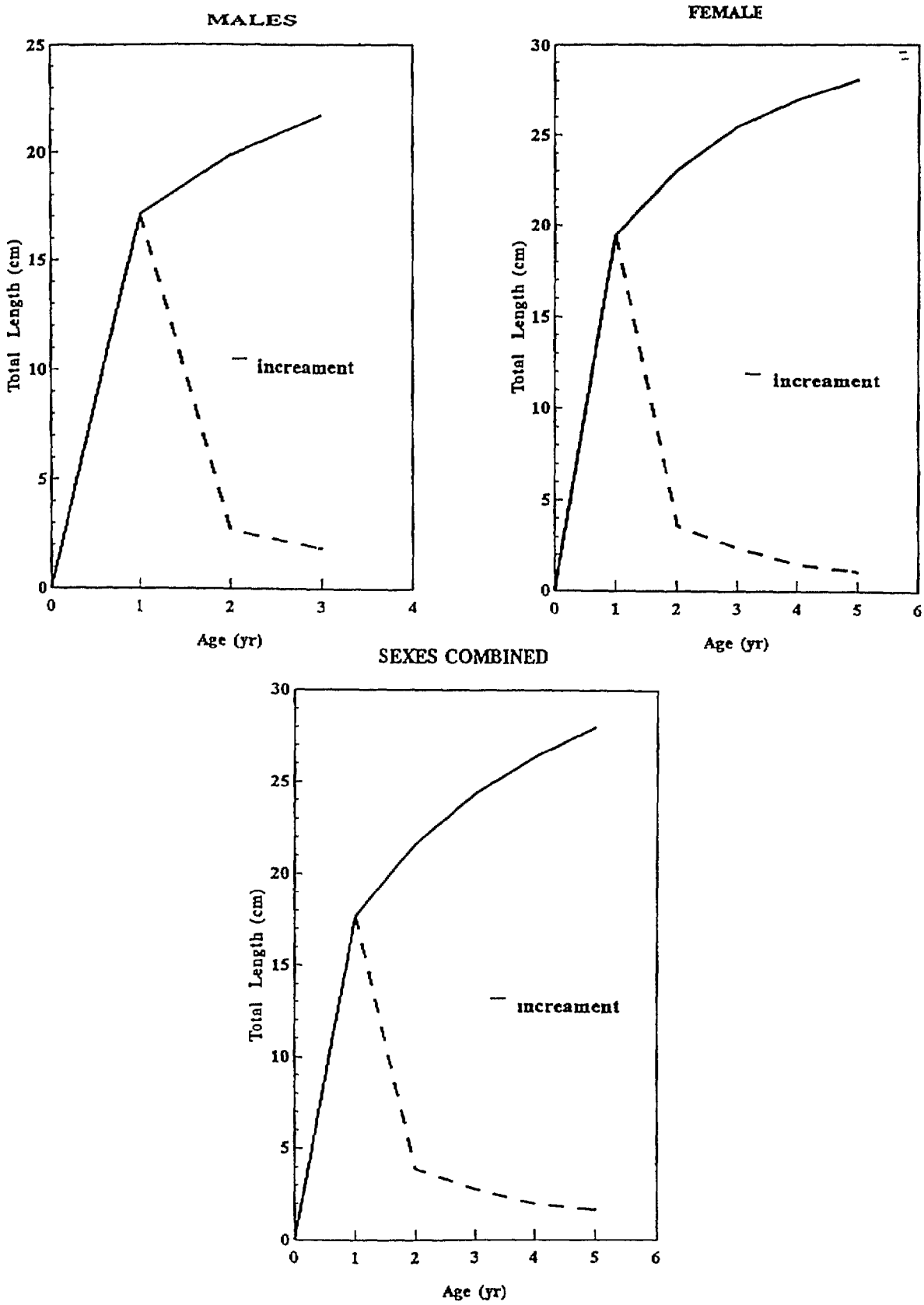
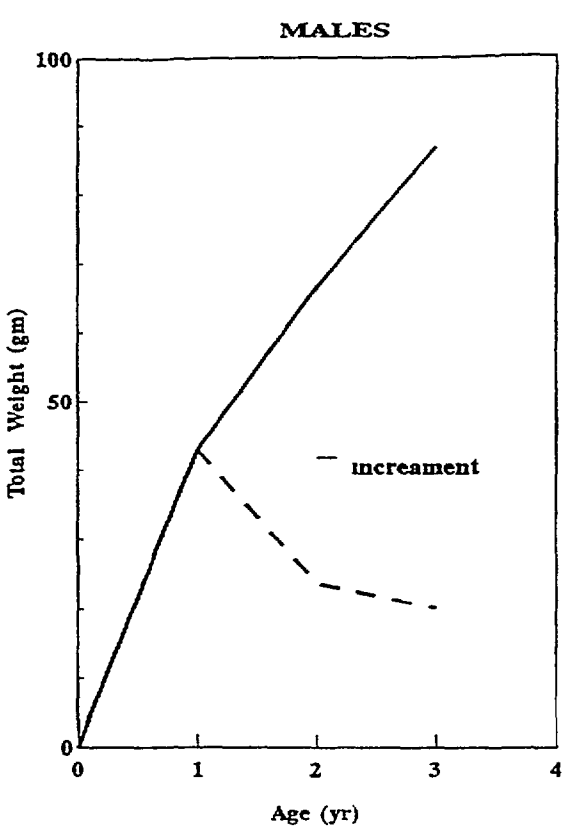
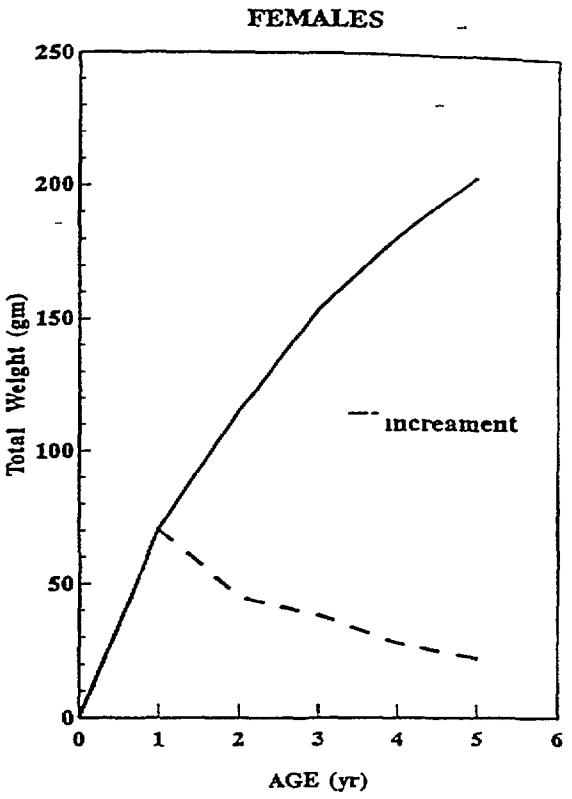


Fig (55) Growth in length and annual increment of *Solea aegyptiaca* collected from Lake Qarun





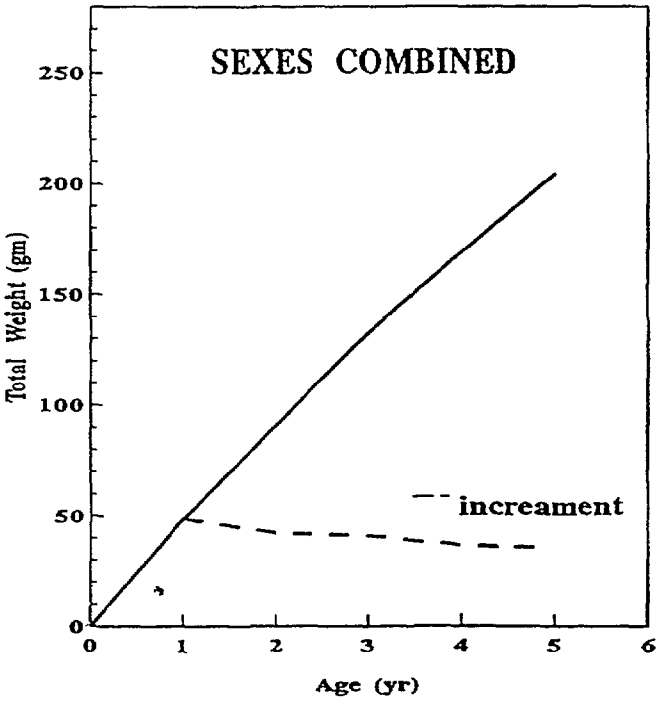


Fig.(56): Growth in weight and annual increment of *Solea aegyptiaca* collected from Lake Qarun.

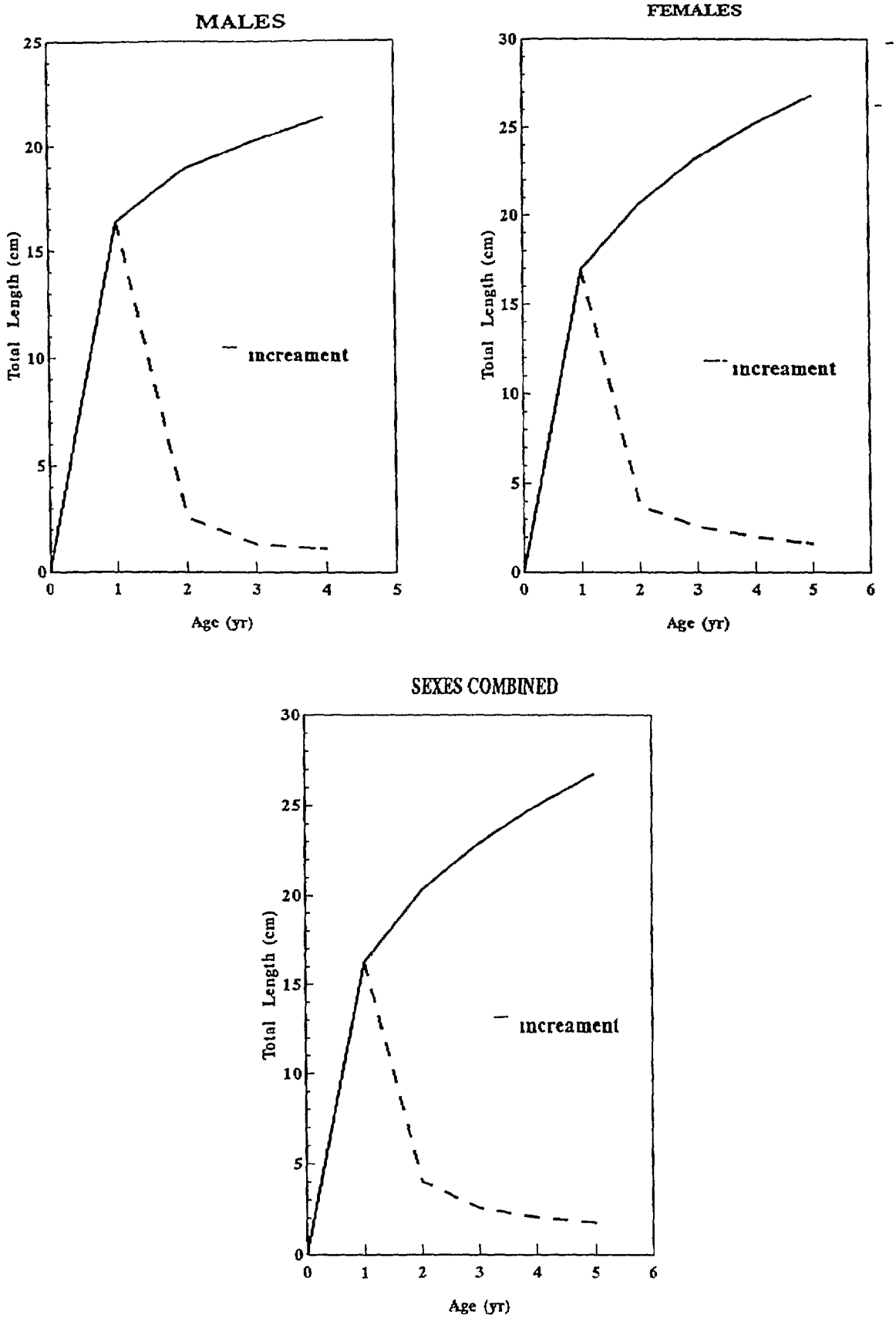


Fig.(57): Growth in length and annual increment of *Liza saliens* collected from Lake Qarun.

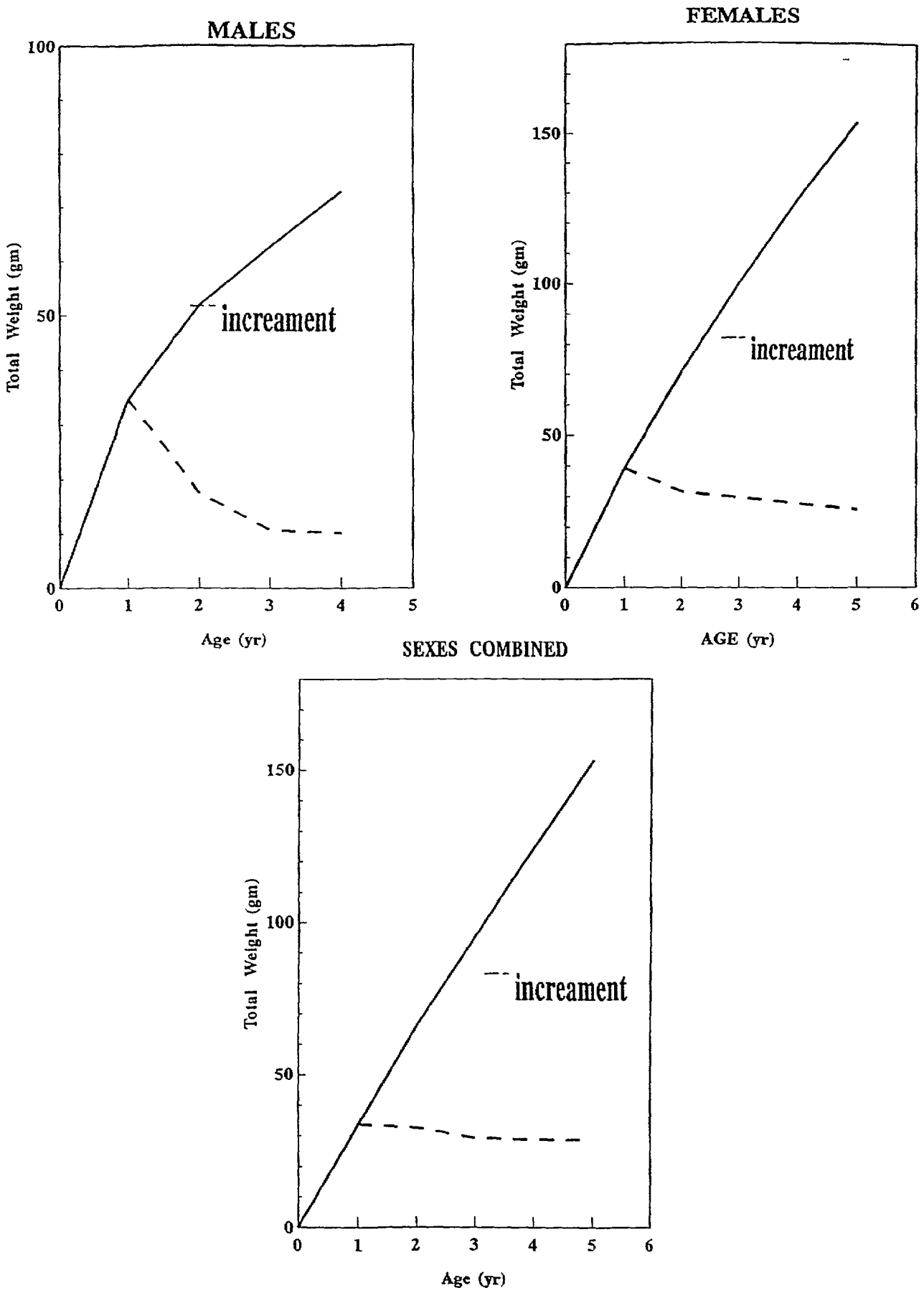


Fig.(58): Growth in weight and annual increment of *Liza saliens* collected from Lake Qarun.

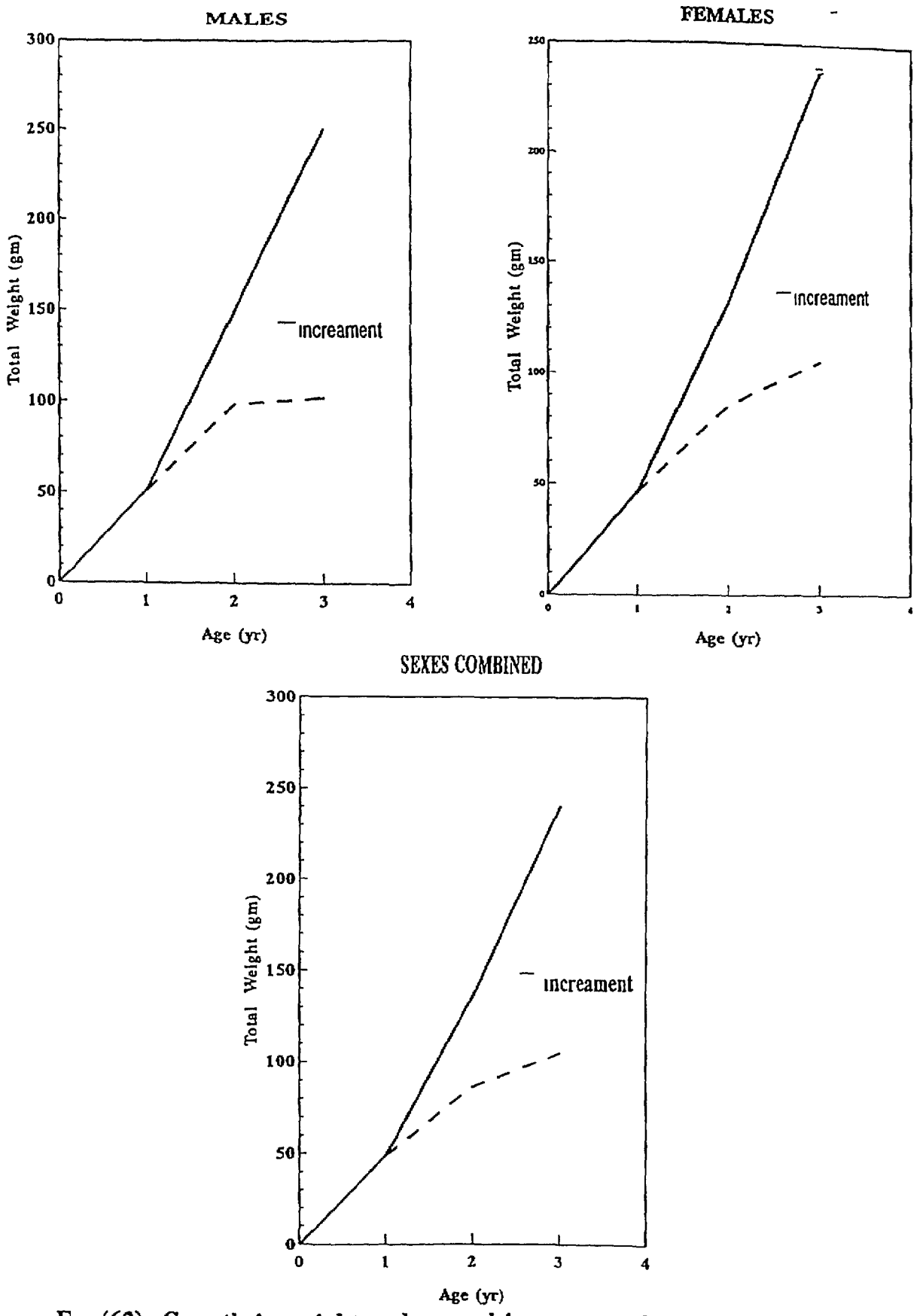


Fig.(62): Growth in weight and annual increment of *Oreochromis aureus* collected from Lake Qarun.

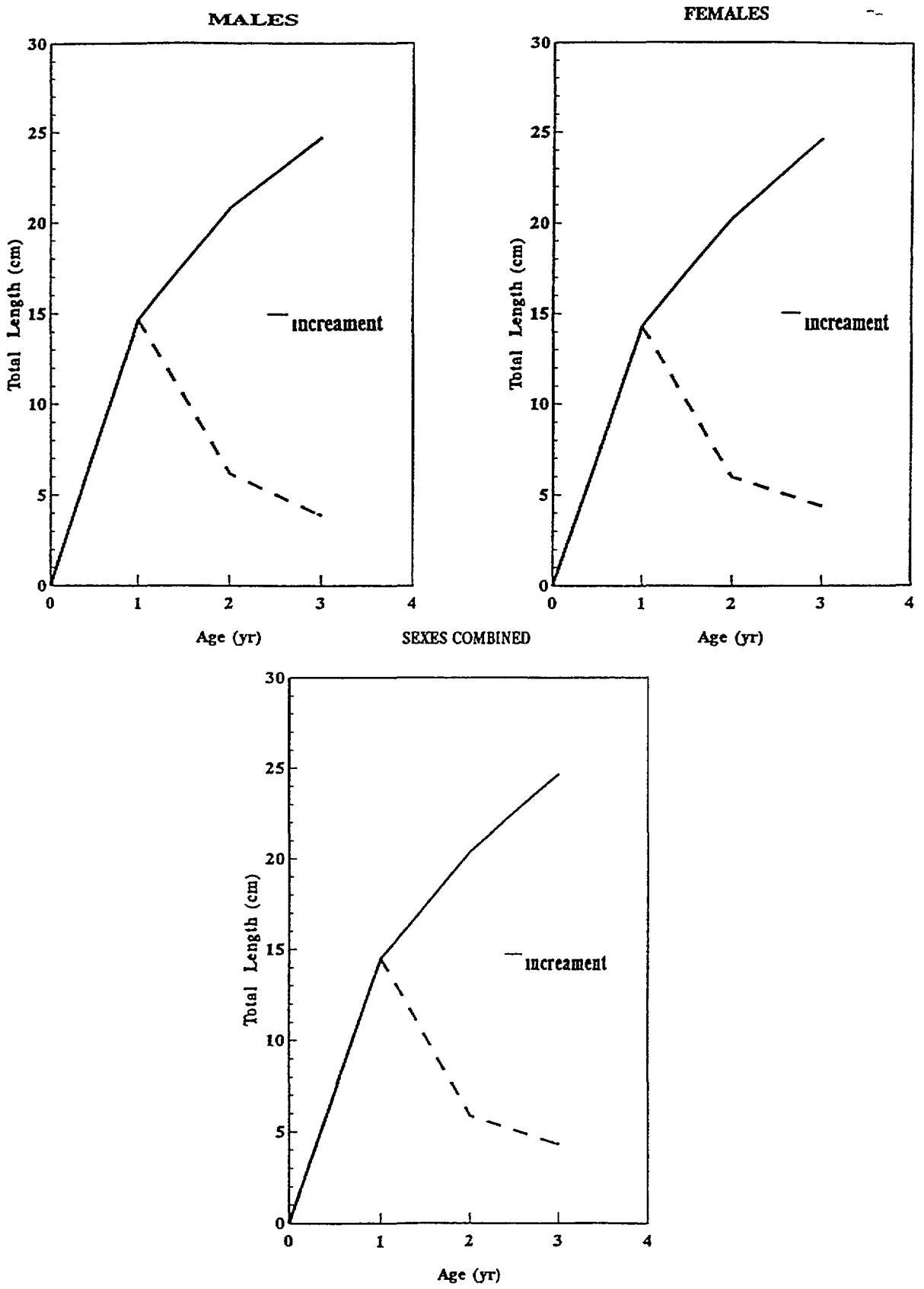


Fig (61): Growth in length and annual increment of *Oreochromis aureus* collected from Lake Qarun.

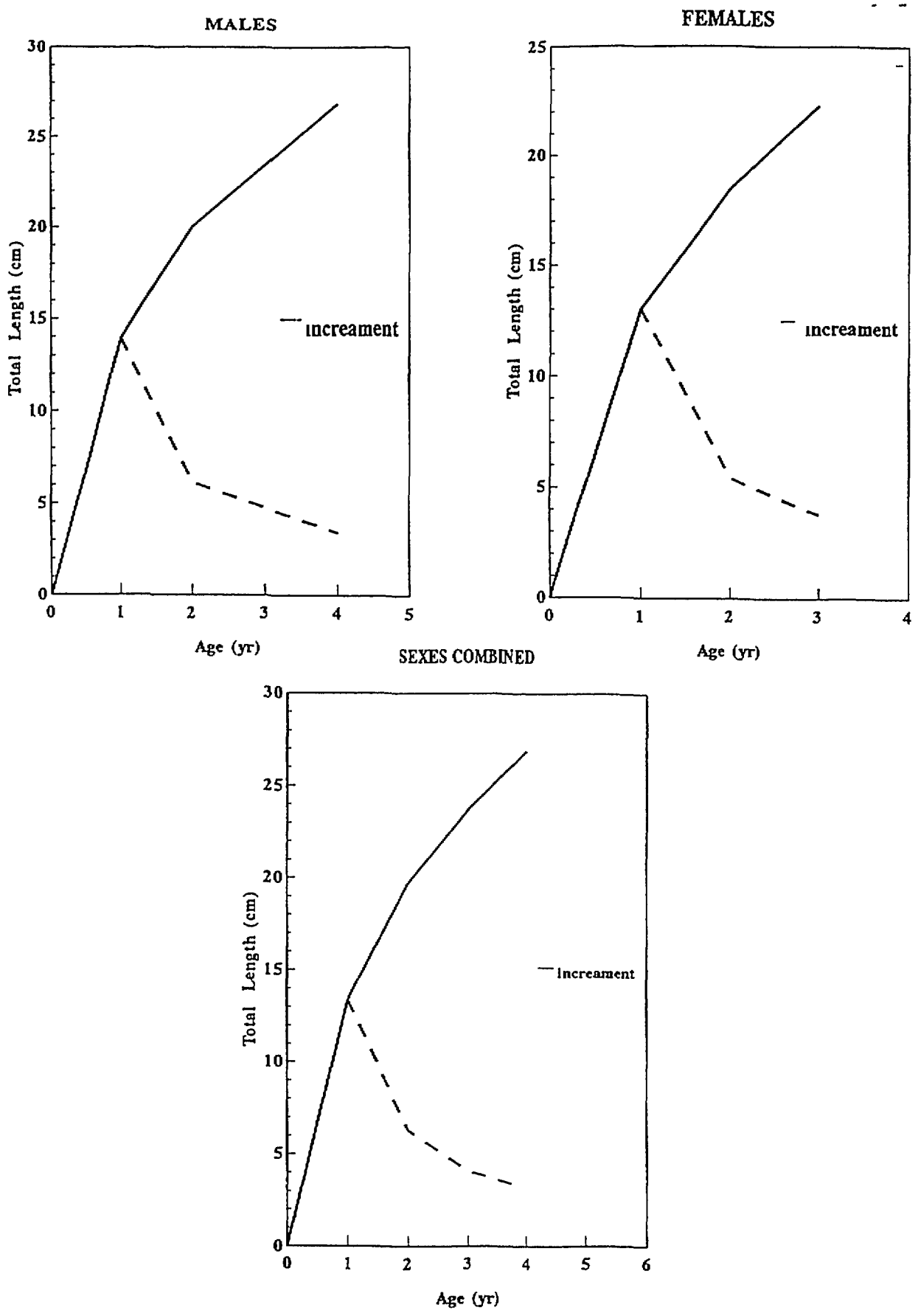


Fig.(63): Growth in length and annual increment of *Oreochromi niloticus* collected from Lake Qarun.

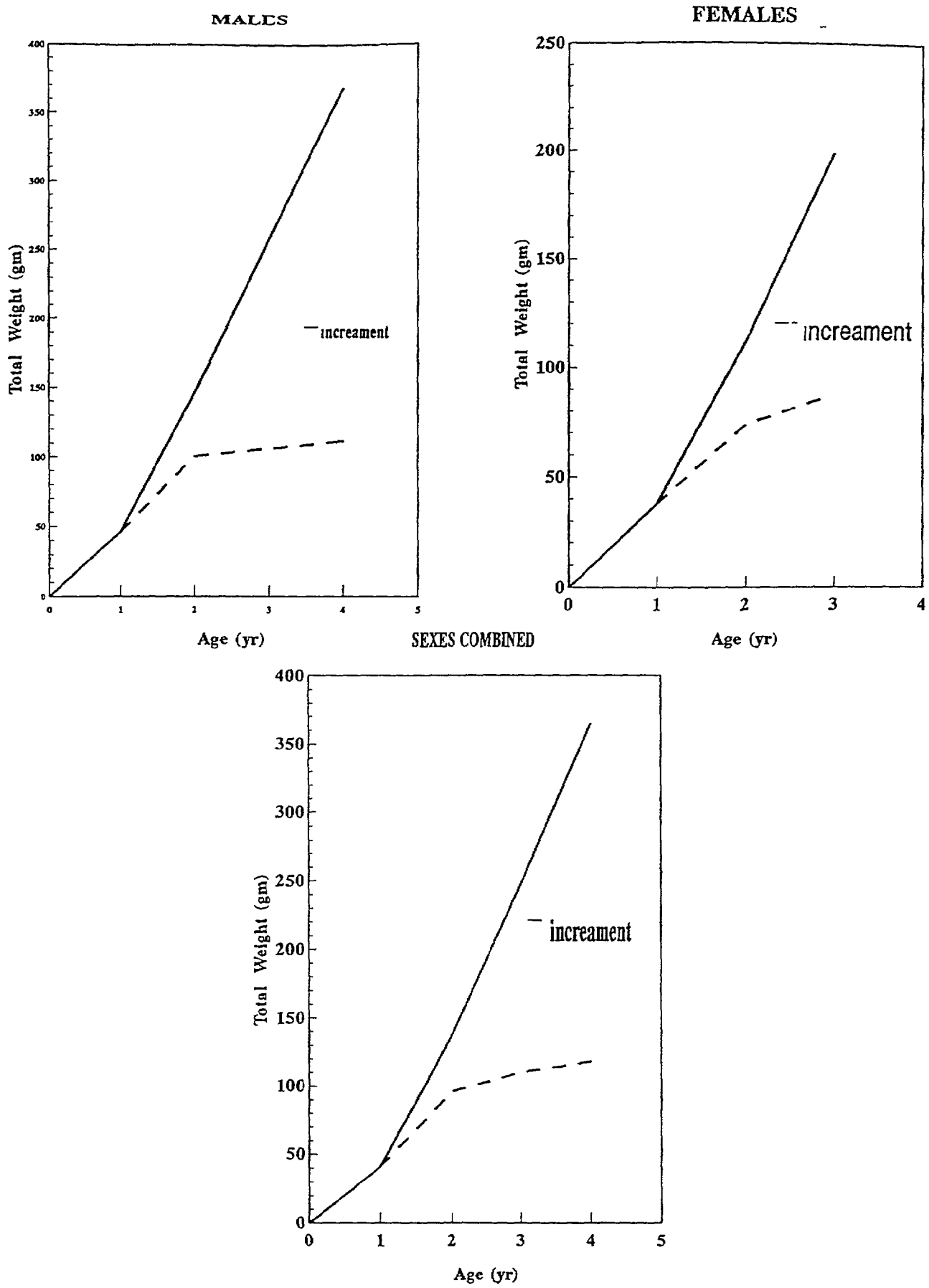


Fig.(64): Growth in weight and annual increment of *Oreochromis niloticus* collected from Lake Qarun.

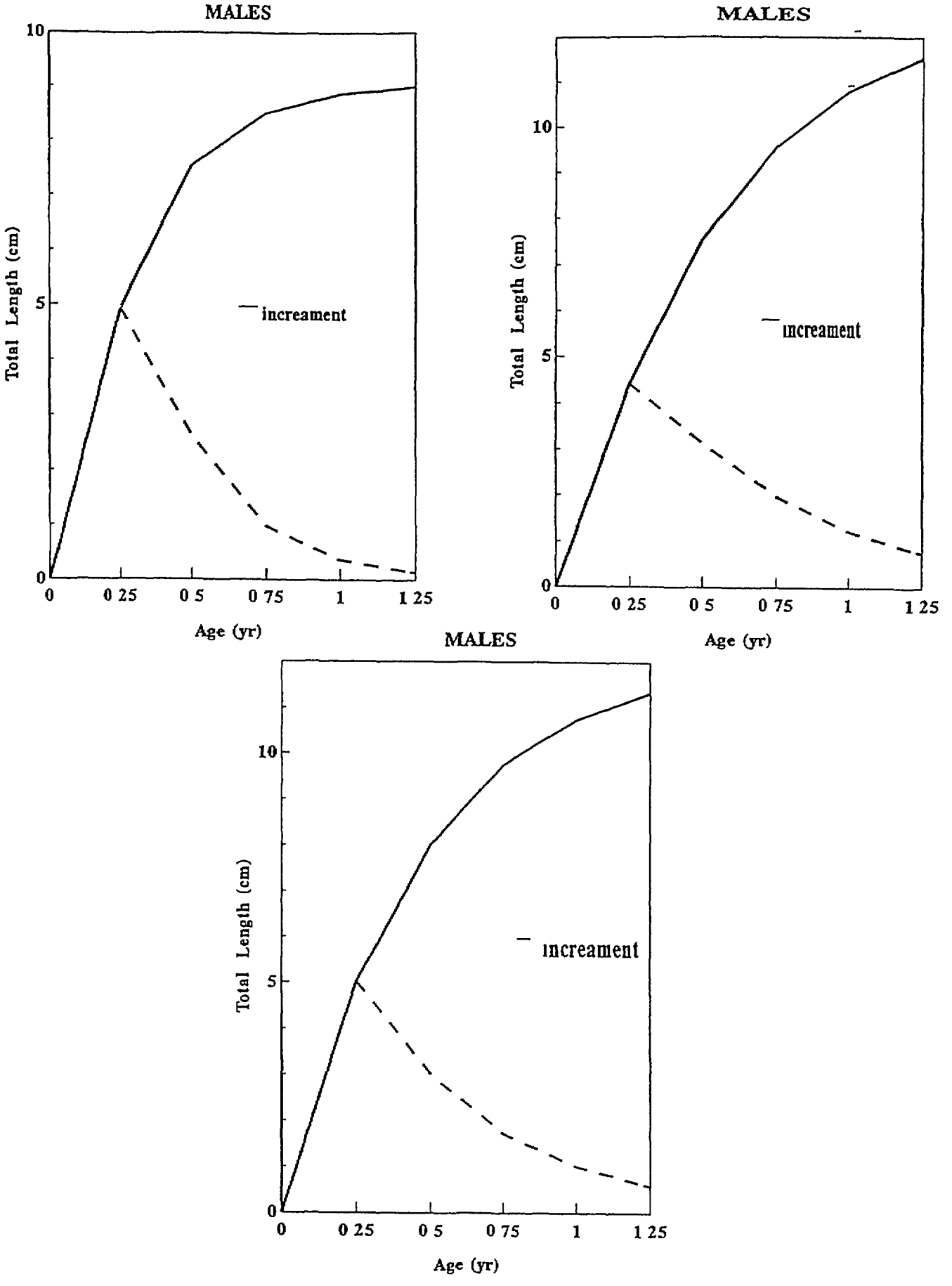


Fig. (65): Growth in length and increment of *Metapenaeus stebbingi* collected from Lake Qarun.

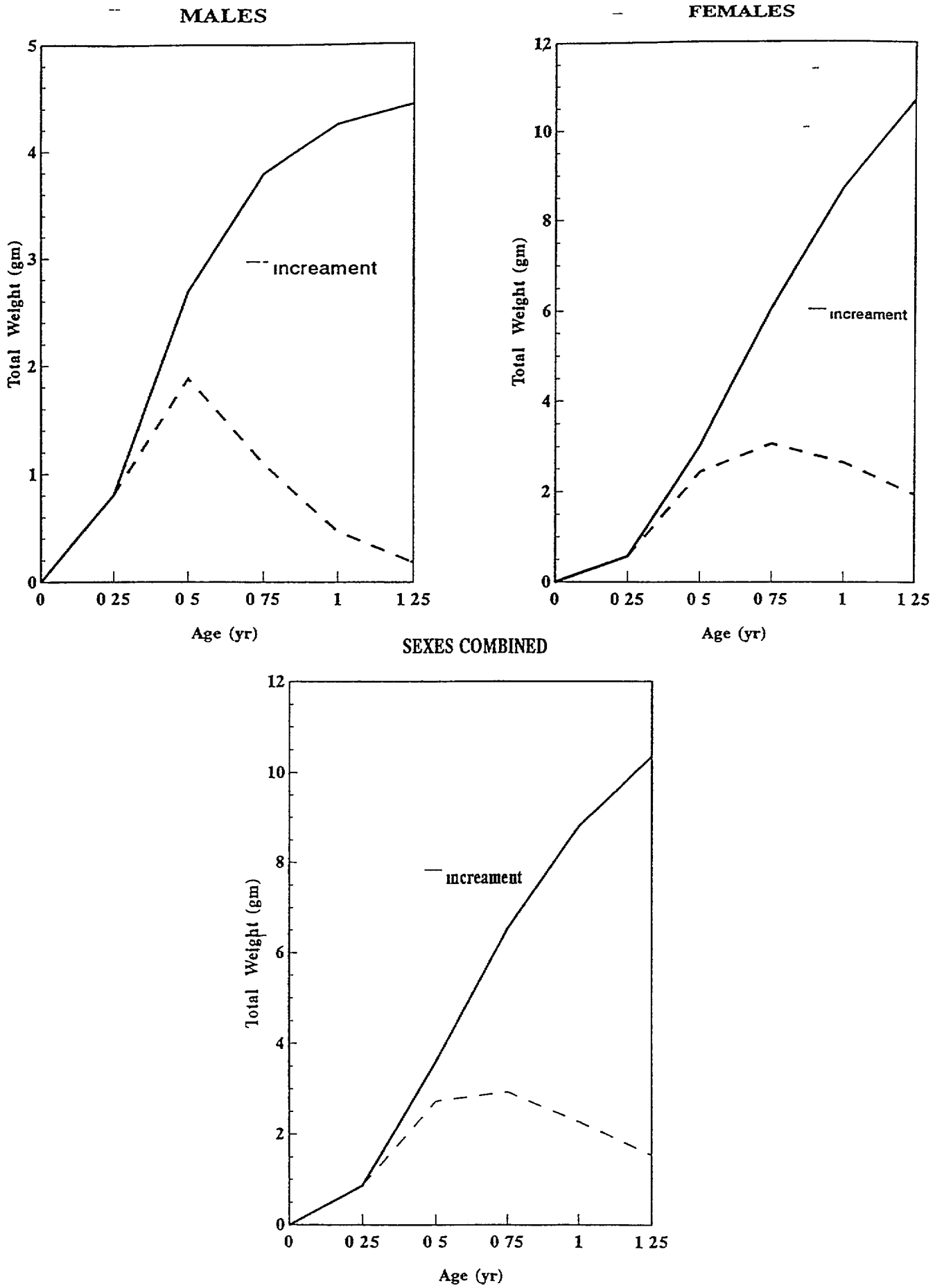


Fig.(66): Growth in weight and increment of *Metapenaeus stebbingi* collected from Lake Qarun.

The most widely applied model was that of VBGF Table (5) summarizes the results of VBGE constant for the different fish species, for the separate sexes as well as for the combined sexes

- **Food and Feeding habits ·**

The percentage composition of the different food items recorded in the stomachs of different species collected from Lake Qarun is shown in Fig (67) and can be summarized as follows

For *Solea aegyptiaca*, it was found that the major part of their food consists of detritus It is believed that most of the detritus is digested food The bottom fauna were mostly represented by crustacea and annelida, comprising about 38 45% of the total consumed food The results indicated that the soles were carnivorous bottom feeder

The crustacea contributed about 35 88% of the food of *Liza saliens*, while food of plant origin formed 30% of its needs Detritus constituted about 23% of the total consumed items

Food of plant origin which constituted about one third of the total food of *Tilapia zillii*, constituted mainly of bacillariophyceae, macrophytes, cyanophyceae and dinophyceae, in order of their importance The benthos formed about 18 35 % of the total food intake, while the crustacea alone contributed about 13 61% The rest of the food consisted of detritus, comprising 44 85%

Oreochromis aureus and *O niloticus* consumed benthic organisms with the following percentages 21 11 and 33% The organisms were constituted mainly of crustacea (20 22% and 27 09 %) The major part of their food was detritus which comprised 66 and 58 54% for *Oreochromis aureus* and *O niloticus*, respectively

Detritus formed the main food of *Metapenaeus stebbingi*, while the other components of the stomach were benthos (19 43%), protozoa (2 14%) and diatoms (3 0%)

In general, the results indicated that almost all the adult fish species as well as shrimp stocks in Lake Qarun are bottom feeders especially on crustacea, while the fry are plankton-feeders

- **Reproduction**

◊ **Gonado-Somatic index**

Monthly variations in GSI of the different fish species collected from Lake Qarun are shown in Fig (68)

The monthly variation of gonado-somatic index of the female soles' showed a marked increase from September to February, followed by a significant decrease, reaching its minimum in August For the males, there was no significant variations in the GSI value throughout the year, except in December when a slight increase was observed It was noticed that the testes of soles were very small and did not show any significant maturation peculiarities during the year This leads one to conclude that the spawning season of soles extends from early November till late February, while the ripeness reaches its maximum in late February

Table (5) von Bertalanffy grwoth parameters for the different species collected from Lake Qarun .

Species	Parameter	Males	Females	Sexes combined
Solea aegyptiaca	K	0 3756	0 4155	0 3070
	t_o	-1 9306	-1 5600	-1 6170
	L_∞	25 74	30 05	32 19
	W_∞	143 46	249 76	304 94
Liza saliens	K	0 4762	0 2940	0 3030
	t_o	-1 6700	-1 6800	-1 4545
	L_∞	22 87	31 19	31 05
	W_∞	87 81	240 26	241 94
Tilapia zillii	K	0 2894	0 3714	0 2754
	t_o	-0 9688	-0 5353	-0 9370
	L_∞	26 62	24 23	27 16
	W_∞	346 87	275 80	373 12
Oreochromis aureus	K	0 4573	0 3064	0 3081
	t_∞	-0 4019	-0 6089	-0 6488
	t_o	31 26	36 83	36 51
	W_∞	513 62	783 67	777 05
Oreochromis niloticus	K	0 4201	0 3578	0 3640
	t_o	-0 4370	-0 5324	-0 4125
	L_∞	31 57	31 06	33 54
	W_∞	613 26	553 70	730 47
Metapenaeus stebbingi	K	3 974	1 947	2 181
	t_o	0 053	0 036	0 005
	L_∞	9 069	12 749	12 145
	W_∞	4 545	14 421	12 751

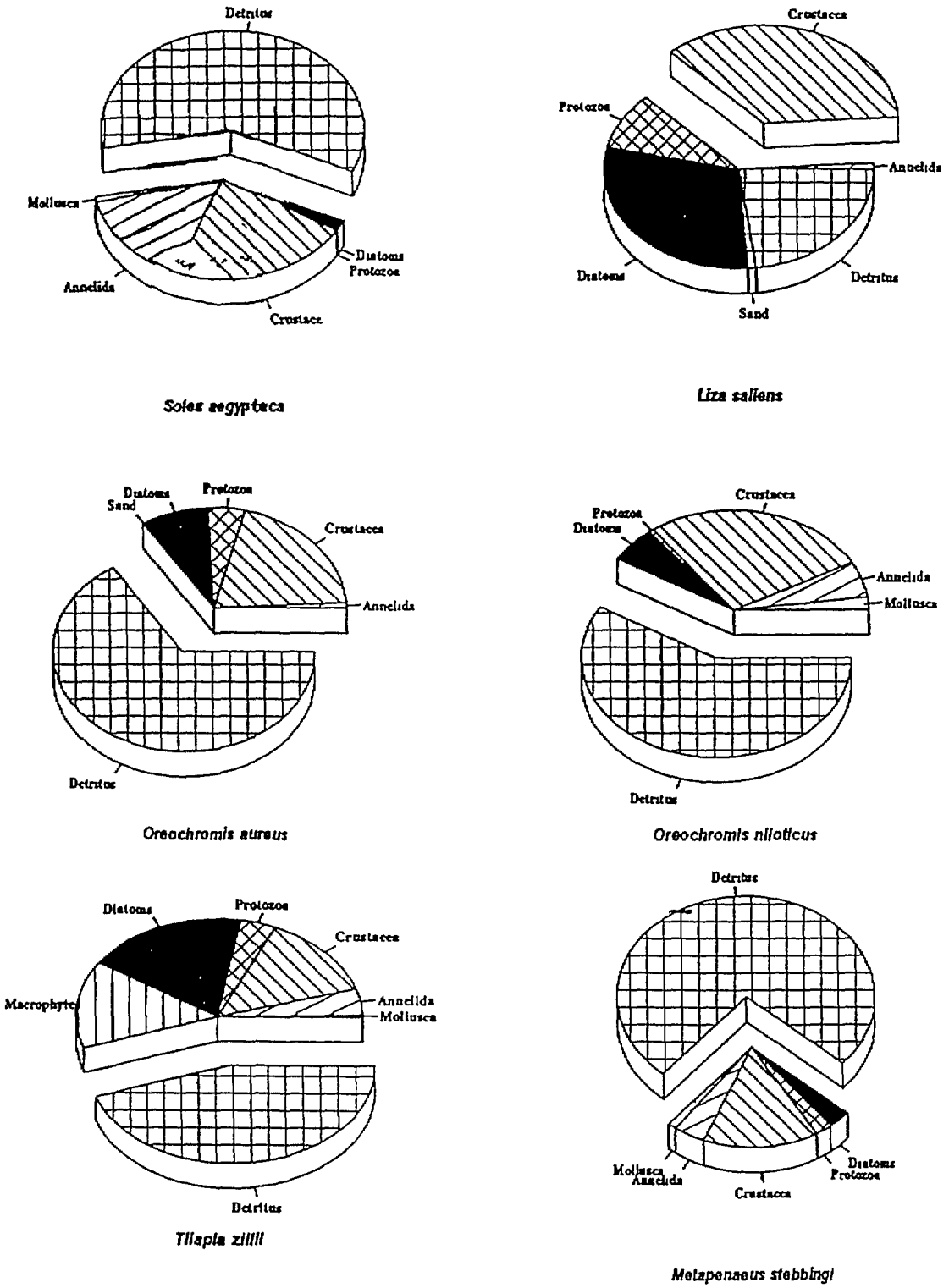


Fig.(67): Percentage composition of the different food items recorded in the stomachs of different species collected from Lake Qarun.

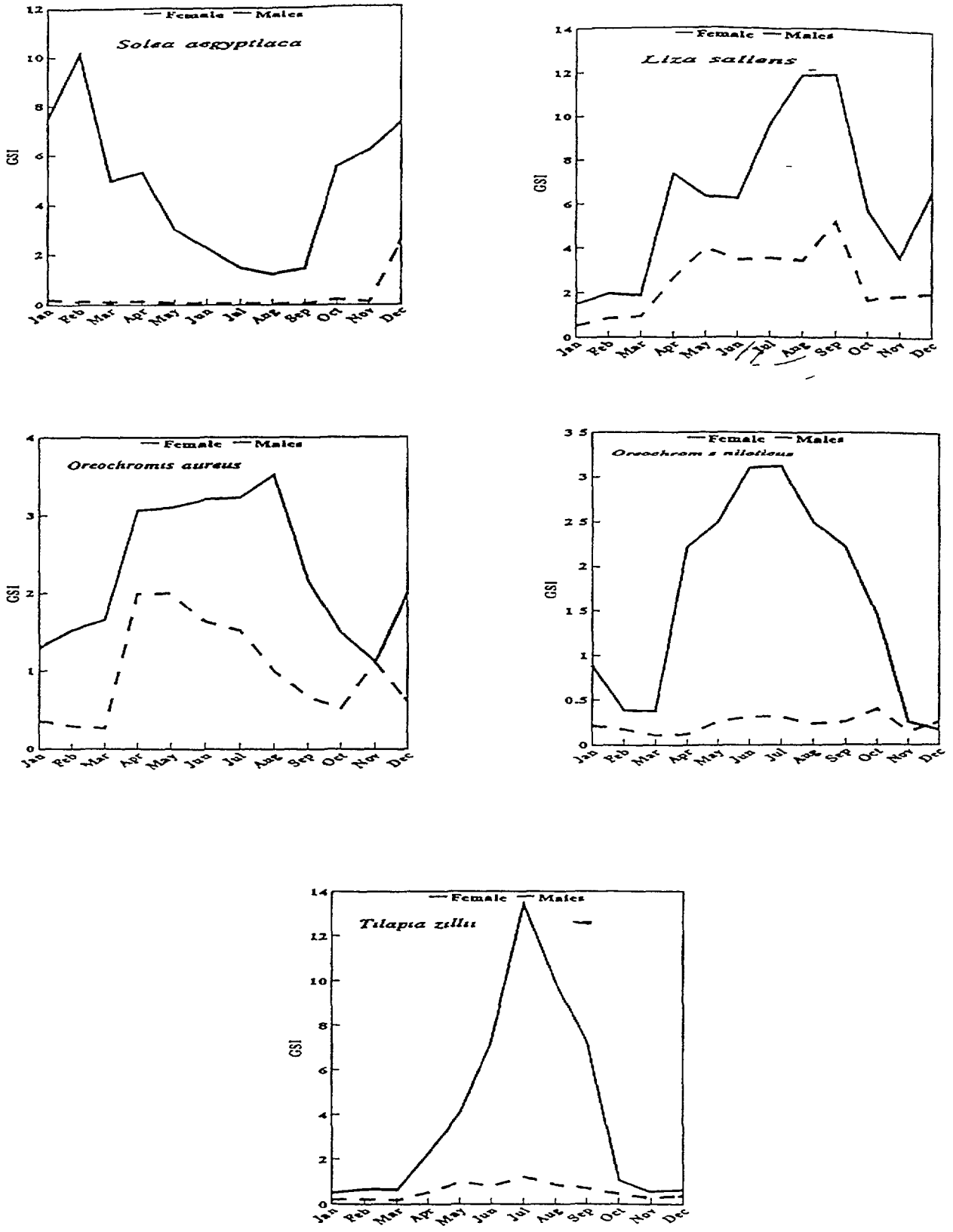


Fig.(68): Monthly variation of Gonado-somatic index of the different fish species collected from Lake Qarun.

For *Liza saliens*, two peaks were noticed during April and August-September, the latter is higher than the former These peaks were clear for both sexes Thus it appears that two spawning periods take place, one in the spring (April), and the other in late summer (August-September) Therefore, it can be concluded that ripe fish release an early patch of eggs during April

For both of *O aureus* and *O niloticus*, the results indicated a long and protracted spawning season from April to September For *T zillii*, one peak was noticed during July

◊ **Size at first sexual maturity**

The size and age at first sexual maturity, which is defined as the length at which 50% of a given fish stock reaches sexual maturity, is an important parameter in assessing the optimal size and age at first capture A graphical method was used to determine the length at first sexual maturity It consists of a simple fitting maturation percentage curve with length The length at first sexual maturity is then graphically estimated as the point on X-axis corresponding to 50% point on the Y-axis

As mentioned above, testes of soles showed no significant maturity throughout the year Thus, length at first sexual maturity was determined for the females only and was estimated at 20 8 cm. In conjunction with the analysis of length frequency distribution (as will be discussed later), about 38% of the soles were fished before attaining the first sexual maturity

Length at first sexual maturity was determined at 16 4 and 16 8 cm for males and females of *Liza saliens*, respectively From length frequency, the results indicated that 30% and 9% of the males and females, were fished before reaching their first maturity

With respect to *Tilapia zillii*, the length at first sexual maturity was estimated at 13 3 and 10 2 cm for males and females, respectively This means that from length frequency distribution, 58% and 43% of the males and females were caught without undergoing any spawning

As for *Oreochromis aureus*, it was found that length at first sexual maturity was 15 3 and 12 4 cm for females and males, respectively Length frequency data indicated that about 40 and 9 % of males and females were landed before reaching their first sexual maturity

Length at first sexual maturity (L_{50}) was estimated to be 20 3 and 13 5 cm for males and females of *Oreochromis niloticus*, respectively This means that about 89% and 45% of the males and females were caught prior to reaching the sexual maturity

In general, the results indicated that the exploited fish stocks in Lake Qarun are heavily exploited before attaining sexual maturity To protect the recruitment for the spawning stocks in the lake size limits must be established to lengths greater than the (L_{50})

- **Management Studies**

◊ **Population structure**

◊ **Length frequency distribution**

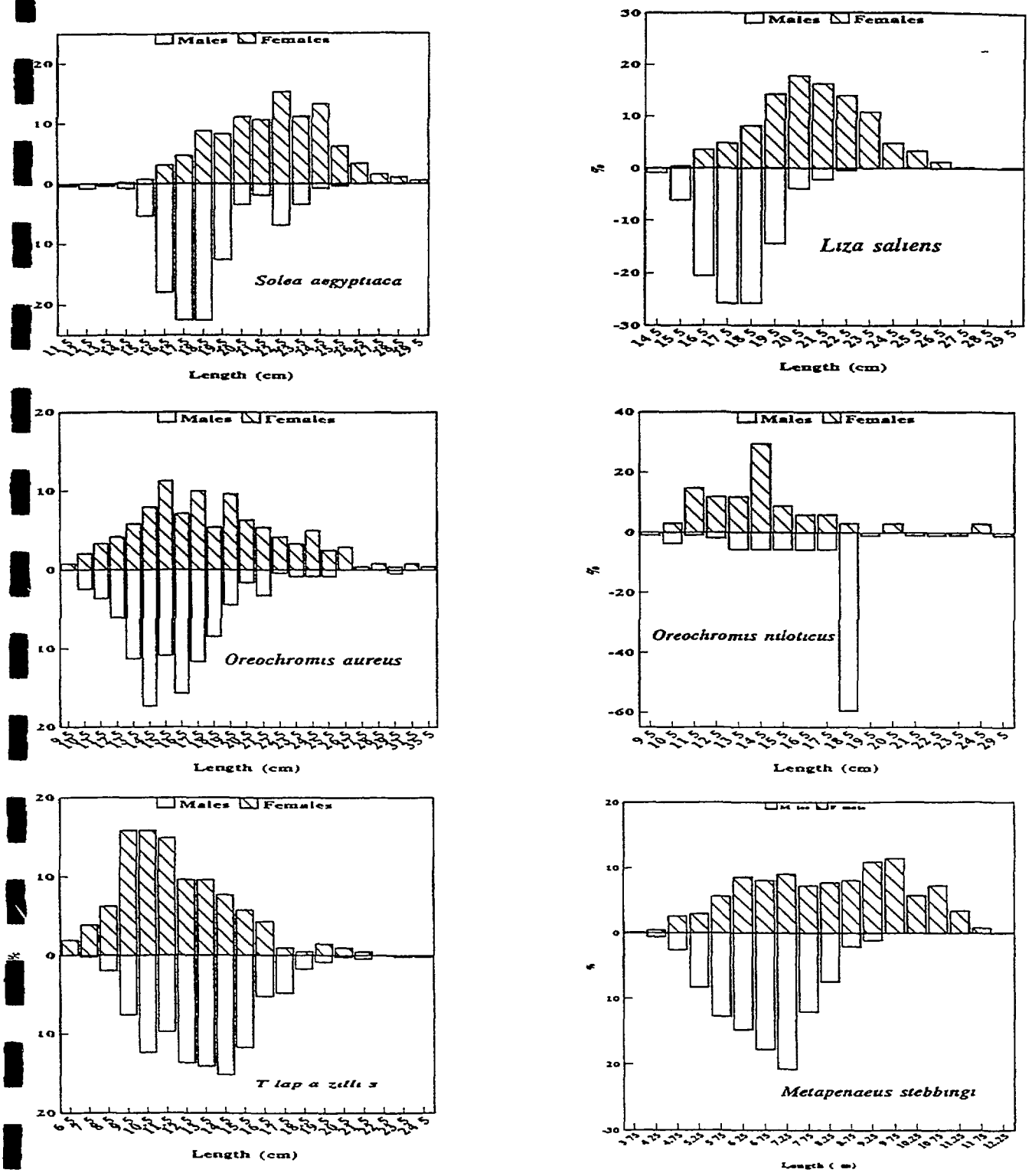
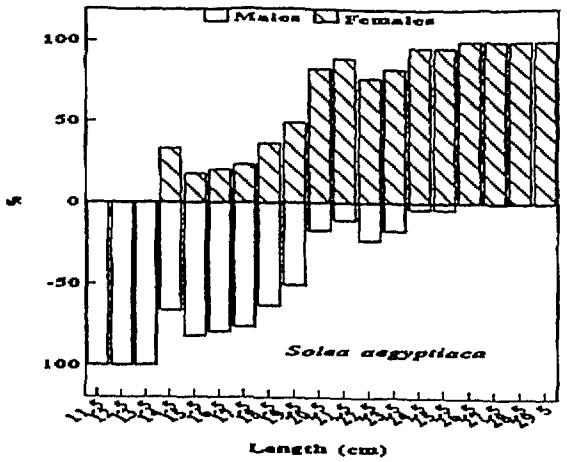
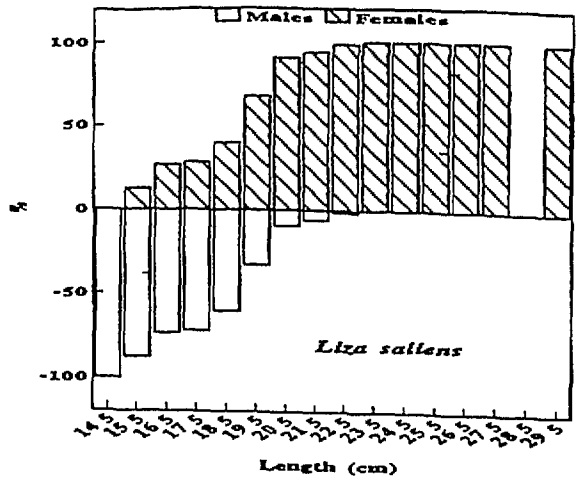
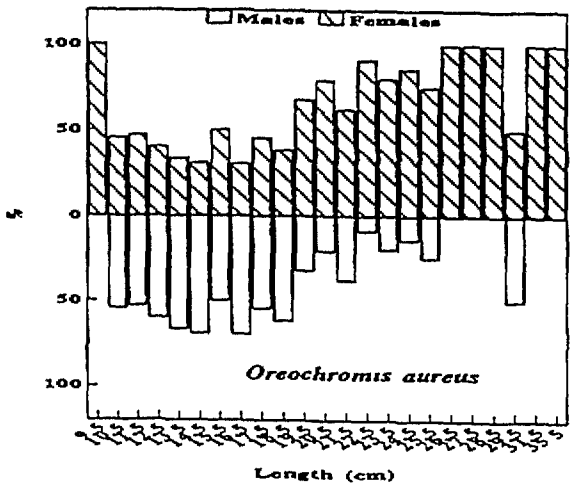
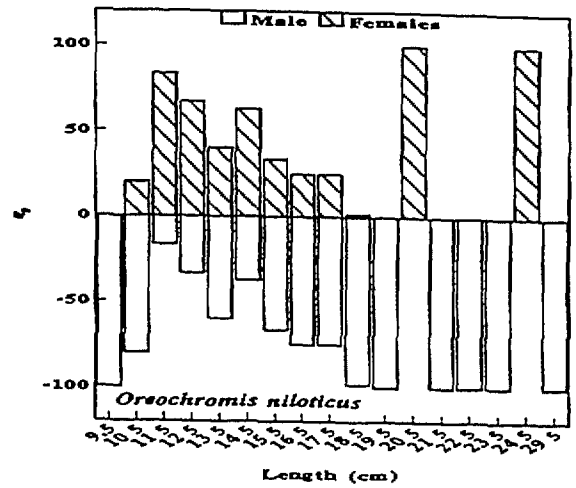


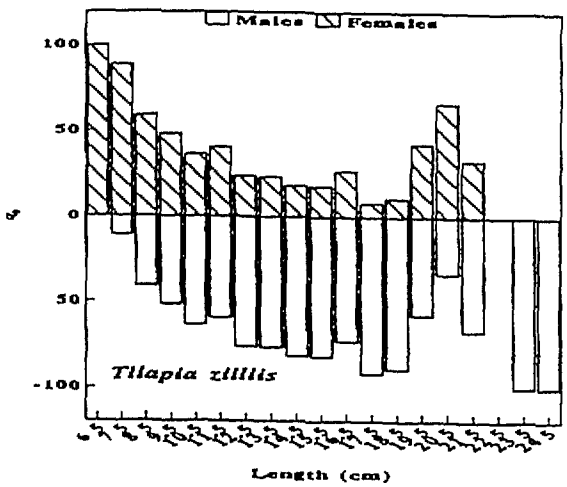
Fig.(69): length frequency distribution for the different fish species collected from Lake Qarun.











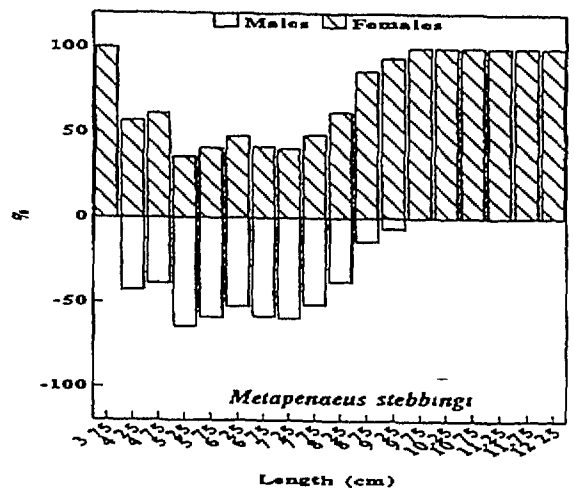


Fig.(70): Sex ratio among the different length group for the different fish species collected from Lake Qarun.

Length frequency distributions for the fish species collected from Lake Qarun are shown in Fig 69 For *Solea aegyptiaca*, the males ranged from 11 4 to 22 1 cm, while for the females their lengths range of about 14 7 to 29 1 cm. The graph showed a polymodal distribution of length frequencies for both males and females It is evident from the graph that almost all the males (about 85%) are small in size (15 5-20 5 cm.) On the other hand, most of the females (about 70%) are medium-sizeed fishes (ranging from 19 5 to 25 5 cm)

The lengths of *Liza saliens* in the catch varied between 15 7 and 29 5 cm for the females, and from 14 1 to 22 1 cm, for the males A great proportion (about 95%) of the males in the commercial catch were small in size (from 15 5 to 19 5 cm) while a considerable percentage (75%) of the females was medium sized (from 19 5 to 23 5 cm)

The size composition of *Tilapia zillii* males varied between 7 8 and 24 9 cm, that of the females ranged from 6 2 to 21 6 cm. The catch comprised about 75% of small-sizeed fishes, their lengths ranged from 9 5 to 15 5 cm.

Polymodal distribution of length frequency could be easily distinguished for both males and females of *Oreochromis aureus* The males ranged from about 10 1 to 29 0 cm, while females were distributed through a length range of about 9 5 to 35 5 cm. As to *Oreochromis niloticus*, its sizes varied between 9 2 and 29 6 cm, with an average length of 18 5 cm. The size of females ranged between 10 6 and 24 7 cm. A polymodal distribution of length frequencies are quite evident among females

Size composition of *Metapenaeus stebbingi* males varied between 4 1 and 9 3 cm, with modal length of 7 2 cm. Length of females ranged from 3 9 and 12 0 cm. The graph revealed a polymodal distribution of length frequency in case of females

◊ **Sex ratio** ·

Sex ratios among the different length groups for the different fish species collected from Lake Qarun are represented in Fig 70 For *Solea aegyptiaca*, *Liza saliens* and *Metapenaeus stebbingi*, among the small fishes the males outnumbered the females, while in larger length groups, the females are dominant In general, for the three species, females were more abundant than males The ratios of males to females were 1 1 473, 1 2 087 and 1 1 579, for the soles, mullet and shrimps, respectively

For both of *Tilapia zillii* and *Oreochromis niloticus*, in the small length groups, the females outnumbered the males, while in the larger length intervals the males were more abundant than females Sex ratio of males to females were 1 0 450 and 1 0 321 for the two species, respectively Concerning *Oreochromis aureus*, the ratio of males to females was 1 0 968

Age and growth studies revealed that there was a difference in growth in length and weight between males and females of *Solea aegyptiaca*, *Liza saliens*, *Metapenaeus stebbingi*, *Tilapia zillii* and *Oreochromis niloticus* The difference in the growth rates could explain the reason for the dominance of a definite sex in the catch As fishes attained larger size and heavier weights they are more vulnerable to be caught in the nets, hence they are more abundant in the catch For soles, mullets and shrimp, the females reached older ages, larger size and heavier weights Accordingly, they outnumbered the males in the catch For *Tilapia zillii* and

Oreochromis niloticus, the males attained older ages, larger size and heavier weights and as a result they outnumbered the females in the catch

◊ Age composition

The age compositions for the different fish species collected from Lake Qarun are summarized in Table 6 The results indicate that except for *Oreochromis niloticus*, the fishery depends on age Group I The fishery for *Oreochromis niloticus* depends mainly on age Group 0

◊ Mortality coefficients

Instantaneous total mortality, natural mortality, fishing mortality as well as survival rates of the different fish species are shown in Table 7 The results show that *Metapenaeus stebbingi* and *Solea aegyptiaca* sustained the highest mortality rates They also had the lowest survival rate, 0 75 and 0 89, respectively *Oreochromis niloticus* had the lowest mortality rate, and the highest survival rate

◊ Yield Per Recruit

Beverton and Holt (1957) yield per recruit model was applied to calculate yield per recruit for the different fish species in Lake Qarun, as a function of natural mortality coefficient and age at first capture (Figs 71 - 82) The results showed that all fish stocks in Lake Qarun are overexploited The results indicated also that the increase of age at first sexual maturity, and/or decrease in natural mortality, is associated with a pronounced increase in the yield per recruit

For *Solea aegyptiaca*, Figs 71 and 72, it was found that with the decrease in natural mortality from 0 23 (present value) to 0 13, the maximum yield per recruit increases from 51 99 to 74 39, i e the yield increases about 43 08% On the other hand, the increase in age at first sexual maturity (t_c) from 1 2 to 1 6 leads to an increase in maximum yield per recruit from 51 99 to 55 26

The exploitation rates were estimated for the different fish species Relative yield per recruit (Y'/R) as well as relative biomass per recruit (B'/R) models were estimated for the different species (see Figs 83 - 88) Table (8) represents exploitation rate, relative yield per recruit and relative biomass per recruit for the investigated species at the present level of exploitation as well as at the exploitation rate corresponding to the maximum yield per recruit The results showed that all fish stocks in Lake Qarun are overexploited It is necessary that the exploitation rate be decreased to achieve the maximum yield per recruit This could be done by lowering the fishing mortality rates As a result, the yield of the different fish species will increase, especially that for tilapias

Table (6) - Age composition of the different fish species collected from Lake Qarun .

Species	Sex	Age groups					
		0	I	II	III	IV	V
Solea aegyptiaca	Males	39 53	50 35	9 88	0 24		
	Females	34 02	45 75	18 18	0 88	0 59	0 59
	Combined	37 8	48 30	13 58	0 52	0 26	0 26
Liza salienS	Males	9 13	75 80	13 24	1 37	0 46	
	Females	2 83	62 39	32 39	1 52	0 65	0 22
	Combined	4 86	66 72	26 22	1 47	0 59	0 15
Tilapia zillii	Males	28 57	49 15	20 34	1 45	0 48	
	Females	42 68	39 49	16 56	1 27		
	Combined	32 46	46 49	19 03	1 40	0 35	
Oreochromis aureus	Males	46 69	47 12	5 79	0 41		
	Females	27 78	36 32	30 34	5 56		
	Combined	37 39	41 81	17 86	2 94		
Oreochromis niloticus	Males	65 91	25 00	6 82		2 27	
	Females	67 65	26 47	2 94	2 94		
	Combined	66 67	25 64	5 13	1 28	1 28	

Table (7) Natural mortality (M), Fishing mortality (F), Instanteneous total mortality (Z), Survival rate (S) and Annual mortlity rate (A) for the species collected from Lake Qarun .

Species	M	F	Z	S	A
Solea aegyptiaca	0 2322	1 3337	1 5659	20 89%	79 11%
Liza saliens	0 2605	1 0125	1 2730	28 00%	72 00%
Tilapia zillii	0 1730	1 1811	1 3541	30 90%	74 18%
Oreochromis aureus	0 2192	1 0677	1 2869	27 62%	72 38%
Oreochromis niloticus	0 2393	0 9348	1 1741	30 91%	69 09%
Metapenaeus stebbingi	0 6613	4 229	4 890	0 75%	99 25%

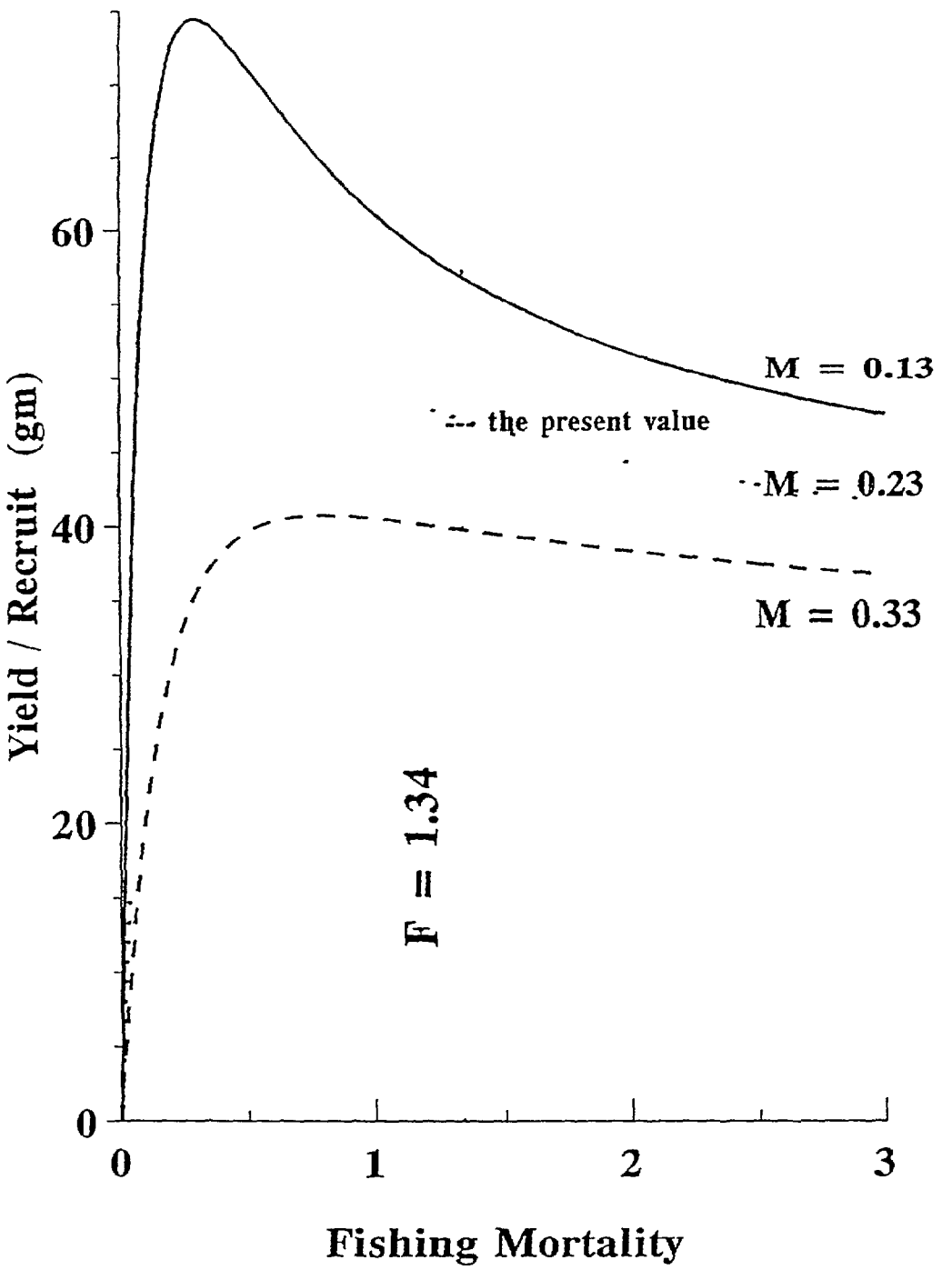


Fig. (71) : Yield per recruit (gm) of *Solea aegyptiaca* collected from Lake Qarun as a function of fishing mortality (F) and different levels of natural mortality (M).

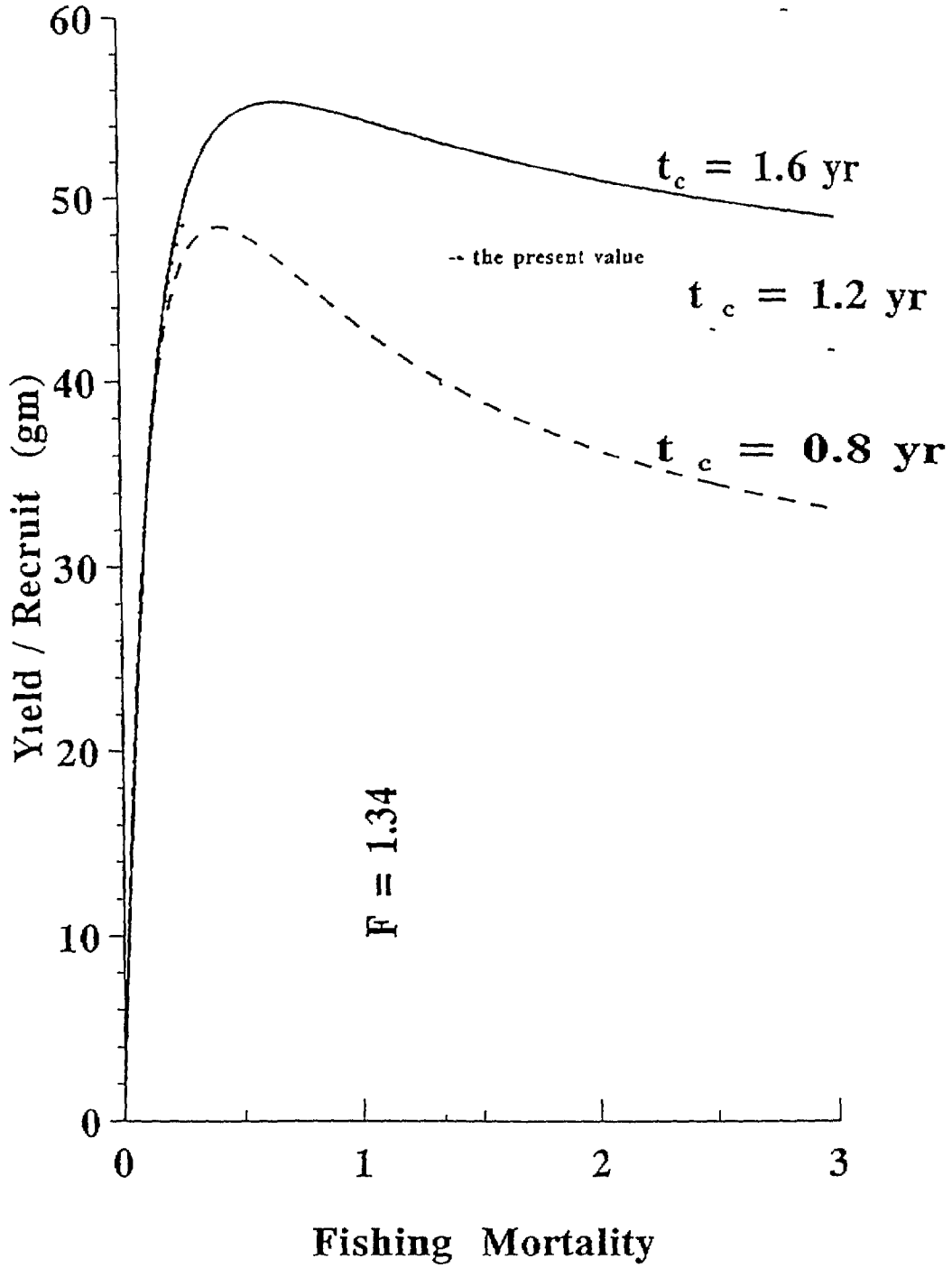


Fig. (72): Yield per recruit (gm) of *Solea aegyptiaca* col from Lake Qarun as a function of fishing mortality (F) and differnt ages at first capture (t_c).

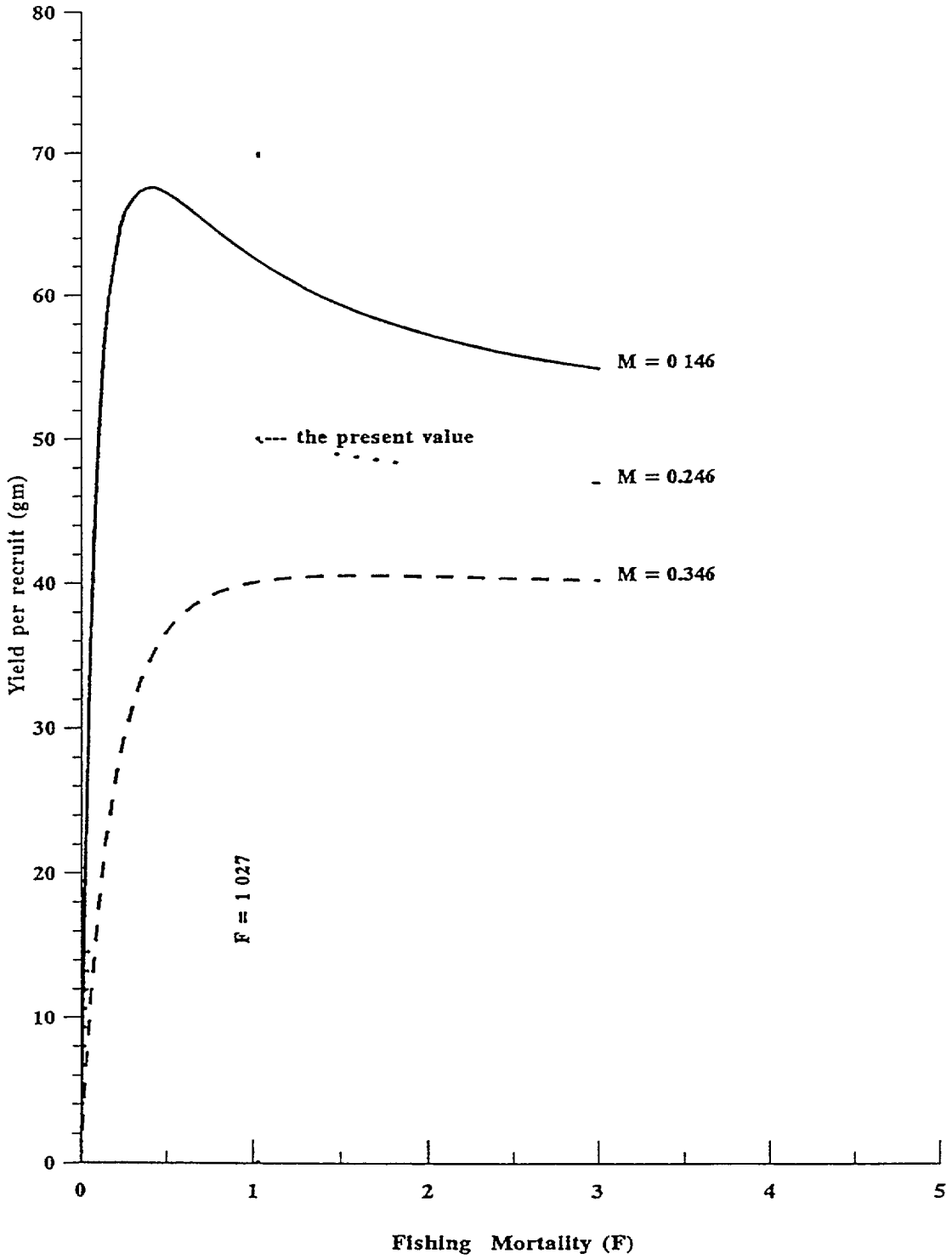


Fig (73) Yield per recruit (gm) of *Liza saliens* in Lake Qarun as a function of fishing mortality (F) and different levels of natural mortality (M)

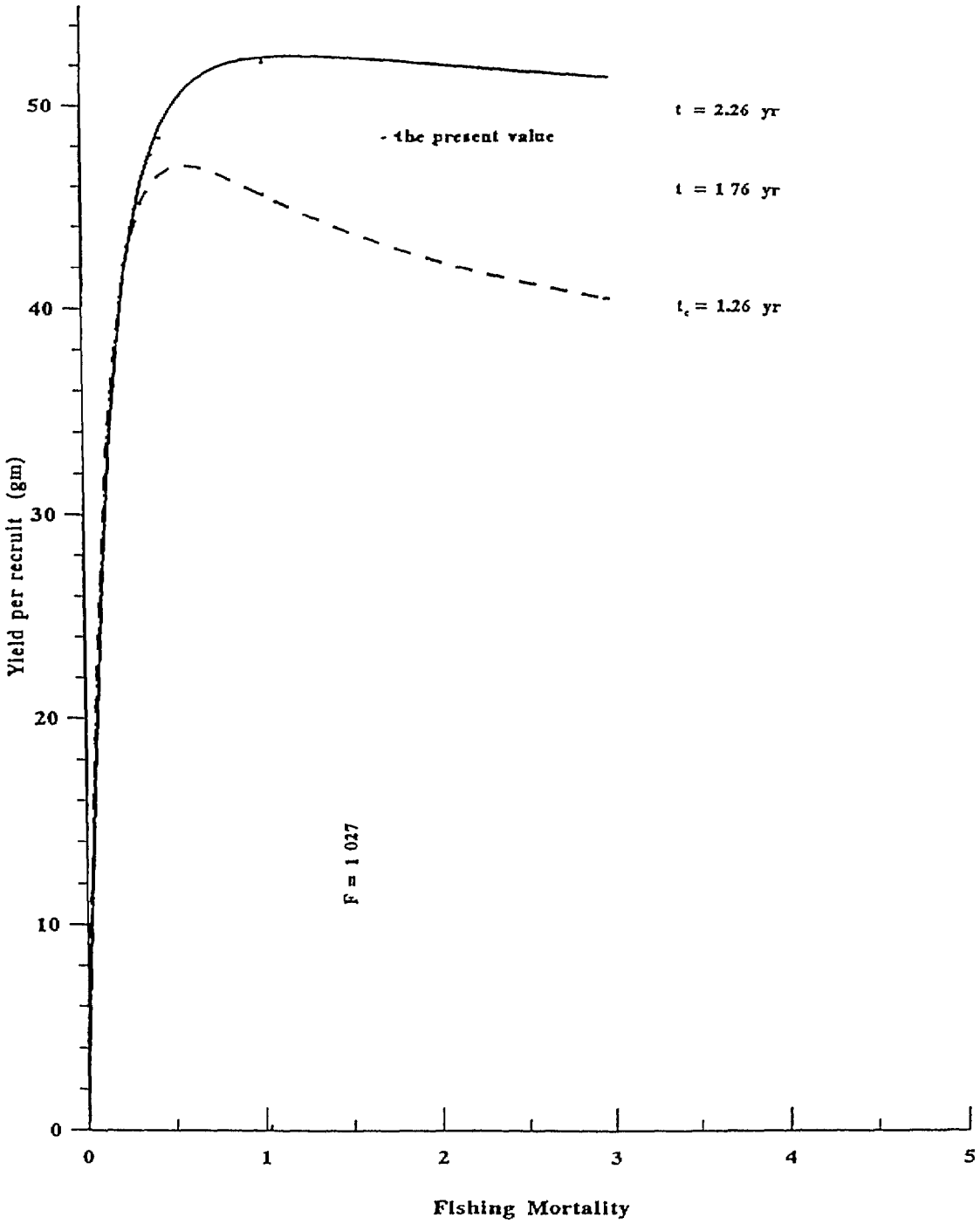


Fig (74) Yield per recruit (gm) of *Liza saliens* in Lake Qarun as a function of fishing mortality (F) and differnt ages at first capture (t_c)

360

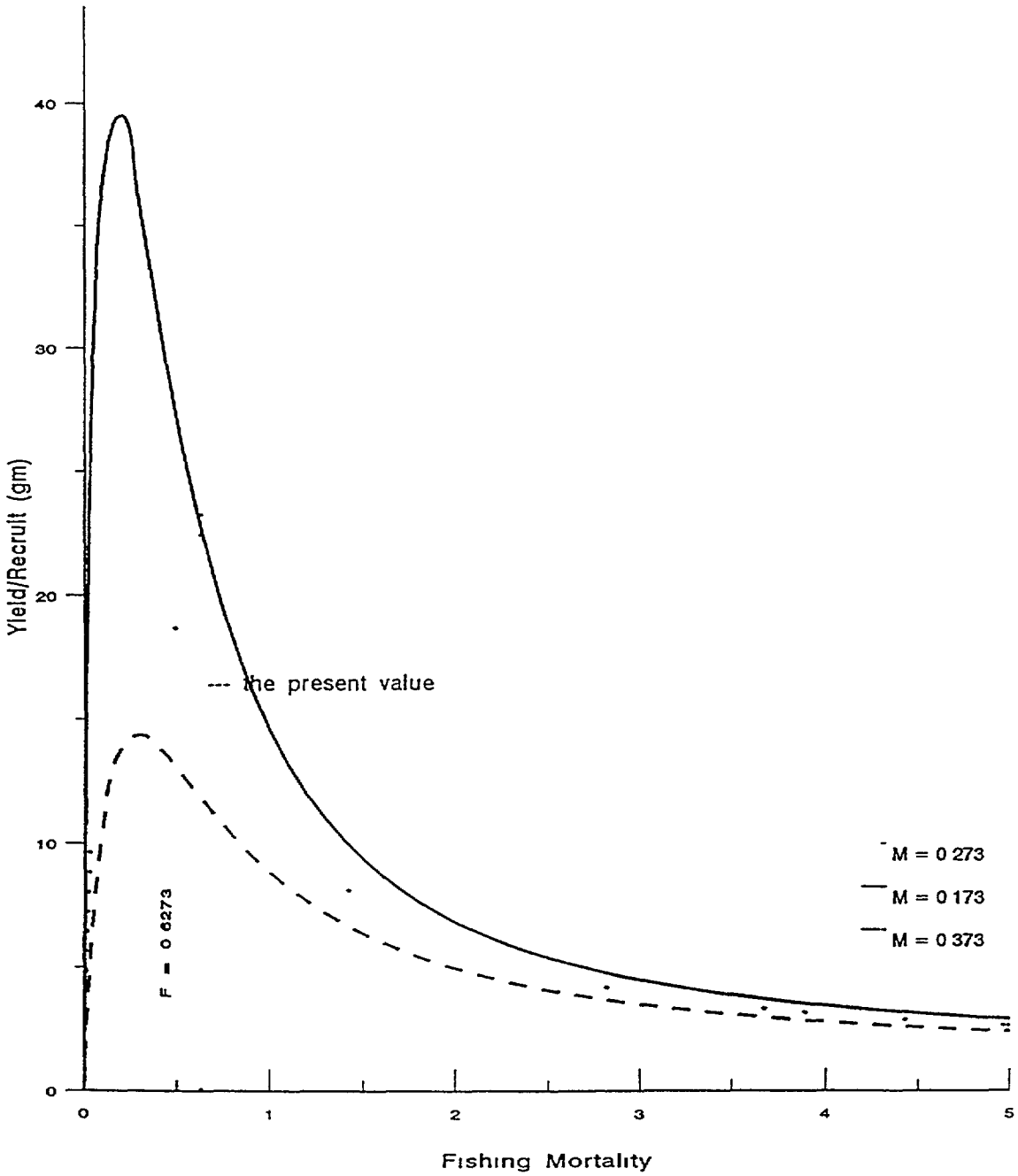


Fig (75) Yield per recruit(gm) of *Tilapia zillii* collected from Lake Qarun as a function of fishing mortality (F) and different levels of natural mortality (M)

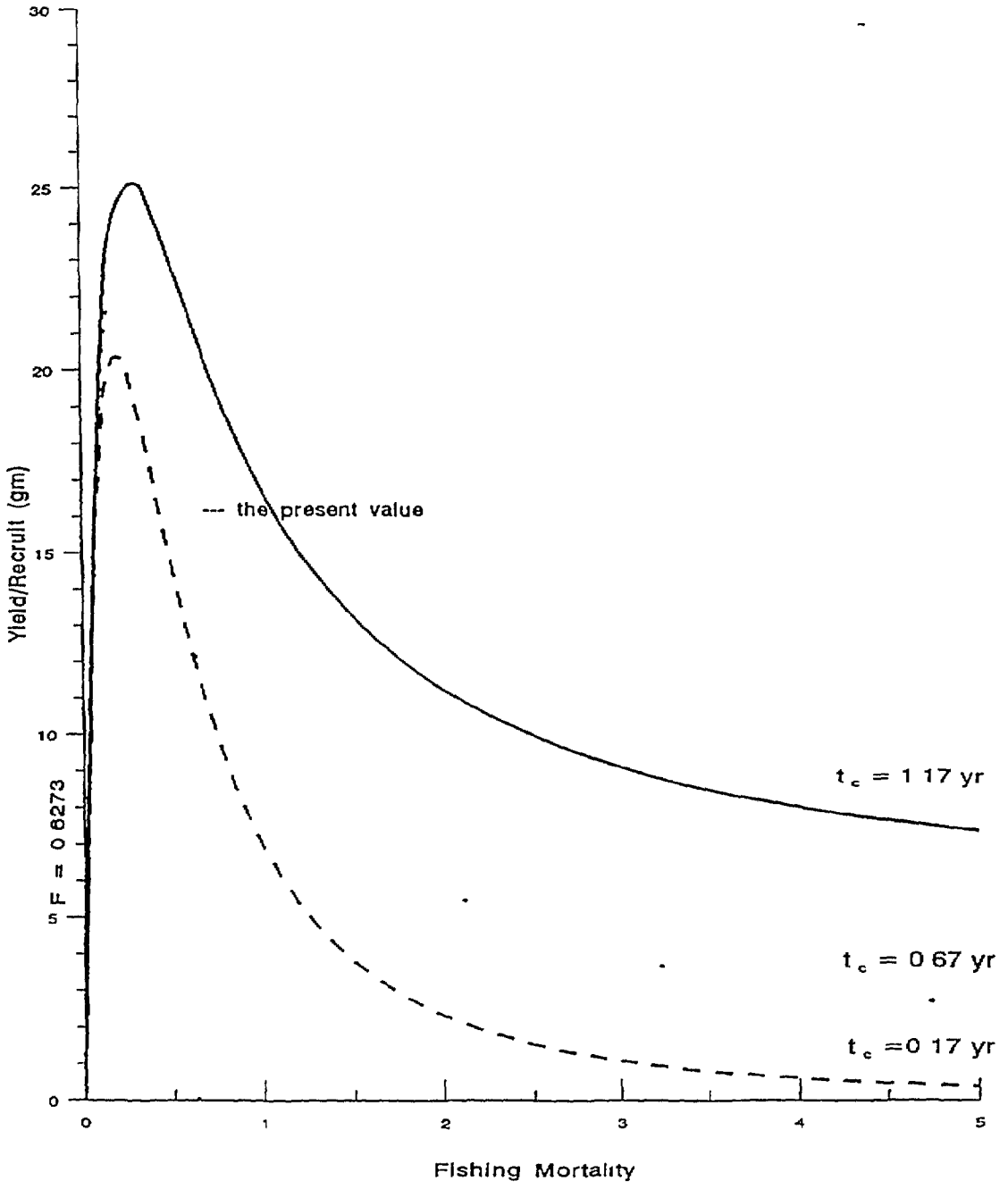


Fig (76) Yield per recruit(gm) of *Tilapia zillii* collected from Lake Qarun as a function of fishing mortality (F) and different ages at first capture(t_c)

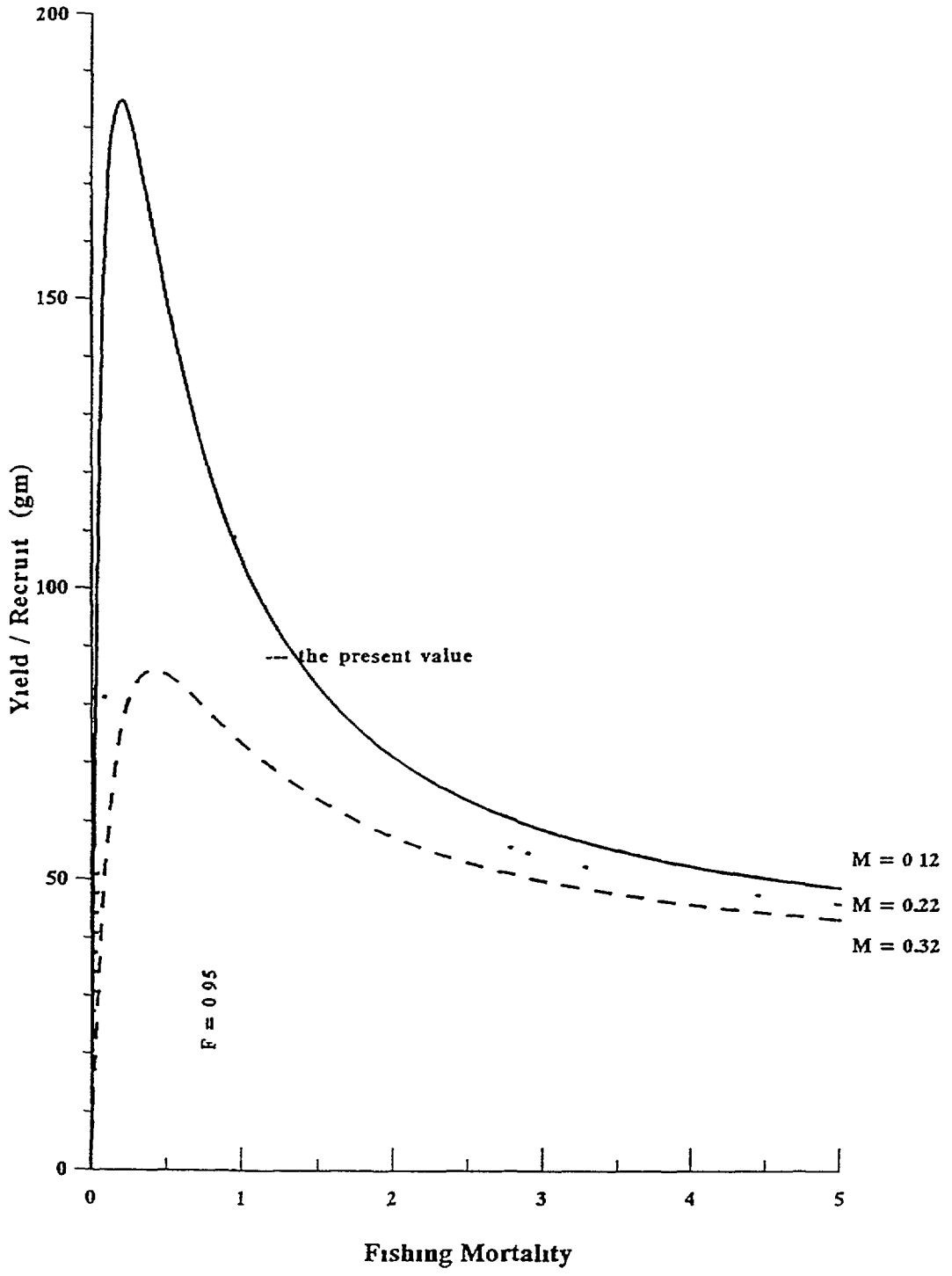


Fig (77) Yield per recruit (gm) of *Oreochromis aureus* as a function of fishing mortality (F) and different levels of natural mortality (M).

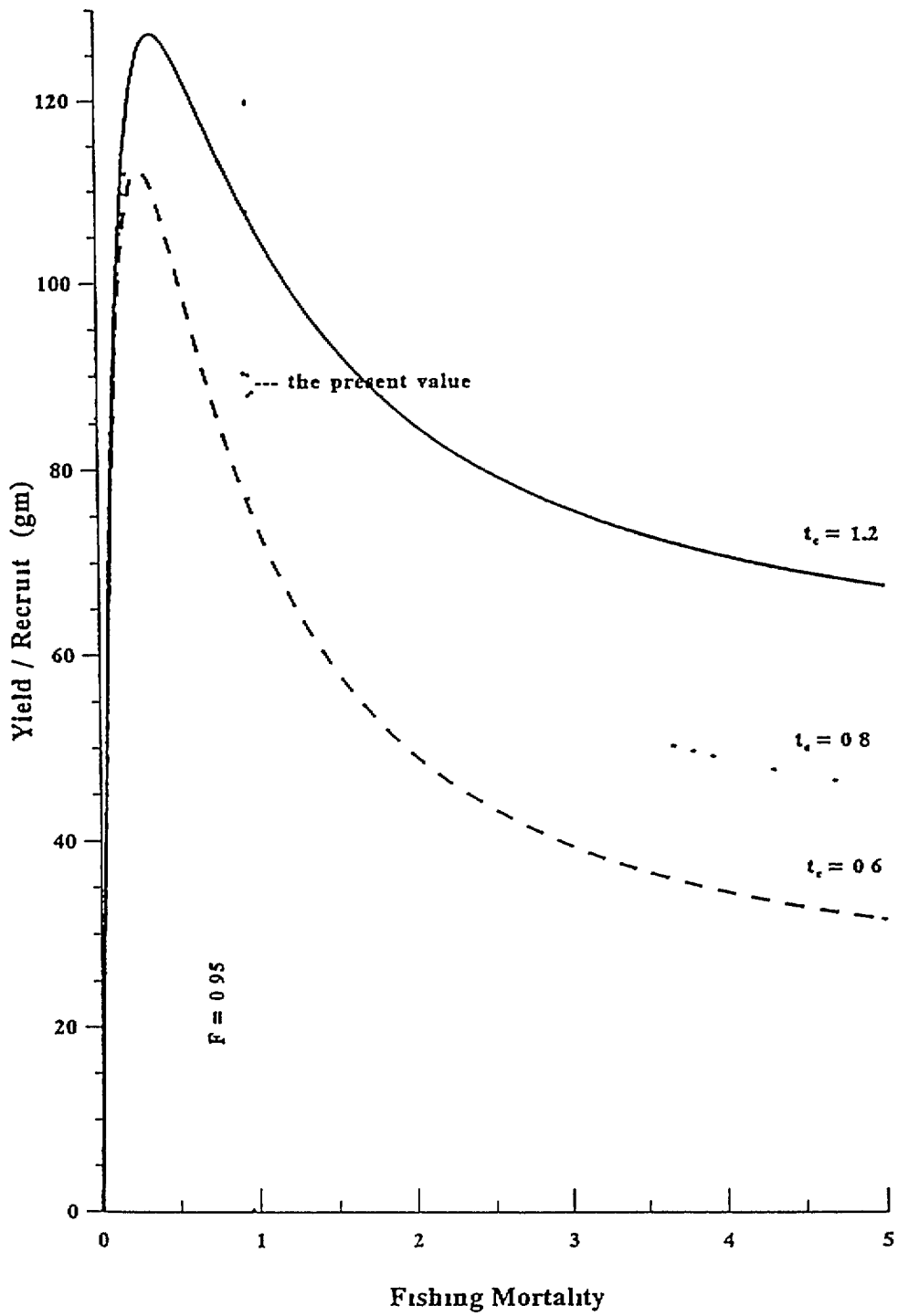


Fig (78) Yield per recruit (gm) of *Oreochromis aureus* as a function of fishing mortality (F) and differnt ages at first capture (tc)

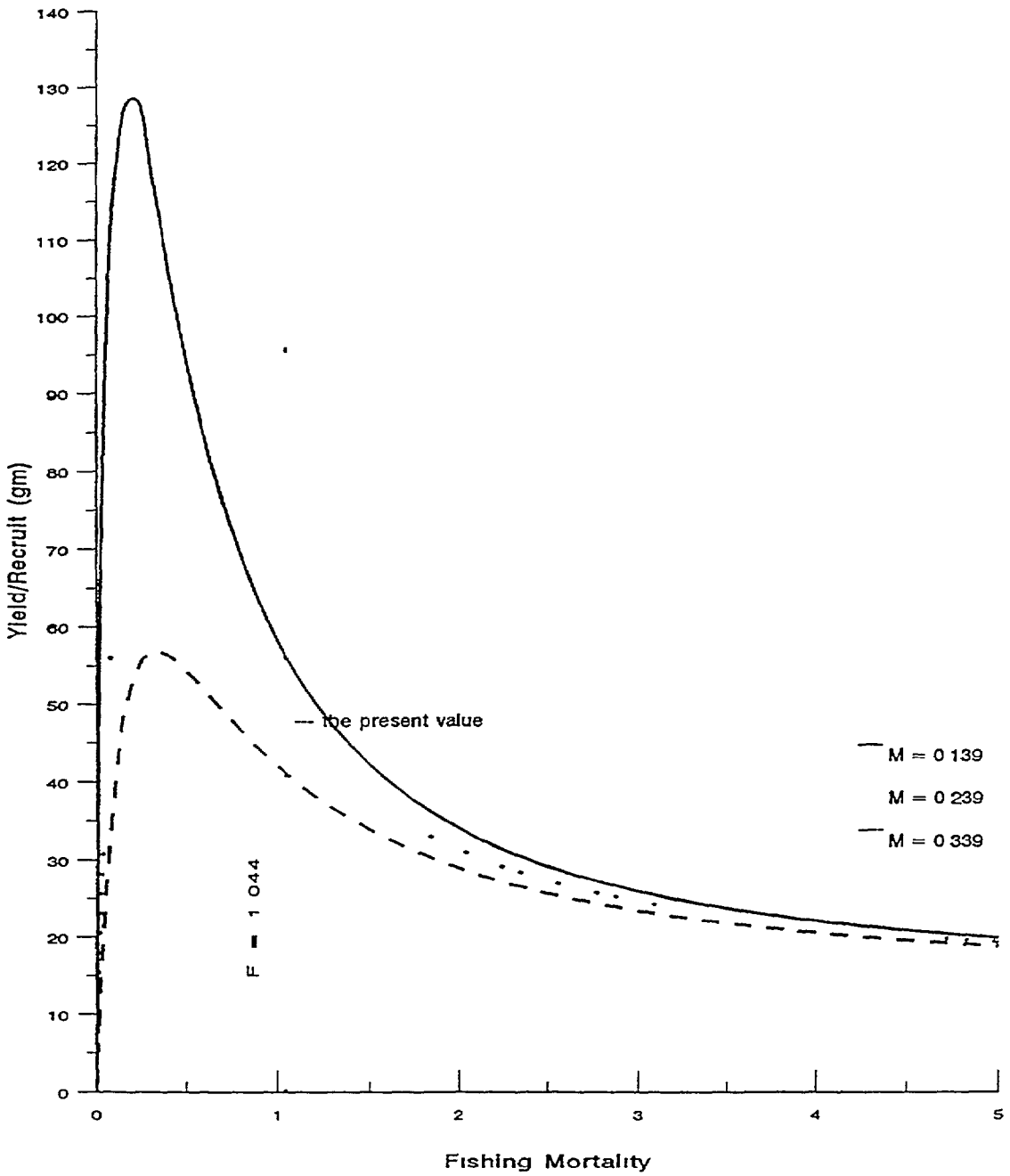


Fig (79) Yield per recruit(gm) of *Oreochromis niloticus* collected from Lake Qarun as a function of fishing mortality (F) and different levels of natural mortal,ty (M)

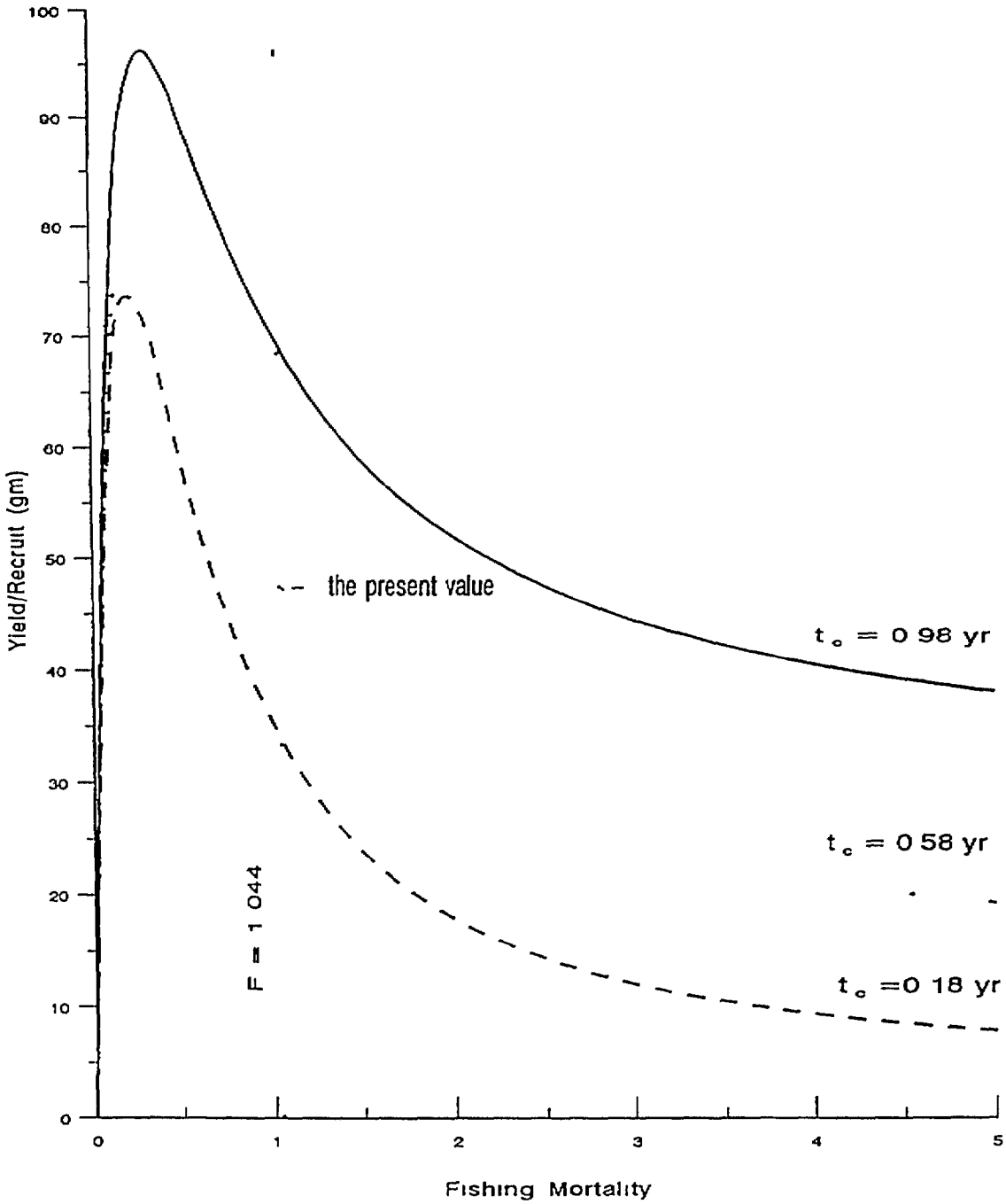


Fig (80) Yield per recruit(gm) of *Oreochromis niloticus* collected from Lake Qarun as a function of fishing mortality (F) and different ages at first capture(t_c)

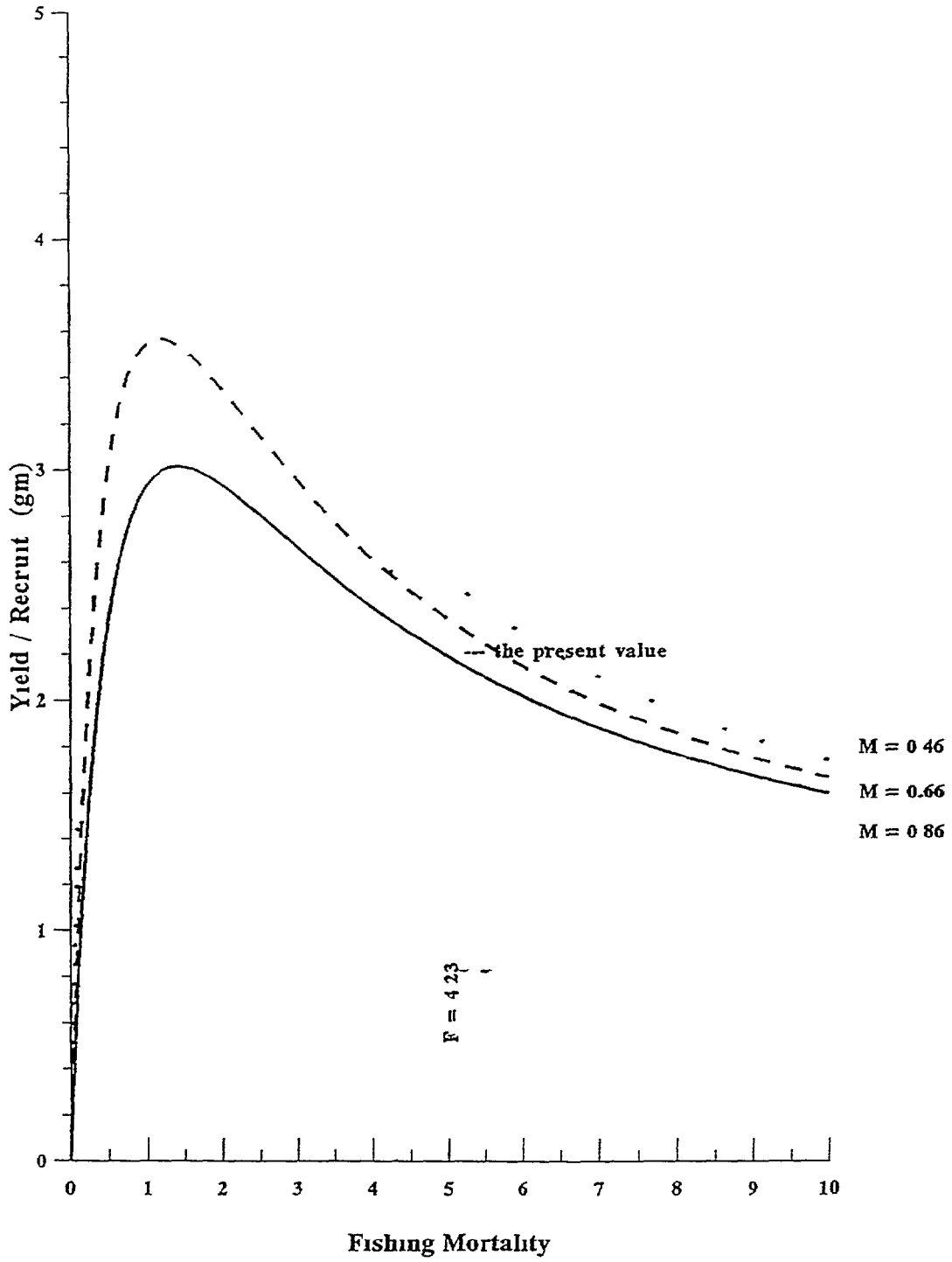


Fig.(81). Yield per recruit (gm) of *Metapenaeus stebbingi* as a function of fishing mortality and different levels of natural mortality

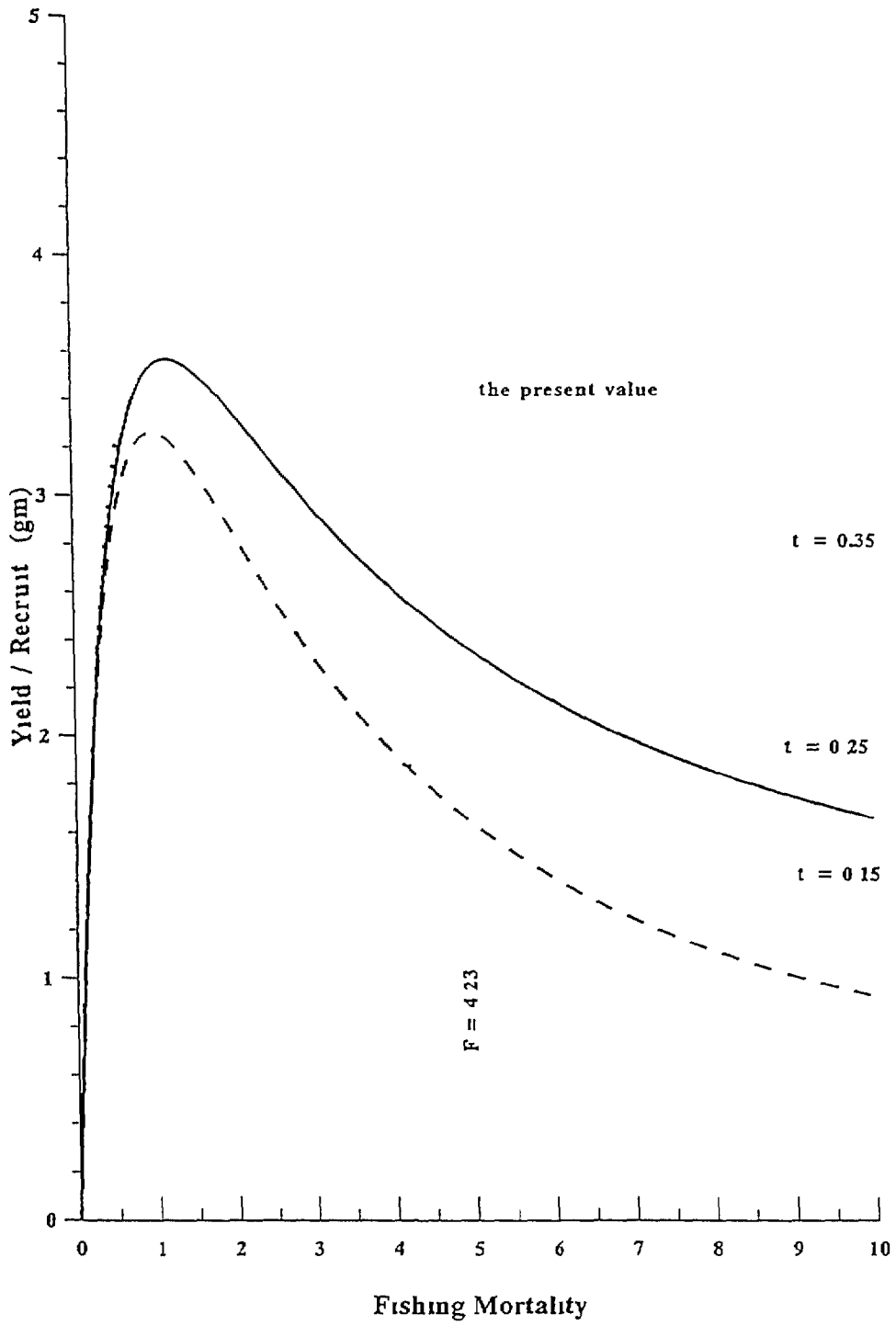


Fig (82) Yield per recruit (gm) of *Metapenaeus stebbingi* as a function of fishing mortality (F) and differnt ages at first capture (tc)

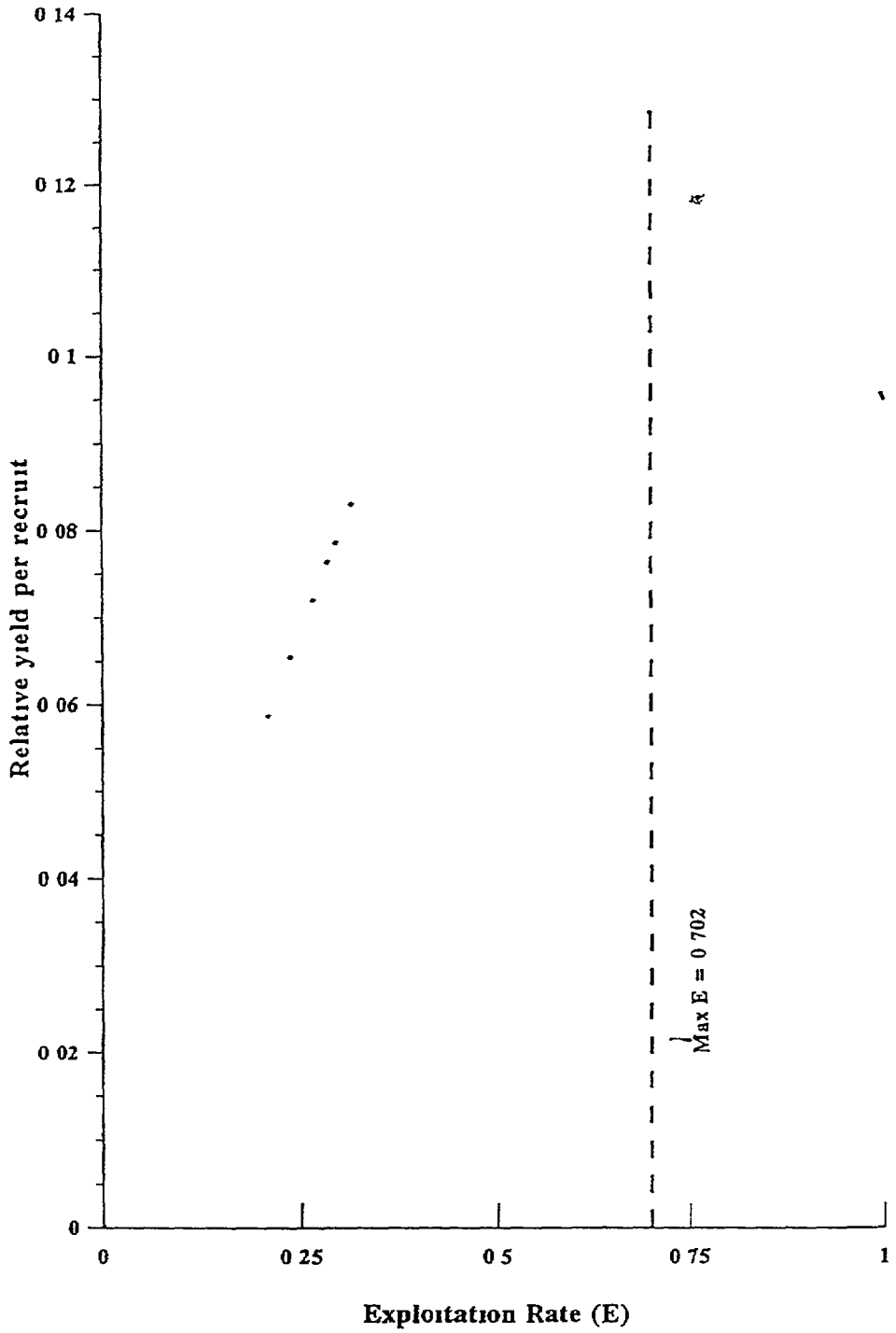


Fig.(83) Relative yield per recruit of *Solea aegyptiaca* as a function of exploitation rate

369

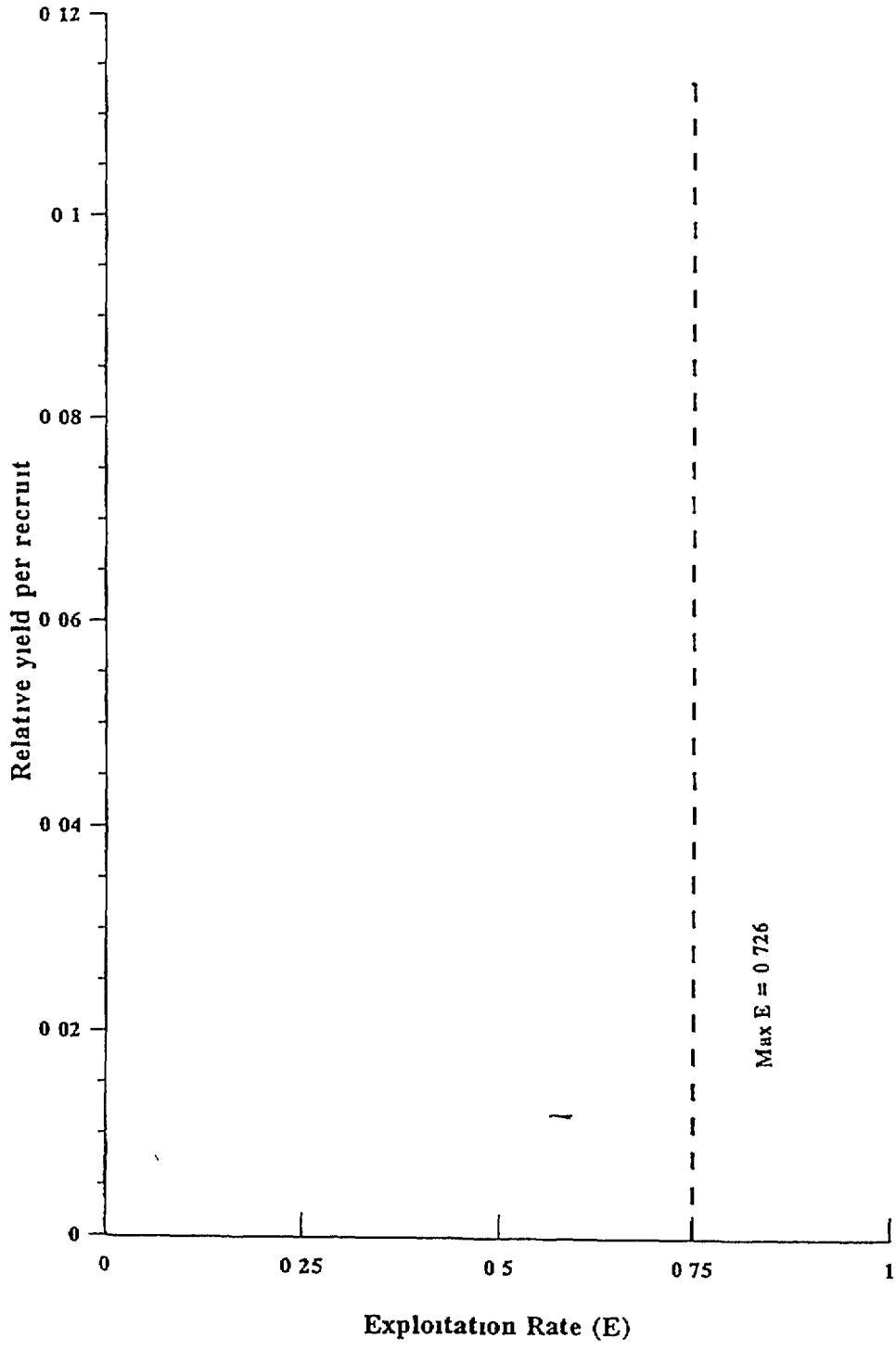


Fig (84) Relative yield per recruit of *Liza saliens* as a function of exploitation rate

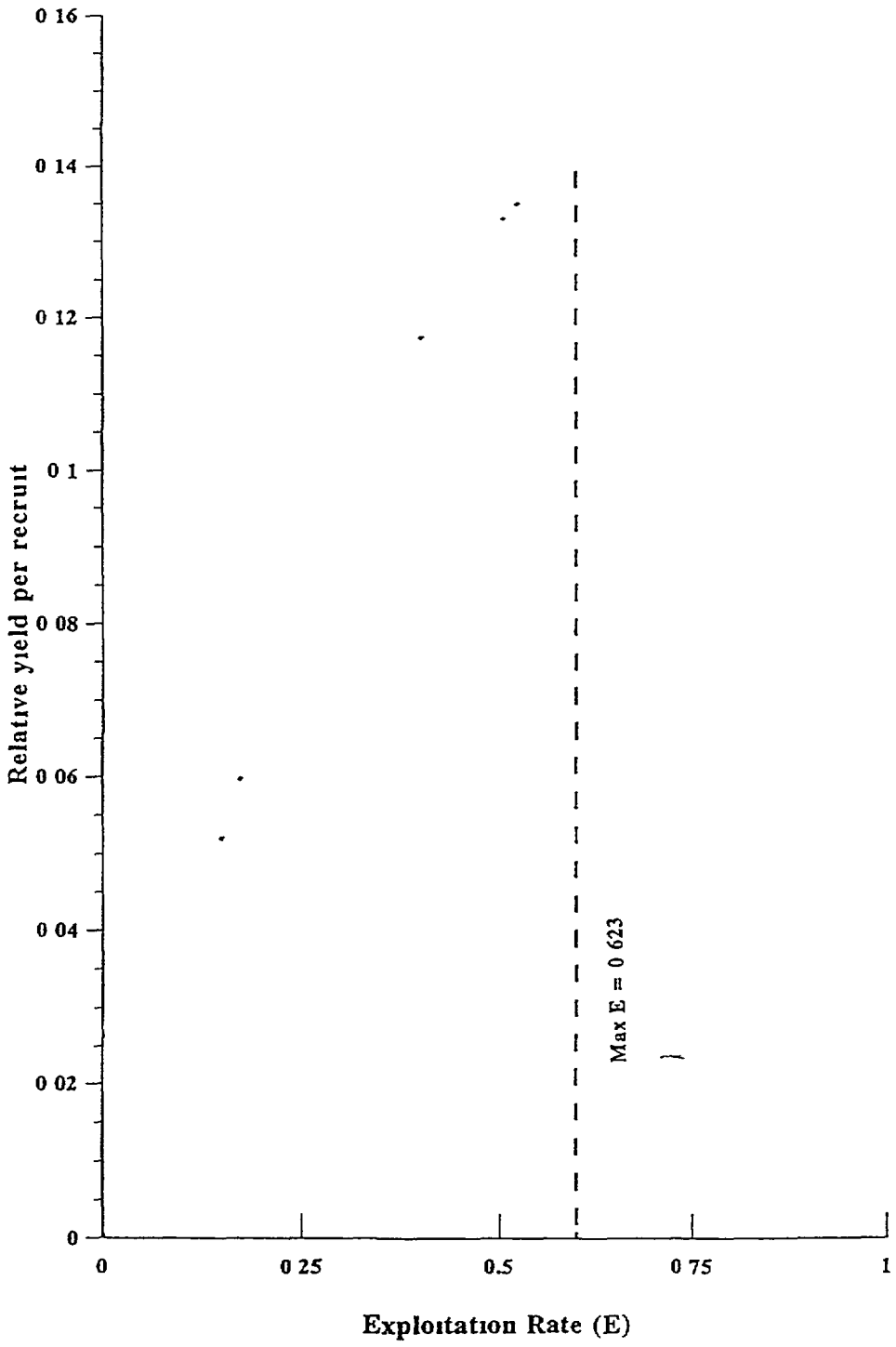


Fig.(85) Relative yield per recruit of *Tilapia zillii* as a function of exploitation rate

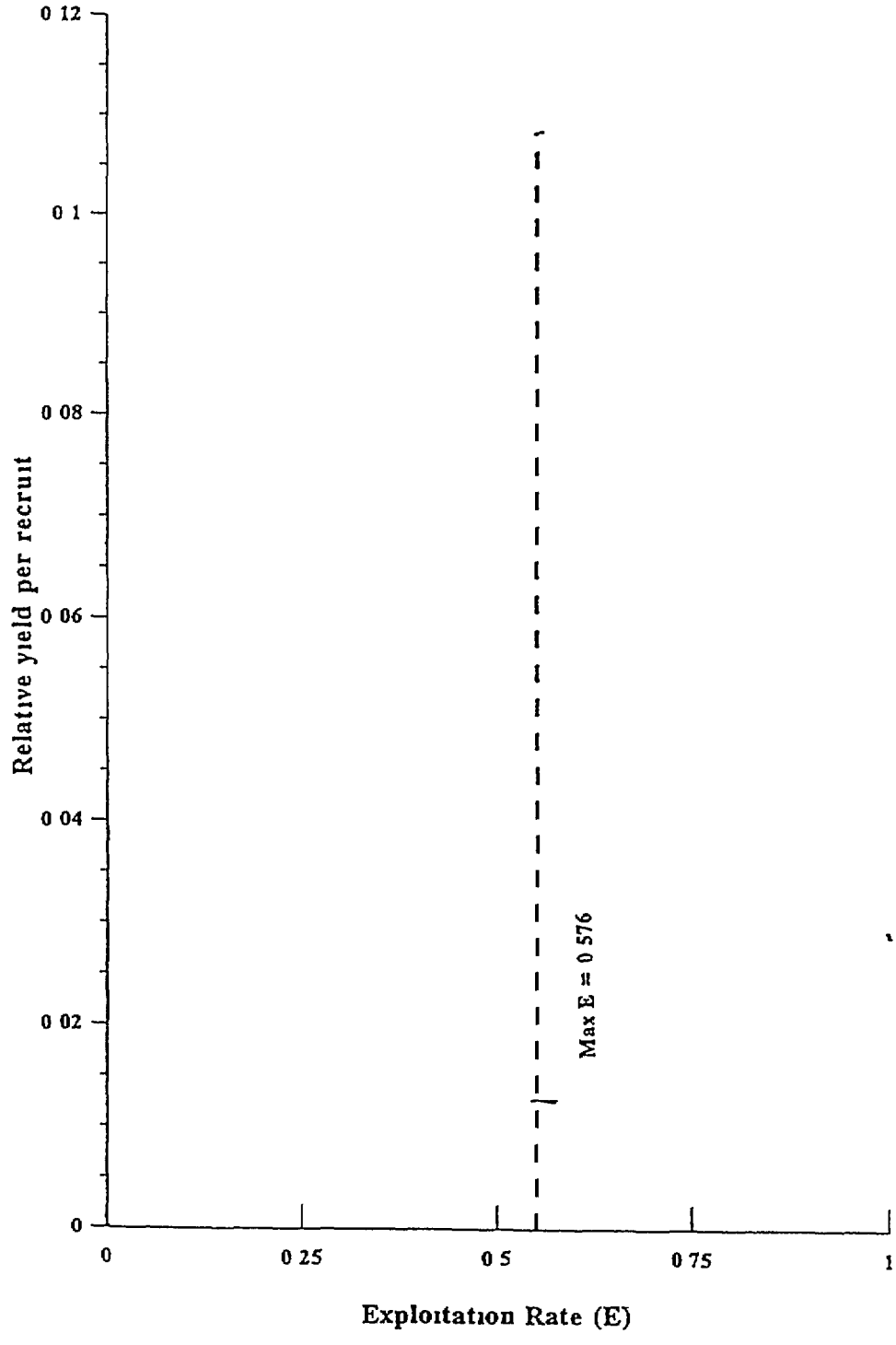


Fig (86) Relative yield per recruit of *Oreochromis aureus* as a function of exploitation rate

372

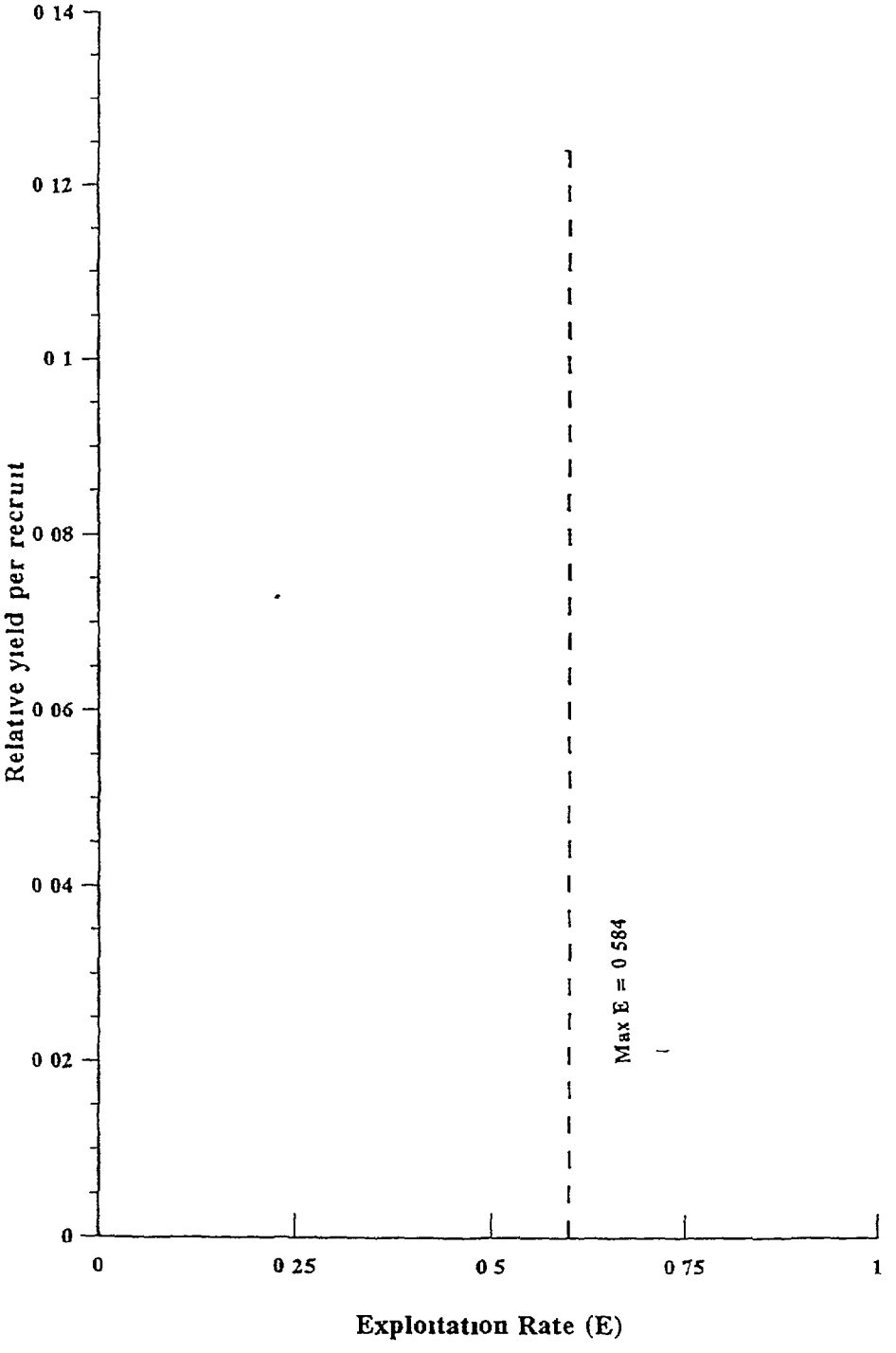


Fig (87) Relative yield per recruit of *Oreochromis niloticus* as a function of exploitation rate

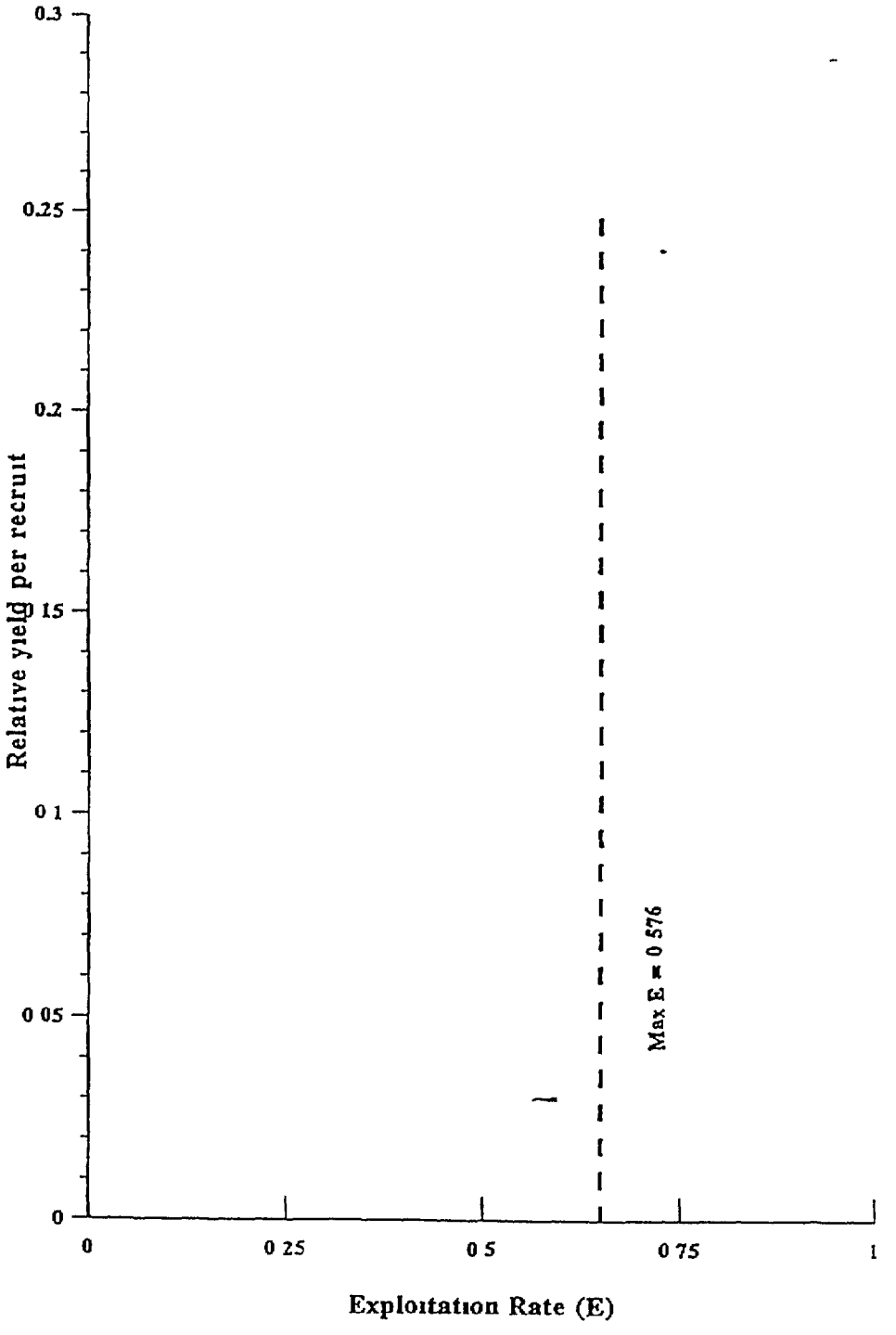


Fig.(88) Relative yield per recruit of *Metapenaeus stebbingi* as a function of exploitation rate

DISCUSSION

Before implementin the Lake Qarun Project, a workshop was held in July 1992 at Shakshouk Research Station (Project site) in the presence of the representative of the General Authority for Fish Resources Development (G A F R D) During this meeting the leaders of the research groups of the project presented the objectives, plan of work and the assignments given to them. The fisheries management problems of Lake Qarun were discussed in great detail with the representative of G A F R D

In January 1993, the implementation plan of the project's objectives commenced and continued for 4 successive years Comprehensive researches have been carried out under this project on the ecology, fish pathology and fisheries of Lake Qarun The lake lies in the Western Desert of Egypt It is the only saline lake among the Egyptian Inland Water Lakes, receiving agriculture drainage water from the surrounding cultivated fields through two main drains, namely El-Bats and El-Wadi In addition, numerous small drains as well as pumping stations discharge the agriculture drainage as well as sewage into the lake

The present study showed that to a great extent, water temperatures follow great the corresponding air temperatures Therefore, there is no thermal stratification recorded in the lake Several authors have maintained that this is mainly due to shallowness of the lake which is considered to be homothermic in nature The average water temperature during the four years varied from 22-25 °C, while the recorded 1989 value was 21 7 °C (Abdel-Monem, 1991) For air temperature, the average value of 24 38 °C was lower than that recorded in 1989 (7 3 °C)

The general climate of the lake area, as reported by the previous investigators, depended on the data collected by weather station of Fayoum Governorate, located about 35 km southwest of the lake This is far from representing the actual meteorological changes in the lake region

In January 1996, the weather station purchased through the Project was installed on the lake and began recording the various meteorological parameters

The meteorological data collected by the weather station served to correct the previous information e g wind direction NE winds are prevailing during January & February, while strong unstable NW winds are prevailing in spring, summer and autumn The previous reports were completely different and showed, that SW winds are prevailing in winter, while NE winds are prevailing during other seasons The data on wind gust are completely new and indicated that its maximum values of 8 89 m sec^{1} was recorded in June, while its lowest value of 3 7 m sec^{1} occurred in December

On the other hand, all the data on net radiation, relative humidity and other meteorological conditions are completely new and gave correct figures of some parameters e g rain fall and evaporation rate During 1996, the precipitation (rainfall) in the lake was recorded only in March, April and May, and its values were 0 28, 0 01 and 1 8 mm, respectively The previous rainfall information indicated that its annual average value was 13 8 mm/year (Abdel-Monem, 1991) With regard to evaporation rate, its average value was 2013 6 mm $year^{1}$, while the

previously recorded value was 2,550 mm year^{1} The relative humidity data revealed the dry weather of the lake area as the humidity did not exceed 58 8%

The depths of the lake showed wide fluctuations during the study period, its minimum average value of 4 02 m was recorded in 1994 and showed a gradual increase reaching the maximum of 4 33 m in 1996 The depths recorded during this comprehensive study were much high compared to the previous data which gave an average depth of 3 64 m (Abdel-Monem, 1991) This wide variation in the depths are mainly due to the fluctuations in the amounts of agriculture drainage water discharge into the lake, while the evaporation and seepage have the least effect on the water level

Secchi disc readings recorded during this investigation ranged between 0 68 and 0 97 m, these values were much higher than that recorded by Abdel-Monem (1991), who reported that the annual average secchi disc value of Lake Qarun was 0 445 m. This means that the turbidity of the lake water in 1989 was higher than the corresponding values recorded during the project Abdel-Monem (1991) mentioned that the euphotic zone does not extend to the bottom of the lake and this had an adverse effect on benthic and epiphytic algae His assumption was based on the calculation of euophotic zone by multiplying the Secchi disc readings by a factor of 3 The present survey indicated that the correct factor for estimation the euophotic zone from Secchi disc reading is 5 4 as determined by applying the linear regression equation on Secchi disc readings and the actual compensation depth (at which 1% incident light was detected) In this connection Girgis (1980) attributed the high turbidity of Lake Qarun water to the agriculture drainage water which was loaded with suspended particles and was discharged into the lake via the drains

The turbidity data did not show any correlation with either the phytoplankton standing crop or biomass as represented by chl. *a* This can be attributed mainly to the suspended nonbiological particles because the fine clay constituted 21 62% of the bottom sediments of the lake This view agrees with the conclusion of Abdel-Monem (1991) who contend that suspended solids in Lake Qarun are mainly represented by suspended particles rather than planktonic organisms He also reported that the suspended particles of the lake are autocathonous

The pH spectrum of Lake Qarun's water revealed the predominance towards alkaliphilous side Its values showed a narrow variation and were always above 8 On the other hand, the dissolved oxygen concentrations in the lake were always high and suitable for growth and survival of heterotrophic organisms Its values in the surface waters were higher than the corresponding values in the bottom layer and gradually decreased from 1993, reaching a minimum of 6 89 mg L^{1}, in 1995 and its highest value of 8 5 mg L^{1} occurred in 1996 The present DO data are closely similar to the previous results reported by Abdel-Monem (1991) who attributed the oxygen fluctuations in Lake Qarun to wind activities rather than to phytoplankton photosynthesis In the meantime, the previous investigators attributed the pH variations in the lake to temperature, salinity, carbonate and bicarbonate systems rather than the primary producers During this investigation, a new equipment (Environmental Monitoring System) recorded the variations in temperature, pH and DO every 5 minutes for 72 hours The results of these parameters are at variance with previous assumptions regarding the factors affecting pH & DO in the lake It is now clear from the results that the photosynthesis and

respiration of the primary producers play an important role in regulating the pH and DO values in Lake Qarun Fig (46)

Salinity of the lake generally increases as one moves away from the discharge points of the two main drains Salinity is considered to be the main factor responsible for the deterioration of the environmental conditions of the lake and the decline in its fish production The annual average salinity value recorded in 1989 was 32-49‰ (Abdel-Monem, 1991) Salinity values have significantly increased during the study period, its annual average levels were 34 06‰, in 1993, 37 79‰, in 1994 , 38 72‰, in 1995, and 40 93‰, in 1996 Abdel-Monem (1991) reported that the annual increase in salinity of the lake during the period from 1979 to 1989 was 0 199 ‰ This figure hass completely changed during the last four years (1993-1996) when its rate reached 1 72 ‰ This abnormal increase in the annual accumulation rate represents a dangerous effect on the biological productivity and fish production of the lake not only in the present time but also in the near future The sharp increase in the accumulation rate of salts in the lake is not attributed to meteorological changes because there were no significant variations in evaporation rate and air temperatures recorded in the area The only reason for the increase is the Amisal Salt Company which has a stock of brine waters (300 ‰) consisting mainly of NaCl & MgO The Company was established to produce Na_2SO_4, NaCl and MgO in amounts equal to or exceeding the accumulated salts in the lake Therefore, its construction was aimed at reducing or even keeping the salinity of the lake at some suitable level for the survival of the fauna and flora inhabiting this aquatic environment

Since the construction of this company in 1987 the only production line was Na_2SO_4, while the other lines for NaCl & MgO production have yet to start The sharp increase in accumulation rate proved without any doubt that the company discharges the brine waters into the lake This conclusion is supported by the Company claim during the workshop held in 1992 The major problem is the filling of its reservoirs by brine waters with a total salts of 60,000 tons The technical staff of the Company proposed to release brine waters with agriculture drainage water to the lake This proposal was rejected ats it has an adverse effect on ecology and fish production of the lake

The conductivity values were closely correlated with salinity in that its concentrations had progressively increased with time, reaching the maximum of 47 69 g L^{1} in 1996, whereas its least value was 35 12 g L^{1} which occurred in 1993

The total alkalinity (CO_3^{2} & HCO_3) of Lake Qarun had significantly decreased in 1993 when its values were 58 93 & 142 07 mg L^{1} for CO_3^{2} and HCO_3, respectively Carbonate & bicarbonate values recorded in the following years showed a narrow variations For HCO_3, its values were more or less similar to its value reported by Abdel-Monem (1991) being 192 96 mg L^{1} On the other hand, the present CO_3^{2} concentration was higher than the previously recorded value of 62 32 mg L^{1} It is well known that alkalinity is positively correlated with biological productivity and consequently fish production (Ball, 1948 and Carlander, 1955) Since hard water (of alkalinity above 40 ppm) are more productive than soft waters (Barrat, 1953), accordingly, Lake Qarun can be designated as very hard waters and highly productive It was reported that total alkalinity values up to 20 ppm indicate poor production, while 40-90 ppm signify medium production, and values above 90 ppm show production (Jhingran, 1986)

The Chemical Oxygen Demand (COD) data showed narrow variations, although its value of 17 04 mg L^{1} recorded in 1996 was high compared to its concentrations in the preceding years The present COD values agreed with the previous value of 14 67 mg L^{1} given by Abdel-Monem (1991) who attributed the high COD levels in the lake to the allocthonus material introduced the lake with the drainage waters via the two main drains

Abnormal decrease in sulphate concentration was observed between the present values and those reported by Abdel-Monem (1991), who reported that the annual average SO_4^{2} values in surface and bottom water of the lake were 4 81 and 5 39 g L^{1}, respectively During the present study, SO_4^{2} concentration did not exceed 834 14 mg L^{1} In this respect, it is noteworthy that Amisal Salt Company at the Shakshouk region (Project site) started a project for increasing Na_2SO_4 production from the lake since 1990 During 1995 and 1996 new lines for Na_2SO_4 production were opened, this explains the severe decrease in SO_4^{2} during 1995 and 1996 to less than half the values recorded in 1993 and 1994

Nitrogen is a basic constituent of protein and occurs in water as free nitrogen (N), as ammonia (NH_4 and NH_3), nitrate (NO_3) and nitrite (NO_2), in addition to the organic forms of dissolved organic nitrogen (DON) and particulate organic nitrogen (PON)

During the four successive years investigation, NO_3 – N, the most stable inorganic nitrogen, was always high compared with the NO_2 - N & NH_4 - N, except in 1993 when NH_4 - N was the dominant form.

Ammonia in natural water is usually present as NH_4 and as un-dissociated NH_3 the latter is highly toxic to aquatic organisms, especially fish (Trussel,1972) The proportions of NH_4 & NH_3 are dependent on the dissociation dynamics which are governed by pH and temperature Since the pH of Lake Qarun water is always > 8 but below 8 5, the approximate ratio of NH_4 to NH_3 in the Lake is > 5 1 (Hutchinson, 1957) The NH_4-N level in the Lake (75 8 µg L^{1}) was lower than that reported by Abdel-Monem (1991) who gave the value of 89 95 µg L^{1} He attributed the variations of NH_4-N in the Lake of to the fluctuations in the levels of the drainage waters During this study, the estimated annual average NH_4 - N discharged to the lake via the drains was 312 tons This amount certainly has an effect on the variation of NH_4 - N, considering the total water volume of the lake which is 907 2 x 10^6 m^3 It should be noted that, the annual amount of agriculture drainage waters discharged into the lake is 400 x 10^6 m^3

The unstable NO_2 -N was the least inorganic nitrogen compounds studied in lakewater Its values had considerably decreased from the beginning of the investigation and reached the minimum of 2 6 µg L^{1} in 1996 The amount discharged with the drainage amounted to waters 8 4 8 tons year ^{1}

Nitrate represents the most stable form among the inorganic nitrogenous compounds Its concentration was much lower than that reported by Abdel-Monem (1991) who reported a value of 307 µg L^{1} The same author stated that the drainage waters represent the major source of NO_3 - N to the lake This view is supported by the calculated amount of NO_3 - N discharged into the Lake via the drains that reached 600 tons year ^{1} The NO_3 - N NH_4 - N ratio of Lake Qarun was 1 12 1, while the ratio recorded in 1989 was 4 6 1 (Abdel - Monem, 1991) In this connection, it should be mentioned that in unpolluted lakes this ratio is

25 1 as reported by Wetzel (1983) This means that Lake Qarun is polluted by sewage and that pollution has significantly increased with time NH_4 - N is the most important inorganic nitrogen affecting phytoplankton standing crop and biomass as represented by *Chl a* concentration in Lake Qarun (r = 0 71 & r = 0 94, respectively)

In this connection, it was reported that NH_4 - N is usually the most preferred inorganic nitrogen for uptake by phytoplankton (Dugdale & Goering, (1967) Clearly, this does not apply to all ecosystems, as it could change depending primarily on the species composition of phytoplankton Abdel-Monem (1991) reported a slight correlation between NH_4 - N and phytoplankton standing crop during his work on Lake Qarun in 1989 (r = 0 53)

Concerning the organic nitrogen (PON and DON), the data indicate the high levels of PON compared to the corresponding DON values The PON data showed a gradual decrease during the investigation years and reached their minimum of 2 57 mg L^{1}, in 1996 PON in the Lake was closely related to phytoplankton biomass as represented by chl a (r = 0 87) On the other hand, a weak correlation was observed between DON and phytoplankton biomass (r = 0 48) The organic nitrogen contents in Lake Qarun were significantly high in summer This agrees with the findings of Abdel-Monem (1991) who reported that the highest level of organic nitrogen in the Lake occurred in summer and winter He further observed the positive relation between phytoplankton and TON, and concluded the autocthonous nature of organic nitrogen in the Lake A significant portion of the algal intracellular nitrogen (10 to 20%) is released extracellularly, mainly as protein and ammonia with a smaller amount of nitrite and amino acid (Meffert and Zimmerman - Telschow, 1979 - C F Wetzel, 1983)

Phosphates are usually considered as primary limiting nutrient production in natural waters Their concentrations in Lake Qarun showed an obvious gradual decrease, reaching their minimum value of 13 11 µg L^{1} in 1996 On the other hand, the organic phosphorus contents varied within a narrow range, while their values in 1995 had significantly increased to 97 13 µg L^{1} The present data of phosphate level in the lake were comparatively lower than those recorded in 1989 by Abdel-Monem (1991), who attributed the PO_4 variations in the Lake to the amounts of phoshates discharged via the two drains This, in part, agrees with our observations that the drainage water is not the main source of PO_4 in the Lake, although it represents an important source The calculated PO_4 - P discharged into the lake via the drain was 84 8 tons year ^{1}, in addition to the 28 8 tons year ^{1} organic phosphorus This is beside the amounts of OP excreted or accumulated in the phytoplankton cells and released to the water as a result of their normal physiological activities, and after the death and decomposition of their cell contents The importance of PO_4 - P to phytoplankton growth in Lake Qarun is indicated by the strong positive correlation between PO_4 - P and phytoplankton crop (r = 0 54) and Chl a (r = 0 87) This finding agree well with that reported by Abdel-Monem (1991)

Silicates in Lake Qarun showed narrow fluctuations during the four successive years of investigation, however obvious increase was noted in 1994 The Si O_3 - Si did not show any correlation with the population density of diatoms This is due to the presence of SiO_3 - Si in concentrations far exceeding the demands of diatoms The data revealed positive relation between SiO_3 - Si values and temperature (r = 0 62) and this relation was previously reported by Mckeague and Cline (1963 a & 1963 b) and Abdel - Monem (1991) The latter author reported a positive correlation between SiO_3 - Si and diatoms in Lake Qarun (r = 0 83) As

mentioned above, this phenomenon was not recorded during the present study, due mainly to the difference between class composition as well as the main dominant phytoplankton species during this study and those recorded by Abdel - Monem (1991)

The cations, represented by Na & K, showed narrow variations, although their concentrations in the last two years (1995 & 1996) were higher than the corresponding values recorded in 1993 & 1994 Sodium concentrations were always higher than potassium. The levels of Na is usually affected by its concentration in the agriculture drainage water and the annual production of Na_2 SO_4 by Amisal Salt Company On the other hand, the brine waters discharged by the Company into the lake (consisting mainly of Na Cl and MgO) play an important role in Na fluctuations in Lake Qarun

Calcium contents of the lake water did not show any correlation with salinity This means that variations in calcium in Lake Qarun are controlled by its precipitation as carbonate This finding agrees with the observations of Beadle (1932) and Caljon (1983) who recorded this phenomenon in lakes with water salinity higher than 10 g L^{1} On the other hand, Mg variations were closely related to salinity in that their values had gradually increased during the study period, reaching the maximum of 5983 33 mg L^{1}, in 1996 On the other hand, Mg is usually found as soluble bicarbonate This represents another evidence against Amisal Salt Company case and a good proof for the release of brine waters into the lake, since, as mentioned before, MgO and Na Cl are the main salts in the brine water

The variations in mineral composition of Lake Qarun sediments were concentrated in the heavy mineral fractions, especially in the grain size of phi 3 and 4 These fractions are characterized by the ultra stable minerals The fluctuations of heavy minerals distribution explains the deposition of the Lake environment and reflects different dynamic processes generally, the heavy mineral contents decrease with increasing the depth of the lake The mineralogy data of the sand samples indicate that they contain the following main groups of heavy minerals Opaque, Pyroxenes, Amphiboles, Epidotes and Zircon arranged in a descending order of abundance The data revealed that heavy minerals in Lake Qarun consist mainly of iron ores (Opaques) Three provenance's have been identified as follows Opaques - pyroxenes characterized its predominance (87 5%) The mixed opaques - pyroxenes - amphiboles provenance constituted 10% The opaques provenance was represented by scattered samples and constituted 5% These provenances indicate that the deposition in subaerial condition and that the lower pyroxenes reflected the dominance of brackish environment at the time of deposition Sediments of Lake Qarun contained economic amounts of Zirconium deposits

The clay fraction of sediment consisted of montmorillonite, illote and kaolinite The non clay minerals were calcite, quartz and felldspars The obvious decrease in montmorillonite in the middle and western regions of the lake can be attributed to its transformation to other minerals (Hamdi, 1967) On the other hand, the increase in kaolinite percentage in the middle and western regions of the Lake was also reported by Nage *et al* (1981) The lake sediment is characterized by the predominance of montmorillonite shich has high exchange capacity

Lake Qarun sediments adsorb a portion of dissolved nutrients which encourage development of benthic algae - natural food organisms for fish and prawn The data on benthic algae

biomass in Lake Qarun, as represented by chl a are completely new The results indicate the marked increase in benthic algal biomass in the eastern region compared to the middle and western regions This is mainly attributed to the abnormal increase in suspended organic matters in this area that lies under the influence of waste waters discharged from El- Bats Drain

Important soil chemical conditions which influence the productivity of Lake Qarun were determined and presented in the results Average electrical conductivity values showed that the western region was highly saline (13 61 m. mhos Cm^{1}) compared to the eastern and middle regions (11 89 & 11 88 m. mhos Cm^{1}, respectively) pH values of the three areas lie in the alkaline side (always above 8) Total phosphorus and total Kjeldahl -N were high, their maximum values amounted to 1052 8 and 2334 3 mg Kg^{1}, in the eastern and western regions, respectively Bioavailable - P, TOC, TOM and TC points to the high fertility of the western regions compared to the other areas Lake Qarun soils are generally fertile as they contain essential nutrients necessary for benthic flora, fauna and consequently fish production

During the present investigation levels of organochlorine pesticides and heavy metal residues were investigated in the Lake sediments and water As mentioned before the pesticide residues measured during this study were those commonly used at Fayoum Governorate according to the information received from the Gizza Seeds Exporting Company The results showed obvious decrease in pesticide residues during the last three years (1994,1995) This can be attributed to the new policy of Ministry of Agriculture and Land Reclamation that depends on application biological control techniques for controlling agriculture pests instead of intensive use of pesticides According to this approach the amounts of pesticides used for controlling pests had significantly decreased The most dominant organochlorine pesticides were Alpha - Endosulfan, BHC - Beta, Ortho, Para - DDT, Alpha - Chlordan, and Quintozene in that order The application of DDT, BHC and other organochlorine insecticides was prevalent in Egypt for almost 20 years (1952 - 1971) throughout agricultural and medical pest programmes (Abd-Allah and Ali, 1994) The amounts used in 1961-76 (53,300 metric toms, mostly DDT and lindan) were reported by El-Sebae (1981)

Concerning the pesticide residues in Lake Qarun fishes, random fish samples were collected from the middle and western regions and underwent to pesticide analyses In general, the pesticide concentration in the muscles was always much lower than1$\mu g\ g^{1}$ Table ____ shows the pesticide levels in the muscles of *Solea aegyptiaca* and *Mugil capito* The most dominant pesticide was Archlor 1248, its maximum concentration of 120 ng g^{1} (0 12 $\mu g\ g^{1}$) occurred in *M capito* collected from the western region

Table 8 Pesticide residues in fish muscels (ng g^{1})

Pesticide	*Solea aegyptiaca*		*Mugil capito*
	west	middle	west
HCB	2 8	3.5	6 4
Alpha HCH	0.4	0 8	1 2
Beta HCH	N D.	0.2	0 9
Gama HCH	6 4	9 6	12 5
Aldrin	8 3	12 5	19.3
Heptachlor	8.3	13 4	17.5
P P DDD	2 4	5 4	9.2
P P DDE	10 4	22 4	34.2
P P DDT	6 3	14 4	23.4
P P TDE	29 4	27 6	42.1
Ar 1242	43	64	95
Ar 1248	64	82	120
Ar. 1254	30	42	60

Since Lake Qarun receives considerable amounts of agriculture drainage waters which are loaded with pesticides, it is recommended to continue to put emphasis on the least persistent pesticide and decreasing reliance on the use of persistent chlorinated hydrocarbons

The trace metal studies included their level of concentration in water and sediments of the lake and the two drains Their concentrations in the lake and drains waters indicated that Fe was the most dominant metal followed by Co and Zn In summer and autumn, the trace metal concentrations in the lake water were high compared to their corresponding values in the drains, however, the reverse was true during winter and spring This indicates that Lake Qarun is not heavily polluted by trace metals and that their fluctuations in the drains depend on the source of waste water, mainly pesticides and sewage-containing metallic ions In the sediments, Fe was the major ion, followed by Cr and Zn As reported in the mechanical and mineralogical properties of the lake sediments, iron ore is the dominant fraction This leads to the conclusion that most of trace metals in Lake Qarun, especially iron are of autocthonous origin This findings agree well with the actual situation of Fayoum Governorate (lake region) which shows that there is no industrial development in the area and consequently there is no noticeable influx of industrial wastes into the lake It can be concluded that the levels of heavy metals in Lake Qarun are normal and their concentrations are within the permissible limits, except iron which originates from the lake sediments Other metals such as Al and As were also analyzed in lake sediments For Al, its concentrations varied from 248 mg kg^{1} in the east

to 290 mg kg ^{1} in the western region The levels of As in the lake sediments ranged between 1 74 mg kg ^{1} in the east and 4 23 mg kg ^{1} in the middle region These data indicate that these two metals are found in the lake sediments (autochtonous) rather than introduced through the drains

Concerning the biological parameters, the present data demostrate the high productivity of Lake Qarun, starting from phytoplankton to the benthic organisms Phytoplankton communities of the Lake are represented by six main classes, namely Bacillariophyceae Dinophyceae, Cyanophyceae, Euglenophyceae, Chlorophyceae, and Cryptophyceae Generally, two plankton pulses have been recorded every year, the major one always occurred in summer, except in 1996 when the outburst of phytoplankton was observed in late spring The minor peaks were usually recorded in late autumn and late winter, except in 1994 when the least phytoplankton standing crop was found in early spring The same phytoplankton classes were also recorded in the Lake by the previous investigators (Ibrahim,1979) and Abdel-Monen,1991) They reported that members of Chlorophyceae and Euglenophyceae are allochathonous and enter the lake via the drains This finding is corroborated by the fact that the species of these two classes were recorded only at the discharging points of the two drains into the lake Abdel-Monen (1991) recorded two phytoplankton peaks in the lake, a major one in summer and a minor one in autumn The seasonal cycle of phytoplankton in Lake Qarun does not exhibit the classical pattern for low temperate regions (mainly the northern hemisphere) as reported by Raymont (1980)

The data show strong positive corelation between phytoplankton standing crop and both PO_4 - P & NH_4 - N (r = 0 54 & 0 71, respectively) This leads to conclusion that both N & P are the prime limiting nutrient for phytoplankton in Lake Qarun This conclusion is at variance with the findings of Abdel - Monen (1991) who reported positive corelation between phytoplankton and both salinity and temperature This means that salinity has positive effect on phytoplankton standing crop, however the reverse was observed during the present investigation

During this study the phytoplankton peaks were mainly due to the predominance of diatoms, except in summer 1993, when the dinoflagellates were dominant Diatom species appearing in significant numbers were *Nitzschia* spp, *Cyclotella* spp, *Melosira* spp and *Chaetoceros* spp It is evident that phytoplankton communities in Lake Qarun showed year to year and month to month changes in magnitude and specific dominance The predominance of diatoms in Lake Qarun has also been reported by the previous investigators (Nossoeir and Abou El-kheir, 1970 , Ibrahim, 1979, Abou El-Keir and Ismail, 1986, and Abdel-Monem, 1991) During the present study a total of 74 diatom taxa were recorded in the lake, while Abdel - Monem (1991) gave 119 diatom taxa Our results did not reveal any correlation between diatoms and silicate This is mainly due to the presence of SiO_3 - Si in concentrations far exceeding the demands of diatoms The most abundant diatom species during the four years survey was *Nitzschia closterium* which is known to flourish at high nutrient levels and when the temperature shifts to higher values (Werner, 1997)

As to the other phytoplankton classes, the dinoflagellates were the most important, they occupied a position second only to diatoms, except in summer 1993 when they were dominant Their main representative species were *Peridimum* sp , *Exuviaiella apora* and

Prorocentrum micans The least abundant class was Cryptophyceae that was recorded only in 1993 and represented by *Chromonas* spp and *Rhodomonas* spp

The results of chl a showed that its maximum values were always recorded in spring, except in 1993 when its highest value occurred in summer The chl a of different phytoplankton fractions revealed the dominance of nanoplankton (> 20 µm) during 1993, while in the following years its values showed a wide fluctuation between the different fractions A slight positive relation between phytoplankton crop and Chl a was observed (r = 0 5), while a strong positive correlation was observed between the chl a and NH_4 - N & Po_4 - P (r = 0 94 and 0 87, respectively) In this connection Abdel - Monem (1991) reported that chl a maximum in Lake Qarun occurred in autumn, while the least value was in summer The weak correlation between chl *a* and phytoplankton density is due to the wide variations in species composition and cell sizes In this context, Nebakken (1988) reported the chl a variations among phytoplankton species and cells of the same species as well, depending on their growth phase and conditions In general, as shown from chl *a* data, Lake Qarun can be designated as super-eutrophic (>7µg chl *a* L^{1}, c f Kostiainen, 1969)

The distribution of phytoplankton biomass in Lake Qarun as represented by chl *a* is affected by nutrient concentration levels, turbulence and grazing The present study revealed a negative corelation between phytoplankton biomass and zooplankton densities (r = -0 5) This indicate the role of zooplankton grazing in controlling phytoplankton biomass

Zooplankton communities in Lake Qarun are represented by three main groups, namely Rotifers, Copepoda and Protozoa Rotifers were always the most dominant group throughout the investigation period, followed by Copepoda and Protozoa, except in 1995 when Protozoa occupied the second prominent place Their annual average standing crops showed wide variations, reaching their maximum in 1996, whereas the minimum values occurred in 1993 The maximum zooplankton numbers were always recorded in autumn except in 1996, when their maximum numbers occurred in late summer The grazing experiments demonstrated the effects of zooplankton grazing activity on phytoplankton The grazing pressure of zooplankton which was dominated by *Brachionus plicatilis* was significantly high and effective on nanoplankton (> 20 µm)

In general, the zooplankton data reflect the eutrophic nature of Lake Qarun and the availability of high zooplankton densities

Bottom organisms in Lake Qarun are represented by four main groups, namely Arthropoda, Annelida, Mollusca and Coelentrata In general, Arthropoda were always the most dominant group followed by Annelida, Coelantrata and Mollusca, except in 1995 when Mollusca occupied the third dominant place The seasonal cycles of benthic fauna showed that their maximum densities were recorded in spring in 1995 & 1996 and in winter during 1993 & 1994 Their densities showed a gradual decrease from (1993) and reached their least density in 1995 The importance of bottom biota as fish food is well established On the other hand, the periphyton communities in Lake Qarun play an important role in the biological productivity of the lake The seasonal cycles of their biomass were previously discussed with sediments

The biological conditions of Lake Qarun indicate several important points concerning the availability of natural food In the first place, the lake, as was stated above, can be designated as super-eutrophic judging from the food web biomass The prime limiting phytoplankton nutrients were N & P as indicated from the close relation between these major elements and phytoplankton production, and also from nutrient limitation experiments On the other hand, the problem of significant increase in salinity and its impacts on biological production of the lake, was shown from the data which revealed positive relation between salinity and both zooplankton & benthos crops (r = 0 83 & 0 68) while it has strong negative corelation with phytoplankton biomass (r = - 0 89) This means that salinity has deleterious effects on the biomass of primary producers, that should cause adverse effects on the other components of the food chain

With regard to the bacterial counts of total and fecal coliform, the data showed abnormal increase in bacterial counts during 1994 This is mainly attributed to the amounts of waste waters discharged into the lake via the two main drains and the high nutrient levels In the meantime, the organic matters in the sediments and waters are sufficiently high to stimulate bacterial growth On the other hand, the total and fecal coliforms showed noticeable increases during summer, while their minimum counts occurred in autumn The main factors affecting this cycles were temperature and the amounts of raw sewage discharged into the lake via the drains In the meantime, the abnormal increase in fecal coliform counts in the drains and their discharging points in the lake revealed the high level of sewage pollution in the drain's water This means that the drains' waters consist not only of agricultural drainage water but also substantial amounts of raw sewage

As to the bacterial diseases, the high load of organic pollution (sewage) and high biological productivity are optimum conditions for the appearance and flourishing of pathogenic bacteria The most important case recorded during this investigation was the mass mortality of *Solea aegyptiaca* Information of this incident was received from the representative of G A F R D and the local fishermen Close examination revealed that this mortality was realized to Vibriosis, and that 50% of the examined *S aegyptiaca* samples were infected In the meantime, 30% of mullets and *Tilapia Zilli* were infected with Yersinia and Streptococcus The bacterial diseases recorded in the lake infect the endemic and transplanted fish species All pathogenic bacterial species were recorded in the Lake and were not introduced with the transplanted mullet fry This suggests that the lake environment is greatly affected by the heavy load of raw sewage discharged from the drains This leads us to recommend that raw sewage and waste waters, in general, should be treated before discharge into the lake

In addition to bacterial diseases, the paracytological studies indicated the presence of numerous parasites, encysts metacercaria and ectoparasites in both endemic and planted fish species The distribution and identification of these parasites were previously explained in details In general, *Trichodinids* are servely infecting *M cephalus*, while tillapia fishes are heavily infected by encycted metacercaria in the muscles and viscera, which proved to be potentially dangerous to humans Preliminary data showed that the growth of the mullets is adversely affected by the large numbers of trematodes invading their intestines The most important finding was that concerning the paracytological status of mullet fry transplanted from the Mediterranean Sea near the discharge point of the Nile Damietta Branch This area is

heavily polluted with raw sewage of Dominate City The fry were examined just before introducing them into the lake The results revealed that 100% of the fry were infected with large numbers of trematodes in their intestine, 9% were infected with encysts metacercaria and were 31% infected with ectoparasites These findings were discussed with the representative of General Authority for Fish Resources Development We recommended the importance of changing the collection site of the fry from El-Gerbi at Damietta to Ashtom El-Gamil at Port Said This recommendation was supported by the paracytological examination of mullet fry collected from the new site As was expected, only 10% of the fry were infected with trematodes In this connection our recommendation for the near future is the need to construct a hatchery for the production of grey mullet fry at Fayoum Governorate for the annual stocking of Qarun and Wadi El-Raiyan Lakes with healthy fry This should avoid the adverse effects of the parasites on survival and growth rate of fry collected from the Mediterranean Sea It Is worth mentioning that the annual stocking of Qarun and Wadi El-Rayian Lakes fry is 45 X 10^6 fry and the parasites detected in Qarun Lake are exotic and represent protozons (e g *P olique* & trichodinids of *O aureus*) which invaded the endemic fish species in massive numbers

Ezzat *et al* (1979) on their studies on the biometric variations in soles in Lake Qarun gave the vertebral count as 41 ± 2 161 That is to say, the range of vertebral count varied from 39 to 43, the same range as mentioned for the Egyptian sole by Quéro *et al* (1986), who gave the vertebral count range for S vulgaris between 46 and 52 This was another evidence that this species has been wrongly identified Several investigators, especially those who used scales in aging, biologically interpret the intercept as the fish length at which the hard structure is formed However, as discussed before, otoliths are formed during the embryonic stages Thus, the sign of intercept depends on the length range of the collected samples It could be argued that if the collected samples comprise the whole range of very small as well as very large fishes, the intercept would be zero Accordingly, it is better to accept the propose of Hile (1970) that intercept is best regarded as a mathematical constant that makes the equation works (Duncan, 1980)

The important accomplisments of the present investigation is the proper identification of Lake Qarun soles as *Solea aegyptiaca* and the record of *Oreochromis aureus* for the first time in the commercial catch with a considerable percentage

The history fisheries of Lake Qarun indicated that the existence of the lake fisheries depends mainly on the continuous and regular transplantation of mullet fry The declared number of transported fry is about 30 million fry Accordingly, using the yield per recruit model, the yield of mullets should be about 1500 ton yearly However, this figure is not achieved This may be attributed to the transportation and handling loss of fry and/or that the declared number is not accurate Thus, it is recommended that a better attention to the process of mullet fry transportation and acclimatization be given

Analysis of fisheries statistics revealed that intensive shrimp fisheries has a destructive effects fish stocks in Lake Qarun, especially for the natural spawners soles and tilapias Thus, prohibiting shrimp fisheries during July is recommended to give the soles the chance to rebuild their depleted stock Moreover, closed fishing season during January and February each year is also important in maintaining the species

Age and growth studies showed that, for almost all fish stocks, the maximum increments in length and weight are achieved at the end of the first year of life However, population structure studies as well as the study of length at first sexual maturity, showed that a considerable percentage of fish were caught in age group i e before attaining their sexual maturity To protect the recruitment (for the spawning stocks), size limits must be established, i e to lengths greater than the (L_{50})

The results of the food and feeding studies revealed that almost all fish stocks in the lake are bottom-feeders and they showed a special preference to feeding on crustacea In light of this, a filter-feeder species could be elected to be transplanted to the lake in an effort to improve the status of the lake ecosystem. Needless to say that the selected species shall be able to withstand the high salinity of the lake, and would be able to spawn naturally in the lake

It is worth mentioning that in the course of the present investigation, mortality rates, estimates of exploitation rates as well as yield per recruit estimated were calculated for the first to Lake Qarun fishes The results obtained indicated that fishes in the lake are suffering from overexploitation and that rapid measures should be taken in order to maintain the health and sustainability of the lake fisheries

REFERENCES

A P H A (1975)
Standard methods for the examination of water and wastewater 4th ed , APHA, AWWA, WPCF, N Y Washington, USA

A P H A (1985)
Standard methods for the examination of water and wastewater 16th ed , APHA ANWA WPCF American public Health Association 1015 pp Fifteenth St N W Washington D C 20005

A P H A (1992)
Standard methods for the examination of water and wastewater 18th ed , A P H A , AWUA WPDýCF American public Health Association 101 spp Fifteenth St N W Washington D C 20005

Abd-Allah, A M A and Ali H A (1994)
Residue levels of chlorinated hydrocarbon compounds in fish from El-Max Bay and Maryut Lake, Alexandria, Egypt Toxicological and Environmental Chemistry 42 107 - 114

Abdel - Monen, A M (1991)
Changes in the phytoplankton composition of Lake Qarun in relation to variation of salinity M Sc College for Girls, Ain Shams University 154 pp

Abdel- Malek, S A (1990)
Fish introductions of Lake Qarun Egypt Eight sessions of the Commities of Inalnd fisheries of Africa (CIFA) , Cairo, Egypt 21 - 25 Oct , 1990

Abdel Malek, S A and M M Ishak, (1980)
Some Ecological aspects of Lake Qarun, Fayoum, Egypt, Part II Production of plankton and benthic organisms Hydrob 75 201 - 208

Abdel-Malek, S A (1972 a)
Food and feeding habits of some Egyptian fishes in Lake Quarun Part I *Tilapia zillii* (Gerv) C according to different length groups Bull Inst Ocean & Fish , vol 2 203 - 213

Abdel-Malek, S A (1972 b)
Food and feeding habits of some Egyptian fishes in Lake Quarun Part I *Tilapia zillii* (Gerv) B according to different sexes Bull Inst Ocean & Fish , vol 2 239 - 259

Abdel-Monem, A M (1991)
Changes in the phytoplankton composition of Lake Qarun in relation to variation in salinity M Sc Thesis, Ain Shams Univ , 154 pp

Abo El-Kheir, W S (1987)
Changes in the diatom flora of Lake Qarun with time Bull Fac Sci , Ain Shams Univ , vol 26 b

Abou El- Gheit, E N , Moustafa, M and Seliem, T A E (1995)
Effect of sewage pollution on bacterial infections among tilapia fish J Egypt Veter Med Assoc 55, No (4) 829 - 841

Abou El-Keir, W S and Ismail, G H (1986)
Notes on aquatic habitats of macrohydrohytes and associated algae in various regions in Egypt 1-El-Fayoum region Phytologia Vol 60(7) 469 - 482

Abu-Samra, M (1936)
Report on the salinity of Lake Qarun Inst Ocean & Fish

Ahmed, N K., (1994)
Studies on zooplankton of Lake Qarun, M Sc Thesis, Cairo Univ 160 pp

Aleem, A A (1958)
A taxonomic and paleoecological investigation of the diatom flora of the extent Fayoum lake (upper Egypt) Bull Fac Sci , Alex Univ , 2 (1) 99 - 138

AlKholey, A and S A , Abdel-Malek (1972)
Food and feeding habits of some Egyptian fishes in Lake Quarun Part I *Tilapia zillii* (Gerv) A according to different localities Bull Insti Ocean & Fish , vol 2 187 - 201

Amlacher, E (1970)
Textbook of fish diseases T F H Pub Jersy USA 117 - 135

Anonymous, (1981)
Final report of the research project no 2/18 " Increasing Lake Qarun yield" Academy of Scientific Research and Technology June 1981 111p

Anonymous, (1990)
Development Horizons Conference El-Fayoum Province and Academy of Scientific Research and Technology, El-Fayoum 15 - 17 March 1990 107p

Arthur, J R and Lom, J (1984)
Some trichodinid ciliates (Protozoa Peritrichisa) from Cuban fishes, with a description of *Trichodina cubanensis* n sp from the skin of Cichlasspma tetracantha Trans Am. Microsc Soc , 103(2) 172 - 184

Ball, J (1939)
Contributions to the geography of Egypt, Cairo, Government Press, 308p

Ball J (1939)
Contributions to the geography of Egypt Egypt Survey and Mines Department, Cairo, pp 178 - 289

Barnes, H and A R Fol - Kard, (1951)
The determination of nitrite Analyst 96 599

Basson, L , Van As, J G Paperna, I (1983)
Trichodinid ectoparasitic on freshwater fish from Southern Africa and Israel Systematic Parasitology, 5 245 - 257

Beadle, L C (1932)
The waters of some East African Lakes in relation to their Fauna and Flora J Limm. Soc (Zoll) 38 157 - 211

Bertalanffy von, L (1938)
A quantitative theory of organic growth (Inquiries on growth laws II) Hum. Biol , 10 181 - 213

Beverton, R J H and S J , Holt (1957)
On the Dynamics of Exploited Populations Fish Invest Minist Agri Fish Food UK., (Series 2), no 19 533 p

Bishai, H M and S Y , Kirollus (1988)
Net selectivity of *Solea vulgaris* in Lake Qarun, Egypt Bull Fac Sci Cairo Univ , 56 209 - 219

Booth, R L and L B Labring, (1973)
Evaluation of Auto-Analyser II A Progress Report In "Advances in Automated Analysis 1972 Technical International Congress, Vol 8, P 7 Medial Inc , Torrytown, N Y

Boraey, F A (1974)
Biological study of the family mugilidae in Lake Qarun Ph D thesis, Ein-Shams University, 296 p

Boulos, R and M B M , Ashour (1973)
Studies on the female reproductive cycle of some fishes at Lake Qarun (Faiyum, Egypt) Bull Fac Sci Cairo Univ , 46 253 - 273

Caddy, J F (1982)
Use of Beverton and Holt yield tables for preliminary assessment of effects of changes in size at first capture and fishing effort in a mixed species fishery FAO Fish Rep , 236 141 - 149

Caljon A G (1983)
Brackish-water phytoplankton of the Flemish Lowland Developments in Hydrobiology 18 Junk Publ The Hauge 65 - 92

Caton, Thompson, G and Gardiner, E W (1929)
Recent work on the problem of lake Morris, Geogr J Egypt, Cairo 73 20 - 26

Chapman, D G (1961)
Statistical problems in dynamics of exploited fisheries population Proc Fourth Berkeley Symp on Mathematical Statistics and Probability pp 153 - 168

Chapman, D G and P S , Robinson (1960)
The analysis of catch curve Biometrics, 16 354 - 368

Chow, D T and R J Robinson (1953)
The forms of silicate available for colourimetric determination Anal Chem. 25 646

Coque, R (1975)
La cuvette du Fayoum Aspects et problems geomorphologyiques In BERNAND E Recueil des inscriptions grecques du Fayoum. Brill, Leiden, 1 1-10

Dugdale, R C and Goering, J J (1967)
Uptake of new and regenerated forms of nitrogen in primary production Limnol and Oceano 12 196 - 206

Duncan, K W (1980)
On the back-calculation of fish length, modifications and extensions to the Fraser-Lee equation J Fish Biol , 16 725 - 730

Eissa I A M , Badran A F and Mervet S H (1993)
Control of disease problems among cultured freshwater fishes in Kafr El- Sheikh Governorate J Egypt Vet Med Ass 53, 505 - 512

El-Maghraby, A M & Dowidar, N M , (1969)
The occurrence of marine plankton organisms in Lake Qarun (Egypt) Commission Int pour L'Expt Sci de La Mer Medit Monaco, 19 849-851

El-Sayed, A I (1986)
Contribution AL'ETUDE Biogeologique De Bassins paraliques Egyptiens pour obtenir Le grode de Docteur D'ETAT Es Science Unversite de Nates 252 pp

El-Seabe, A H (1981)
Overview and summary of the present situation of pesticides in Egypt Background contamination of the environment in Egypt Background contamination of the environment with pesticides pollution Proc 1st Egyptian - Hungarian Conf Plant Protection Plant Pathology, Entomology and pesticides Budapest, Hungary 27 - 30 May pp I - XIII

An account of the herring investigation conducted at Plymouth during the years from 1924 - 1933 J Mar Biol Ass U K., 19 305 - 348

Fraser, C MCL (1916)
Studies of age determination of fish Part II a survey of literature Fishery invest , London, Ser 2 (2) 50p

Gales, M E , Jr E C and R C Kroner (1966)
Method for quantitative determination of total phosphorus in water J Amer Water Works Ass 58 1363

Gardner, E W (1932)
Some lacustrine mollusca from the Fayoum Depression Mem. Inst d'Egypt, 18 1-123

Gayanilo, F C Jr , Sparre, P and D , Pauly (1996)
FAO-ICLARM stock assessment tools (FiSAT) User's manual FAO Computrized Information Series, Fisheries, 126 p

Giorgetti Gr and Ceschia G (1982)
Vibriosis in rainbow trout , *Salmo gairdneri* R in freshwater in north eastern Italy J fish dis 5, 125 - 130

Girgis, R B, (1959)
Okolgische untcosuchuorgen in Lake Qarun (Agypten) Dissertation, Universitat Kiel

Gulland, J A (1971)
Science and Fisheries Management J Cons CISEM, 33 (3) 471 - 477

Gulland, J A (1983)
Fish Stock Assessment A manual of basic methods FAO/Wiley series on Food and Agriculture vol 1, 223 p

Gulland, J A and J , Holt (1959)
Estimation of growth parameters for data at unequal time intervals J Couns Int Explor Mer , 25 47 - 49

Hile, R 1970
Body-scale relation and calculation of growth in fishes Trans Am. Fish Soc , (99) 468 - 474

Hussein, M F , Naguib, M and Bolous, R (1964)
Ecological studies on Lake Qarun (limit of visibility and turbidity of the lake water and their significance Bull Fac Sci , No 39 187 - 199

Hutchinson, G E (1957)
A Treatise on Limnology 1 Geography, Physics and Chemistry New York, Toh Wiley & Sons Inc , 1015 pp

Ibrahim, E A (1979)
Investigation of levels and effects of pollutants on saline lakes and littoral marine environments Part I Ecological studies in Lake Qarun Scientific Report Academy of Scientific Research and Technology Institute of Oceanography and Fisheries 104 pp

Ibrahim, E A (1981)
Investigation of level and effect of pollutants on saline lakes and littoral marine environments Academy of Scientific Research and Technology, Technical report, No 11 165 pp

Ishak, M M , Abdel-Malek, S A and M M , Shafik (1982)
Development of mullet fisheries (Mugilidae) in Lake Quarun, Egypt Aquaculture, 27 251 - 260

El-Seabe, A H (1981)
Overview and summary of the present situation of pesticides in Egypt Background contamination of the environment with pesticides pollution Proc 1st Egyptian - Hungatian Conf Plant Protection Plant Pathology, Entomology and pesticides Budapest, Hungary 27 - 30 May pp I - XIII

El-Zarka, S (1960)
Tilapia fisheries investigation in Egyptian lakes I-Annulus formation on the Cichlid fish of *Tilapia zillii* (Gerv) and its validity in age and growth studies, Notes Hydrobiol Dep Minist Agric UAR, (62)

El-Zarka, S (1961)
Tilapia fisheries investigation in Egyptian lakes II-a biological study of the fisheries of *Tilapia zillii* (Gerv) in Lake Quarun, UAR, Notes Hydrobiol Dep Minist Agric UAR, (66) 44p

El-Zarka, S (1962)
Tilapia fisheries investigation in Egyptian lakes III-Maturity, spawning and sex ratio of *Tilapia zillii* (Gerv) in Lake Quarun, UAR, Notes Hydrobiol Dep Minist Agric UAR, (67) 24p

El-Zarka, S (1963 a)
Acclimatization of *Solea vulgaris* (Linn) in Lake Quarun, Egypt J Cons Explor Mer, 28 (1) 126 - 136

El-Zarka, S (1963 b)
Acclimatization of *Mugil saliens* (Risso) in Lake Quarun, United Arab Republic Proc Gen Fish Coun Medit , 7 337 - 346

El-Zarka, S (1968)
Rehabilitation of fisheries of an inland saline lake in the United Arab Rupublic Stud Rev Gen Fish Coun Medit , 35 21 - 43

El-Zarka, S and F , Kamel (1965)
Mullet fry transplantation and its contribution to the fisheries of inland brackish lakes in the United Arab Rupublic Proc gen Fish Coun Medit , 8 209 - 226

El-Zarka, S and H , El-Sedafy (1970)
The biology and fishery of *Mugil saliens* (Risso) in Lake Quarun UAR Bull Inst Ocean Fish Cairo, 1 3 - 26

Ezzat, A A , Hashem, M T and M M , El Gharabawy (1979)
Biometric variations in *Solea vulgaris* acclimatized in Lake Quarun, Upper Egypt J Fish Biol , 14 39 - 46

Faouzi, H (1938)
Rapports sur les pêcheries d'Egypt en 1935 Ministère du Commerce et de l'Industrei 133p

Fauzi, H (1936)
Successful stocking of Lake Quarun with mullets (Mugil cephalus Linn , and *Mugil capito*, Cuv) from the Mediterranean Int Rev Hydrobiol , 33 434 - 439

Fishar, M R A (1993)
Studies on bottom invertebrates in Lake Qarun, Egypt M Sc Thesis, Fac Sc , Benha, Zagazig Univ , 177 pp

Ford, E (1933)

Ismaial , M M , A M Eissa and M S Hanafi (1990)
Vibriosis in marine fishes of Qarun Lake, Zagazig Vet J 18,5, 94 - 105
Jackson, M L (1967)
Soil chemical analysis Censtable and Co Ltd , London
Jackson, M L (1969)
Soil chemical analysis Advanced course 2nd published by the author Department of Soil Sci, Univ of Wisconsin, Madison wis
Kamel, S A and M M , Fathalla (1995)
Histological observations on the gills, livers and ovaries of some fish species in Lake Qarun J Union Arab Biol , Cairo, vol 4 (A) 67 - 86
Katz H and E Navone (1964)
Method for simultaneous determination of Calcium and Magnesium. J Amer Water Works Ass 56 121
Khalifa, U S A (1995)
Biological studies on gilthead sea bream *Sparus aurata* Linnaeus, 1758 (Pisces, Sparidae) in Lake Bardawil M Sc Thesis, Faculty of Science, Cairo University 308 p
Kilmer, V J and L T Alexander (1949)
Methods of making mechanical analysis of soil Soil Sci , 58 15 - 24
Kirollus, S Y (1977)
Biological studies of *Solea vulgaris* in Lake Qarun, Egypt M Sc thesis, Faculty of Science, Cairo University
Kostiainen, R (1969)
Klorofyllimenetelma Kasviplanktonian Biomassan maarity smenetelmana Limnologi symopsion 1986 44 - 52
Lee, R M (1920)
A review of the methods of age and growth determination in fishes by means of scales Fish Invest Min Agr Fish , Ser 2, 4 (2) 1 - 32
Leung C K., Huang Y W and Pancrobo, O C (1992)
Bacterial pathogens and indicators in catfish and pond environments, J Foods, Part 55, 6, 424 - 427
Lom, J (1985)
A contribution to the systematies and morphology of endoparasitic trichodinids from amphibians, with a proposal of uniform specific characteristics J protozool , 5 251 - 263
Lom, J and Dykova, I (1992)
Protozoan Parasites of Fishes Elsevier science publishers, Amsterdam, 315 pp
Macarthy D H , Stevenson J P and Roberts M S (1974)
Vibrosis in rainbow trout J Wildl Dis 10 2-7
Macfaddin, J F (1980)
Biochemical tests for identification of medical bacteria Williams and wilkins Co , Baltimore
Mckeague, J A and Cline, M G (1963 a)
Silica in soil solutions 1 The form and concentrations of dissolved silica in aqueous extracts of some soils Can J Soil Sci 43 70 - 82
Mckeague, J A and Cline, M G (1963 b)

Silica in soil solution II The adsorption of monosilicic acid by soil and by other substances Can J Soil - Sci 43 83 - 96

Mckenizie, H A and H S Wallence (1954)
The Kjeldhal determination of nitrogen A critical study digestion condition Aust J Chem. 7 - 55

Meffert, M E and Zimmermann - Telschow, H (1979)
Net release of nitrogenous compounds by axenic and bacteria containing cultures of *Oscillatoria resekei* (Cyanophyta) Arch Hydrobiol 87 125 - 138

Meshal, A H (1973)
Water and salt budget of Lake Qarun, Fayum, Egypt Ph D Thesis Alexandria University, 109 pp

Messiha-Hanna, R G (1992)
Sequential extraction of metals in Cooks River sediments Miskiewicz, A G (Ed) (1992) Proceedings of bioaccumulation workshop Assessment of distribution, Impacts and Bioaccumulation of contaminants in Aquatic environments Water Board and Australian Marine Science Association Inc , Sydney

Mosaad, M N M (1990)
Biological studies on five fish species from Lake Quarun, Egypt 1- length-weight relationship and condition factor Proc Zool Soc A R Egypt, 21 331 - 344

Munn C B (1978)
Haemolysin production by *Vibrio abguillarum* FEMS Microbiology Let 3, 265 - 268

Naguib, M (1958)
Studies on the ecology of Lake Qarun (Faiyum - Egypt)part 1 Kiel Meeresforach, 14 (2) 187-222

Naguib, M (1961)
Studies on the ecology of Lake Qarun (Faiyum-Egypt) part 2 Kiel Meeresforach, 17(1) 94-131

Nebakken, J W (1988)
Marine Biology An Ecological Approach 514 pp Hupper and Row Publication New York

Nossier, M A and Abou El-Kheir, W S (1970)
Effect of dissolved nutrients on the distribution of algal flora in selected lakes of U A R 1-Qarun Lake Bull Fac Sc Ain Shams Univ Noý 6

Nydal, F (1976)
On the optimum conditions for the reduction of nitrate by cadmium. Talanta 23 - 349

Pauly, D (1983)
Some simple methods for the assessment of tropical fish stocks FAO Fish Tech Rep , 234 52 p

Pauly, D and M L , Soriano (1986)
Some practical extensions to Beverton and Holt's relative yield-per-recruit model, p 491 - 496 In J L Maclean, L B Dizon and L V Hosillo (eds) The first Asian fisheries forum. Asian Fisheries Society, Manila, Philippines

Popoff M (1984)
Genus 111 Aeromonas Kluyver and von Niel in Bergey's manual of systematic bacteriology, vol 1 (ed by N R Krieg and J G Holt) pp 545 Williams and Wilkins Co , Baltimore

Quéro, J -C , M Desoutter and F Lagardére (1983)

Soleidae In Fishes of the North-eastern Atlantic and the Mediterranean Whitehead , P J P , Bauchot, M -L , Hureau, J -C , Nielsen, J and E , Tortonese (eds) UNESCO pp 1308 - 1328 D and esoutter

Raymont, J E G (1980)
Plankton and Productivity in the Ocean 2nd edition Vol 1 Phytoplankton Maxwell, R Oxford, Pergamon Press

Richer, W E (1975)
Computation and Interpretation of Biological Statistics of Fish Population Bull Fish Res Bd Cand , 191, 382 p

Rossum, J R and Villarrug (1961)
Suggested methods for turbidiometric of sulphate in water J Amen water works Ass 53 873

Said, R (1962)
The Geology of Egypt Cairo, American Elsevier publishing company, 377 pp

Shafik, M M (1991)
Biological studies on *Mugil cephalus* (Linn) and *Liza ramada* (Risso) of Lake Qarun with special emphasis on the fisheries of the lake and principals of inducing breeding of *Mugil cephalus* (Linn) M Sc thesis, Fac Sci Cairo University 381p

Strickland, J D H and Aarson (1965)
A Manuel of Sea Water Analysis 2nd ed Fisheries Research Board of Canada, Ottawa

Stricklard, J D H and Parson (1968)
A Practical Handbook of Seawater Analysis Fisheries Research Board of Canada, Ottawa, 311 pp

Swaroop (1951)
The range of variation of the most probable number of organisms estimated by the dilution method Indian J Med Res , 39 107

Thingran , A G (1986)
Artificial recruitment and fisheries management of Indian reservoirs Central Inland Fisheries Research Institute, Bull No 45, 52 pages

Torres J L , Shariff M and Law A T (1990)
Identification and virulence screening of *Aeromonas* sp isolated from healthy and epizootic ulcerative syndrome (EUS) infected fish In The second Asian fisheries forum (ed by R Hirano and T Honya) pp 663 - 666 Asian fisheries society Manila

Trussel, R P (1972)
The percent of unionized ammonia in aqueous ammonia solutions at different pH levels and temperature T Fish Res Bd Can 29 1505 - 1507

Ursin, E (1967)
A mathematical model of some aspects of fish growth, respiration and mortality J Fish Res Bd Can , 24 2355 - 2453

Van As, J G & Basson , L (1989)
A further contribution to the taxonomy of the Trichodinidae (Ciliophora Peritrichida) and a review of the taxonomic status of some fish ectoparasitic trichodinids Sys Parasitol , 14 157 - 179

Walford, L A (1946)
A new graphic method of describing the growth of animals Biol Bull , 90 141 - 147

Wellborn, T U (1967)

Trichodina (Ciliata Urceolaridae) of freshwater fishes of the southern United States J Protozool 14 (3) 399 - 412

Werner, D (1997)
The Biology of Diatoms Blackewell Scientific publication Osney Mead, Oxford O x 2 OEL 498 pp

Wetzel, R G (1983)
Limnology Saunders College Publishing Second Edition 767 pp

Wimipenny, R S , (1936)
The ova and larvae of *M capito* Cuv from Lake Qarun, Egypt Ann Mag Nat Hist , Ser 10,17 405 - 413

Wimpenny, R S and H Faouzi (1935)
The breeding of grey mullet, *Mugil capito*, Cuv in Lake Quarun, Egypt Nature, Lond , 135 (3425) 1041