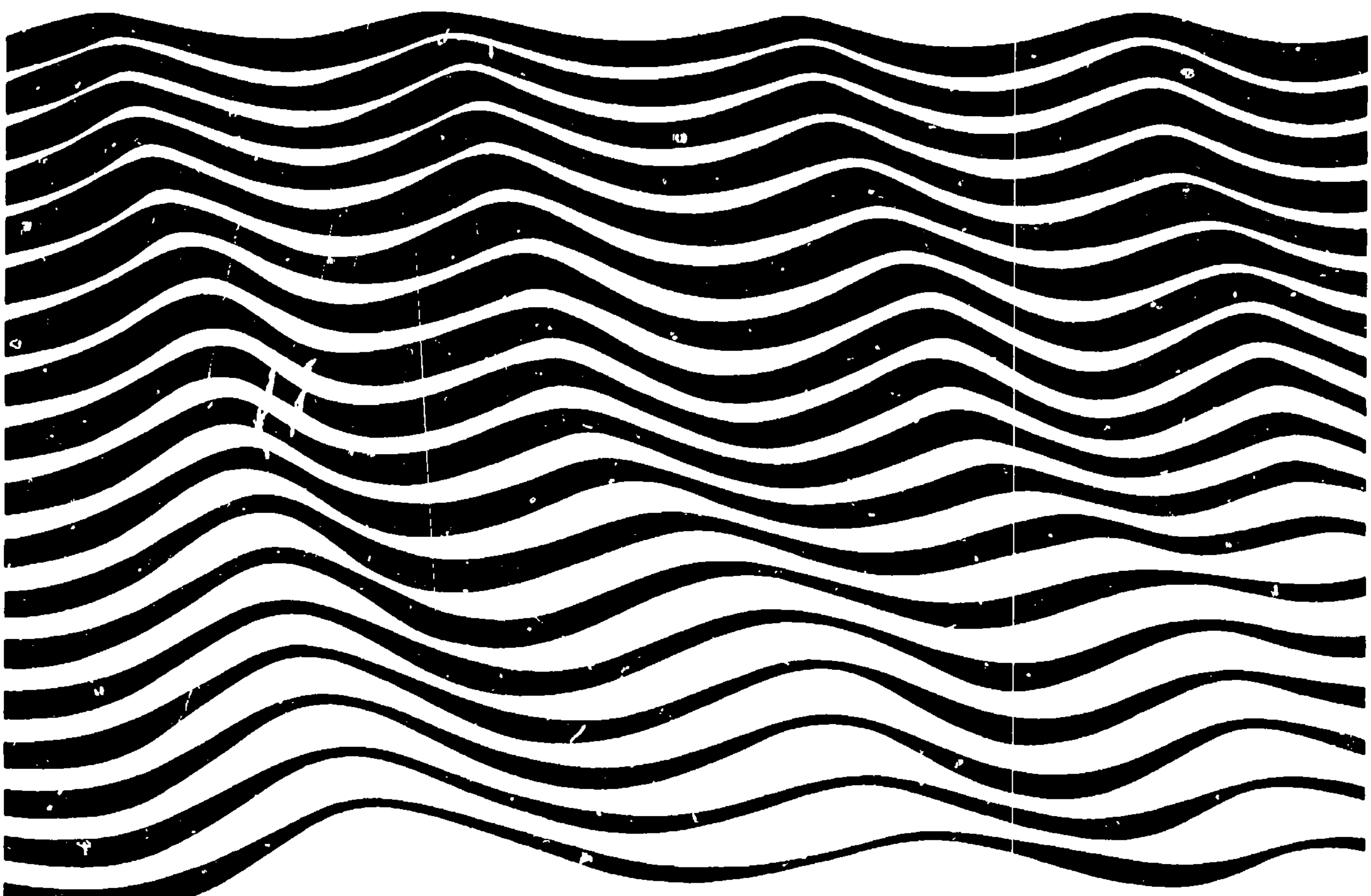
Unesco reports
in marine science 29

Eutrophication in coastal marine areas and lagoons: a case study of 'Lac de Tunis'



Unesco, 1984

UNESCO REPORTS IN MARINE SCIENCE

No.		Year
1	Marine ecosystem modelling in the Eastern Mediterranean Report of a Unesco workshop held in Alexandria, Egypt, December 1974 English only	1977
2	Marine ecosystem modelling in the Mediterranean Report of the Second Unesco Workshop on Marine Ecosystem Modelling English only	1977
4	Syllabus for training marine technicians Report of an IOC/Unesco workshop held in Miami, Florida, 22-26 May 1978 Available in English, French, Russian and Spanish	1979
5	Marine science syllabus for secondary schools Report of an IOC workshop held at United World College of the Atlantic, United Kingdom, 5-9 June 1978 Available in Arabic, English, French, Russian and Spanish	1979
6	Organization of marine biological reference collections in the Mediterranean Arab countries Expert meeting held in Tunis, 20-23 September 1978 Available in Arabic, English and French	1979
7	Coastal ecosystems of the southern Mediterranean: lagoons, deltas and salt marshes Report of a meeting of experts, Tunis, 25-27 September 1978 Available in Arabic, English and French	1979
8	The mangrove ecosystem: Human uses and management implications Report of a Unesco regional seminar held in Dacca, Bangladesh, December 1978 English only	1979
9	The mangrove ecosystem: scientific aspects and human impact Report of the seminar organized by Unesco at Cali, Colombia, 27 November-1 December 1978 Available in English and Spanish	1979
10	Development of marine science and technology in Africa Working Group of Experts sponsored by ECA and Unesco, Addis Ababa, 5-9 May 1980 Available in English and French	1980
11	Programa de Plancton para el Pacífico Oriental Informe final del Seminario-Taller realizado en el Instituto del Mar del Perú, El Callao, Perú, 8-11 de septiembre de 1980 Spanish only	1981
12	Geología y geoquímica del margen continental del Atlántico Sudoccidental, Informe final del Taller de Trabajo organizado por la Unesco en Montevideo, Uruguay, 2-4 de diciembre de 1980 Spanish only	1981
14	Marine science and technology in Africa: present state and future development Synthesis of Unesco/ECA survey missions to African coastal states, 1980 Available in English and French	1981
15	Fishery science teaching at the university level Report of a Unesco/FAO workshop on university curricula in fishery science, Paris, May 1980 Available in Arabic, English, French, Russian and Spanish	1981
16	Marine and coastal processes in the Pacific: ecological aspects of coastal zone management Report of a Unesco seminar held at Motupore Island Research Centre, University of Papua New Guinea, 14-17 July 1980 English only	1981
17	The coastal ecosystems of West Africa: coastal lagoons, estuaries and mangroves A workshop report, Dakar, 11-15 June 1979 Available in English and French	1981
18	Coral reef management in Asia and the Pacific: some research and training priorities Report of a Unesco workshop held in Manila, Philippines 21-22 May 1981 English only	1982
19	Mareas rojas en el Plancton del Pacífico Oriental Informe del Segundo Taller del Programa de Plancton del Pacífico Oriental, Instituto del Mar, Callao, Perú 19-20 de noviembre de 1981 Spanish only	1982
20	Quantitative analysis and simulation of Mediterranean coastal ecosystems: The Gulf of Naples, a case study Report of a workshop on ecosystem modelling Ischia, Naples, Italy, 28 March to 10 April 1981 Organized by the United Nations, Educational, Scientific and Cultural Organization (Unesco) and the Stazione Zoologica, Naples English only	1983
21	Comparing coral reef survey methods A regional Unesco/UNEP workshop, Phuket Marine Biological Centre, Thailand, December 1982 English only	1983
22	Guidelines for marine biological reference collections Prepared in response to a recommendation by a meeting of experts from the Mediterranean Arab countries Available in English, French and Arabic	1983
23	Coral reefs, seagrass beds and mangroves: their interaction in the coastal zones of the Caribbean Report of a workshop held at West Indies Laboratory, St. Croix, U.S. Virgin Islands, May, 1982 English only	1983
24	Coastal ecosystems of Latin America and the Caribbean The objectives, priorities and activities of Unesco's COMAR project for the Latin America and Caribbean region Caracas, Venezuela, 15-19 November 1982 Available in English and Spanish	1983
25	Ocean engineering teaching at the university level Recommended guidelines from the Unesco/IOC/ECOR workshop on advanced university curricula in ocean engineering and related fields, Paris, October 1982 Available in English, French, Spanish, Russian, Arabic and Chinese	1983
26	Global survey and analysis of post-graduate curricula in ocean engineering English only	1984
27	Productivity and processes in island marine ecosystems. Recommendations and scientific papers from the Unesco/IOC sessions on marine science co-operation in the Pacific, at the XVth Pacific Science Congress, Dunedin, New Zealand, February 1983 English only	1984
28	Oceanographic modelling of the Kuwait Action Plan (KAP) Region. Report of simposium/workshop; University of Petroleum and Minerals, Dhahran, Kingdom of Saudi Arabia 15-18 October 1983 English only	1984
29	Eutrophication in coastal marine areas and lagoons: a case study of 'Lac de Tunis' Report prepared by Dr M. Kelly and Dr M. Naguib English only	1984

Unesco reports
in marine science 29

Eutrophication in coastal marine areas and lagoons: a case study of 'Lac de Tunis'

Report prepared by:
Dr. M. Kelly and Dr. M. Naguib

Unesco, 1984

Published in 1984 by the United Nations Educational,
Scientific and Cultural Organization,
Place de Fontenoy, 75700 Paris.
Printed in Unesco's workshops.

PREFACE

Unesco Reports in Marine Science are designed to serve specific programme needs and to report on developments in projects conducted by the Unesco Division of Marine Sciences, including those involving collaboration between the Division and the Intergovernmental Oceanographic Commission, particularly in the field of training, education, and mutual assistance in the marine sciences.

Designed to serve as a complement to the *Unesco Technical Papers in Marine Science*, the *Reports* are distributed automatically to various institutions and governmental authorities. Individuals may, at their request, receive copies of specific titles, but cannot be included on the automatic distribution list. Both the *Reports* and the *Technical Papers* series are free of charge.

Requests for copies of specific titles or for additions of institutions or authorities to the mailing list should be addressed, on letterhead stationery if possible, to:

Marine Information Centre
Division of Marine Sciences
Unesco
Place de Fontenoy
75700 Paris
France.

ABSTRACT

During the period from September 6 through 18, 1982 a workshop was conducted in Tunis, Tunisia to discuss and teach about problems of eutrophication in coastal marine areas. The history of the concept of eutrophication, as developed for north-temperate lakes, was discussed. The major processes involved, including nutrient enrichment, excess algal growth, oxygen depletion, and the microbial processes in anaerobic environments were described. Participants described eutrophic conditions found in coastal areas of their respective countries (all bordering the Mediterranean). The eutrophication of lac de Tunis, perhaps the most eutrophic embayment in the world, was discussed and presented as a case study. During the workshop we realized that coastal eutrophication is more common than is usually recognized. We also realized that the concepts of cultural eutrophication as originally described for north-temperate lakes apply imperfectly to the marine environment. But the processes in both environments are similar, with the addition of large quantities of nutrients, excessive algal growth, depletion of oxygen with consequent microbial and chemical changes, and the death of large numbers of animals and complete change of ecosystem structure.

RESUME

Du 6 au 8 septembre 1982 s'est tenu à Tunis (Tunisie) un séminaire de réflexion et d'information sur les problèmes d'eutrophisation en milieu marin côtier. Après l'historique de la notion d'eutrophisation, apparue en relation avec des lacs de régions septentrionales tempérées, les principaux processus en jeu - enrichissement en élément nutritifs, prolifération excessive d'algues, appauvrissement en oxygène - et les réactions microbiennes intervenant en milieu anaérobie ont été exposés. Les participants ont décrit les problèmes d'eutrophisation côtière existant dans leurs pays respectifs (tous riverains de la Méditerranée). Ils ont étudié en détail le cas du lac de Tunis, sans doute la lagune la plus eutrophique du monde. Ce séminaire a permis de constater que l'eutrophisation en zone côtière est plus courante qu'on ne le croit généralement. On s'est aussi rendu compte que les définitions de l'eutrophisation culturelle, formulées à l'origine pour des lacs de régions septentrionales tempérées, ne convenaient pas parfaitement au milieu marin. Il n'en reste pas moins que les processus en jeu sont similaires dans l'un et l'autre cas : apport d'éléments nutritifs en grande quantité, prolifération excessive d'algues, appauvrissement en oxygène entraînant certaines modifications microbiennes et chimiques, mort de nombreux animaux et transformation complète de la structure de l'écosystème.

RESUMEN

Del 6 al 18 de septiembre de 1982, se celebró en Túnez un seminario donde se dictaron conferencias sobre la eutroficación de las zonas marinas costeras y se debatieron los problemas relacionados con ese tema. Se examinó la historia del concepto de eutroficación desarrollado para los lagos templados del norte. Se describieron los principales procesos que intervienen, a saber, enriquecimiento de nutrientes, crecimiento excesivo de algas, disminución del oxígeno y los procesos microbianos en medios anaeróbicos. Los participantes describieron las condiciones eutróficas detectadas en las zonas costeras de sus respectivos países (todos a orillas del Mediterráneo). Se analizó y se presentó como caso de estudio la eutroficación del lago de Túnez, probablemente la albufera más eutrófica del mundo. Durante el seminario comprendimos que la eutroficación costera es más corriente de lo que se admite generalmente. También comprendimos que los conceptos de eutroficación relacionados con los cultivos acuáticos, tal como se describieron originalmente para los lagos templados del norte, no se aplican perfectamente al medio marino, aunque los procesos son similares en los dos medios, con la adición de una gran cantidad de nutrientes, excesivo crecimiento de algas y disminución de oxígeno con los consiguientes cambios microbianos y químicos y la desaparición de grandes cantidades de animales y un cambio completo en la estructura del ecosistema.

РЕЗЮМЕ

В период с 6 по 18 сентября 1982 г.в Тунисе /г. Тунис/ состоялся семинар по рассмотрению и изучению проблем эутрофикации в прибрежных морских зонах. Был обсужден вопрос возникновения концепции эутрофикации озер северного полушария, расположенных в зоне умеренного климата. Было дано описание основных характерных процессов, включая обогащение питательной среды, чрезмерное развитие водорослей, кислородное истощение и микробные процессы в анаэробной среде. Участники семинара описали эутрофные условия, обнаруженные в прибрежных зонах своих стран /прилегающих к Средиземному морю/. Была обсуждена и изложена в виде тематического исследования эутрофикация озера Тунис, являющегося, по-видимому, наиболее эутрофным заливом в мире. В ходе семинара был сделан вывод о том, что прибрежная эутрофикация является более распространенным явлением, чем обычно принято считать. Был также сделан вывод, что концепции эутрофикации, возникающей в результате деятельности человека, которые первоначально были разработаны для озер северного полушария в зонах умеренного климата, едва ли применимы к условиям морской среды. Однако процессы, происходящие в той и другой среде, сходны между собой и характеризуются поступлением большого количества питательных веществ, чрезмерным развитием водорослей, кислородным истощением с возникновением последующих микробных и химических изменений, гибелью значительной части фауны и полным изменением структуры экосистемы.

ملخص

في الفترة من ٦ الى ١٨ سبتمبر/أيلول ١٩٨٢ عقدت حلقة عمل في تونس العاصمة للمناقشة والتدريس بشأن مشكلات الانتاج العضوي الزائد في المناطق البحرية الشاطئية. وانصبت المناقشة على تاريخ تطور مفهوم الانتاج العضوي الزائد في البحيرات الشمالية المعتدلة . ووصفت العمليات الأساسية المرتبطة به بما فيها وفرة المواد الغذائية والنمو المفرط للطحالب ونضوب الأوكسجين والعمليات الجرثومية في البيئات اللاهوائية. ووصف المشتركون في الحلقة ظروف وفرة الانتاج العضوي في المناطق الشاطئية في بلدانهم (التي تقع جميعها على ساحل البحر المتوسط). ونوقشت وفرة الانتاج العضوي في بحيرة تونس التي ربما تكون أكثر التشكيلات الخليجية وفرة في الانتاج العضوي في العالم ، وعرضت في صورة دراسة حالة . وأثناء حلقة العمل أدركنا أن وفرة الانتاج العضوي الشاطئية منتشرة على نطاق أوسع مما يسلم به عادة . وأدركنا أيضا أن مفاهيم وفرة الانتاج العضوي الاستنباتية كما جرى وصفها أصلا بالنسبة للبحيرات الشمالية المعتدلة لا تنطبق بصورة كاملة على البيئة البحرية . ولكن العمليتين متشابهتان مع زيادة كميات كبيرة من المواد الغذائية وافراط في نمو الطحالب ونضوب في الأوكسجين بما يترتب عليه من تغييرات جرثومية وكيمياوية ونفوق أعداد كبيرة من الحيوانات وتغيير كامل في بنية النظام الايكولوجي .

摘　　要

1982年9月6日至18日期间在突尼斯的突尼斯城举办了一个讲习班，讨论与讲授关于近海区域的滋育问题。对于为北温带湖泊制定的滋养的概念的历史进行了讨论。说明了涉及的主要过程，如营养富集、过量藻类的生长、缺氧现象，以及无氧环境中的微生物过程。讲习班参加者论述了在各自国家（均以地中海为国界）海岸区域发现的滋养条件。对可能是世界上最具有滋养性的海湾突尼斯湖的滋养作用进行了讨论，并将其提出作为一项实例研究。在讲习班期间，我们认识到，沿海的滋养作用比人们通常看到的更为常见。我们还认识到，最初为描述北温带湖泊而制定的栽培滋养的概念不能完全应用在海洋环境方面。但是，只要加上大量的营养物质、大量藻类的生长、缺氧现象及由此引起的微生物和化学方面的变化，以及大量动物的死亡和生态系统结构的完全改变这些内容，两种环境的过程还是相似的。

TABLE OF CONTENTS

INTRODUCTION

Most of the world's population centers are found either in coastal marine areas or on rivers. The historical reason is simple: until the 20th century commerce required harbors, and commerce produced cities. But harbors must be partially separated from the sea, if for no other reason than protection of shipping. Separation from the sea means that harbors are easily polluted: wastes from neighboring cities can accumulate and there is limited flushing to the ocean.

Until the 19th century most towns and cities were small and most waste was transported back to farmland for use as fertilizer. More recently, agricultural production has become separated from the cities, the centers of consumption. At the same time we have learned to produce synthetic nutrients, particularly nitrate and phosphate, and farms have become independent from towns as a source of fertilizers and nutrients; there is little recycling. Urban wastes, high in concentrations of nitrate and phosphate, are discharged to rivers and to the sea.

Improvements in agricultural technology combined with technological development have resulted in rapid increases in the populations of cities. More population has meant more waste discharge to harbors. The discharge of nitrate and phosphate to enclosed harbors and coastal lagoons has produced an increased growth of plants, that is, macroscopic algae and phytoplankton. The decomposition of those plants produces a depletion of oxygen, an accumulation of hydrogen sulfide, fish kills, and a variety of other problems. This syndrome in the marine environment is analagous to problems that have occurred in fresh-water lakes, where it has been called eutrophication, or more precisely, cultural eutrophication.

Many nations hope to develop their economies through tourism, and tourism often requires water for boating and swimming. Many nations also depend on fish as an important protein source. And all people enjoy the beauty of coastal waters. This syndrome, when it occurs in near-shore marine waters, prevents recreational water use and destroys fish production and the aesthetics of a beautiful environment.

The urbanization of port cities, combined with changes in the economic distribution of food resources, has produced problems of coastal eutrophication in almost all of the maritime nations. Those problems are particularly acute for nations that depend on coastal fisheries and tourism.

SCOPE OF THE WORKSHOP

The original intent of this workshop was to examine the problems of eutrophication in the nations of the Southern Mediterranean and to inform young scientists from those nations about the means for studying and practically approaching those problems. As the composition of the participants in the workshop became known, however, it was clear that the format of a training workshop was inappropriate and that we should address basic problems of the eutrophication process. The scientific coordinators, Kelly and Naguib, first presented a history of the eutrophication concept and a description of the basic processes involved. Naguib described the biogeochemical processes in the very important anaerobic environment and Kelly gave some examples of coastal eutrophication from various environments throughout the world. Each participant presented a description or example of the coastal eutrophication problem as it occurs in his country. The result was a unique workshop in which all participants learned of the problems and processes from a diverse set of environments. Current research techniques and problems were also presented and discussed.

Throughout the workshop we examined the particular problems of lac de Tunis, an extremely eutrophic bay adjacent to the site of the meeting. Thus this report focuses in particular on the problems in that rather extreme environment.

In order to provide an aim for the workshop we decided to address a particular question: "Can the concept of eutrophication, as developed for temperate lakes, be applied to coastal ecosystems?" That question addresses nearly all aspects of coastal eutrophication. The idea of eutrophication was first developed for inland lakes, particularly in the temperate areas of Europe and North America. We simply asked whether the same concept should be applied to coastal waters or whether the processes there are so different that other concepts must be applied. As will be seen, we soon realized that as the word eutrophication is commonly used it is a vague term that is difficult to define and that tries to describe a syndrome of processes and problems occurring in both marine and freshwater environments.

This report touches on most of the important problems and processes pertaining to eutrophication in the marine environment, but it is not intended to be either a verbatim presentation of the material presented in the workshop nor a complete review of the available literature.

The workshop was organized in the "Institut National Scientifique et Technique d'Océanographie et des Pêches" (INSTOP), Tunis. The present report was prepared by the Scientific Coordinators of the workshop, Dr. Mahlon G. Kelly, from the Dept. of Environmental Sciences, University of Virginia, U.S.A., and Dr. Monir Naguib, from the Max Planck Institut fur Limnologie, Plon, F.R.G.

AN HISTORY OF THE EUTROPHICATION CONCEPT

As the term is presently applied by the layman, an eutrophic body of water is usually considered to be polluted, with bad odors and a "slimy" green color associated with excess algal growth. Eutrophication is also usually considered to be a symptom of pollution, whereby addition of excess nutrients leads to excess growth of algae with undesirable aesthetic conditions and depletion of oxygen perhaps leading to high mortality of heterotrophic organisms, particularly fish. Thus to most people "eutrophication" seems to mean striking change in an ecosystem due to addition of nutrients from a variety of human activities.

The idea of eutrophication is intimately tied in with the idea of a limiting nutrient. During the latter half of the 19th century Justus von Liebig and other chemists and agriculturalists pointed out that the growth of a crop is usually limited by the availability of a single nutrient. During the first half of the 20th century those ideas came to be generalized as "Liebig's 'law' of the minimum", which was applied to both crops and natural populations, and when it became apparent that this "law" was too narrow Shelford's "law" of limiting factors, which could include the climate and biota, was proposed (Odum, 1971). The simplistic ideas of a single limiting nutrient or single limiting factor are now rejected by most biologists, yet they persist in the idea of eutrophication. Both biologists and laymen often believe that the addition of a single nutrient to lakes or coastal marine systems is responsible for a catastrophic change in the conditions of the ecosystem. This is, of course, a misapplication of Liebig's "Law" since that idea should only be used with single species, not whole trophic levels. Nevertheless a single nutrient may dominate the eutrophication process.

It is apparent that under some circumstances very undesirable conditions develop in both coastal waters and lakes as a result of the addition of nutrients, usually phosphate or nitrate. Whether those problems should be called eutrophication is debatable, and it is instructive to look at the origin of the word, since the meaning has changed several times in the past 75 years.

The word "eutrophication" has had many shifts in meaning, and has often meant different things to British, Continental and American workers. It was not applied to the marine environment until the mid 1960's, and then only informally. The definition of eutrophication has often been confused with the application of indices for deciding whether a particular body of water is eutrophic. For example, strict species lists have been proposed by many authors as defining eutrophic lakes, even though those lists only applied in temperate water bodies in certain locations (for example see Teiling, 1955). Other authors have attempted to define eutrophication in lakes in terms of temperature distribution, oxygen distribution, chlorophyll concentration, biomass distribution, and multivariate indices combining all or many of those factors (see Taylor et al. 1979 for a summary). Almost all work has concentrated on producing indices for detection of eutrophication rather than a definition of the term. And eutrophication indices have been confused with definitions. There can be little doubt that damaging changes occur in water bodies as a result of the addition of excess nutrients, but what is eutrophication?

The concept of eutrophication (literally the process of becoming well-nourished) was first developed by Forel in research conducted at the turn of this century on the basis of physical conditions in German lakes. The word was applied to bogs by Weber (1907), and was again applied to North American lakes by Birge and Juday (1911) on the basis of the stratification of oxygen. It is unclear whether those authors were aware of each other's work, but they certainly differed in their ideas of what eutrophication was, and their ideas were very different from those of modern workers. Naumann (1917) in Sweden was the first to connect eutrophication with primary production and nutrients. He developed a classification scheme for lakes based on the richness of plankton in the trophogenic (euphotic) zone and he recognized nutrients as dominant factors. Thienemann (1918), in Germany, developed a similar but different scheme by which lakes were classified on the basis of the tropholytic zone, using the benthos (chironomids) and oxygen. Thienemann also added the concept of dystrophy, based on the presence of humic acids. Naumann and Thienemann together laid the basis of Seetypenlehre, or lake typology. Birge and Juday in the United States accepted the concepts of Naumann and Thienemann but continued to emphasize physical and chemical factors.

During the 1920's and 1930's various workers on the continent, in Britain, and in the United States refined the ideas of Naumann and Thienemann until a classification of lakes by trophic status became widely accepted. To oversimplify, it was considered that a lake went through a natural "aging" process whereby the addition of nutrients and the accumulation of sediments led to changes in species and increases in biomass at all trophic levels, accompanied by a gradual shallowing of the lake. This was considered to be accompanied by declining hypolimnetic oxygen and an increase in mean temperature of the lake due to a decrease in hypolimnetic volume. To again give an overly simplistic description, lakes were considered to pass through several distinct phases, from oligotrophic (low nutrients, low primary production, clear water) through mesotrophic (intermediate) to eutrophic (high nutrients, high primary production, turbid water), and sometimes continuing to dystrophic (low productivity, shallow, bound nutrients, clear but brown water with high humic acid concentrations) with eventual formation of a bog mat and, further on, passage to a complete bog and eventually a forest. This sequence of stages came then to be generally known as lake succession or the process of eutrophication. Hutchinson (1967) gives a good summary of the concepts as they were applied in this context. It is important to note that the idea of eutrophication was developed almost entirely in lakes of the north-temperate regions of North America and Europe, that the lakes were almost all of glacial origin, and most importantly, that they were relatively undisturbed by human activity.

Thus until the mid 1950's eutrophication was considered to be a natural process of ecological succession. Only in the last 25 years has it been considered that what is now known as cultural eutrophication is an acceleration of the natural process (Hutchinson, 1967), initially as a result of Edmondson's work on Lake Washington in the United States (Edmondson et al. 1956), and the work of Ohle (1955) (who termed it rasante seen Eutrophierung) on North German lakes, but that idea may be an oversimplification. Certainly the species, shoreline vegetation and other characteristics are often different between culturally and naturally eutrophic lakes, and natural eutrophication does not necessarily lead to undesirable conditions. Nevertheless the term eutrophication has come to be used to describe both the natural process of succession and the results of nutrient pollution. And the latter use of the word is what the layman knows, often leading to emotional discussion of lakes that are "prematurely aged". It was of course the pollution processes that were addressed in the workshop.

The recognition of the damage to lake ecosystems by cultural eutrophication has led to considerable research. Most of the work has centered on the study of the dynamic processes of eutrophication (which will be discussed in the next section), the detection and definition of eutrophication by various indices, both biological and chemical, and the restoration of eutrophied lakes.

A very wide variety of methods for detecting and classifying eutrophication have been proposed, none of them completely successful. They can roughly be classified as species indicators, indicators of community metabolism, and measurements of nutrient concentration or nutrient effects. The simplest (and perhaps least successful) indices involve the use of one or a few indicator species (see above). More complex are indices involving multiparametric classifications based on a variety of species, usually of phytoplankton, but they often produce ambiguous results because they have usually been developed in lakes of particular geomorphologies, geochemistries, or geographical locations (For an early example see Thunmark, 1945; more recently see Tarapchak, 1973 for examples of the problems). Indices based on species diversity, of which many have been proposed, have shown similar problems (Hutchinson, 1967 gives a thorough discussion of the idea; Kalff and Knoechel, 1978, discuss the problems). It should be noted that indicator species may be more helpful in the shallow marine environment: there eutrophication seems to be almost always accompanied by excessive growth of macroalgae of the genera Ulva, Enteromorpha, and/or Cladophora, but the applicability of such indicator organisms has not been systematically studied.

Indices based on community metabolism have an intrinsic appeal because nearly every aquatic ecosystem has both autotrophs and heterotrophs with energy transfer between them. The simplest "index" of this sort is the oxygen concentration in the hypolimnion. If a lake develops an anaerobic hypolimnion without input of saprobial waste many would immediately consider it to be eutrophic. Another simple index is the concentration of chlorophyll. Since the chlorophyll concentration is proportional to the photosynthetic rate it is an indicator of excess phytoplankton growth, presumably caused by excess nutrients. Although most workers would agree that waters with extreme levels of planktonic chlorophyll are probably eutrophic, chlorophyll gives no satisfactory indication of eutrophication at intermediate levels. The most complex metabolic indices involve the relationship between community gross production (P) and total community respiration (R). The simplest of these is the P/R ratio, which is presumably greater than one if biomass is accumulating in the community, and that might be considered a definition of eutrophication. More complex, often graphical, indices have been developed, usually involving a plot of P vs. R, and mostly based on the work of H. T. Odum (1956).

Indices based on nutrients have either been based on their absolute concentrations, the amounts bound in biomass, or the effects of the nutrients on algal growth. The concentrations are usually of limited use because so many other factors affect algal development. The most popular measurement of effect on algal growth is the standard algal assay, in which filtered samples from the water body are added to algal cultures and their effects observed, with and without controlled nutrient addition. Algal assay methods are still subject to controversy, but they are not relevant here because they have been used only with fresh-water species.

Restoration of water bodies is difficult because even if the source of nutrients is removed, internal recycling may retain the productivity at a high level unless there is excellent flushing and a short retention of the water. Several types of restoration attempts have been made including symptomatic treatment by algicides (usually copper sulfate) or by artificial mixing, direct removal of nutrients from the water, reduction of nutrient input, and harvesting of benthic plants and perhaps dredging of sediments to remove nutrients. The methods vary in their success. Algicides are only practical in small water bodies and they must be applied frequently. They are most successful in removing taste and odor causing phytoplankton from drinking water supplies, and they are commonly used by local water supply authorities in some countries. Artificial mixing is usually brought about by bubbling air from compressed air lines laid across the bottom. That is expensive and practical only in small water bodies. It has two effects: oxygenated water is mixed into the hypolimnion and algae are mixed out of the lighted zone, retarding their growth. Artificial mixing is again used by local water supply authorities to remove taste and odor, often from hydrogen sulfide, when hypolimnetic water is being used as a potable supply. Direct nutrient removal may be possible by oxidizing the surface of the sediments, for example by aeration, thus trapping sedimentary phosphate with a layer of oxidized iron (see below). Phosphates can be removed from the water column by chemical precipitation with alum.

The other two methods offer longer term solutions but are expensive and of varying success. The removal of nutrient sources, for example by chemical tertiary sewage treatment or by land use legislation, may be impractical for political or economic reasons, and is successful only if flushing of the water body or sedimentation will remove remaining nutrients. The restoration of Lake Washington in the U. S. is a successful example (Hutchinson, 1973), while the expensive U. S. EPA Shagawa Lake project was unsuccessful (unpublished). Removal of sediment and plant biomass to remove residual nutrients must of course be accompanied by eliminating inputs. It is practical only in shallow, small water bodies. The best known successful examples are for lakes in Sweden (Bjork, 1972a, 1972b, Bjork et al., 1972).

There have been at least two attempts at restoration in coastal marine environments. The removal of duck farm waste from inputs to eastern Great South Bay, New York, resulted in a decline of green algal phytoplankton (unpublished). Harvesting of macroscopic green algae, using the techniques applied to Lake Truman was tried in lac de Tunis (Bjork, 1972), but was unsuccessful because technical problems prevented continued removal. Restoration from eutrophication may or may not be successful, but it is always difficult and expensive. Prevention is preferable by far.

It should be obvious that the "classical" definition of eutrophication as lake succession cannot be applied to the marine environment. Nevertheless over the past 10 years it has become more common to refer to some marine systems as being eutrophic, including both polluted environments (such as lac de Tunis) and systems naturally enriched by nutrients (such as the Peru upwelling). There has been little systematic study of cultural eutrophication in marine systems; most studies have centered on applied problems in specific locations, and many have never been published in the reviewed literature. Perhaps the first study of cultural eutrophication in the marine environment (although it was not called eutrophication) was the work of Bumpus et al. (1954) in Great South Bay, south of Long Island, New York, U. S. A. Since then there have been numerous examples found in nearly every coastal nation, although they have not always been referred to as eutrophication. Some examples are summarized later.

THE PROCESSES OF EUTROPHICATION

The ecosystems of lakes are complex, and those of marine systems are more so, because except for certain coastal embayments marine ecosystems are unbounded and transport and circulation of the water is hard to define. Since cultural eutrophication involves nearly all of the processes in these ecosystems it is also very complex. The following is a necessarily simplified account of the processes involved; it is not a complete review and makes no attempt at providing complete references. This account also reflects the expertise of the participants and scientific coordinators. In particular little attention is paid to the effect of eutrophication on higher trophic levels, which has received little attention in the marine environment. This account also is to a great degree based on what is known of the eutrophication process in lakes, since that is where most work has been done, although most of the described processes should apply as well to the marine environment.

Cultural eutrophication may simplistically be thought of as the ecosystem changes that occur as a result of the addition of excessive nutrients to a water body with subsequent excess plant growth and increases in heterotrophic activity. To understand the processes involved in eutrophication we must at a minimum examine the nutrient types, their cycles and transformations, the factors influencing algal growth, and the fate of organic photosynthetic products as they are used by heterotrophic organisms. The transport and mixing of the water is also important, although it varies so much in marine environments that it is not discussed in detail here.

The nutrients most important in eutrophication are phosphate, nitrate and inorganic carbon. Phosphate is most commonly the controlling nutrient in lakes, with nitrate usually being present in excess. That is because phosphate is readily sequestered by iron oxides and hydroxides and by clay minerals which usually retain phosphate in the soil. In the marine environment that does not pertain, and even where clay particles or iron hydroxides are present the high salinity enables phosphate release. The role of inorganic carbon as a controlling nutrient in the marine environment has been little studied, largely because at the pH values and alkalinities of seawater enough carbon dioxide and bicarbonate, both of which are taken up by algae, should be present to prevent growth limitation. (A more complete description of the transformations of inorganic carbon is given below.) Thus the nutrient of interest in this discussion is inorganic nitrogen.

The nitrogen cycle (outlined in Fig. 1) is presented in any elementary textbook of ecology or limnology and is thus not treated in detail here. The details of the complex biogeochemical reactions are given by Stumm and Morgan (1981). Fixed inorganic nitrogen may enter the water by three routes: fixation by blue-green algae, atmospheric precipitation, or in runoff. The first two are natural sources and are relatively unimportant as causes of cultural eutrophication, although there has been some debate whether atmospheric input of anthropogenic nitrates is becoming a significant source of nutrients. Runoff may contain fixed nitrogen from natural sources as well as from domestic and industrial effluents, domestic sources most often being the causes of eutrophication. Nitrogen is present in domestic wastes in four forms: nitrate, nitrite (which is rapidly oxidized to nitrate and thus usually in very low concentration), ammonia, and organic compounds. Both nitrate and ammonia are readily used by plants, and the organic nitrogen is readily released as ammonia by bacterial mineralization.

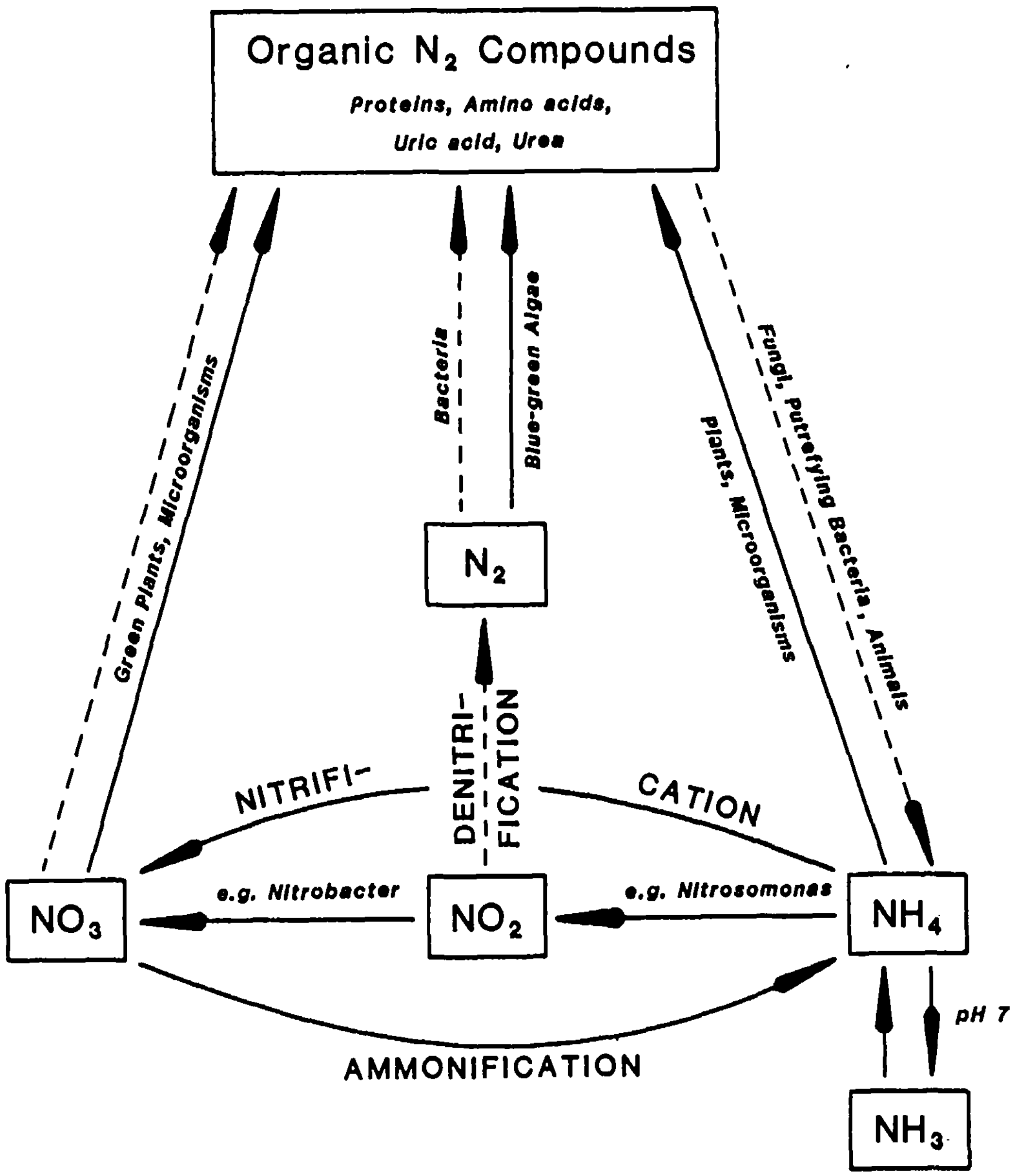


Fig. 1. The main transformations in the nitrogen cycle.

Within the water the major transformations are uptake by plants and release by bacteria and higher organisms. Nitrogen is incorporated into plant tissues primarily as the amine groups in proteins. Thus ammonia is needed, but nearly all algae contain nitrate reductase which reduces nitrate to ammonia. Algae therefore use either nitrate or ammonia although the latter is used preferentially and more efficiently. The kinetics of uptake appear to be approximately described by the Michaelis-Menten equation ($U = Umax\ N / (Km + N)$ where U is uptake rate, Umax is the maximum uptake rate, and Km is the half-saturation concentration, or the concentration at which the uptake rate is half the maximum, and N is the nutrient concentration) and when algae are nitrogen limited that equation also seems to give a reasonable description of the nitrogen controlled growth kinetics, although luxury uptake may cause problems. The organic nitrogen fixed by algae passes through the food chain, either being mineralized by invertebrates and fish or going to the decomposing bacteria. In the marine environment nearly all of these consumers release ammonia as the degredation product. Under oxygenated conditions ammonia is rapidly oxidized by bacteria (and to a lesser extent by free chemical reactions) to nitrite which is even more rapidly oxidized to nitrate. Thus in the open ocean nitrite and ammonia are unimportant or even undetectable except in unusual circumstances where very rapid organic decomposition is proceeding, such as in the oxygen minimum layer often found near regions of upwelling. In shallow waters and embayments however active sources of ammonia are often present because of anaerobic decomposition in sediments and deoxygenated waters. Thus ammonia is frequently an important nutrient source in eutrophic coastal waters. As discussed below, lac de Tunis is an excellent example of this.

Algal growth is basically controlled by only three factors: nutrient availability (in the marine environment usually nitrogen), light availability, and the response of the algae to nutrients and light, which depends on the species composition and the adaptations of the species, for example whether they are sun or shade adapted. That generality is, however, misleading since the availability of light and nutrients is controlled by complex factors, especially vertical mixing in the water column . Of course, actual increase of algal biomass is also influenced by grazing, respiration, and loss to decomposers (usually by sinking).

As mentioned above, if other factors do not change, the growth kinetics of algae (or more precisely phytoplankton) related to nutrient concentration seem to be fairly well described by the Michaelis-Menten equation, whereby the rate of growth per unit concentration is highest at low concentrations, with saturation occurring at high concentrations so that further addition of nutrient does not result in an increased growth rate (Eppley et al., 1971). Actually this is a rather gross approximation since algae are able to store nitrogen, that is they exhibit what is known as luxury uptake, and other equations are more precise although whether the increased precision is important in describing the kinetics of mixed populations is debatable (Droop, 1974). At any rate a point is reached at which further increases in nutrient concentrations will have little effect on algal growth. That is not to say that addition of nutrients to the system will not increase eutrophication, for the added nutrients may replace nutrients bound in organic material.

The relationship between algal growth and light is similar except that it is even better described by the Michaelis-Menten equation - there being no luxury uptake. Thus the photosynthetic rate per unit light (efficiency) is highest at low light intensities and decreases as light intensity increases until further increase results in no increase in photosynthesis (see Harris, 1978 for review).

It is misleading, however, to examine the effects of nutrients and light on eutrophication as if the algae were in culture in the laboratory. The natural system is much more complex. Nutrient effects are complicated by the rate of turnover and the light regime is affected by turbidity and physical mixing processes. Nutrient turnover is affected by the rate at which nitrogen that is bound in organics is mineralized and returned to the euphotic zone. For example in deep, strongly stratified lakes or oceanic areas with a permanent thermocline turnover is slow. On the other hand in shallow embayments turnover will be quite fast. The rate of mineralization may also be affected by the fauna. For example in lac de Tunis nitrogen release by the filter feeding, reef forming polychaete, *Ficopomatus (Mercierella) enigmatica* Hove (Fauvel) results in very rapid nitrogen turnover. Rapid turnover sustains a high rate of photosynthesis, which in turn can support large community respiration and large oxygen demand. Of course other factors also influence turnover times, which are very hard to predict. Those factors include temperature, the type of microbial flora, the distribution of anoxic zones in sediments and water, and the redox distribution. Although the relationship between nutrient concentration and photosynthetic rate is easily described it is not so simple to relate nutrient input to eutrophication.

The effects of light on total photosynthesis in the water column is controlled by light penetration and by the vertical distribution of algae. Light penetration is well described by Beers Law, with the attenuation coefficient determined by the absorbance and scattering of light, the latter usually being of more importance. Scattering is caused by turbidity, which is in turn either due to suspended sediments or plankton. Sediments are likely to be most important in shallow waters and can have particular effects on the light available to, and therefore the distribution of, benthic vegetation. The lower depth at which macroalgae epiphytize seagrasses in Great South Bay, New York, for example seems to be determined by turbidity caused by suspended sediment. In other locations turbidity may be caused by phytoplankton. In that way a eutrophic bloom may actually limit itself by self-shading. It should be apparent that light limitation of eutrophication will be less likely in mid and equatorial latitudes.

Vertical mixing in the water column influences the vertical distribution of phytoplankton and thus the light intensity to which the average phytoplankton cell is exposed. If the mixed layer is deep, well below the level where respiration exceeds photosynthetic input, then there will be much less net gain of algal biomass. If on the other hand stratification is shallow and strong most algae will be held in the well lighted zone and the total photosynthesis and algal biomass will be higher. It is possible to precisely describe the photosynthesis-light relationship, and if the vertical mixing is also well known equations for photosynthesis and mixing can be combined. Such an approach is usually the "core" for models of eutrophication. The main problem is that it is not easy to either measure or predict vertical mixing with the accuracy needed. Ecosystem modelling is not treated here because it is covered in another UNESCO report (1977). Suffice it to say that a good description of vertical mixing is needed before eutrophication can be adequately predicted.

Besides the availability of inorganic nutrients and the photosynthetic fixation of organic matter by algae the fate of the organic matter must be considered, for it is the decomposition of organic matter that leads to oxygen depletion, which is probably the most damaging aspect of cultural eutrophication. The fate of the organic matter is intimately tied to the inorganic carbon cycles. Organic matter fixed by the autotrophs may be considered to have two ultimate fates: it may be removed from the biological system by export or storage as refractory compounds or it may be metabolised. Metabolism may be by green plants and animals, in the aerobic environment, or by the heterotrophic microbial flora, either aerobically in the oxygenated waters or anaerobically in deoxygenated waters and sediments.

Aerobic respiration, whether by bacteria, animals or plants, has the ultimate end product of carbon dioxide Although the pathways are complex (and treated in any biochemistry text), the end result is simple. One mole of carbon dioxide is produced for every mole of organic carbon with the uptake of about 1.3 moles of diatomic oxygen. It is the transformations of carbon dioxide in the water that are of interest. The following is a brief discussion. Stumm and Morgan (1981) should be consulted for a more complete and technical presentation. When carbon dioxide enters the system it very rapidly reaches equilibrium, being partitioned between dissolved carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions according to the reactions

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \quad HCO_3^- + H^+ \quad CO_3^= + 2H^+$$

The dissociation constants of the reactions are well known and are a function of ionic strength and temperature. The partitioning of the chemical species is determined by the pH and the carbonate alkalinity of the water, defined as

$$ALK = HCO_3^- + 2*H_2CO_3^= + OH^- - H^+.$$

In fresh waters the carbonate alkalinity and the total alkalinity, which may be defined as the amount of hydrogen ions that must be added to a solution to convert all bicarbonate and carbonate to carbonic acid and carbon dioxide, are nearly the same because there are rarely other buffers. Other buffers do occur in sea water, but for purposes of consideration of eutrophication the alkalinity of sea water may be considered constant, and because the alkalinity is high the pH varies little as well. Although the release of carbon dioxide by respiration does tend to lower the pH while uptake by photosynthesis tends to raise it the changes are too small to have effects on biota. (The same is not true in fresh waters where daily pH variation due to photosynthesis and respiration may be as great as three units or more.)

The importance of the inorganic carbon system in the sea is that it acts to buffer the effects of photosynthesis and respiration. Respiratory release and photosynthetic uptake of carbon dioxide produce little change in either the concentration of the inorganic carbon species or in pH. The sea also acts as a massive buffer for atmospheric carbon dioxide although the rate of exchange across the sea surface is too slow to prevent some atmospheric accumulation of carbon dioxide due to burning of fossil fuels and deforestation. And because of the alkalinity and small pH variation there is little variation in the availability of carbon dioxide and bicarbonate for use as nutrients. Thus, while in fresh waters wide variation of pH and carbon dioxide availability is one of the undesirable effects of excess algal growth, and in fresh waters carbon dioxide may be a limiting nutrient, the same is not true in the ocean. This is a major difference in the effects of eutrophication on marine and fresh-water systems.

The aerobic respiration of organic matter of course requires oxygen, the exact amount ultimately being determined by the ratios of carbohydrates to proteins to lipids in the organic material, which determine the respiratory quotient (R.Q.) of the community, defined as the molar ratio of inorganic carbon release to oxygen

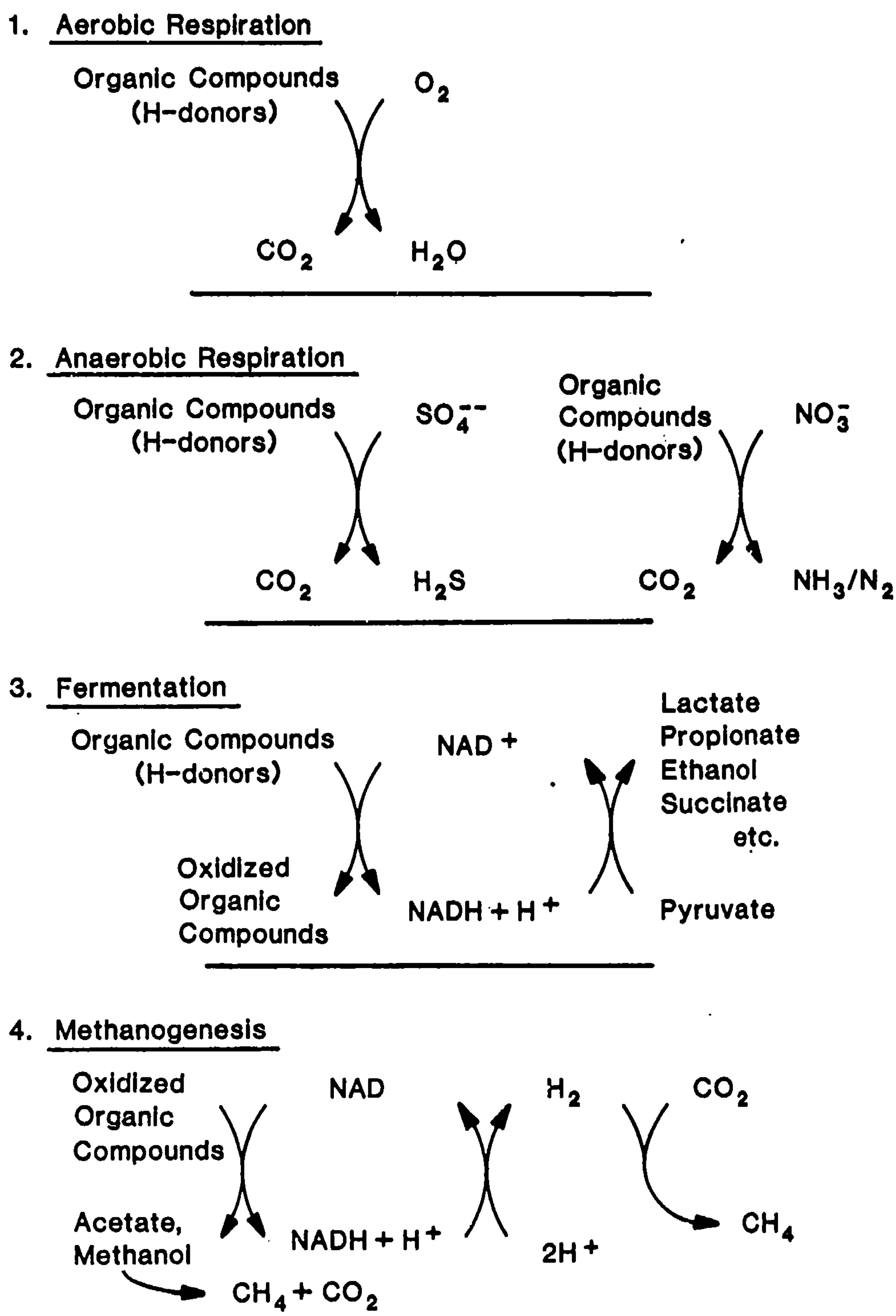


Fig. 2. Electron flows in the major biodegradation proc.

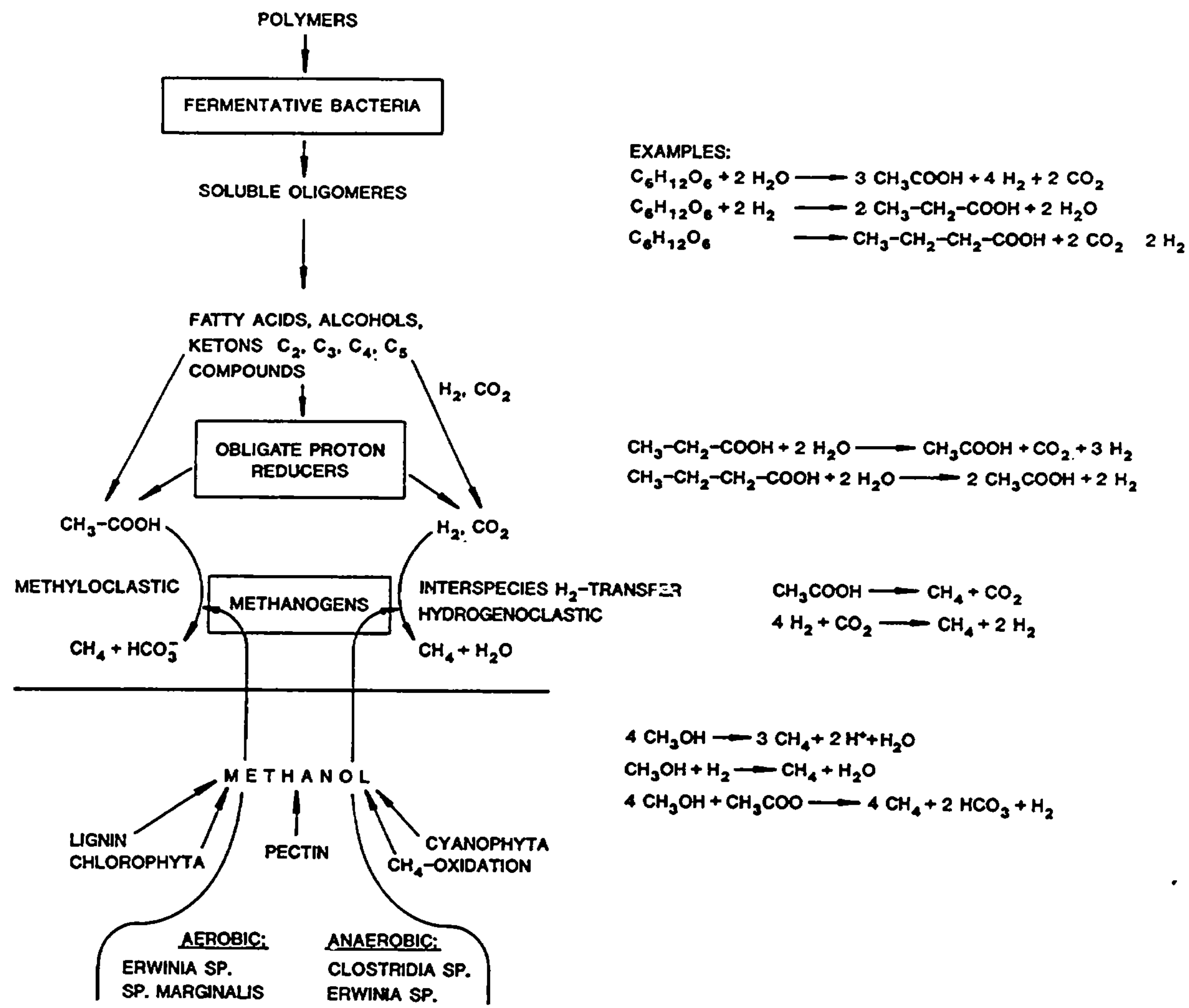


Fig. 3. The pathways of methanogenesis.

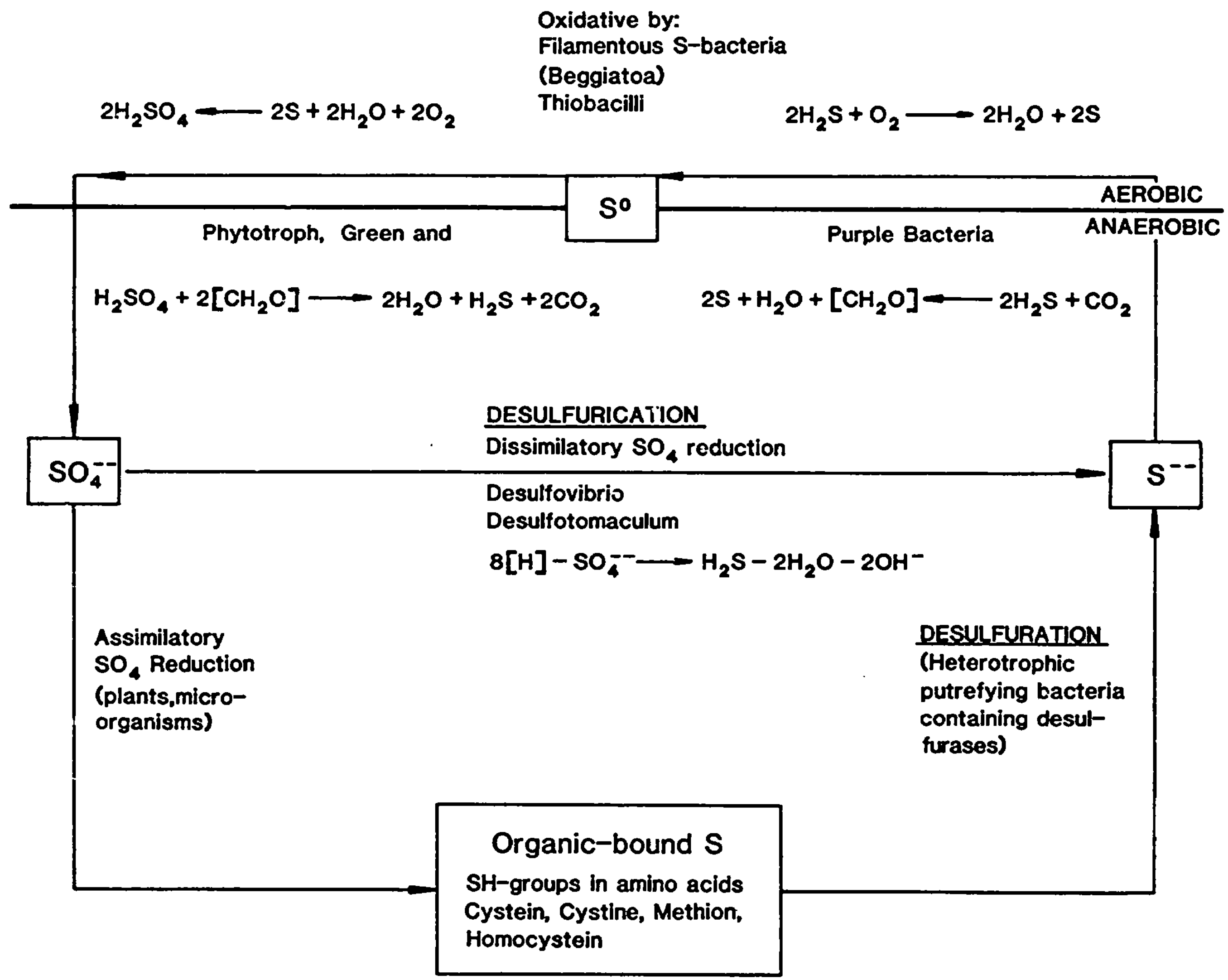


Fig. 4. The main transformations of the sulfur cycle.

uptake (a typical value is 0.75; respiration of pure carbohydrate would produce an R.Q. of one). The presence of a large production of organic material will lead to an increase in both biomass of microbial flora and of animals, resulting in an increased oxygen demand. If a portion of the ecosystem is poorly linked, physically, to the atmosphere or the region of photosynthetic oxygen release deoxygenation of the water will result. In lakes this occurs in the hypolimnion and in sediments. Although shallow marine sediments are usually anaerobic (and marine infauna have corresponding adaptations) that is rarely so for open marine waters. Only in the most extreme conditions do open marine waters become anaerobic. Examples are the bottom waters of the New York bight (although that is directly caused by dumping of sewage sludge, not eutrophication), and as we shall see Elefsis Bay near Athens. Even if the waters do not become anaerobic, however, anaerobic decomposition in bottom sediments may release important amounts of hydrogen sulfide (which is toxic and may kill fish and invertebrates), methane, and ammonia to overlying waters.

The processes of biodegradation of organic material, whether aerobic or anaerobic, are described in terms of the electron flow from donors to acceptors. The differences between aerobic and anaerobic respiration, fermentation, and methanogenesis are shown in Fig. 2. The end products of aerobic respiration are carbon dioxide and water. Oxygen functions as the terminal electron acceptor. In the case of anaerobic respiration, other terminal electron acceptors than oxygen are needed and these are almost always sulfates or nitrates with hydrogen sulfide and ammonia being produced as the reduced end products. Fermentation and methanogenesis proceed through the reduction of nicotine-adenine-dinucleotide, NAD, passing the electrons to organic compounds and carbon dioxide respectively. Fermentation and methanogenic processes are coupled directly or indirectly so that the fermentation products are further degraded to C-1 (carbon dioxide, formate) and C-2 (acetate and methanol) compounds as well as to diatomic hydrogen through proton reducing bacteria. Methanogenesis is thus the terminal process of anaerobic carbon biodegradation. The entire process is represented in Fig. 3.

The formation of hydrogen sulfide takes place as a part of the sulfur-cycle and is produced, as mentioned, from anaerobic sulfate reduction and/or the putrefaction of organic-bound sulfur. Fig. 4 demonstrates the sulfur cycle under anaerobic and aerobic conditions.

It has long been thought that in the presence of large concentrations of sulfate, as in most marine environments, the sulfate will be the terminal electron acceptor of choice and methane will not be produced. Recent evidence suggests that is not so and that methanogens and sulfur reducers can coexist, at least in sediments (Oremland et al., 1982). Although the toxicity of methane is very low that is not true of hydrogen sulfide, which may cause fish kills. Methane is both lost to the atmosphere by bubbling through the water column and is oxidized by methane oxidizing bacteria, typically at the aerobic - anaerobic interface, producing oxygen demand and further increasing the anaerobic problem. (In lakes in winter, under ice cover, the methane-oxidation still proceeds and may cause a total depletion of oxygen which results in massive fish mortality, a phenomenon known as winter kill.)

The fate of phosphorus, its availability and mobility, is bound to that of iron and to whether the environment is reduced or oxidized. Under oxygenated conditions oxidized iron is precipitated in the form of ferric hydroxides and oxides (a brown-yellow complex sometimes known as ochre responsible for the surface color of many sediments). This complex strongly sequesters phosphorus, and although there is some evidence that the bound phosphorus may be available to algae if it remains suspended, it usually precipitates to the sediments where it acts to seal phosphate in the bottom. At low redox potential the iron is reduced to the ferrous state and is dissolved with consequent release of phosphate. If diffusion from the anoxic zone is rapid enough then phosphate is recycled to the algae. This is a very important mechanism for phosphate turnover in fresh-water environments, but because phosphate is rarely a controlling nutrient in marine environments it is not commonly important there.

The above account of the processes of eutrophication is perhaps oversimplified and overgeneralized and in parts pertains mainly to fresh waters. Specific examples of eutrophication in the marine environment must be examined.

EUTROPHICATION IN THE MARINE ENVIRONMENT

Coastal marine waters, particularly embayments and estuaries, are typically much more fertile than the open ocean, even in undisturbed conditions. That is partly because of nutrient input from the adjacent land, partly because the shallow bottom allows rapid recycling of nutrients without the nutrient trap of the permanent thermocline found in oceanic waters, and partly because the salt wedge in some estuaries results in a net shoreward transport of bottom water, retarding loss of nutrients. Thus coastal embayments are nutrient traps. Under natural conditions that makes them an ideal environment for a rich fauna and flora as well as important fisheries grounds.

As mentioned in the introduction, coastal bays, harbors and estuaries are also frequently the sites of urbanization, for historical reasons of the development of commerce. The increased urban populations of the 19th and 20th centuries have resulted in increased nutrient loading to coastal water bodies. The development of modern agricultural methods and synthetic nutrient sources has meant that farm land is separated from the urban areas of food consumption and the recycling of nutrient containing wastes has become impractical. The result is still further nutrient input to coastal embayments, which are such good nutrient traps. (The same applies for pollution by heavy metals and long-lived toxic organics. Thus many coastal areas in the world are particularly threatened by the processes of cultural eutrophication.

Most studies of cultural eutrophication have focused on fresh waters. Thus knowledge of the occurrence of eutrophication in marine systems has remained mainly anecdotal, either based on casual observations and verbal communication by researchers or buried in local water quality reports. The following consists of a summary of the global distribution of eutrophication problems, with some examples from temperate environments, a detailed examination of the extreme problems in lac de Tunis, and other examples from the Mediterranean region presented by the participants in the workshop.

Perhaps the best example of the superficial aspect of coastal eutrophication is given by the shallow bays behind the barrier islands and spits along the south shore of Long Island, New York (Fig. 5). They provide a gradient from fairly undisturbed in the east to very polluted near New York City in the west. The following account is based on observations by M. Kelly and conversations with other workers. Surprisingly there has been no systematic study of these problems in this area. Moriches Bay and Shinecock Bay (the two eastern-most bays), and the eastern third of Great South Bay are relatively undisturbed, receiving mostly drainage from farm land and low density residential housing. The bottom to a depth of about 3 meters is covered with beds of the seagrass _Zostera marina_ wherever the wave energy is low enough to prevent wave erosion. Travelling to the west in Great South Bay, increasing amounts of macroscopic algae of the genera _Ulva_, _Enteromorpha_ and _Cladophora_ are found growing as epiphytes on the seagrasses, especially in late summer. Housing density along the north shore increases in the same direction, mostly with septic systems draining into a sandy soil with free access to the bay. Progressing to the west, as the epiphytization increases the vigor of the seagrass decreases until where Hempstead bay is entered the seagrass disappears almost entirely and the bottom is colonized by the algal macrophytes.

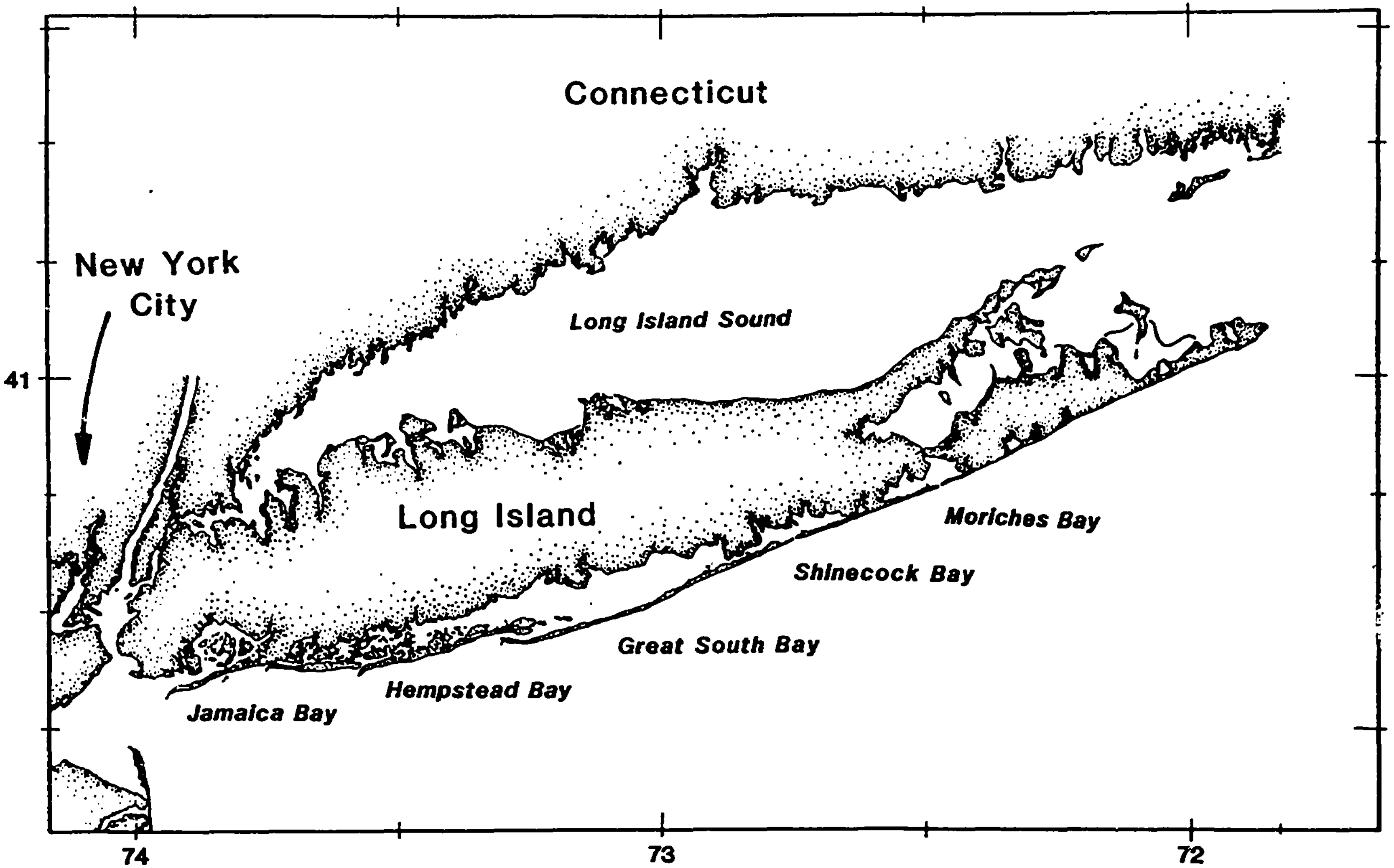


Fig. 5. Long Island, New York.

During the seagrass blight of the 1930's Zostera almost completely disappeared from this region, recovering only in the early 1950's. Recovery progressed from east to west and it was thought that the lack of seagrasses in bays from Hempstead to the west was simply a delay in recovery. Now it seems that recovery was impossible because of competition for light with the epiphytes. The epiphytes apparently cannot grow rapidly enough at low nutrient concentrations to outcompete the seagrasses, which obtain nutrients from the sediments, but at high concentrations the seagrasses are severely disadvantaged. Seagrasses apparently disappeared from lac de Tunis during the 1930's at the same time as massive growths of Ulva appeared, perhaps because of a similar competition for light.

Progressing further to the west in Hempstead Bay during late summer the density of algal macrophytes increases strikingly, with "rafts" of detached algae floating on the surface and being driven over the bottom in shoal areas. There is major production of hydrogen sulfide in the lower portions of the algal mats due to the decaying vegetation. Although bivalve molluscs seem to be able to withstand this temporary "smothering", polychaetes and other more delicate invertebrates are killed in large numbers.

Further to the west Hempstead Bay is replaced by Jamaica Bay which, although originally shallow, was dredged to as much as 7 meters during the 1890's in an aborted attempt to make another port for the city of New York. There the water is mostly too deep to allow growth of either seagrasses or benthic macrophytic algae but large biomasses of phytoplankton develop. The bottom waters become anoxic in late summer with production of hydrogen sulfide and ebullition of methane from bottom sediments. Jamaica Bay is adjacent to the New York City buroughs of Brooklyn and Queens and until the 1960's received raw sewage from more than 2000 separate outfalls. Paper fibers, indicative of accumulated domestic sewage sludge, have been found in core samples to depths of 4 meters in the sediments, which are almost entirely organic. Presumably the anaerobic conditions are caused by oxygen demand from these sediments, although it is difficult to separate the oxygen demand due to accumulated decomposing sludge from that due to eutrophication. This illustrates the complementary effects of eutrophication and organic pollution that may occur under extreme conditions. Nutrients continue to enter the bay from sanitary landfills on the northern margin and from two large secondary sewage treatment plants as well as many unintercepted raw sewage effluents.

The bays along the south shore of Long Island therefore illustrate along a geographic gradient, the progressive effects of increasing eutrophication and ultimately organic waste loading that occur as a result of increasing urbanization with poor waste treatment. The most striking effect is the destruction of the seagrass habitat by massive growths of epiphytic algae.

Although there are undoubtedly other effects of the nutrient enrichment, many of which may be more important, this pattern of dominance by macroscopic green algae seems to be the most noticeable effect of eutrophication in nearly all shallow marine environments. The following are other examples from the eastern coast of the United States. The harbors of Portland Maine and Boston Massachusetts have large growths of green algal macrophytes that, because the intertidal and subtidal areas are largely rocky, outcompete brown algae of the genera Fucus, Ascophyllum and Laminaria, among others, rather than seagrasses. The notebooks of Alexander Agassiz indicate that this was occuring as early as the 1880's in Boston Harbor. To the south, seagrass beds in the mouth of the Delaware Estuary, which receives wastes from many urban areas, are heavily epiphytized. The Potomac Estuary, adjacent to Washington D. C., is too deep and turbid to support much development of macrophytes but there is oxygen demand due to the organisms dependent on massive growths of phytoplankton. The eutrophication problem in this area is currently receiving much attention from the U. S. Geological Survey and the U. S. Environmental Protection Agency. Further south the seagrass beds near the mouth of the Chesepeake Bay and James River are heavily epiphytized, and there is concern that the extensive shellfish industry in that region may be damaged.

Still further south there are large shallow coastal lagoons behind the barrier islands that comprise the Outer Banks of North and South Carolina. There is little epiphytization there and little urban development. The most southern embayment in the United States, Biscayne Bay adjacent to Miami Florida, is divided roughly into two halves by shoal areas. The northern half, which receives wastes from Miami, has much development of macrophytic green algae with no seagrass beds and much different benthic communities than are found in the southern half, where there are extensive, diverse, natural communities, including beds of the seagrass Thalassia testudinum. The southern half of Biscayne Bay receives almost no domestic or industrial waste.

The development of problematic macrophytic green algae seems to occur as a symptom of nutrient enrichment throughout temperate and tropical coastal regions of the world. The following are other examples that the editors are aware of: In North America, Tampa, Galveston, and San Fransisco Bays. In Northern Europe the mouths of the Thames and Clyde estuaries, areas of the coasts of Normandy and Brittany, and the harbors of Amsterdam, Bremerhaven, Kiel, Aarhus (Denmark), Copenhagen, Tallin (Estonia) and Gdansk. In the Indian Ocean the harbors of Bombay, Madras and Colombo (Sri Lanka). In Australia the harbor of Sydney and the Peel-Harvey estuarine system south of Perth. The latter is one of the few systems where algae have received extensive systematic study (McComb et al., 1980). Those examples are certainly a very small proportion of locations with this problem.

But as was discussed above, the problems of coastal eutrophication are much more complex than simply the growth of macroscopic green algae. The best way to understand the complexity is to examine one of the most extreme cases of coastal eutrophication.

LAC DE TUNIS - A CASE STUDY

During summer months lac de Tunis develops extreme symptoms of eutrophication. Masses of Ulva develop that may cover nearly a third of the surface, and during still, calm periods the entire water column may become anaerobic, with blooms of red sulfur-reducing, photosynthetic bacteria, fish kills that seriously damage the fishery in the lac (which makes a major contribution to the total Tunisian fishery yield), vigorous and conspicuous bubbling of methane from the bottom in some areas, and release of hydrogen sulfide that causes a stench which may be strong more than a kilometer from the lac. Because of these problems, and because lac de Tunis is a potential source of tourism, the lac has probably received more study than any other eutrophic coastal water body (although surprisingly few published accounts have resulted). It has been studied by consultants and agencies from France, Germany, the Netherlands, Sweden, Tunisia, and the United States and Yugoslavia. Although numerous recommendations have been made and various remedial solutions have been tried, none have been successful. The following discussion is largely extracted from presentations made during the workshop by Moheiddine Belkhir and other Tunisian workers, a manuscript by Jeanne Zaouali, (Appendix A) the thesis of Belkhir, a manuscript in preparation by Kelly and Belkhir, and from Keene (1980), although reports from various consultants have also been used.

Lac de Tunis (Fig. 6) has an area of 48.6 sq km, and a mean depth of 1 m. It is divided into two halves by a ship canal with an embankment on the south of the canal and a causeway on the north that bears a rail bed and highway. Although lac du Sud, the southern portion of lac de Tunis, receives industrial effluents it does not show the extreme symptoms of eutrophication that are apparent in lac du Nord; it is lac du Nord that is the subject of this account. Lac du Nord (hereafter referred to as "the lac") receives treated and untreated domestic sewage from the city of Tunis, a small amount of industrial waste, runoff from storm sewers (which may be extreme during the wet season), and thermal effluent from a power plant. As will be seen, the eutrophication problems are probably due to the domestic sewage and have largely developed during this century. The lac is almost completely separated from the sea, being connected only by a canal of 500 m length and 40 m breadth through the barrier spit at the town of Kherredine and by three very small cuts that connect to the ship canal. Salinity varies from 25 ppt during the wet season to 45 ppt during early summer, with most of the salinity increase probably being due to evaporation. This poor connection with the sea increases the eutrophication problem.

The history of the development of lac de Tunis and the eutrophication problem is of interest but also controversial. Harbridge (1974) based in part on Pimienta (1959) postulated that during Carthaginian times (the ports of Carthage lie on the northern spit separating the lac from the sea) the lac was open to the Mediterranean. He then states that the barrier spit separating the lac from the sea developed during the first millenium AD due to sediments transported by the southerly coastal current to the east. The sediments may have been carried to the sea by the Medjerda River, which lies to the north, and they may have been derived from erosion caused by deforestation and agriculture during Roman and Byzantine times. His postulated changes in the geomorphology are summarized in Fig. 7. It is interesting if his hypotheses are correct, since the present environmental problems could be traced to Roman agricultural practices of almost 2000 years ago. There are problems, however, with his arguments. Classical authors refer to a "stinking lake" near Carthage, which might have been what is now Sebkhet Sedjoumi to the southwest. If Harbridge's hypothesis is correct and the lac was much deeper then,

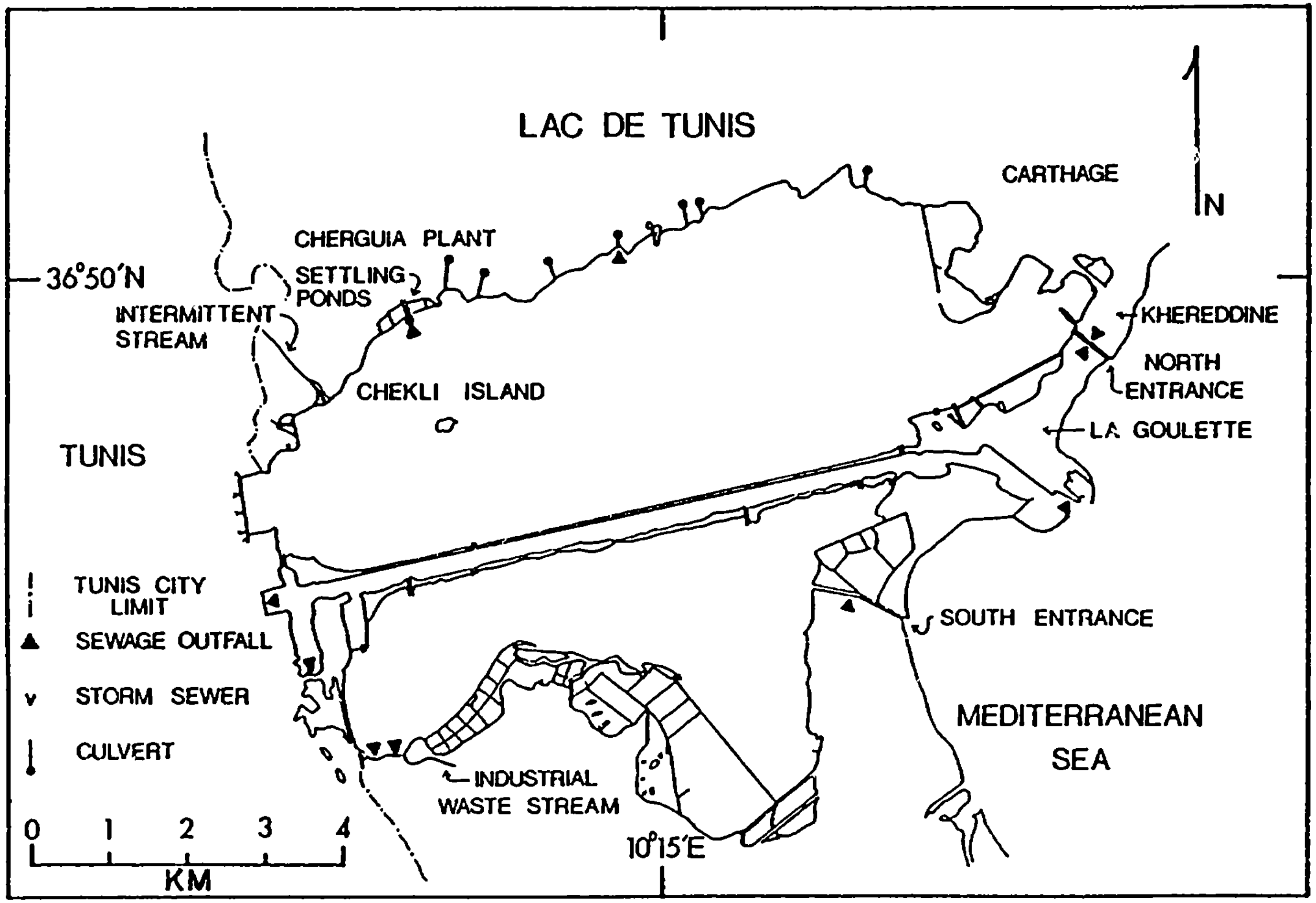


Fig. 6. Lac de Tunis, Tunisia.

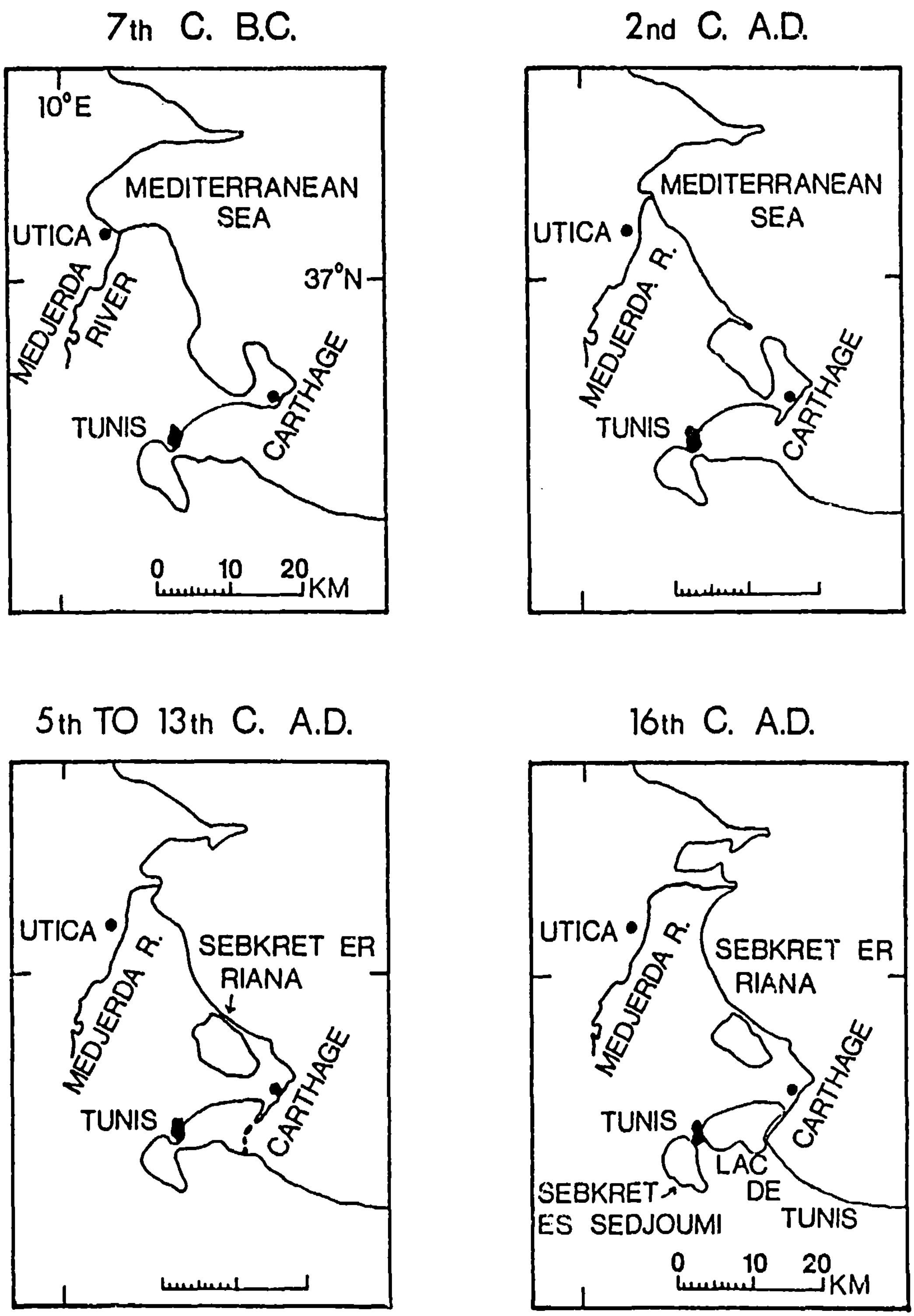


Fig. 7. The geomorphological evolution of the coastal region of Tunis.

the sebkhet would not have been a seasonal lake but a permanent water body. The "stinking lake" also could have been one of the very small (ca. 200 m diameter) dredged Carthaginian military or commercial ports that are now receiving intense archaeological investigation. A further argument against Harbridge's hypothesis is this: If lac de Tunis was deep and partly open to the sea why did the Carthaginians dredge two artificial ports?

Zaouali has developed a detailed history of lac de Tunis (Appendix A) that gives further, detailed arguments against Pimienta's hypothesis based on very extensive research of Roman, Byzantine, Arab and Turkish sources. Although it is not relevant to a report on eutrophication, lac de Tunis has fascinating cultural, commercial and military histories, involving the Punic wars, Roman commerce, the occupation of North Africa by the Vandals, the Byzantine occupation, the early history of Islam, the Crusades, the development of the Turkish Empire, and French colonialism. Although the separation of lac de Tunis from the sea was necessary for the development of the present eutrophication problem, when it occured is of secondary importance since it appears that the present symptoms have developed as a result of a series of events during the latter half of the 19th and the first half of the 20th centuries.

Although records are not completely clear, it appears that prior to 1880 most of the 1.5 km distance between the eastern wall of the old city of Tunis (the Medina) and the present western edge of the lac was a salt marsh, perhaps with some islands occupied by fishermen. During the French colonial period the marsh was filled to form what is now Avenue Habib Bourguiba and the main commercial part of Tunis. Prior the fill, the marsh would have presumably received most of the wastes from the Medina, and if it acted like most salt marshes it would have been a very effective tertiary sewage treatment plant, causing not only the oxidation of organic waste but also the uptake of nutrients into marsh plants, preventing extreme nutrient input to the lac. It thus appears likely that the extreme eutrophication problems did not occur prior to the expansion of Tunis outside its walls. This idea is reinforced by the lack of eutrophication in lac du Sud, which was separated from lac du Nord during the 1880's.

Prior to 1920 sewage was discharged raw into the lac, but because of public health problems a primary treatment plant was constructed during the 1920's. That did not, of course, remove any of the nutrients or much of the sewage sludge. In the 1950's, because of an overload to the existing treatment plant and because of odor problems, a new, secondary treatment plant was constructed at Chergui̇a, which discharged into the northwestern margin of the lac (Fig. 2). 50,000 to 80,000 cu m/day are discharged of which only 30,000 cu m are treated. As much as 144,000 cu m/day may be discharged in the wet season. It is important to note the location of that outfall, for it is the epicenter of most of the present eutrophication problems. During the past three years a very extensive, new program of sewage treatment for Tunis has been started (again because of public health problems, not to alleviate the eutrophication problem) that will eventually result in complete treatment of wastes with the release of effluent to the Mediterranean and nutrient disposal by irrigation. At present an interceptor canal has been constructed on the western shore of the lac and wastes are temporarily discharged into the ship canal. The new program has not been active long enough to have affected the eutrophication problem, however.

Although the increased nutrient discharge to lac de Tunis may have been enough to have caused a eutrophication problem, the problem was increased by the introduction of an exotic species. Ficopomatus (Mercierella) enigmatica Hove (Fauvel) entered the Mediterranean from the Red Sea soon after the construction of the Suez canal. It is a reef building, tube dwelling polychaete that is a detritus feeder and that found an almost ideal habitat in lac de Tunis. Ficopomatus reefs harbor a host of other invertebrates and a rich microbial flora which, along with the polychaetes themselves, release a very large amount of ammonia to the water. The annelid was first noted as present in the lac in 1924 and reefs were present but few in 1931 (Lucas, 1959). At present the Ficopomatus reefs occupy nearly a third of the lac and extend nearly to the surface. They provide an excellent mechanism for recycling nitrogen from detrital organic material.

Almost ideal conditions for development of eutrophication are therefore presented. Rapid discharge of nutrients from an urban center (Tunis) is accompanied by rapid turnover of the nitrogen (in this case caused by the Ficopomatus reefs). The result is very rapid growth of macroscopic green algae (Ulva) and phytoplankton resulting in the conditions described at the beginning of this section.

Most of the algal growth problem developed in the same period that the Ficopomatus reefs grew. A vegetation map made by Heldt in 1929 (unpublished) showed small areas dominated by Ulva but others dominated by Ruppia, Zostera and Acetabularia, all of which are typically found in clean waters and none of which were found in the lac in 1954 and 1955 (Vuillemin, 1965). Belkhir (1980) made extensive studies of the distribution and growth of Ulva and other algae in the lac between 1975 and 1978. The following is derived from a manuscript in preparation by Belkhir and Kelly.

The algae important for biomass development were in the genera Ulva, Enteromorpha, Cladophora, Chaetomorpha (all green algae) and Gracillaria (a red alga). The largest biomasses developed in the central portion of the lac (where Ficopomatus reef development is also greatest), perhaps because of the available hard reef-substrate for attachment. The biomass was mostly Ulva which was always dominant except in the most eastern portion of the lac, where Gracillaria was found in large quantities.

As regards algal development the year could be divided into three periods: 1) A winter-spring period from October to April, characterized by low to moderate biomasses of all species (means of 185 to 616 g/sq m or 5464 to 18,195 tonnes total). Enteromorpha, Chaetomorpha, and Cladophora were dominant in that period. 2) A spring-summer period from April to July with low to moderate biomasses dominated by Ulva (means of 185 to 616 g/sq m or 5464 to 12,849 tonnes total). The low total algal biomass was caused by a decline of all of the greens except Ulva, which increased. 3) A summer-autumn period from July to October characterized by a very high total biomass that was almost entirely Ulva (means of 435 to 1,479 g/sq m or 12,849 to 43,685 total tonnes). The greatest problem is therefore presented by Ulva which grows and declines from late-spring through mid-autumn.

Growth rates of Ulva were also measured over the lac and over the year. Ulva grows both attached to the bottom and floating free in the water. Doubling times were found to range from 1.85 to 38.53 days, with a mean of 5.65 days. It is not surprising that Ulva causes a problem. The mean doubling time would allow Ulva to increase by a factor of nearly 32 in 30 days, more than ten times the actual observed biomass change. Thus much of the Ulva growth is presumably lost to decomposers and herbivores, presumably contributing greatly to oxygen demand. Growth is probably light limited, both because of self-shading and turbidity of the water. Growth experiments at one meter depth showed a disappearance of the alga, presumably caused by senescence and decomposition. Thus we have a development of the alga near the surface with a removal below, and although the water column is rarely stratified this must represent considerable loss of oxygen. Even in the most luxuriant growths of Ulva on the Ficopomatus reefs in the middle of the lac the lower portions of the algal mass are obviously dark and decomposing. Nevertheless immense thalli are found - one had a wet weight of 713 g and dimensions of 331 by 275 cm. Development of other algae (except Gracillaria in the eastern portion of the lac) is severely limited, being confined to a few crustose browns growing on the reefs. This is presumably caused by competition with Ulva. Phytoplankton biomass, although abundant, is at a minimum in the central waters of the lac; the maximum is in the north-west region, near the Cherguia sewage-treatment plant outfall. Although it is tempting to explain the relatively low phytoplankton concentrations in the central region by competition with Ulva the reefs are very efficient filter feeders in those clear waters and probably remove much of the phytoplankton. Nutrient concentrations are also usually highest in the northwest part of the lac.

The Ficopomatus reefs seem to serve two roles in the development of eutrophication. They provide an ideal physical substrate for the growth of Ulva and they provide very efficient nutrient recycling. A possible third role is providing clear water for macroalgal growth. Keene (1980) performed experiments between December 1976 and June 1977 in each of which two large plexiglas containers were used to isolate areas of reef and sediment while a third contained only water and plankton. He found that the reefs actively excreted large amounts of ammonia at certain times during the day and were responsible for uptake of much oxygen, large quantities of which were produced by the phytoplankton. In a typical experiment dissolved oxygen in the plankton-container ranged from 9 mg/l at the start at 0800 hr to more than 17 mg/l (9 mg/l supersaturated) at 1500 hr, and declined to 14 mg/l by the end of the experiment at 0800 hr the next day. In the reef enclosure the beginning and maximum concentrations were similar, but the water became anoxic by the end. Respiration by the reef organisms (whether the polychaetes or associated organisms cannot be said) obviously represented an important oxygen demand. Keene also observed that the water in the reef container became strikingly clearer. During the same experiment nitrate concentrations declined from 16 to 9 mmol/cu m in the plankton container, indicating very active uptake (ammonia went from 9 to 0 mmol/cu m), while in the reef container nitrate increased from 16 to nearly 45 mmol/cu m (ammonia declined from 9 to 0 and then increased again to 9 mmol/cu m). Over the several months' period of study reef respiration varied from 3 to 10 g/sq m day. Release rates for total nitrogen as high as nearly 23 mmol/sq m day were found. The diurnal changes in nitrogen and oxygen and the rates of nitrogen release, respiratory oxygen uptake and photosynthetic oxygen release by phytoplankton are nearly as high as any reported from any environment except sewage treatment lagoons. And the measurements were made in winter and spring, not during the summer when organic sources for the polychaetes and temperatures and thus metabolic activity would be highest. Although for a variety of reasons Keene's data cannot be extrapolated to give the effect on the nitrogen and oxygen budgets of the lac as a whole, it is obvious that the Ficopomatus reefs must play a very important role in accelerating nitrogen turnover and increasing oxygen demand.

During all years the most extreme conditions occur in late summer with the development of temporary and local anoxic conditions and the release of hydrogen sulfide to the atmosphere, with noxious odors detectable more than a km from the lac. The most extreme conditions are reached during crises on years when there is an extended calm period. The symptoms are rafting of algae over the lake surface, development of anoxia through much of the lac, disappearance of much of the algae, and, under the most extreme conditions, development of pinkish or reddish waters and fish kills. In 1975 the fish kill amounted to 10% of the annual catch from the lac. Although those crises have not been systematically studied it is possible to hypothesize a sequence of events leading to the crisis. Under calm conditions with much of the surface of the lac covered by algae, circulation through the water column and reaeration from the atmosphere would be cut off at the same time as shading stopped photosynthetic release of oxygen. This would be combined with large supplies of organic material for the decomposers, rapidly leading to anoxic conditions. As anaerobic bacteria took over the decomposition of the organics hydrogen sulfide would be produced in large quantities, presumably from decomposition of the algae as well as of phytoplankton and detritus. As the algae disappeared (either by decomposition or sinking) under such extreme conditions of anoxia instead of regrowth of phytoplankton there could be a bloom of photosynthetic bacteria (Thiorhodaceae) reducing the hydrogen sulfide to elemental sulfur and accounting for the red water. Fish could be killed by either the hydrogen sulfide or the lack of oxygen. This appears to be one of the most extreme occurrences of the symptoms of cultural eutrophication reported for any natural environment.

What does the future hold for lac de Tunis? Keene (1980) stated that "Oswald (1972) estimated that if the present rate of sedimentation continues, lac de Tunis will become a sebkhet, or seasonally dry basin, within the next century. The reefs and attached macroalgae are also effective barriers to water movement, contributing to a general stagnation problem." One must wonder if Sebkhet Eriana and Sebkhet Sedjoumi had similar origins. Keene further summarizes the situation:

> Numerous previous studies have concluded that the problem in lac de Tunis could be greatly reduced by diverting the major sewage outfall away from the lagoon and by enlarging the connecting canals to increase exchange with the sea (Rudis, 1966; Bonifica, 1969; Plummer, 1971; Bjork, 1972; Oswald, 1972; Ingenieurs Conseils Neerlandais, 1975). However, many other exogenous point and non-point sources of sewage exist. The sediment is also a large reservoir from which nutrients move into the water column during the frequent periods of anoxic conditions. Should the above recommendations be enacted, these secondary nutrient inputs, together with the nutrient pumping property of the polychaete reefs, would continue to maintain a state of active producer metabolism. The massive reef formations would prevent rapid flushing of the north basin despite increased exchange in the vicinity of the canals. Lac de Tunis appears to be past the point of recovery, and even after an extensive clean-up program, will continue to pose health and odor problems for the foreseeable future.

Whether or not such pessimism is justified may be shown by Tunis' major program to construct new sewage interceptors for virtually all of the outfalls and to divert the sewage to new treatment plants, whose effluents will be either dumped to the sea or used for land-disposal. If nutrient sinks such as sedimentation and flushing to the sea are adequate to reduce the symptoms of eutrophication, that will be a very hopeful prospect for other locations facing similar problems. It will be of global significance if a third-world nation such as Tunisia, with limited economic resources to spend on environmental reclamation, can solve the problems of one of the most severely damaged aquatic environments known.

OTHER EXAMPLES FROM THE MEDITERRANEAN REGION

Although none of them are nearly severe as lac de Tunis, three other examples of eutrophication problems in the Mediterranean and Adriatic were given by participants in the workshop. Luckily in all cases there is much better flushing to the open sea. The examples were Elefsis Bay near Athens (reported by Friligos), Kastela Bay near Split, Yugoslavia (reported by Maresovic) and Alexandria Harbor (reported by Sultan). They illustrate the very diverse and complex conditions under which eutrophication may develop in marine environments.

The following summary of conditions in Egyptian waters has been taken from the presentation by Sultan. Further details are available in Halim et al. (1980) and Sultan (1982a, b). Physical and chemical conditions and the standing crop and productivity of phytoplankton have been monitored for many years in Alexandria's Eastern Harbor and at three stations offshore. Prior to construction of the Aswan High Dam there was a fall bloom in the waters offshore associated with the coastal transport of the seasonal effluent from the Nile. That bloom, the fertility of the water, and the phytoplankton biomass and productivity have declined - a reverse of the rest of the situations discussed in the workshop. Since the mid-1960's red tides of the dinoflagellate Alexandrinium minutum have occurred in Alexandria harbor itself, probably associated with an increase in nutrient concentrations. In 1970 there were two peaks, one in May and another in July. There was a complete absence of other phytoplankton species in May and a decline of other species in July, suggesting some sort of inhibitory process.

The following biochemical mechanism has been proposed to explain the inhibition by Alexandrinium: Several species of phytoplankton including Exuviella cordata were grown under variable light and temperature to find the optimal conditions for growth. RNA, DNA, carbohydrates, lipids and pigments were estimated in the exponential and stationary phases. In E. cordata RNA and DNA increased in the stationary phase while in all other species they decreased. The supernatant from E. cordata in stationary phase inhibited growth of other phytoplankton. It was hypothesized that some autoinhibitory factor blocked ribosomal activity allowing accumulation of DNA and RNA and preventing growth of both the dinoflagellate and other species. It has been hypothesized that this mechanism caused the inhibition found associated with the bloom of A. minutum in Alexandria Harbor. If the conditions in Alexandria Harbor can be described as eutrophication, then the development is greatly affected by intraspecific interaction within the phytoplankton. It illustrates the complexity of the eutrophication process.

Kastela Bay, which receives waste from Split, Yugoslavia, has developed increased phytoplankton productivity and red tides of dinoflagellates. The following summary was prepared by Marasovic. Further details have been published by Pucher-Petkovic and Marasovic (1980).

The phytoplankton of Kastela Bay has been systematically studied since before 1956. Before 1972 there were two blooms each year, in the spring and fall, but since 1972 there have been three blooms, in spring, summer and fall. During the last ten years the dominant diatoms became Nitzschia seriata, Skeletonema costatum and Leptocylindricus danicus, although before 1972 those species did not exist or were found only in very small numbers in the bay. Also since 1972 typical eutrophic species such as Eucampia cornuta have been found more often. From 1962 to 1977 the cell numbers increased by a factor of ten, from .08 to .8 million cells per liter, and the primary productivity nearly doubled, from 115 to 206 g C/sq m yr. During a calm, hot period in September 1980 a red tide of Gonyaulax polyedra occurred with numbers of 18 million cells per liter accompanied by populations of Prorocentrum micans and Eutreptiella pascheri with numbers of more than a million each. Under those conditions nutrient concentrations became undetectable and the bloom disappeared after five days, to be followed by mass mortality of fish, a bottom oxygen of less than 0.5 mg/l (1.5 mg/l at the surface), and a pH between 7.7 and 7.9. One day after the mass mortality the cell count of Gonyaulax polyedra rose suddenly, possibly indicating a new red tide. Although the events leading to eutrophication were probably caused by increased urban waste discharge, and although the red tide was probably triggered by calm and hot conditions, it is unclear why the strange disappearance and reappearance occurred and whether occurrences of red tides may be expected in the future.

Elefsis Bay, which receives wastes from Athens and Piraeus, Greece, has a sill partially separating the deep waters, which become anaerobic each summer, from the sea. The situation has been described in detail by Friligos (1981, 1982), who provided the following summary.

The changes in the concentrations of silicate, phosphate and inorganic nitrogen in Elefsis Bay, an intermittently anoxic basin, were related to the changes in the physical properties of the water for two seasonal cycles. Winter convection resulted in a very small vertical gradient of temperature, salinity, oxygen and nutrients. Stratification started to develop in May and persisted for about six months. High values of silicate, phosphate, and ammonia occurred during the anoxic conditions prevailing in summer. The consumption of oxygen in the lower water column was directly related to density differences in it. The regeneration of nutrients was related to the consumption of oxygen, with seasonal differences in the regeneration of nitrate and silicate. A stoichiometric model indicates that planktonic organisms in Elefsis Bay had approximate atomic ratios for C:N:P of 105:14:1, whereas the ratio of change for nitrogen and phosphorus in the water was only 2:1 by atoms. The water - plankton relationship in Elefsis Bay appears to be very similar to that of the Baltic Sea.

The detailed example of eutrophication in lac de Tunis and the summaries of the very different situations in more open water bodies in the Mediterranean show that the effects of nutrient enrichment in the marine environment are very complex and poorly understood. The connections of Elefsis Bay, Kastela Bay and Alexandria Harbor with the open sea are sufficient that it is unlikely problems will ever become as severe as in lac de Tunis, and cessation of nutrient input to those water bodies would almost certainly reduce or eliminate the effects of eutrophication. Nevertheless it seems apparent that the processes involved in eutrophication in the marine environment need to be much better understood. Basic research is needed on mixing and circulation, the biogeochemical cycles of nutrients, the relationships between nutrients and algal growth, and the ecological relationships among the algae that respond to eutrophication and other species of algae, as well as higher trophic levels and the microbial flora. Applied research is needed on methods for predicting the response of ecosystems to various attempts at ameliorating the symptoms of eutrophication. The situation in lac de Tunis shows that trial and error is too expensive and too unreliable.

DOES THE EUTROPHICATION CONCEPT APPLY IN MARINE ENVIRONMENTS?

Obviously ecosystem disturbances with undesirable results occur as a result of artificial nutrient enrichment in coastal marine environments. It also seems obvious that the natural process of eutrophication as a successional sequence in lakes, which was the concept of eutrophication applied for many years by limnologists, is not applicable in the marine environment. But the natural processes of succession appear mainly to occur in temperate lakes of glacial origin while many tropical and subtropical lakes that have received nutrient pollution are described as eutrophic. In other words, even in lakes, eutrophication has different definitions. What definition applies in the marine environment? That was the subject of a discussion near the end of the workshop.

For many reasons the processes of eutrophication in marine systems must be different from in lakes. Although algae of the genera Enteromorpha and Cladophora occur in lakes they rarely produce the same problems as green algae do in marine systems. They may epiphytize vascular macrophytes but do not seem to eliminate the naturally occurring plants as in the marine environment, and there are no known examples of green algal growth in fresh waters equivalent to that in lac de Tunis or south of Long Island. Differences are also due to differences in water chemistry. Because of the larger concentrations of sulfate in marine environments methanogenesis is much less intensive. And instead of phosphorus, nitrogen is usually the most important nutrient. While pH fluctuations may be damaging in fresh waters and inorganic carbon may be an important nutrient, the higher alkalinity in the ocean reduces the importance of the carbon cycle. And the generalities about the C:N:P ratios made for Elefsis bay by Friligos would not be possible for the wide ranging chemistries of lakes.

Major differences between fresh-water and marine eutrophication are also due to the organisms involved. Benthic filter feeders (especially molluscs and polychaetes) are much more common in marine systems - it is difficult to imagine a process in fresh waters similar to that mediated by Ficopomatus in lac de Tunis. There can be no interaction in fresh waters similar to that between green algae and seagrasses. Nor are any freshwater phytoplankton known to produce antibiosis similar to that in Exuviella or Alexandrinium (and other marine dinoflagellates), and red tides, with their associated fish-kills are not found in fresh waters as they are in Kastela Bay (although blue-green algae may sometimes be toxic).

Finally, the obvious geomorphological differences between coastal bays and lakes have profound effects on the eutrophication processes. While some fresh-water lakes have shapes and flushing rates similar to lac de Tunis, the latter is unusual as a marine bay. Most marine systems have much better flushing with the open sea and therefore less accumulation of nutrients; they are not as susceptible as lakes although they are more often subjected to urban waste.

It seems that the term "eutrophication" is not well defined for fresh water systems, sometimes meaning a natural succession in temperate lakes of glacial origin and sometimes meaning a pollution process caused by addition of excess nutrients. It is even more poorly defined for marine systems, and yet there is a syndrome caused by the addition of excess nutrients with resulting undesirable conditions. In trying to agree on a definition of eutrophication that would apply to marine and fresh water systems we were able to only produce a very general statement:

> "A culturally eutrophic system (usually polluted) is one in which a high availability of nutrients produces high productivity which in turn produces high respiration. The autotrophic component is separated from the heterotrophic in time or space. Aesthetically undesirable effects are often produced, but they may differ greatly in frequency and significance. This concept of cultural eutrophication applies to coastal marine systems, but natural eutrophication defined as a succession sequence for temperate freshwater lakes does not."

The biology, chemistry, morphology and physical dynamics of coastal marine ecosystems vary greatly. The problems of eutrophication and their processes and symptoms vary accordingly. Although it may be necessary to treat different coastal ecosystems individually, there is a great need for further studies of the effects of nutrient pollution in such environments. It is not sufficient to attempt to understand the processes by analogy with freshwater systems.

LITERATURE CITED

Birge E. A. and C. J. Juday. 1911. The inland lakes of Wisconsin. Wisc. Geol. and Nat. Hist. Survey Bull. 22, No. 7.

Bjork, S. 1972. Projet de restauration du lac de Tunis, Project completion report, Ministry of Agriculture. Tunisia.

Bonifica. 1969. Assainissement des lacs de Tunis. Ministry of Agriculture, Tunisia.

Droop, M. R. 1974. The nutrient status of algal cells in continuous culture. J. Mar. Biol. Assoc. U. K. 54:825-895.

Edmondson, W. T., G. C. Anderson, and D. R. Peterson. 1956. Artificial eutrophication of Lake Washington. Limnol. Oceanogr. 1:47-53.

Eppley, R. W. et al. 1971. Phytoplankton growth and composition in shipboard cultures supplied with nitrate, ammonium, or urea as the nitrogen source. Limnol. Oceanogr. 16:741-751.

Friligos, N. 1981. Enrichment by inorganic nutrients and oxygen utilization rates in Elefsis Bay (1973-1976). Mar. Pol. Bull. 12:431-436.

Friligos, N. 1982. Some consequences of the decomposition of organic matter in the Elefsis Bay, an anoxic basin. Mar. Pol. Bull. 13:103-106.

Halim, Y., A. S. Samaan, and H. A. Sultan. 1980. Primary productivity of the Eastern Harbor of Alexandria. Acta Adriatica. 21.

Harbridge, W. F. 1974. Hydrography and Sedimentation in the Lake of Tunis, Tunisia. M.S. Thesis, Duke University, Durham, North Carolina.

Harris, G. P. 1978. Photosynthesis, productivity and growth: the physiological ecology of phytoplankton. Arch. Hydrobiol. Beih. Ergeb. Limnol. 10:1-171.

Hutchinson, G. E. 1967. A Treatise on Limnology, II. Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, New York.

Hutchinson, G. E. 1973. Eutrophication. Amer. Sci. 61:269-279.

Ingenieurs Conseils Neerlandais. 1975. Assainissement du Grand Tunis. Recherche de conditions de rejet dans le canal de navigation. Fourth preliminary report, Ministry of Agriculture, Tunisia.

Kalff, J. and R. Knoechel. 1978. Phytoplankton and their dynamics in oligotrophic and eutrophic lakes. Ann. Rev. Ecol. Syst. 4:475-495.

Keene, W. C. 1980. The importance of a reef-forming polychaete, *Mercierella enigmatica* Fauvel, in the oxygen and nutrient dynamics of a hypereutrophic subtropical lagoon. Estuar. Coast. Mar. Sci. 11:167-178.

Lucas, G. 1959. Deux examples actuel de 'biolithoseres': construits par des annelides. Bull. Soc. Geologique de France. 1:385-389.

McComb, A. J., R. P. Atkins, P. B. Birch, D. M. Gordon and R. J. Lukatelich. 1980. Eutrophication in the Peel-Harvey Estuarine System, Western Australia. In. B. Nielson and A. Cronin, (eds.), Nutrient Enrichment in Estuaries, Humana Press, N. J.

Naumann, E. 1917. Undersokningar ofrer fytoplankton och under den pelagiska regionen forsigaende gyttye-och dybildingar in om viss a syo-och mel-lasvenska ubergsvatten. K. Svenska Vetensk. Aka. Handl. 56(6):1-165.

Odum, E. P. 1971. Fundamentals of Ecology. Saunders, New York.

Odum, H. T. 1956. Primary production in flowing waters. Limnol. Oceanogr. 1:102-117.

Ohle, W. 1955. Die Ursachen der rasanten Seen-eutrophierung. Verh. Intern. Verh. Limnol. 12:373-382.

Oremland, R. S., L. M. Marsh and S. Polcin. 1982. Methane production and simultaneous sulphate reduction in anoxic, salt marsh sediments. Nature. 296:143-145.

Oswald, W. J. 1972. Treatment and Reclamation of Tunis Sewage. Report to USAID, Tunisia.

Pimienta, J. 1959. Le cycle Pliocene-actuel dans les bassins paraliques de Tunis. Mem. Soc. Geol. France, 38:176 pp.

Plummer, A. W. 1971. Assainissement des lacs de Tunis, Ministry of Agriculture, Tunisia.

Pucher-Petkovic, T. and I. Maresovic. 1980. Developpement des populations phytoplanctoniques caracteristiques pour un milieu eutrophise (Baie de Kastela, Adriatique centrale). 21:79-93.

Rudis. 1966. Lac de Tunis Nord Assainissement. Project completion report, Ministry of Agriculture, Tunisia.

Stumm, W. and J. J. Morgan. 1981. Aquatic Chemistry. 2nd Ed. Wiley, New York.

Sultan, H. A. 1982a. Effect of high concentration of nutrient salts on the rate of growth and maximum crop of marine phytoplankton. VIth workshop on marine pollution of the Mediterranean.

Sultan, H. A. 1982b. Hetero- and auto-inhibition of dinoflagellates. VIIth workshop on marine pollution of the Mediterranean.

Tarapchak, S. J. 1973. Studies on Phytoplankton Distribution and Indicators of Trophic State in Minnesota Lakes. Ph.D. Thesis, University of Minnesota.

Taylor, W. D., L. R. Williams, S. C. Hern, and V. W. Lambou. 1979. Phytoplankton water quality relationships in U. S. Lakes, Part VII:

Comparisons of some new and old indices and measurements of trophic state. EPA-600/3-79-079. U. S. Enviromental Protection Agency, Las Vegas, Nevada.

Teiling, E. 1955. Algae. Some mesotrophic phytoplankton indicators. Proc. Int. Assoc. Limnol. 12:212-215.

Thienemann, A. 1918. Untersuchungen uber die Beziehungen zwischen dem Sauerstoffgehalt des Wassers und der Susammensetzung der Fauna in nord deutschen Seen. Arch. Hydrobiol. 12:1-65.

Thunmark, S. 1945. Zur soziologie des susswasser-planktons. Eine methodologish-okologische studie. Fol. Limnol. Scand. 3:1-66.

Unesco. 1977. Marine Ecosystem Modelling in the Eastern Mediterranean. Unesco Reports in Marine Science. Unesco, Paris.

Vuillemin, S. 1965. Contribution a l'etude ecologique du Lac de Tunis. Biologie de Mercierella enigmatica Fauvel. Ph.D. thesis, University of Paris, France.

Weber, C. A. 1907. Aufbau und vegetation der Moore Norddeutschlands. Beiblatter Botanische Jahrbucker fur Systematik, Pflanzengeschichte und Pflanzengeographie. 90:19-34. Supplement to Bot. Jahrbuch.

APPENDIX A

Lac de Tunis is of particular interest as an eutrophic system because of its long history, because of the controversy centering on the history, and because of the implications of the history for the eutrophication process. For that reason the presentation of Mme. J. Zaouali on the history of the lac, which is not available elsewhere, is reproduced completely here. It has been translated from the French original.

LAC DE TUNIS: 3000 YEARS OF ENGINEERING AND POLLUTION

A BIBLIOGRAPHICAL STUDY WITH COMMENTS

by J. Zaouali, docteur-es-sciences,
The Tunisian National Institute of Agronomics, Fisheries section

Because of its exceptional geographic position lac de Tunis has for a long time acted as a defensive moat for the city of Tunis. Unintentional distortions in old maps (Ortelius' map, 1535; the map of 1633; Figs. 1 and 2) show the importance of this area in the minds of contemporaries. The first map gives the lake a surface larger than half that of the Gulf of Tunis, while in reality it is not more than a fifth of the size of the Gulf, even taken with the latter's strictest limitations (extending to Cape Gammarth and Cape Fartass). The second map, although it was drawn a century later, rather than correcting those proportions on the contrary added an area equal to the lake's surface representing the La Goulette fortification zone, thus confirming the idea of the protection of the city by this body of water.

In 1959 Pimienta, in his geological study of paralic basins (basins in marine and continental deposits) in the Tunis region, gave an historical survey of the lakes evolution and dated its closure from the sea to the XVIth century, an hypothesis which has since been accepted by researchers. In order to confirm or invalidate this hypothesis I have undertaken a bibliographical study, trying to go back as far as possible in time. The works consulted allow the relevant documents to be divided into several groups corresponding to the ebb and flow of historical events that affected this key region of the Mediterranean.

Even at the dawn of civilization the Tunisian sea and Tunisia were places where marvelous discoveries were made; the phenomenon of tides, so obvious in the Gulf of Gabes, amazed the earliest navigators and, according to legend, the origin of a number of Greek myths is to be found in the famous Lake Triton (Chott el Jerid).

Many authors believe, on the basis of ancient texts, that the city of Tunis existed well before Carthage. The Phoenicians, excellent navigators that they were, may well have settled there even before occupying Utica. In search of safe harbors for their ships they may have found one in the lake which, at that time, nearly 3000 years ago, would not yet have been completely closed. Hence one wonders why, around 800 BC they finally settled in Carthage. Several reasons can be imagined: the first is that the lake had closed up and was no longer deep enough for navigation; the second, given by many historians, is that Carthage would have been used to defend the lake as La Goulette did later. The natives may have driven the Phoenicians away from Tunis and the Phoenicians would have got round this difficulty by turning into ports the little lagoons on the peninsula that commands entry into the lake. They would thus have been able to keep watch on a strategic zone that they were no longer able to occupy.

The texts that allow us to find whether in those remote times the lake was closed or not are, in fact, very few. In any case, already in 150 BC Polybius (in de Folard, 1730) tells us that Carthage was in a gulf on a "salient peninsula, bordered by the sea on one side" (Sebkha Ariana was not yet formed) "and by a lake on the other side." He explicitly states that there was a fortress above Thynes (Tunis) and that "the city is right next to the lake." Appian, in 150 AD (in Tissot, 1884) described the tombolo (spit or sand-bar): "a narrow strip of land about half a stade wide" (i.e. 75 m) and "stretching towards the west" (which is the exact direction of this piece of land) "between the lake and the sea." Did the two regions communicate? It is almost certain that they did. How? It is hard to know, but we can suppose that the point of contact was close to Carthage; the distance between the Punic ports and the lake must not have been very great and the digging of a canal would not have been difficult. Many historians have thought that this part of the lake must have served as a maritime arsenal for the Carthaginian fleet. Finally, in 150 AD Antoninus (in Tissot, 1884) says the distance between Carthage and Maxula Prates (Rades) was ten miles, which is the estimated land distance between those two points by way of the tombolo or "Maxulitanum litus."

Carthage having been taken by the Vandals, then the Byzantines, we come to a second group of documents which dates from the Vth and VIth centuries. Heron de Villefosse (1898) cites a Vth century text found by R. P. Delattre mentioning "the toll that had to be paid in order to cross over to the southern coast by means of rataria", a kind of ferry for rivers and lakes. Pimienta in referring to this text concluded that the lake was not closed at this time; I do not agree with him because if the lake was not like it is today why use a boat made for lakes? Furthermore, small boats of the same kind are still used, in spite of all the other modern means of transport that are available. In the VIth century Procopius (in Tissot, 1884) tells us that at "40 stades from Carthage (6 km) there is a port called Stagnum where there is no anchorage." Stagnum is, in fact, not only the port but also the lake, and can only be what was later to become La Goulette; in fact, the distance between La Goulette and Carthage is just 6 km. Thus it can be concluded that in the VIth century the lake was indeed closed and that there was a passage at the center of the bar, though a very narrow one. The confusion between the name of the port which gives access to the lake and lake itself is interesting to note because it was to persist for a very long time: in 1608 the port is Mersa Rades (Mersa = port in Arabic) and the lake is the "Rades Sea" (El Bekri); in 1724 the port is La Goulette and the lake, Lake La Goulette (Peysonnel).

The third group of documents dates from the year 1000 and consists of Arab sources. Those writings are very interesting because they are the product of true scientific and ethnographic explorers. In 1068 El Bekri allows us to recreate the history of the lake from the beginning of the Arab conquest. He gives us the first historical account of the major works carried out on the tombolo at the beginning of the VIIIth century: "at the order of El Hassan, the Copts" (i.e. the Egyptians) "dug a canal near the arsenal." This canal, he writes, "brought the waters of the sea as far as the lake." This provides us with several pieces of information: in the VIIth century the lake not only existed but, furthermore, it was closed and apparently partly dried up; the key zone of the gulf was no longer Carthage, but Rades (the lake is called the Rades Sea). Continuing his historical survey, El Bekri gives us a second piece of information concerning an important undertaking of great interest: the construction around the year 900, by the Aghlabits, of two big basins for raising marine fish in the southern part of the lake near the open sea. Were these really basins or fixed fishing installations? It is hard to tell but we shall see further on that it is possible to lean towards the second hypothesis. Besides this information El Bekri gives us geographical details: "the lake is 24 miles around. In the middle lies an island called Chekla (Chikli) where fennel grows and the remains of an old castle can be seen; its circumference is two miles." He continues by giving information concerning the part of the lake that is linked with the sea: "the port is called Mersa Rades; to the south there is a castle, the Chain Castle, to the north a stone wall, and between the two lies a canal closed by a chain." Then comes some biological information: "Fish are very abundant in the lake and each type frequents it for one month of the year, then completely disappears until the same month the following year." The types are "abance" (sea perch? sole?), "octobrien" (salena), "archbarus" (Chrysophrys aurata), "menkous" (which has retained its name and is the striped bream) and the very abundant and appreciated "bacounis" (probably the common mullet, Mugil cephalus). These observations give us some valuable ecological information: fishing at a given time of the year is done by means of fixed traps set up at the outlet of a lagoon towards the sea; in fact the migrations of lagoon fish of marine origin are essentially connected with reproduction and thus take place during relatively brief periods at the times of year when the fish are sexually mature. Furthermore, the brevity of the list given, compared, for example, with that furnished by Idrissi (1116) for Lake Bizerte containing 12 species, indicates an environment with few species, all of them lagoonal; that is, a very shallow, selective and eutrophied environment with abundant production. If it is compared with the situation today Chrysophrys, mullet, sea perch and sole are still abundant while on the other hand salema and striped bream, which thrive in clear lagoons, have practically disappeared.

The second Arab author to write about the lake was Idrissi (1116). He refered to El Bekri's observations, distorting them somewhat since he wrote about "a lake dug by human hands" which was really only a channel, but he added new topographical details: "the lake is 8 miles long and 6 miles wide, it communicates with the sea by a channel, Foum el Wadi (= mouth) 4 miles long, 40 cubits wide (around 20 m) and 3 to 4 fathoms deep (from 6 to 8 m). The bottom is sludge. Near the sea it becomes wider and its depth increases. Here it is called Waccoun. This is where ships anchor. They are unloaded by means of small boats capable of sailing in shallower waters. The lake opening is three and a half miles from Carthage" (if one of these miles equals one and a half Roman miles, this is the length of the northern part of the bar as far as the present La Goulette).

In 1270 St. Louis and his troops landed at Carthage and settled on a sort of Island "one league long and three cross-bow shots wide" offering "an outlet at each end." In "this isthmus there is no fresh water but several cisterns are to be found near a great tower guarded by the Saracens" (in Prevault, 1842 and Wallon, 1880). This tower was probably the "Tour d'Eau" (a reservoir tower, a kind of early water tower) shown in the 1574 engraving (Fig. 3) near a canal or "fossus transitus" located roughly where the present Kherredine canal is found. If one league equals 4 km and if 3 cross-bow shots equal 450 m this gives us the length of the tombolo between Kherredine and Rades, and approximately its present mean width.

In 1306 the Arab geographer Abulfeda named the lake "Bohayre Tounes Almalih", in other words the Tunis Lagoon. He informs us "that from the shores of the lake near Tunis, up to its opening into the sea the distance is 10 miles, it circumference is 24 miles" (the measures given by El Bekri 230 years earlier.) "There is an island in this lake where the city dwellers go for amusement". At this period Tunis was a city at the height of its splendour and, as a corollary of this expansion, the eutrophication of the lake which had been indirectly indicated by El Bekri's observations was begining to pose a problem. Abulfeda noted, in fact, that all of the city's refuse accumulated in the part of the lake near Tunis.

After these observations comes a fourth group of documents, bequeathed to us by the historians of the Spanish and then the Turkish conquests, and by European travellers.

In 1470 Adorne (in Brunschvig, 1936) mentioned an arsenal where ships were enclosed and adds "in the summer the lake smells strangely foul". Thus we can be sure that the eutrophication of the lake is not a recent phenomenon, but the inevitable consequence of two factors: the proximity of a large city, Tunis, and the existence of a shallow expanse of water nearly always exposed to strong sunlight. Adorne also tells us that on the lake "there are many birds resembling storks but which are not storks" (in fact pink flamingos). "The little channel which communicates with the sea is as wide as a ship, its banks are walled, it is called Goulette and it is guarded by a tower called Rades" (probably what El Bekri calls the Chain Tower).

Then follow some historical and iconographical documents. In 1533 - 1534 Barbarossa gathered 20,000 Christian slaves to enlarge part of the Goulette Canal in order to turn it into a harbor and he had a second canal (The "Fossus transitus") dug to connect the lake to the sea near the Tour d'Eau. The Rades tower is called the Salt Tower; salt-works must have been set up in this part of the lake where they still exist today. In 1573 Philippe II ordered the construction of the Tunis arsenal near Bab el Bhar and asked a French engineer to reinforce the La Goulette defences and the constructions at Ile Saint Jacob (Chikli). In 1574 the Turks attacked La Goulette and dismantled the fortifications. An engraving illustrating this battle (Fig. 3) gives interesting indications as to the lake's topography and furnishes precise details of the location of the main structures and of the two canals connecting the lake to the sea (Poinssot, 1932).

In 1604 de Brevet (published in 1628) confirmed the delapidated condition of La Goulette's fortifications and pointed out the "remains of two ditches in which sea water flowed." These are the two canals already mentioned. The first, he says, "is 15 m wide" (i.e. the "Fossus transitus"; "the other is wider - a ship could sail down it." The author also described in a very detailed way, and very poetically, the thousands of birds that frequent the lake: "the Moors call them Louze and the Turks Calcaveafi; they have thin, very frail legs... a body covered with white feathers, the wings crimson and the large feathers black, and a very long neck covered with down, pinkish like the inner part of a newly blossomed white rose."

In 1625 Granchamp (published in 1938) confirmed the pollution of the lake, "a shallow pool of dead and dirty water." In 1656 Marmol (in Perrot, 1667) wrote: "the canal (of La Goulette) is so narrow that a galley cannot be rowed through it into the lake; there are banks of sand everywhere and one can only get boats through along the channels where the current flows."

In 1686 Dapper illustrated the narrative of his voyage to Tunisia with an engraving (Fig. 4) showing the lake. Near La Goulette can be seen the two fortification zones mentioned by the preceding authors: the Tour d'Eau to the north and the La Goulette bastions near the harbor. The Kherredine Canal does not appear in the picture (it had probably been filled in) whereas the southern part of the lake seems to be partly open to the sea and barred by fences made of reeds. Thus traps for catching fish as they swam out of the lake seem to have been set up at this spot, the same place where El Bekri situated the basins for breeding marine fish. That these fences indicate fishing areas is attested by the mention of fishermen's huts.

The documents that follow become more and more precise, corresponding to the arrival of a fifth group of travellers: naturalists and engineers. In 1724, Peysonell tells us that the lake is two and a half leagues long (10 km) and one and a half leagues wide (6 km); those are its present dimensions. It is "shallow and full of fish." "Between the La Goulette fortresses there is a canal two sandals wide." "Sandals" are flat-bottomed boats that ply the lake, about three meters wide; in other words we see that the canal that was more than 15 m wide in 1604 is now much narrower. The author describes further on two "fish traps formed by a stone and reed labyrinth where great quantities of fish are caught"; we thus have a description of the fish corrals shown by Dapper in 1686. Finally, the author names the algae in the lake; Acetabulum (these didn't disappear from the lake until about 1929, Heldt) and Fucus (?). For ancient authors Fucus saccharinus might be Posidonia oceanica. This marine phanerogam, usually considered characteristic of the open sea, can in fact under certain circumstances colonize lagoon biotopes, even shallow ones; such is the case today in the Bibans lagoon (Zaouali, 1982).

In 1727 Shaw (French edition of 1743) confirmed the narrowness of the La Goulette Canal and the dirtiness of the lake which he says was very shallow almost everywhere because it received all the city's refuse. Its banks were dry and smelly; in the channel in summer there was no more than 7 or 8 feet of water (1.8 to 2 m). He returns to the description of flamingos, for which he gives the name "phenicopters". He wrote again about the lake's fish, namely the "cephali" (Mugil cephalus or mullet), telling us that their flesh is highly prized and their roe made into a delicious dish called bo-targo ("bottarga" is still today one of the main resources of the lake fisheries.)

In 1816 Franck pointed out that the lake was no more than two feet deep (around 70 cm., which is about its present mean depth). The bottom, he says, "consists of slimy ooze, due to the inflow from the city sewers which carry all the filth of streets and latrines into the lake." On Chikli there was a lazarette and the island served as a berth for boats. Since this zone was shallow he recommended cleaning it out (works that have only now been partly realized). He was the first to name the gas that spreads over the lake and he tells us that "the release of sulphuretted hydrogen is favored by southerly winds... so that in some parts of Tunis there is an intolerable stink." He notes elsewhere that "the easterly winds have the disadvantage of carrying the fetid exhalations of this cesspool over to the city." He finally mentions the construction project for a basin in the lateral part of the La Goulette Canal (a Dutch engineer was consulted) and suggests building a lock that would hold back the lake waters, notably in summer (this system was adopted three years ago in the region of the Kherredine Canal).

In 1853 Pellissier spoke of the presence near Tunis of "a black and disgusting sludge whose horrible fumes spread an unbearable stink in the atmosphere." He suggested the dredging of a basin for the creation of a harbor, either in the canal (this was done in 1964), or in the part of the lake near La Goulette (work just now finished in the southern part of the lake).

The sixth group comprises the major works on the lake in modern times. These works, as we shall see, very curiously reproduce those carried out a thousand years ago by the Arabs!

In 1865 the mapping of the Gulf of Tunis region was carried out (Fig. 5): this gives us valuable indications concerning the lake's topography. On the one hand its general shape has not changed; on the other, the waters are already very shallow (between 0.6 and 1.4 m).

In 1880 the La Goulette Canal was enlarged to a width of 25 m and a depth of 6 to 8 m, i.e. just about to its VIIIth-century dimensions.

In 1885 a shipping channel was dug across the lake, 9 km long, 20 m wide (width increased to 45 m in 1950) and the same depth as the La Goulette Canal. It leads to the Port of Tunis, inaugurated in 1893, and divides the lake into two parts, northern and southern. This channel follows the same course and has the same width as the one Idrissi spoke of in 1116 (its outline can still be seen in the 1574 engraving, Fig. 3).

In 1893 the lake was rented out to fishermen. Two reed fish corrals were constructed, one near La Goulette, the other near the Port of Tunis. As we have seen, such installations probably existed already in 900 at the same place (the fisheries indicated by nautical instructions south of La Goulette). These installations were modernized in 1908 (de Fages and Ponzevera), the reeds being replaced by metal fences.

In 1912 a canal was dug at Khereddine, with nearly the same course as the "Fossus transitus" of 1533, but it was not maintained and no longer appears on the 1928 map (Fig. 6); however it was reopened in 1953 and enlarged in 1979.

In 1928 the Rades canal was dug.

Finally, in 1964, there was a complete remodelling of the La Goulette zone - the digging of large commercial docks, the reconstruction of the fishing harbor, and the filling in of the canal between La Goulette and the lake.

The seventh group comprises the scientific studies. They commence at the beginning of the century with a bacteriological study made in 1906 by Charles Nicolle in the first edition of the Revue de l'Institut Pasteur de Tunis. The author mentions the presence of 27,130,000 bacteria per cc in the zone near Tunis and gives the first numerical indication of the lakes salinity: 41.9 ppt. in the central part.

In 1920 fishing rights in the lake were taken over by the state, the profits going to the Salammbo Oceanographic Station, which opened in 1924. Thus began the many studies of the lake carried out by Henri and Jeanne Heldt, notably in the realm of fish and crustacea.

In 1929 J. Heldt made the first map of the northern lake's vegetation and furnished the first observations on the phenomenon called "red waters" caused by hypereutrophication.

In 1940 Bruun made an initial evaluation of the benthic biomass at the level of the La Goulette fish corrals. In 1944 J. Heldt indicated for the first time the presence of the serpulid worms, builders of the Ficopomatus (Mercierella) enigmatica reefs; she believed they appeared in 1924.

In 1954 Molinier and Picard carried out the first ecological study of the lake but they left out the southern lake.

The eighth group of studies concerns the problems of lake purification and the consultants' reports. The first reports date from 1950 (Hydrocure) and 1951 (Neyrpic); in 1955, Chamfrault recommended the construction of a canal for the evacuation of the city's sewage towards La Soukra (project now underway). Between 1961 and 1981 there were 39 reports on the eutrophication of the northern lake (more than 5000 pages). The main recommendations considered were the following:

1965 (Ministry of Agriculture): the possibility of filling in the northern lake.

1966 (Dutch consulting engineers): the digging of a canal to evacuate the waste water from the La Cherguia sewage treatment plant directly into the central canal at the level of the Port of Tunis (this canal has recently been built).

1967: Rudis, a Yugoslavian consulting firm, recommended the purification of the lake in its southern part as well as its northern part.

1969: The Italian consulting firm Bonifica showed the influence of sewage on the proliferation of the macroalga Ulva lactuca and suggested the pumping in of sea water by the Khereddine and Rades canals as well as the construction of one-way sluices (project carried out in 1979).

1972: Bjork, a Swedish consultant, recommended the removal of dead algae.

1973: The Environmental Protection Administration (United States) studied the problem of eutrophication in particular. The work carried out was summarized in a report (1977) published by the Institut Scientifique et Technique d'Oceanographie et de Peche, a state organization which, in 1963, replaced the Salammbo Station, the management of the lake, like that of all Tunisian lagoons, having been given over to the Office National des Peches in 1958.

The ninth group of documents consists of theses and scientific studies of a new kind (dynamic and quantitative studies).

The first doctoral thesis on the subject of lac de Tunis dates, as we have seen, from 1959; it is Pimienta's work and deals with the geology, sedimentology and hydrology of the whole lake. Then came, in 1965, Vuillemin's thesis on Mercierella enigmatica and, in 1974, Zaouali's on the ecology and the malacology of the northern and southern lakes.

To those can be added lower level theses (troisieme cycle): on primary production (Crouzet, 1972 and Belkhir, 1980), on the parasites of mullet (Ben Hassine, 1974), on the biology of those fish (Farrugio, 1975), on Aphanius fasciatus (Bou Maiza, 1979), on sedimentology (Jouirou, 1982), as well as numerous theses carried out by American researchers working in the framework of the E.P.A. project.

Furthermore, nearly 40 articles have been published (see the bibliography in Kelly et al., 1977): they deal with birds, fish population dynamics, spatio-temporal evolution of the benthic populations, isopods, interstitial fauna, foramenifera, and ostracoda; unfortunately in most cases they only deal with the northern part of the lake.

Last but not least, a publication that appeared in Sedimentology gives some very valuable information. That work describes sediment cores reaching bedrock at about -7 m. The sedimentary analysis of the bottom of those cores showed a sandy grey silt characteristic of a sebkha environment (this layer dates from -8000 years, i.e. contemporary with the second Wurmian glacial retreat). It is followed by a layer of grey-green silt (dated by carbon-14 to -6910 ±275 years) corresponding to an open environment (holocene transgression). The upper layers, grey-olive and grey-blue silts (-3130 ±105 years and -2520 ±95 years, environments in the process of closing up) and black silts (closed environments) are layers from historical times. The first (1050 BC) and the second (540 BC) bracket the date of the foundation of Carthage.

The thickness of these layers is also interesting: the base layer (at -7 m) is 50 cm thick, the grey-green layer is 2 m on average, the olive layer is 25 cm to 2 m thick, the grey-blue is 70 cm thick on average, and the black layer is from 2 cm to 1 m thick. Carbon-14 dating of the organic elements encountered in these layers enables us to evaluate the mean annual sedimentation rate; -3130, calcareous algae collected at -2.10 m; -2520, Posidonia found at -.70 m. Thus the analysis of these figures gives us an annual sedimentation rate of 2.2 mm for the first period of 610 years and 0.27 mm for the second period of 2520 years. This latter rate is very low, even abnormally so, and can only be explained by an equilibrium between deposition and flushing toward the sea of silt continually mixed into suspension. In other words, the silting up of the lake can only take place if it is no longer linked with the sea. It would happen, on the one hand if the sediments were not being carried away by outflow and, on the other hand, if the evaporation of water in the summer period was not offset by the inflow of an equal volume of sea water.

Does the presence of calcareous algae (Melobesia) and of Posidonia allow us to conclude that those organisms are without doubt the sign of a typically marine environment? It is possible to reply in the negative. Today Melobesia lives in the hypersaline Lac Bibans (Medhioub, 1979) as do Posidonia (Zaouali, 1982). Those plants would thus already have been able to live in the lagoon rather than the gulf, but they may have been driven out by pollution. The bibliography shows us, in fact, that Posidonia probably still existed in the lake in 1724 (Peysonnel).

CONCLUSIONS

This bibliographic study has allowed us to answer the question asked at the beginning of the paper; the lagoon closed well before the XVIth century, certainly well before 700, the time of its first crisis, and probably as early as 500 BC.

All of the documents consulted - from Greco-Roman historians, Arab geographers, and European voyagers, scientific works, and consultants' reports - show that lac de Tunis can in many ways be considered as a model:

- a model of historical continuity because of its exceptional geographical location linking the western and the eastern Mediterranean, this continuity being attested by the works undertaken which, as we have seen, have been concentrated in the same areas for over 1000 years;

- a model of great scientific interest because of its very high state of pollution, resulting from its proximity to Tunis, a city whose enormous importance during antiquity and in the Middle Ages is often forgotten.

These points have helped to make this lagoon one of the most closely studied in the world ever since the remotest times. To fill it in would be a crime against history, while its purification is an absolute necessity which, as we have seen, was stressed as long ago as 1801 (Franck). It is never too late mend the problem.

All the important works carried out in the lake, probably since the Carthaginian period and certainly since the beginning of the Arab conquest, have required so much energy that we can compare the efforts that have gone into its preservation down to the present day with those that went into the building of the pyramids.

The natural elements most often described, fish and birds, prove that, in spite of all the encroachments of pollution, there has been ecological continuity. Long may it continue.

BIBLIOGRAPHY

Aboulfeda (translated by J. T. Reinaud, 1883). Geographie d'Aboulfeda, 1306. Imp. Nationale (Paris), t. II, vol. I: 327 pp. vol. 2: 320 pp.

Belkhir, M., 1980. Eutrophisation du lac de Tunis: etudes physico-chimiques et biomasses phytoplanctonique et macroalgale. Thesis (Tunis). 194 pp.

Ben Hassine, O. K. 1974. Contribution a l'etude des copepodes parasites des Muges de Tunisie. Thesis (Tunis). 72 pp.

Bou Maiza, M. 1979. Etude d'Aphanius fasciatus, Nardo, 1827 (Pisces, Cyprinodontidea). Thesis (Tunis). 193 pp.

(de) Breves. 1628. Relation des voyages de Monsieur de Breves tant en Grece, Terre-Sainte et Aegypte qu'aux Royaumes de Tunis et Alger. Nicolas Gasse (Paris). 383 pp.

Bruun, A. F. 1940. Etudes quantitatives sur la faune du lac de Tunis et du golfe de Tunis dans la region de Salammbo. Bull. Sta. Ocean. Salammbo. 40:20 pp.

Brunschvig, R. 1936. Deux recits de voyages inedits en Afrique du Nord au XV° siecle: Voyage d'Abdelbasit a Tunis en 1462; Voyage d'Adorne a Tunis en 1470. Larose (Paris). 269 pp.

Chamfrault, G. 1955. La peche dans le lac de Tunis. Bull. Econ. Social, Tunisie. 1:40-56.

Crouzet, P. 1972. Contribution a la connaissance de la physico-chimie et de la production primaire du lac nord de Tunis. Thesis (Tunis)

Dapper, d'O. 1686. Description de l'Afrique. D. Horteneb. 543 pp.

El Bekri (translated by Mac Guckin de Slane, 1913). Description de l'Afrique septentrionale (1068). A. Jourdan (Algeria). 405 pp.

(de) Fages, E. and Ponzevera, C. 1908. Les peches maritimes de Tunisie. Picard (Tunis). 323 pp.

Farrugio, H. 1975. Les Muges (Poissons, Teleosteens) de Tunisie. Repartition et peche. Contribution a leur etude systematique et biologique. Doctoral thesis (Montpellier). 201 pp.

(de) Folard, Ch. 1730. Histoire de Polybe (translated from the Greek by V. Thuillier). P. Gandouin (Paris). t. II: 558 pp.

Franck, L. and Marcel, J. J. 1816. Histoire et description de la Regence de Tunis. 228 pp. 28 pl. 1 map.

Grandchamp, P. 1625. Une mission delicate en Barbarie au XVIII° siecle. Aloccio (Tunis, 1938 edition). 58 pp.

Heldt, J. 1929. Le lac de Tunis (partie nord): resultats de peches au filet fin. Bull Sta. Ocean. Salammbo. 2: 76 pp.

Heldt, J. 1944. Sur la presence de Mercierella enigmatica Fauvel, Serpulien d'eau saumatre, dans les eaux tres salees du lac de Tunis. Notes Sta. Ocean. Salammbo. 30: 4 pp.

Heron de Villefosse. 1898. Appendix to the memoir of R. P. Delattre. pp. 21-26.

Idrissi (translated by R. Dozz and M. J. Goeje, 1866) Description de l'Afrique et de l'Espagne (1116). E. J. Brill (Leyden). 391 pp.

INSTOP / EPA (Hadj Ali, M. et al.). 1977. Research on the eutrophication of the lake of Tunis, background conclusions and recommendations. INSTOP (Tunis). 17 pp.

Jouirou, M. 1982. Contribution a l'etude sedimentologique du lac de Tunis evolution holocene et actuelle. Thesis (Bordeaux).

Kelly, M. G. et al. 1977. Research on the eutrophication of the lake of Tunis: Geology, biology, chemistry and hydrology. INSTOP / EPA. 76 pp.

Medhioub, K. 1979. La Bahiret el Biban. Etude geochimique st sedimentologique d'une lagune du sud-est Tunisien. T. Lab. Geol. ENS. Paris. 13: 150 pp.

Molinier, R. and Picard, J. 1974. Elements de bionomie marine sur les cotes de Tunisie. Bull Sta. Ocean. Salammbo. 48: 47 pp.

Nicolle, Ch. 1906. Experiences sur la pollution des eaux du lac de Tunis dans les conditions actuelles de deversement des eaux d'egout dans ce lac. Arch. Inst. Pasteur Tunis. 1(2):74-77.

Pellissier, E. 1853. Description de la Regence de Tunis. 455 pp., 1 map.

Perrot, N., Sieur d'Ablancourt. 1667. L'Afrique de Marmol. L. Billaine (Paris). Tome II: 578 pp.

Peysonnel, J. A. 1724 and Desfontaines, L. R. 1783-1786. Voyage dans les Regences de Tunis et d'Alger (published by Hureau de la Malle, 1838). Gide (Paris). Vol. 1: 485 pp. Vol 2: 385 pp.

Pimienta, J. 1959. Le cycle Pliocene-actuel dans les bassins paraliques de Tunis. Mem. Soc. Geol. France. 38(85): 176 pp.

Poinssot, L. and Lautier, R. 1932. Les gouverneurs Espagnols de la Goulette Alger. 9 pp.

Prevault, H. 1842. Histoire de Godefroy de Bouillon suivie de l'histoire des Croisades jusqu'a la mort de Saint-Louis. Lefort (Lille). 286 pp.

Shaw, M. D. 1743. Voyages de Monsieur Shaw dans plusieurs provinces de la Barbarie et du Levant. J. Neaulme (La Haye). t. I: 414 pp.

Thornton, S.E., Pilkey, O.H., Doyle, L.J., Whaling, P.J. 1980. Holocene evolution of a coastal lagoon, lake of Tunis, Tunisia. Sedimentology. 27:79-91.

Vuillemin, S. 1965. Contribution a l'etude ecologique du lac de Tunis: biologie de Mercierella enigmatica. SEDES (Paris). 556 pp.

Wallon, H. 1880. Saint-Louis. A. Mame (Tours). 554 pp. 38 pl.

Zaouali, J. 1974. Les peuplements malacologiques dans les biocoenoses lagunaires Tunisiennes. Etude de la biologie de l'espece pionniere Cerastoderma glaucum Poiret. Doctoral thesis (Caen). 345 pp.

Zaouali, J. 1982. Bionomie benthique de la zone centrale et du bassin oriental de la mer des bibans (Tunisie meridionale). Oceanological Acta (in press).

LA GOULETTE, TUNIS ET ENVIRONS, D'APRÈS ORTELIUS, GÉOGRAPHE DE PHILIPPE II (XVI[e] SIÈCLE)

Fig. 1. Map of the eastern part of North Africa (1535). It can be seen that on this map: 1. The lake and the Gulf of Tunis bear a single name "Sinus Carthaginensis". 2. Radès is called Raba. 3. Bizerte is curiously placed south of the Mejerda river (called Bagrada).

(D'après une carte tirée de l'atlas de Mercator — 1633)

Fig. 2. Map of the eastern part of North Africa from 1633. This map faithfully reproduces that of 1535 except for several details: 1. The lake is called "Stagnum": only the Gulf of Tunis is called "Sinus Carthaginensis". 2. The La Goulette fortifications cover the same area as the city of Tunis. 3. The city of Tunis is surrounded by a double wall.

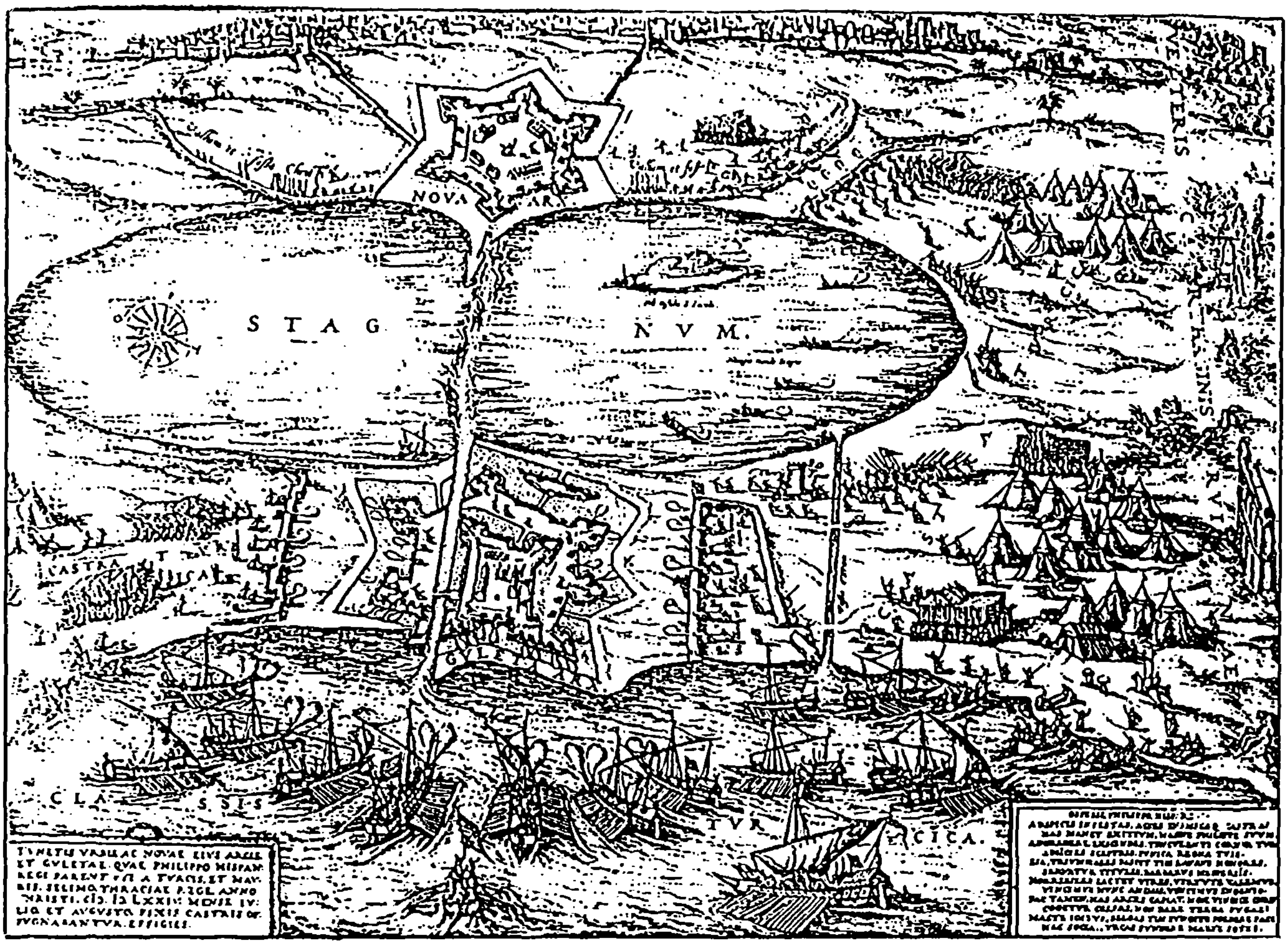


Fig. 3. The siege of Tunis by the Turkish fleet in 1574. Note: 1. The presence of two canals connecting the lake to the sea, the La Goulette canal in the central part of the sandbar and the "Fossus transitus" in the northern part. 2. The difference in size between the ships in the Gulf and the boats on the lake. 3. The difference in size between the boats in the central channel and those on the northern part of the lake.

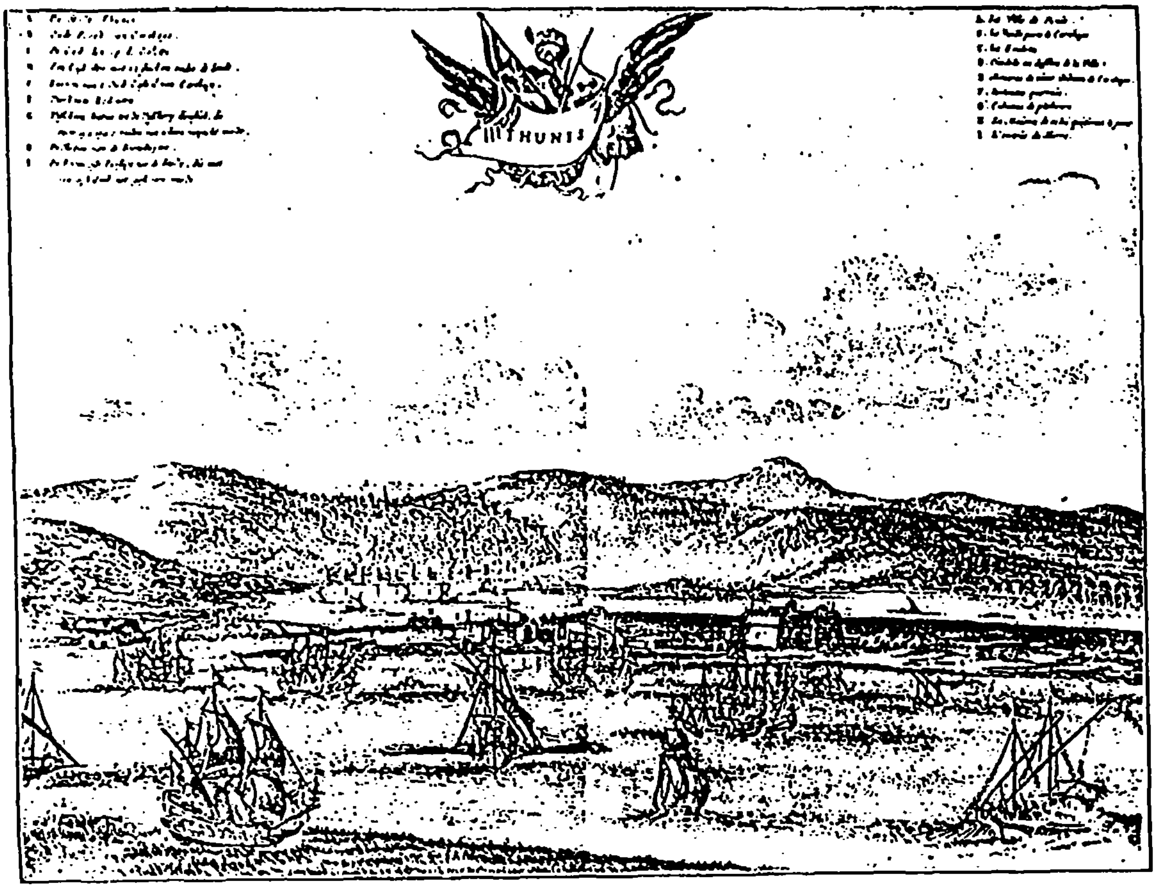


Fig. 4. The lac de Tunis in 1686 (Dapper). This engraving, which shows the lake seen from the bottom end of the Gulf of Tunis, demonstrates: 1. The difference between the size of the boats in the roadstead and on the lake (three masts in the roadstead, only one in the lake). 2. The fences that close off the southern part of the lake on the left of the engraving indicate fisheries (G: fishermen's huts).

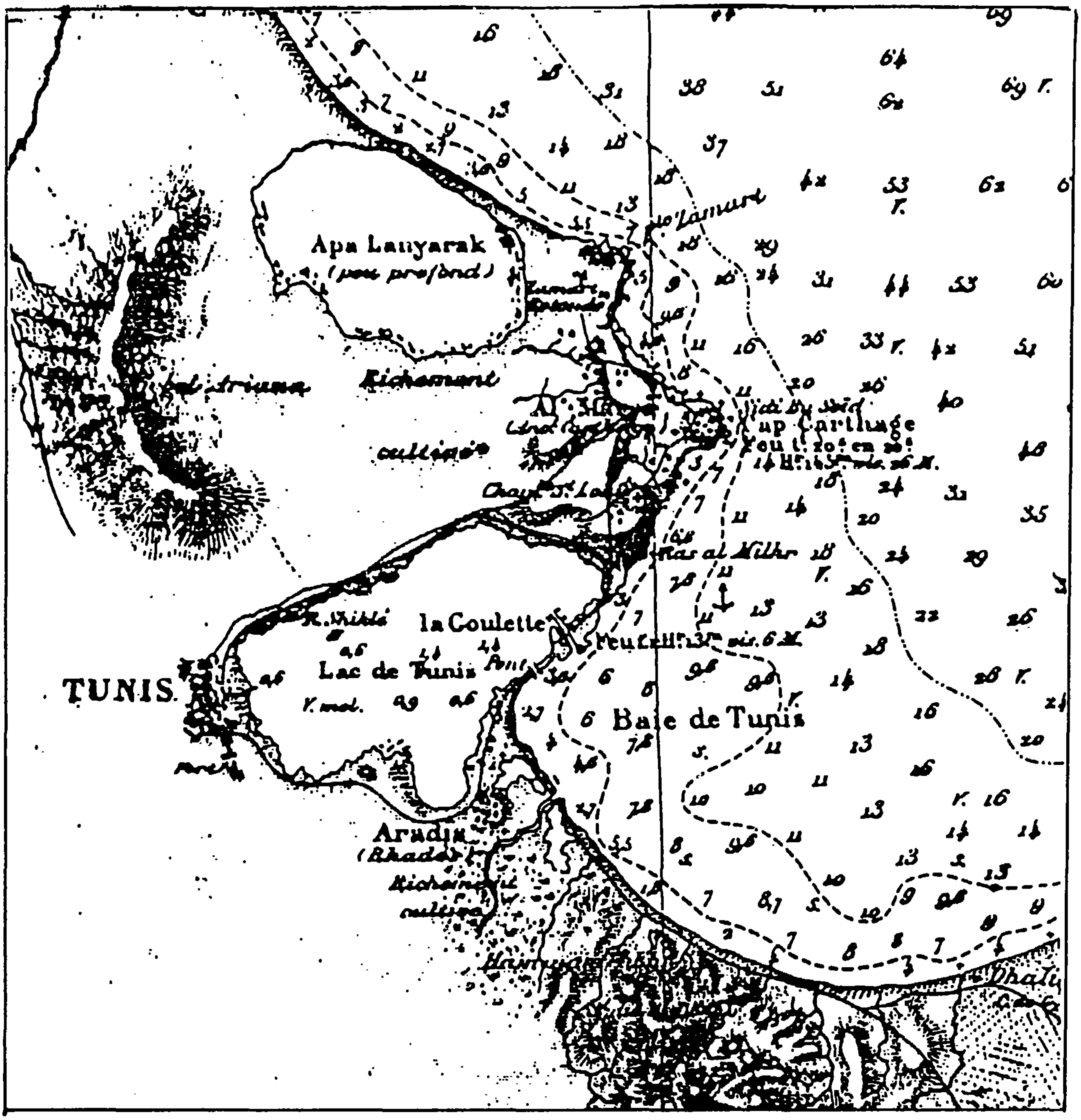


Fig. 5. The Gulf and the lac de Tunis (1865). Apa Lanyarak is the present Sebkha Ariana.

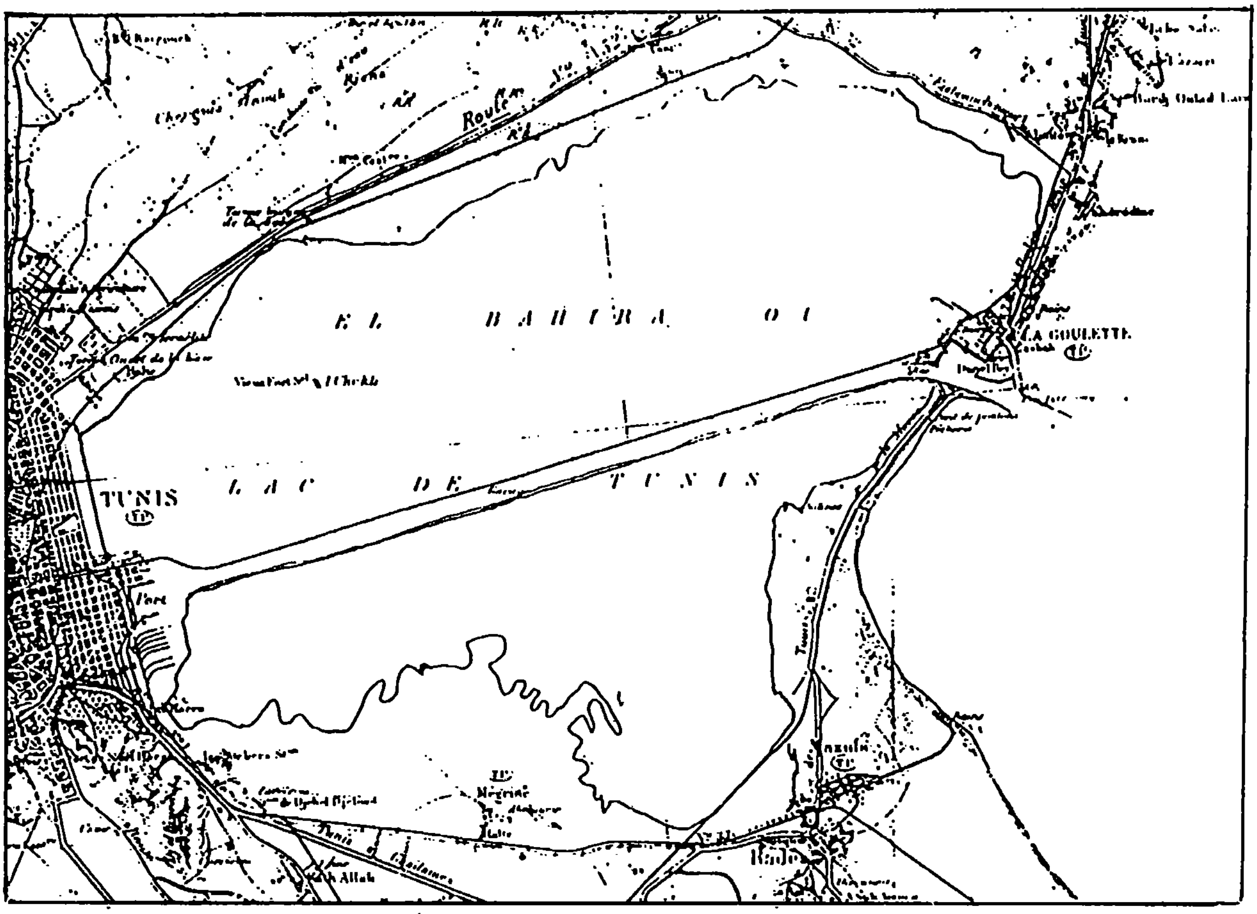


Fig. 6. The lac de Tunis. Map of 1902 with additions made in 1928.

APPENDIX B - SCHEDULE OF MEETINGS

Tues. 7 Sept.

Morning session:

0930 Welcome to Participants. M. Bechir Jedidi, Commissaire General a la Peche du Ministere de l'Agriculture.
0945 Introduction of Participants. M. Hadj Ali Mohammed Salem, Professeur et Directeur, INSTOP.
0950 Introduction to Goals of Workshop. Dr. Mahlon Kelly, Scientific Coordinator of workshop.
1000 Le Lac de Tunis: 3000 Ans d' Ingenierie et de Pollution. Mme. Jeanne Zaouali, Maitre de Conferences, Institut National Agronomique de Tunis.
1100 Break.
1130 The Benthos of Lac de Tunis: Statistical Studies and Water Quality. Mme. Jeanne Zaouali.
1230 A History of the Concept of Eutrophication in Fresh-water Lakes. Dr. Monir Naguib.

Afternoon session:

1330 Lunch break.
1600 Meeting of participants to discuss reorganized plans for workshop.

Wed. 8 Sept.

Morning session:

0830 Eutrophisation Naturelle du systeme lagunaire en milieu semi-aride. Exemple de la Bohiret El Biban. Dr. Noureddine Meddioub.
1030 Break.
1100 Examples of Cultural Eutrophication in a Variety of Coastal Ecosystems. Dr. Mahlon Kelly.

Afternoon Session:

1230 Lunch break.
1400 The Carbon Cycle in Aquatic Environments. Dr. Monir Naguib.
1530 Discussion of presentations.

Thur. 9 Sept.

Morning Session:

0830 Nutrients and the Control of Photosynthetic Rates. Dr. Mahlon Kelly.
1000 Break.
1030 Light and the Control of Photosynthetic Rates. Dr. Mahlon Kelly.

Afternoon Session:

1230 Lunch Break.
1400 Chemical and Physical Conditions in Lac de Tunis. Dr. Moheiddine Belkhir.
1500 Break.
1530 Algal Production in Lac de Tunis. Dr. Moheiddine Belkhir.

Fri. 10 Sept.

Morning Session:

0830 Shipboard tour of waters offshore from Tunis and the port of Tunis. Water and phytoplankton sampling.

Afternoon free.

Sat. 11 Sept.

Morning Session:

0830 Preliminary Observations on Nutrient Cycling and a Stoichiometric Model in Elefsis Bay, Greece, An Anoxic Basin. Dr. Nikolaos Friligos.
0930 Eutrophication and the Hydroclimate in Shallow Tropical Lakes. Dr. Jacques Lemoalle
1030 Break.
1100 Eutrophication in Kastela Bay, Yugoslavia. Dr. Ivona Marasovic.

Afternoon free.

Mon. 13 Sept.

Morning Session:

0830 Anaerobic Environments: Methane, Hydrogen Sulfide and Ammonia. Dr. Monir Naguib.
0930 The Analysis of Methane. Dr. Monir Naguib.
1100 Break.
1130 New and Automated Methods for the Analysis of Carbon and Oxygen Based Productivity. Dr. Mahlon G. Kelly.

Afternoon Session:

1300 Lunch break.
1400 A Comparison of Oxygen and Carbon Based Productivity: What are we measuring? Dr. Mahlon Kelly.
1530 Discussion of the presentations.

Tue. 14 Sept.

Morning Session.

0830 The Plan for Sewage Treatment in Tunis and its Environs. M. Kennou.
0930 Field trip to the sewage diversion project and the Chergula treatment plant.

Afternoon Session:

1300 Lunch Break.
1400 Concurrent presentations:
--- Ivona Marasovitch: Analysis of phytoplankton from waters offshore of Tunis.
--- Jacques Lemoalle: Automated titrimetric measurement of alkalinity.
--- Moheiddine Belkhir: Measurement of productivity using biomass change of Ulva.

Wed. 15 Sept.

Morning Session:

0830 Fishery Statistics for Lac de Tunis. Mr. Krichen Youssef.
1000 Phytoplankton Production and Red Tide formation in the Eastern Harbor of Alexandria and Offshore Waters. Dr. Helmy Adly Sultan.
1100 Break
1130 Biochemical Factors Influencing the Ecology of *Alexandrinium minutum* Halim and Other Phytoplankton. Dr. Helmy Adly Sultan.

Afternoon Session:

1300 Lunch break.
1400 - 1730 Group discussion of the concept of Eutrophication as applied to coastal waters, with preparation of a concluding statement. Dr. Mahlon Kelly, convener.

Thurs. 16 Sept.

Morning Session:

0830 - 1300 Group discussion of the application of modelling to coastal embayments, using Lac de Tunis as an example. Dr. Moheiddine Belkhir and Dr. Mahlon Kelly, conveners.

Afternoon Session:

1330 Lunch as guests of INSTOP.
1600 Field trip to Sebkhet Sedjoumi and Sebkhet Eriana - hypersaline seasonal palaeolagoons.

Fri. 17 Sept.

Discussion of final report outline by organizers and consultants. Hadj Ali, Belkhir, Kelly, Naguib.

Departure of most participants. Visit to laboratories of INSTOP by Naguib and Belkhir to inspect apparatus for possible future workshops.

APPENDIX C - LIST OF PARTICIPANTS

Dr. Moheiddinne Belkhir,
Chef de Laboratoire,
INSTOP / La Goulette,
Tunisia.

Mr. Nidhal Chatta,
6 Cite al Wifak,
La Marsa,
Tunisia.

Dr. Nikolaos Friligos,
Institute of Oceanographic and Fisheries Research,
Aghioskosmas, Hellinikon,
Athens,
Greece.

Prof. Adel Hamwi,
University Faculty,
University of Damascus,
Damascus,
Syria.

Dr. Mahlon G. Kelly,
Dept. of Environmental Sciences,
University of Virginia,
Charlottesville, Va. 22903,
U. S. A.

Dr. Jacques Lemoalle,
ORSTOM,
18 Avenue Charles Nicolle,
Tunis,
Tunisia.

Dr. Ivona Maresovic,
Institute for Oceanography and Fisheries,
58000, Split,
pp 114,
Yugoslavia.

Dr. Noureddine Meddiouk,
Faculte des Sciences,
Sfax,
Tunisia.

Dr. Monir Naguib,
Max Planck Inst. fur Limnologie,
August Thienemann Str.,
D-232 Plon / Holstein,
Federal Republic of Germany.

Prof. Hadj Ali Mohammed Salem,
Directeur,
INSTOP / Salammbo,
Tunisia.

Dr. Helmy Adly Sultan,
Institute of Oceanography and Fisheries,
Kayet Bey,
Alexandria,
Egypt.

Mrs. Souad Turki,
INSTOP / La Goulette,
Tunisia.

Mr. Krichen Youssef,
Cite Khasnadar,
Le Bardo (B.I.A.9),
Tunisia.

Dr. Jeanne Zaouali,
Institut National Agronomique de Tunisie
(Section Halieutique)
Tunis,
Tunisia.

UNESCO REPORTS IN MARINE SCIENCE

Title of numbers which are out of stock

No.		Year
3	Benthic ecology and sedimentation of the south Atlantic continental platform Report of the seminar organized by Unesco in Montevideo, Uruguay, 9-12 May 1978	1979
13	Seminario Latinoamericano sobre Enseñanza de la Oceanografía Informe final del Seminario organizado por la Unesco en São Paulo, Brasil, 17-20 de noviembre de 1978	1981