MEDITERRANEAN ACTION PLAN
MED POL

UNITED NATIONS ENVIRONMENT PROGRAMME

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

FINAL REPORTS ON RESEARCH PROJECTS DEALING WITH EUTROPHICATION AND PLANKTON BLOOMS (ACTIVITY H)

RAPPORTS FINAUX SUR LES PROJETS DE RECHERCHE CONSACRES A L'EUTROPHISATION ET AUX EFFLORESCENCES DE PLANCTON (ACTIVITE H)

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This volume is the thirty-seventh issue of the Mediterranean Action Plan Technical Report Series.

This series contains selected reports resulting from the various activities performed within the framework of the components of the Mediterranean Action Plan: Pollution Monitoring and Research Programme (MED POL), Blue Plan, Priority Actions Programme, Specially Protected Areas and Regional Oil Combating Centre.

Ce volume constitue le trente-septième numéro de la série des Rapports techniques du Plan d'action pour la Méditerranée.

Cette série comprend certains rapports élaborés au cours de diverses activités menées dans le cadre des composantes du Plan d'action pour la Méditerranée: Programme de surveillance continue et de recherche en matière de pollution (MED POL), Plan Bleu, Programme d'actions prioritaires, Aires spécialement protégées et Centre régional de lutte contre la pollution par les hydrocarbures.

INTRODUCTION

The United Nations Environment Programme (UNEP) convened an Intergovernmental Meeting on the Protection of the Mediterranean (Barcelona, 28 January - 4 February 1975), which was attended by representatives of 16 States bordering the Mediterranean Sea. The meeting discussed the various measures necessary for the prevention and control of pollution of the Mediterranean Sea, and concluded by adopting an Action Plan consisting of three substantive components:

- Integrated planning of the development and management of the resources of the Mediterranean Basin (management component);

- Co-ordinated programme for research, monitoring, exchange of information, assessment of the state of pollution and protection measures (assessment component);

- *Framework convention and related protocols with their technical annexes* for the protection of the Mediterranean environment (legal component).

All components of the Action Plan are inter-dependent and provide a framework for comprehensive action to promote both the protection and the continued development of the Mediterranean ecoregion. No component is an end in itself. The Action Plan is intended to assist the Mediterranean Governments in formulating their national policies related to the continuous development and protection of the Mediterranean area and to improve their ability to identify various options for alternative patterns of development and to make choices for appropriate allocations of resources.

MED POL - Phase I (1976-1980)

The Co-ordinated Mediterranean Research and Monitoring Programme (MED POL) was approved as the assessment (scientific/technical) component of the Action Plan.

The general objectives of its pilot phase (MED POL - Phase I), which evolved through a series of expert and intergovernmental meetings, were:

- to formulate and carry out a co-ordinated pollution monitoring and research programme taking into account the goals of the Mediterranean Action Plan and the capabilities of the Mediterranean research centres to participate in it;

- to assist national research centres in developing their capabilities to participate in the programme;

- to analyse the sources, amounts, levels, pathways, trends and effects of pollutants relevant to the Mediterranean Sea;

- to provide the scientific/technical information needed by the Governments of the Mediterranean States and the EEC for the negotiation and implementation of the Convention for the Protection of the Mediterranean Sea against Pollution and its related protocols.

- to build up consistent time-series of data on the sources, pathways, levels and effects of pollutants in the Mediterranean Sea and thus to contribute to the scientific knowledge of the Mediterranean Sea.

MED POL - Phase I initially consisted of seven pilot projects (MED POL I - VII), which were later expanded by additional six pilot projects (MED POL VIII - XIII), some of which remained in a conceptual stage only.

MED POL - Phase I was implemented in the period from 1975 to 1980. The large number of national research centres designated by their Governments to participate in MED POL (83 research centres from 15 Mediterranean States and the EEC), the diversity of the programme and its geographical coverage, the impressive number of Mediterranean scientists and technicians (about 200) and the number of co-operating agencies and supporting organizations involved in it, qualifies MED POL as certainly one of the largest and most complex co-operative scientific programmes with a specific and well-defined aim ever undertaken in the Mediterranean basin.

The overall co-ordination and guidance for MED POL - Phase I was provided by UNEP, acting as the secretariat of the Mediterranean Action Plan (MAP). Co-operating specialized United Nations Agencies (ECE, UNIDO, FAO, UNESCO, WHO, WMO, IAEA, IOC) were responsible for the technical implementation and day-to-day co-ordination of the work of national research centres participating in the pilot projects.

MED POL - Phase II (1981-1990)

The Intergovernmental Review Meeting of Mediterranean Coastal States and First Meeting of the Contracting Parties to the Convention for the Protection of the Mediterranean Sea against Pollution, and its related protocols (Geneva, 5-10 February 1979), having examined the status of MED POL - Phase I, recommended that during the 1979/80 biennium a Long-term pollution monitoring and research programme should be formulated.

Based on the recommendations made at various expert and intergovernmental meetings, a draft Long-term (1981-1990) Programme for Pollution Monitoring and Research in the Mediterranean (MED POL - Phase II) was formulated by the Secretariat of the Barcelona Convention (UNEP), in co-operation with the United Nations Agencies which were responsible for the technical implementation of MED POL - Phase I, and it was formally approved by the Second Meeting of the Contracting Parties of the Mediterranean Sea against pollution and its related protocols and Intergovernmental Review Meeting of Mediterranean Coastal States of the Action Plan held in Cannes, 2-7 March 1981.

The general long-term objectives of MED POL - Phase II were to further the goals of the Barcelona Convention by assisting the Parties to prevent, abate and combat pollution of the Mediterranean Sea Area and to protect and enhance the marine environment of the Area. The specific objectives were designed to provide, on a continuous basis, the Parties to the Barcelona Convention and its related protocols with:

- information required for the implementation of the Convention and the protocols;

- indicators and evaluation of the effectiveness of the pollution prevention measures taken under the Convention and the protocols;

- scientific information which may lead to eventual revisions and amendments of the relevant provisions of the Convention and the protocols and for the formulation of additional protocols;

- information which could be used in formulating environmentally sound national, bilateral and multilateral management decisions essential for the continuous socio-economic development of the Mediterranean region on a sustainable basis;

- periodic assessment of the state of pollution of the Mediterranean Sea.

The monitoring of, and research on, pollutants affecting the Mediterranean marine environment reflects primarily the immediate and long-term requirements of the Barcelona Convention and its protocols, but also takes into account factors needed for the understanding of the relationship between the socio-economic development of the region and the pollution of the Mediterranean Sea.

For this purpose, monitoring was organized on several levels:

- monitoring of sources of pollution providing information on the type and amount of pollutants released directly into the environment;

- monitoring of nearshore areas, including estuaries, under the direct influence of pollutants from identifiable primary (outfalls, discharge and coastal dumping points) or secondary (rivers) sources;

- monitoring of offshore areas (reference areas) providing information on the general trends in the level of pollution in the Mediterranean;

- monitoring of the transport of pollutants to the Mediterranean through the atmosphere, providing additional information on the pollution load reaching the Mediterranean Sea.

Research and study topics included initially in the MED POL - Phase II were:

- development of sampling and analytical techniques for monitoring the sources and levels of pollutants. Testing and harmonization of these methods at the Mediterranean scale and their formulation as reference methods. Priority will be given to the substance listed in the annexes of the Protocol for the prevention of pollution of the Mediterranean Sea by dumping from ship and aircraft and the Protocol for the protection of the Mediterranean Sea against pollution from land-based sources (activity A);

- development of reporting formats required according to the Dumping, Emergency and Land-Based Sources Protocols (activity B);

- formulation of the scientific rationale for the environmental quality criteria to be used in the development of emission standards, standards of use or guidelines for substaces listed in annexes I and II of the Land-Based Sources Protocol in accordance with Articles 5, 6 and 7 of that Protocol (activity C);

- epidemiological studies related to the confirmation (or eventual revision) of the proposed environmental quality criteria (standards of use) for bathing waters, shellfish-growing waters and edible marine organisms (activity D);

- development of proposals for guidelines and criteria governing the application of the Land-Based Sources Protocol, as requested in Article 7 of that Protocol (activity E);

- research on oceanographic processes, with particular emphasis on surface circulation and vertical transport. Needed for the understanding of the distribution of pollutants through the Mediterranean and for the development of contingency plans for cases of emergency (activity F);

- research on the toxicity, persistence, bioaccumulation, carcinogenicity and mutagenicity of selected substances listed in annexes of the Land-Based Sources Protocol and the Dumping Protocol (activity G);

- research on eutrophication and concomitant plankton blooms. Needed to assess the feasibility of alleviating the consequences and damage from such recurring blooms (activity H);

- study of ecosystem modifications in areas influenced by pollutants, and in areas where ecosystem modifications are caused by large-scale coastal or inland engineering activity (activity I);

- effects of thermal discharges on marine and coastal ecosystems, including the study of associated effects (activity J);

- biogeochemical cycle of specific pollutants, particularly those relevant to human health (mercury, lead, survival of pathogens in the Mediterranean Sea, etc.) (activity K);

- study of pollutant-transfer processes (i) at river/sea and air/sea interface, (ii) by sedimentation and (iii) through the straits linking the Mediterranean with other seas (activity L);

As in MED POL - Phase I, the overall co-ordination and guidance for MED POL - Phase II is provided by UNEP as the secretariat of the Mediterranean Action Plan (MAP). Co-operating specialized United Nations Agencies (FAO, UNESCO, WHO, WMO, IAEA, IOC) are responsible for the technical implementation and day-to-day co-ordination of the work of national centres participating in monitoring and research.

The present volume includes final reports on research projects and especially those dealing with eutrophication and plankton blooms. Final editing and compilation of this volume was done by Mr. G.P. Gabrielides, FAO Senior Fishery Officer (Marine Pollution) while Ms V. Papapanagiotou, FAO Secretary, was responsible for the typing.

INTRODUCTION

Le Programme des Nations Unies pour l'environnement (PNUE) a convoqué une réunion intergouvernementale sur la protection de la Méditerranée (Barcelone, 28 janvier - 4 février 1975) à laquelle ont pris part des représentants de 16 Etats riverains de la mer Méditerranée. La réunion a examiné les diverses mesures nécessaires à la prévention et à la lutte antipollution en mer Méditerranée, et elle s'est conclue sur l'adoption d'un Plan d'action comportant trois éléments fondamentaux:

- Planification intégrée du développemet et de la gestion des ressources du bassin méditerranéen (élément "gestion");

- Programme coordonné de surveillance continue, de recherche, d'échange de renseignements et d'évaluation de l'état de la pollution et des mesures de protection (élément "évaluation");

- Convention cadre et protocoles y relatifs avec leurs annexes techniques pour la protection du milieu méditerranéen (élément juridique).

Tous les éléments du Plan d'action étaient interdépendants et fournissaient le cadre d'une action d'ensemble en vue de promouvoir, tant la protection que le développement continue de l'écorégion méditerranéenne. Aucun élément ne constituait une fin à lui seul. Le Plan d'action était destiné à aider les gouvernements méditerranéens à formuler leurs politiques nationales en matière de développement continu et de protection de zone de la Méditerranée et à accroître leur faculté d'identifier les diverses options s'offrant pour les schémas de développement, d'arrêter leurs choix et d'y affecter les ressources appropriées.

MED POL - Phase I (1976 - 1980)

Le programme coordonné de surveillance continue et de recherche en matière de pollution de la Méditerranée (MED POL) a été approuvé au titre de l'élément "évaluation" (scientifique/technique) du Plan d'action.

Sa phase pilote (MED POL - Phase I) avait les objectifs généraux ci-dessous, élaborés au cours d'une série de réunions d'experts et de réunions intergouvernementales:

- formuler et exécuter un programme coordonné de surveillance continue et de recherche en matière de pollution en tenant compte des buts du Plan d'action pour la Méditerranée et de l'aptitude des centres de recherche méditerranéens à y participer;

- aider les centres de recherche nationaux à se rendre plus aptes à cette participation;

- étudier les sources, l'étendue, le degré, les parcours, les tendances et les effets des polluants affectant la mer Méditerranée;

- fournir l'information scientifique et technique nécessaire aux gouvernements des pays méditerranéens et à la Communauté économique européenne pour négocier et mettre en oeuvre la Convention pour la protection de la mer Méditerranée contre la pollution et les protocoles y relatifs;

- constituer des séries chronologiques cohérentes de données sur les sources, les cheminements, les degrés et les effets des polluants de la mer Méditerranée et contribuer par là à la connaissance scientifique de cette mer.

La Phase I du MED POL comportait à l'origine sept projets pilotes (MED POL I - VII) auxquels sont venus ultérieurement s'ajouter six autres (MED POL VIII - XIII) dont certains n'en sont restés qu'au stade de la conception.

La Phase I du MED POL a été mise en oeuvre au cours de la période 1975 - 1980. Le grand nombre de centres de recherche nationaux désignés par leurs gouvernements pour participer au MED POL (83 centres de recherche de 15 Etats méditerranéens et de la CEE), la diversité du programme et sa couverture géographique, l'effectif impressionnant de scientifiques et techniciens méditerranéens (environ 200) ainsi que la quantité d'organismes coopérants et d'organisations d'appui qui y étaient engagés permettent sans conteste de caractériser le MED POL comme l'un des programmes de coopération scientifique les plus vastes et les plus complexes, comportant un objectif spécifique et bien défini, qui ai jamais été entrepris dans le bassin mediterranéen.

La coordination et la direction générales de MED POL - Phase I ont été assurées par le PNUE, faisant fonction de secrétariat du Plan d'action pour la Méditerranée (PAM). Les organismes spécialisés coopérants des Nations Unies (CEE - Commission économique pour l'Europe, ONUDI, FAO, UNESCO, OMS, OMM, AIEA, COI) étaient chargés de l'exécution technique et de la coordination quotidienne des travaux des centres de recherche nationaux participant aux projets pilotes.

MED POL - Phase II (1981 - 1990)

La réunion intergouvernementale des Etats riverains de la Méditerranée chargés d'évaluer l'état d'avancement du Plan d'action et première réunion des Parties contractantes à la Convention pour la protection de la mer Méditerranée contre la pollution et aux protocoles y relatifs (Genève, 5-10 février 1979), ayant examiné la situation de la Phase I du MED POL, a recommandé que, durant la période biennale 1979 - 80, soit formulé un programme à long terme de surveillance continue et de recherche en matière de pollution.

Sur la base des recommandations énoncées lors des diverses réunions d'experts et réunions intergouvernementales, un projet de programme à long terme (1981 - 1990) de surveillance continue et de recherche en matière de pollution (MED POL - Phase II) a été formulé par le secrétariat de la Convention de Barcelone (PNUE), en coopération avec les organismes des Nations Unies chargés de l'exécution technique de MED POL - Phase I, et il a été officiellement approuvé lors de la deuxième réunion des Parties contractantes à la Convention pour la protection de la mer Méditerranée contre la pollution et aux Protocoles y relatifs et réunion intergouvernementale des Etats riverains de la mer Méditerranée chargée d'évaluer l'état d'avancement du Plan d'action, qui s'est tenue à Cannes du 2 au 7 mars 1981.

L'objectif général à long terme de la Phase II du MED POL était de concourir à la réalisation des objectifs de la Convention de Barcelone en aidant les Parties contractantes à prévenir, réduire et combattre la pollution dans la zone de la mer Méditerranée ainsi qu'à protéger et améliorer le milieu marin dans cette zone. Les objectifs particuliers étaient de fournir constamment aux Parties contractantes à la Convention de Barcelone et aux Protocoles y relatifs:

- les renseignements dont elles avaient besoin pour appliquer la Convention et les protocoles;

- des indications et une évaluation de l'efficacité des mesures prises pour prévenir la pollution en application de la Convention et des protocoles;

- des renseignements scientifiques qui pourraient servir à réviser et modifier les dispositions pertinentes de la Convention et des protocoles et à rédiger des protocoles additionnels;

- des informations qui pourraient servir à formuler sur les plans national, bilatéral et multilatéral, les décisions de gestion, respectueuses de l'evnironnement, qui seraient indispensables à la poursuite du développement socio-économique de la région méditerranéenne;

- une évaluation périodique de l'état de pollution de la mer Méditerranée.

La surveillance continue des polluants affectant le milieu marin de la Méditerranée ainsi que la recherche menée à leur sujet répondent en premier lieu aux prescriptions immédiates et à long terme de la Convention de Barcelona et des protocoles y relatifs, mais elles tiennent également compte des facteurs requis pour la compréhension des relations existant entre le développement socio-économique de la région et la pollution de la mer Méditerranée.

A cette fin, la surveillance continue était organisée à plusieurs niveaux:

- surveillance continue des sources de pollution fournissant des renseignements sur la nature et la quantité des polluants directement libérés dans l'environnement;

- surveillance continue des zones situées à proximite du littoral, y compris les estuaires, et qui sont sous l'influence directe de polluants émis par des sources identifiables primaires (émissaires, rejets et sites côtiers d'immersion) ou secondaires (cours d'eau);

- surveillance continue des zones du large (zones de référence) fournissant des renseignements sur les tendances générales du niveau de pollution en Méditerranée;

- surveillance continue du transfert des polluants à la Méditerranée par voie atmosphérique, fournissant des renseignements supplémentaires sur la charge polluante qui atteint la Méditerranée.

Les sujets de recherche et d'étude inclus initialement dans MED POL - Phase II étaient les suivants:

- mise au point de techniques d'échantillonnage et d'analyse pour la surveillance des sources et des niveaux de pollution. Essai et harmonisation de ces méthodes à l'échelle méditerranéenne, et formulation de méthodes de référence. Substances figurant sur les listes de priorité des protocoles sur les opérations d'immersion et sur la pollution d'origine tellurique (activité A);

- mise au point de la présentation type des rapports à soumettre en application des protocoles relatifs à l'immersion, à la pollution résultant de situations critiques et à la pollution d'origine tellurique, (activité B);

- élaboration des fondements scientifiques des critères de qualité de l'environnement qui serviront à définir des normes d'émission, des normes d'usage ou des directives concernant les substances énumérées dans les annexes I et II du protocole relatif à la pollution d'origine tellurique, conformément aux articles 5, 6 et 7 de ce protocole (activité C);

- études épidémiologiques relatives à la confirmation (ou révision éventuelle) des critères de la qualité de l'environnement (normes d'usage) proposés pour les eaux servant à la baignade, à la culture de coquillages et à l'élevage d'autres organismes marins comestibles (activité D);

- mise au point de projets de directives et de critères régissant l'application du protocole relatif à la pollution d'origine tellurique, conformément à l'article 7 de ce protocole (activité E);

- recherches sur les processus océaniques, et particulièrement sur la circulation en surface et les déplacements verticaux. Cette information est nécessaire à la connaissance de la répartition des polluants en Méditerranée et à la mise au point de plans pour parer aux situations critiques (activité F);

- recherches sur la toxicité, la persistance, la bioaccumulation et le caractère cancérigène et mutagène de certaines substances énumérées dans les annexes du protocole relatif à la pollution d'origine tellurique et du protocole relatif aux opérations d'immersion (activité G);

- recherches sur l'eutrophisation et les floraisons de plancton qui l'accompagnent. Cette information est nécessaire pour évaluer la possibilité de prévenir les effets et les dégâts causés par ces floraisons périodiques (activité H);

- étude des modifications de l'écosystème dans les zones soumises à l'influence des polluants et dans celles où ces modifications sont dues à d'importantes activités industrielles sur la côte ou à l'intérieur des terres (activité I);

- effets des pollutions thermiques sur les écosystèmes marins et côtiers, y compris l'étude des effets connexes (activité J);

- cycle biogéochimique de certains polluants intéressant particulièrement la santé (mercure, plomb, survie des organismes pathogènes dans la mer Méditerranée, etc.) (activité K);

- étude des processus de transfert des polluants (i) aux points de contact entre les cours d'eau et la mer et entre l'air et la mer, (ii) par sédimentation et (iii) à travers les détroits qui relient la Méditerranée aux mers voisines (activité L).

Comme lors de la Phase I du MED POL, la coordination et la direction générales de la Phase II étaient assurées par le PNUE, par l'intermédiaire du secrétariat du Plan d'action pour la Méditerranée (PAM). Les organismes spécialisés coopérants des Nations Unies (FAO, UNESCO, OMS, OMM, AIEA, COI) étaient chargés de l'exécution technique et de la coordination quotidienne des travaux des centres de recherche nationaux participant au programme de surveillance continue et de recherche.

Le présent volume comprend les rapports finaux sur les projets de recherche, et notamment sur ceux consacrés à l'eutrophisation et aux efflorescences de plancton. La préparation, l'édition et la compilation de ce volume ont été assurées par M. G.P. Gabrielides, FAO, Fonctionnaire Principal des Pêches (Pollution Marine), et Mlle V. Papapanagiotou, Sécretaire FAO était chargée de la dactylographie.

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EUTROPHICATION AND CONCOMITANT PLANKTON BLOOMS IN THE CENTRAL ADRIATIC

by

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ABSTRACT

The project studies were undertaken in order to gain better knowledge of the red-tide phenomenon, frequently recorded in the coastal waters of the Adriatic. Long-term observations in the most threatened areas were aimed at determining the circumstances preceding the red-tide phenomenon and which species caused it.

The results obtained show a very high level of biological activity (pH 8.4-8.7, oxygen saturation 100%, primary production 915.22 mg C m^{-2} day^{-1}) due to an increased eutrophication in the bay. In the summer, due to the poorer vertical and horizontal circulation in some parts of the water surface, stratification occurs with layers manifesting characteristics different from the rest of the bay. These phenomena seem to be responsible for the concentration of phytoplankton organisms, fostering the growth of the monospecific blooms of those organisms that show certain competitive advantages in relation to the other organisms (in our studies *Gonyaulax polyedra* 1.6 x 10^7 cell l^{-1} and *Olisthodiscus luteus* 3 - 5 x 10^7 cell l^{-1}). In addition to a whole range of other competitive advantages, such as photoadaptation, resting cysts, temporary cysts (*G. polyedra*) and production of certain metabolites which enable them to exclude other organisms from the environment, these flagellate organisms are highly motile. Such an intensive phytoplankton bloom eventually leads to its self-destruction; the resulting anoxic state of the environment causes a mass mortality of marine organisms (*G. polyedra* bloom, September 1980 - 0.5 ml O_2 l^{-1} and July 1985 - 2 ml O_2 l^{-1}).

1. INTRODUCTION

There are several large urban and industrial centres, situated in the Central Adriatic, and coastal waters in their vicinity show high levels of eutrophication. The most extensive of these, the Split region, is considered as one of the most threatened areas of the eastern Adriatic coast. Therefore, a whole range of multidisciplinary activities was carried out, during the period from January 1983 to June 1985.

Phytoplankton studies were undertaken, in order to determine the cause of frequent excessive phytoplankton blooms, occasional red-tides, and to try to find a way to rehabilitate the sea in this region.

The studies were mostly carried out in Kastela Bay (K), near Split, where five permanent stations were sampled. In the case of irregular blooms, research extended to the wider region of the town of Split as well as to some other regions of the Central Adriatic such as Sibenik Bay (S) and the channel area between Crikvenica and the island of Rab (C) (Fig. 1).

Phytoplankton investigations were carried out simultaneously with physicochemical and zooplankton studies. The estimate of the basin productivity was reached, on the basis of the primary production measurements. In the same period, a dynamic study of the exchange of the basin water with the surrounding sea in the varying circumstances of the distribution of the water masses (vertical stratification and homogeneous distribution) was carried out.

2. MATERIALS AND METHODS

The sampling was carried out seasonally but during the extraordinary blooms the investigations were extended in time and covered a wider area.

(i) Phytoplankton: primary production (C^{14} Steeman - Nielsen); pigments (Chlorophyll *a* fluorometric technique; qualitative-quantitative composition (Settling techniques by Utermöhl on inverted microscope);

(ii) Zooplankton: qualitative-quantitative structure of copepods (Hansen net);

(iii) Environmental parameters: temperature, salinity, transparency alkalinity, dissolved oxygen, oxygen saturation, phosphates, nitrates, ammonia, silicates.

Standard methods were used to determine physical and chemical parameters of the waters.

3. RESULTS

Dynamic measurements in Kastela Bay show that water circulation in the Bay is mostly influenced by the wind (Zore-Armanda, 1980), so that there is a significant decline during long periods of calm weather as is usual in the summer season. At the same time, the inflow of fresh water into the Bay has much less influence on the water exchange between the Bay and the surrounding region, as there is a considerable reduction during the summer.

The average values of the sea temperatures and salinity for the years 1982, 1983 and 1984 are shown in Table I, the minimum sea temperatures being 9.5 °C (February 1984), and the maximum 26 °C (July 1984).

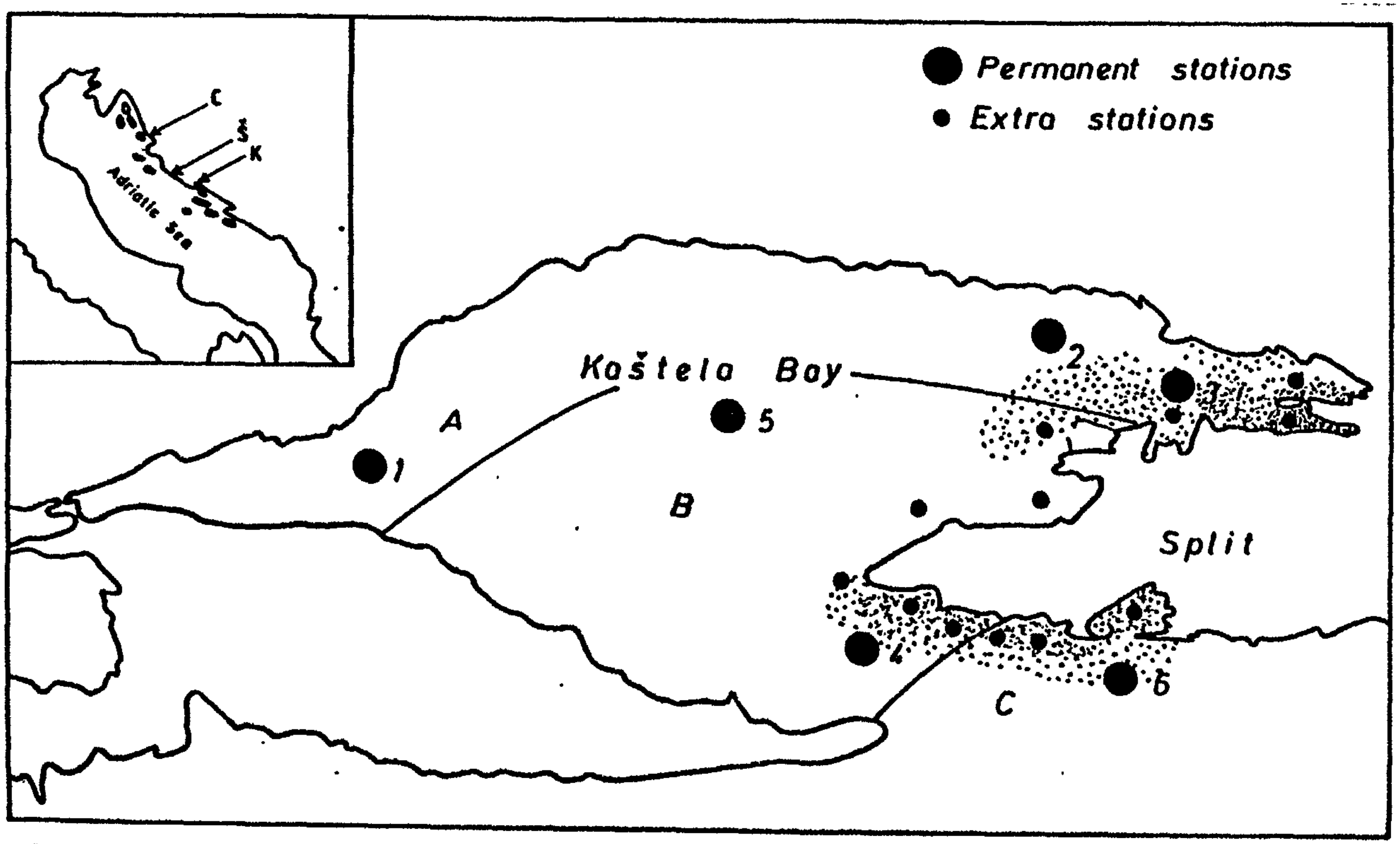

Fig. 1 Map of Kastela Bay showing the areas of investigations

Table I

Temperature (^{o}C) and salinity ($s \times 10^{-3}$) long term means (1982, 1983 and 1984) in Kastela Bay.

Station	$T^{o}C$	$S \times 10^{-3}$
1	17.20	36.25
2	17.75	35.72
3	17.99	36.84
4	16.78	37.27
5	16.77	37.16

The quantities of the nutrients in the Bay do not show significant seasonal variations and the values tend to be similar. Nor are differences between the stations (Table II) very noticeable, which indicates the very quick nutrient turn-over by phytoplanktons.

Table II

Long-term means of nutrients (1982, 1983, 1984) in Kastela Bay ($\mu g\text{-at } l^{-1}$).

Stations	PO_4-P	NH_3-N	NO_3-N	NO_2-N
1	0.057	0.91	0.75	0.070
2	0.066	1.10	0.72	0.069
3	0.061	1.10	0.79	0.069
4	0.062	0.97	0.74	0.072
5	0.056	1.04	0.78	0.078

Measurements of the primary organic production in the Bay show that the average daily production of this basin amounts to 915.22 mg C m^{-2}, which must rank it amongst the most productive regions of the Adriatic. Table III indicates the values for the chlorophyll a quantities recorded at the stations (in 1982, 1983, 1984 and part of 1985), expressed in fluorescence units. They are in inverse proportion to the transparency in the Bay, as illustrated in Figs. 2 and 3. The stations inside the Bay show the lowest transparency and the highest chlorophyll a values, both at the surface and at the bottom.

The number of phytoplankton cells recorded per litre shows the highest values during the summer monospecific blooms inside the Bay (1.7×10^7 cells l^{-1} - July 1984), while these values vary between 10^5 and 10^6 cells l^{-1} during the rest of the year.

Up to ten years ago, there was a regular seasonal pattern in the appearance of the phytoplankton blooms; however, it has been much disturbed since then, and the blooms now appear in all seasons (Pucher-Petkovic and Marasovic, 1980; Marasovic and Pucher-Petkovic, 1983). The only difference now observed is in the type of blooms, mostly flagellate types in the warmer periods and diatomic blooms in the colder weather.

The various parts of the Bay show differences in phytoplankton quantity, as well as qualitative differences; those recorded in the summer season are much more significant.

In the winter season, the qualitative differences among the stations in the Bay compared to those outside the Bay are not important as illustrated in Tables IV and V.

These differences are even more obvious, if presented in terms of the SORENSEN similarity quotient (Table VI); it is seen that the phytoplankton population inside the Bay has only a weak similarity with the one outside the Bay.

The main reason for this phenomenon is the poorer circulation in the summer, which results in wholly different conditions deep inside the Bay, compared to the rest of it. Because of such conditions the red tide has appeared regularly inside the Bay every summer in recent years. Three times (in 1980,1985 and 1987) it was followed by the mass mortality of the marine organisms (Marasovic and Vudakin, 1982; Marasovic, 1989). The cause of the mass mortality was the anoxic state of the environment (September 1980 - 0.5 ml O_2 l^{-1}, July 1985 - 2.16 ml O_2 l^{-1} and September 1987 - 1 ml O_2 l^{-1}), due to bacterial disruption of great quantities of organic material (dead phytoplankton cells). Gonyaulax polyedra was always present, and the accompanying species were Prorocentrum micans and Eutreptiella pascheri.

In September 1980, the number of cells recorded increased to the amount of 2×10^7 cells l^{-1}, while in the other years it varied around 10^7 cells l^{-1}. In the summer of 1984 simultaneously with the G. polyedra red-tide occurrence inside the Bay, another red-tide bloom outside the Bay developed. It was caused by another organism, Olisthodiscus luteus (Marasovic and Pucher-Petkovic, 1985; Marasovic and Pucher-Petkovic, 1987). Due to the sensitivity of the organism (the cells broke up during fixation), precise density values could not be achieved, and these ranged from $3\text{-}5 \times 10^7$ cells l^{-1}. Accompanying species were P. triestinum, E. lanowii, E. pascheri and Carteria sp.

Table III

Comparative data on chlorophyll a content (fluorescence units) from five stations in Kastela Bay (1982, 1983, 1984, 1985).

Station	Depth	Mar. 1982	Apr. 1982	May 1982	Mar. 1983	May 1983	July 1983	Nov. 1983	Mar. 1984	June 1984	July 1984	May 1985	Average means	
1	0 m	8.7	7.5	0.7	3.0	6.5	1.7	7.3	2.5	6.0	1.0	2.2	4.28	
	bottom	5.8	9.8	0.3	5.1	4.0	1.3	7.1	1.3	1.9	1.1	1.8	3.59	3.9
2	0 m	12.0	30.8	6.7	12.0	30.0	3.5	5.9	5.8	9.9	3.7	3.2	11.20	
	bottom	9.0	7.9	1.4	7.7	4.8	2.2	5.6	2.5	1.1	12.3	1.0	4.27	7.7
3	0 m	6.6	27.3	2.6	11.3	15.0	3.4	5.9	5.3	20.6	1.6	5.0	9.51	
	10 m	6.0	8.8	0.8	12.7	-	2.9	7.3	-	1.5	3.6	1.2	4.95	6,5
	bottom	9.0	9.9	1.1	4.7	7.6	3.1	6.7	3.4	4.4	2.2	4.0	5.14	
4	0 m	7.3	6.3	0.5	7.7	2.5	1.0	3.9	3.5	5.0	0.7	1.0	3.86	
	10 m	5.0	2.3	1.2	3.4	-	5.5	4.2	-	0.2	0.8	0.4	2.97	3.1
	bottom	2.1	3.0	-	2.8	1.3	1.6	4.0	1.0	1.1	1.2	-	2.62	
5	0 m	3.3	11.8	2.6	6.6	2.2	0.9	3.8	3.0	6.0	1.5	1.8	3.95	
	10 m	5.1	13.4	1.1	9.1	3.0	1.4	4.2	-	1.0	1.3	2.0	4.06	3.6
	bottom	2.3	2.1	0.4	3.8	8.5	1.0	4.0	2.7	1.4	1.9	2.0	2.7	

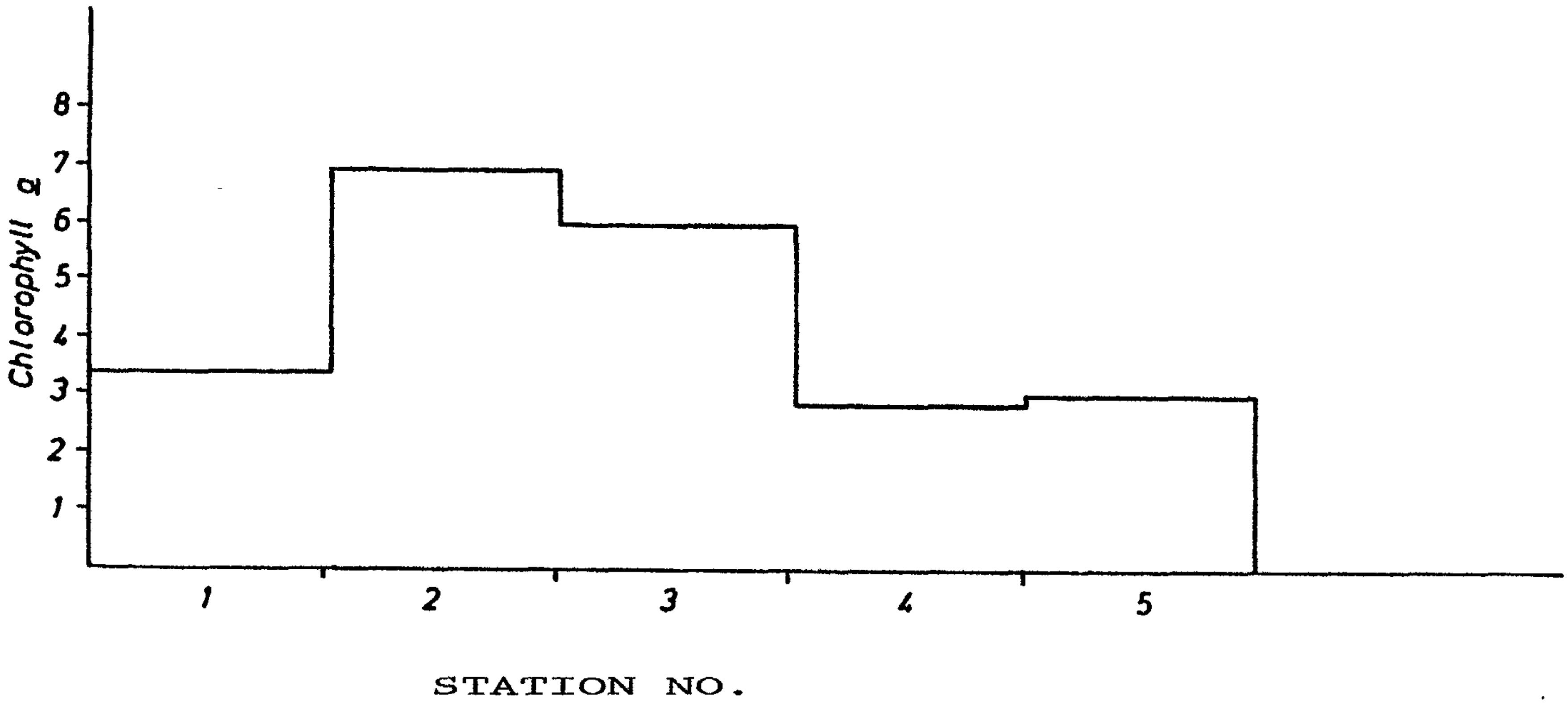

Fig. 2 Chlorophyll a content (fluorescence units) at five sampling stations in Kastela Bay (long-term means 1982, 1983, 1984)

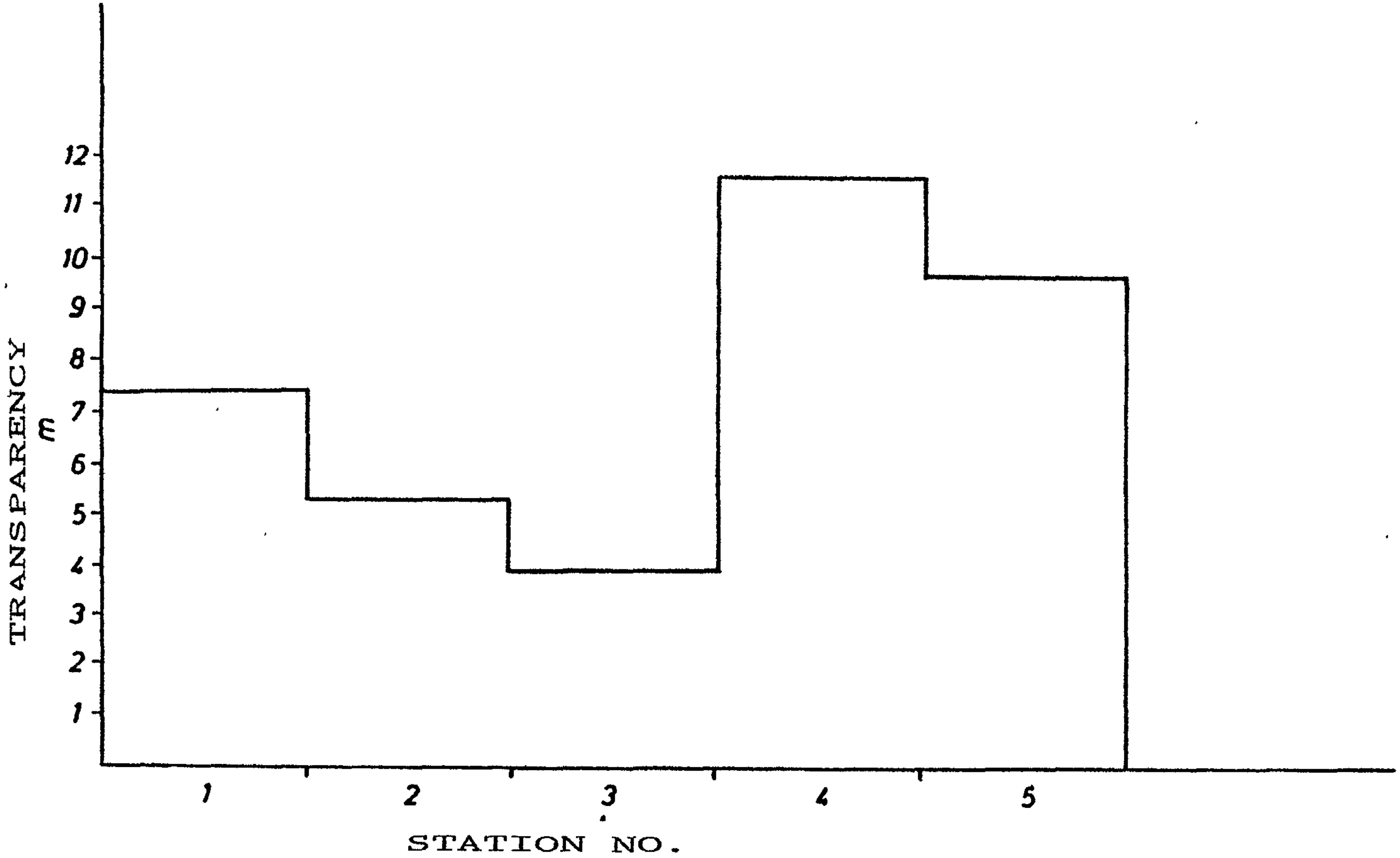

Fig. 3 Transparency (m) in Kastela Bay (long-term means 1982, 1983, 1984)

Table IV

List of phytoplankton species recorded on August 30, 1984
and relative abundance (%) of phytoplankton groups.
(see Fig. 1 for the areas).

Area A	Area B	Area C
Rhizosolenia alata f.gracillima	Skeletonema costatum	Skeletonema costatum
Thalassionema nitzschioides	Leptocylindrus adriaticus	Leptocylindrus adriaticus
	Rhizosolenia alata f.gracillima	Rhizosolenia stolterfothii
Prorocentrum micans	Rh.fragilissima	Rhizosolenia styliformis
		var.longispina
P. maximum	Rh.setigera	Chaetoceros curvisetus
P. triestinum	Rh.stolterfothii	Ch.danicus
Dinophysis sacculus	Chaetoceros curvisetus	Ch. pseudocurvisetus
Gyrodinium sp.	Ch.danicus	Chaetoceros sp.
Glenodinium sp.	Ch.pseudocurvisetus	Thalassionema
nitzschioides		
Scripsiella trochoidea	Eucampia cornuta	Amphora sp.
Gonyaulax polyedra	Thalassionema nitzschioides	Nitzschia delicatissima
Ceratium karstenii	Navicula sp.	N. longissima
Oxytoxum longiceps	Nitzschia delicatissima	N. seriata
Calciosolenia murrayi	N. longissima	Prorocentrum micans
Rhabdosphaera longistylis	N. seriata	P. minimum
Dictyocha speculum	Prorocentrum micans	P. triestinum
Eutreptiella pascheri	P. triestinum	Gymnodinium sp.
	Gyrodinium pingue	Glenodinium sp.
Diatoms 1%	Glenodinium sp.	Heterocapsa triquetra
Dinoflagellates 94%	Heterocapsa triquetra	Scripsiella trochoidea
	Scripsiella trochoidea	Gonyaulax polyedra
	Peridinium diabolus	Oxytoxum viride
	P. pyriforme	
	Gonyaulax polyedra	Syracosphaera sp.
		Rhabdosphaera longistylis
	Syracosphaera pulchra	Calciosolenia murrayi
	Syracosphaera spp.	Eutreptiella pascheri
	Calciosolenia murrayi	
	Eutreptiella pascheri	Diatoms 81%
	Carteria sp.	Dinoflagellates 13%
	Diatoms 65%	
	Dinoflagellates 6%	

Table V

List of phytoplankton species recorded on December 24, 1984
and relative abundance (%) of phytoplankton groups.
(see Fig. 1 for the areas).

Area A	Area B	Area C
Thalassiosira rotula	Thalassiosira rotula	Thalassiosira rotula
Thalassiosira sp.	Skeletonema costatum	Thalassiosira sp.
Skeletonema costatum	Leptocylindrus adriaticus	Skeletonema costatum
Leptocylindrus adriaticus	Rhizosolenia fragilissima	Leptocylindrus adriaticus
Rhizosolenia fragilissima	Rh.alata f.gracillima	Rhizosolenia fragilissima
Chaetoceros danicus	Rh.setigera	Chaetoceros sp.
Ch.neopolitanus	Chaetoceros anastomosans	Eucampia cornuta
Ch.lorenzianus	Ch.lorenzianus	Thalassiothrix frauenfeldi
Synedra sp.	Bacteriastrum hyalinium	Th.mediterranea
Thalassiothrix frauenfeldi	Thalassiothrix frauenfeldi	Thalassionema nitzschioides
Th.mediterranea	Th.mediterranea	Striatella unipunctata
Thalassionema nitzschioides	Thalassionema nitzschicides	Licmophora sp.
Pleurosigma angulatum	Cerataulina bergoni	Cocconeis scutellum
Nitzschia delicatissima	Asterionella japonica	Navicula sp.
N.longissima	Pleurosigma angulatum	Nitzschia delicatissima
N.seriata	Navicula sp.	N.seriata
	Amphora sp.	N.longissima
Prorocentrum micans	Diatoma sp.	
Gymnodinium sp.	Nitzschia delicatissima	Pontosphaera spp.
Gyrodinium fusiforme	N.seriata	
Podolampas spinifer	N.longissima	Diatoms 93%
		Dinoflagellates 0%
Calciosolenia murrayi	Pontosphaera sp.	
Pontosphaera sp.		
Diatoms 93%	Diatoms 91%	
Dinoflagellates 2%	Dinoflagellates 0%	

Table VI

Quotient of similarity (SØRENSEN, 1948) for diatoms and dinoflagellates in Kastela Bay.

Summer 1984		Winter 1984	
AREAS	A/B = 38.9%	AREAS	A/B = 60.5%
AREAS	A/C = 35.3%	AREAS	A/C = 61.5%
AREAS	B/C = 69.6%	AREAS	B/C = 66.0%

The quantities of the nutritive salts in the bloom region did not show increased values, as can be seen from Table VII, which compares the nutrient quantities recorded in August, in the same region.

In summer 1983, an extraordinary bloom was recorded in the sea channel between Crikvenica and the island of Rab (C). The phenomenon known as "sea water bloom" ("mare sporco") was observed in this area in July and August 1983. The bloom was highly intensive and large quantities of gelatinous, foamy masses were found floating on the sea surface. A total of 58 different diatoms, 24 dinoflagellate and 10 coccolithophorid species was identified by microscopy, of which benthic and neritic species were predominant. We studied this phenomenon thoroughly and we were able to come up with a new and different approach concerning its origin (Pucher-Petkovic and Marasovic, 1984; Pucher-Petkovic and Marasovic, 1987)).

In Sibenik (S), a highly intensive bloom of Skeletonema costatum occurred amounting to 2.6×10^6 st l^{-1}. Phytoplankton quantities are permanently very high in this area, so that natural fluctuations are not easy to identify; in addition, the stratification of water masses is strongly marked due to the influx of fresh water, so that the greater part of the phytoplankton mass is concentrated in the upper 10 metres. While the upper layers recorded intensive bloom, the lower layers recorded almost no bloom during the same period.

Table VII

Quantity of nutrients in Kastela Bay (Station 3) during the red tide (µg-at l^{-1}).

Date	NO_3-N	NO_2-N	NH_3-N	PO_4-P	SiO_3-Si
27 July 1984	0.43	0.063	0.53	0.053	6.42
30 July 1984	0.47	0.053	0.59	0.048	5.39

4. DISCUSSION

During the three years of the studies, more extraordinary phytoplankton blooms were recorded, the most significant being the dinoflagellate summer blooms in the Kastela Bay and the diatom spring blooms in the island of Rab - Crikvenica area.

The large quantities of micronutrients and macronutrients in Kastela Bay combined with the decreased circulation of the sea, enables the development and supports the red-tide blooms in the Bay.

Due to the considerable biological activity of the Bay (pH 8.4 - 8.7, O_2 6.7 ml l^{-1}, saturation more than 140%), it has been impossible to demonstrate the excessive increase of nutritive salts, as well as the greater seasonal quantity variations. In any cases, the high values of primary production, the abundance of phyto- and zooplankton and the disappearance of seasonal variations indicate the excessive enrichment of the Bay.

The development of the intensive diatom blooms in winter, spring and late autumn is due to the high quantity of nutritive salts, while such diatom blooms are the ideal basis for the growth of dinoflagellate blooms.

Dinoflagellate and flagellate blooms, appearing in the warmer seasons, cause problems, in respect of a change in sea colour and even worse, they are sometimes associated with the mass mortality of marine organisms. Since in Kastela Bay the red-tide blooms always appear in the same locations under the same weather conditions, it follows that the dinoflagellate red-tide blooms re-appear regularly, always in the same locations, during stagnant meteorological conditions and in their majority they are caused by the same organism (G. polyedra). One is led to the conclusion that we are dealing with an autochthonous type of red-tide, namely a bloom caused by a resting stage, which is initiated whenever favourable conditions occur (Steidinger and Haddad, 1981).

In summer, because of an increased inflow of waste waters and the adjacent river Jadro, high sea temperatures and the decreased vertical and horizontal circulations, a homogeneous water mass develops inside the Bay with quite different characteristics from the rest of the bay water. Lowered salinity and high temperatures, combined with sufficient quantities of micronutrients and macronutrients provide favourable conditions for the growth of a dinoflagellate population.

Tables IV and V illustrate clearly the differences in the stations inside and outside the Bay in summer, while in the winter such differences are insignificant.

These seasonal investigations at the selected stations have proved that the threatened areas have changed their behavioural pattern in relation to the open sea; the time gap between the seasonal blooms in the open sea and the blooms in bays burdened with waste waters is in the process of disappearing.

In summer 1984, simultaneously with the bloom inside the Bay, another monotype bloom developed outside it, caused by the species Olisthodiscus luteus. It was the first time that a bloom of this organism was recorded in the Adriatic, although it has appeared in eutrophicated bays all over the world. We concluded that the bloom was partly brought about by the great quantities of soil reaching the sea, after the embankment works in this area were completed; this contributed to the intensive spring bloom of Skeletonema costatum. In turn, Skeletonema costatum was the ideal point of departure for the development of the species Olisthodiscus luteus, since earlier investigations have shown that Skeletonema blooms always precede Olisthodiscus blooms (Tomas, 1980).

The blooms of euryvalent species, the frequent presence of certain toxic phytoplankton species, and on the other hand the disappearance of certain stenovalent species from these regions indicate the appearance of certain ecological changes.

5. CONCLUSIONS

A thorough consideration of these results leads to the conclusion that those regions constantly burdened with waste waters have sufficient quantities of micro and macro nutrients not to cause, but to enable and to support excessive phytoplankton blooms.

In the region studied, whenever the sea temperature exceeds 22 ^{o}C, it initiates such blooms, triggering off an explosive development of certain organisms, mainly those with some competitive advantages (in dinoflagellates-mobility, good photoadaptation, cysts, metabolic products), over other organisms (diatoms) and thus can develop as monoculture in a certain region. In addition, some species of this latter group exercise a direct unfavourable influence on the environment, because of the excretion of certain metabolic products which are toxic for other organisms: or more often they exercise an indirect unfavourable influence, since such excessive blooms always result in an anoxic state.

Some regions in the Central Adriatic have achieved such a high level of eutrophication, that they can be described as hypertrophied. In order to rehabilitate such regions, it is essential to reduce the discharge of waste waters; however, since great quantities of micro- and macro nutrients are deposited in the sediments, these areas will continue to exhibit a high level of eutrophication for a long time.

The results obtained from these studies combined with the results of physical, chemical and dynamic investigations should enable us to reach a more precise evaluation of the basin absorptive capacities i.e. to estimate the quantities of wastewaters that can be discharged without a significant disturbance of the ecological balance.

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EUTROPHICATION AND CONCOMITANT PLANKTON BLOOMS IN THE NORTH ADRIATIC

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ABSTRACT

The occurrence of plankton blooms in the Gulf of Trieste was studied from 1983 to 1985. It was shown that the phytoplankton of this area exhibits intensive fluctuations with maxima developing monthly. It was assumed that the peak of phytoplankton biomass in August 1983 had contributed to the oxygen depletion and the concomitant mass mortality of benthic fauna.

The monospecific red tide of a dinoflagellate was registered in autumn 1984. Its possible toxicity is discussed.

1. INTRODUCTION

The phytoplankton assemblages of the Gulf of Trieste, Northern Adriatic, were studied from 1983 to 1985. This area, the northernmost part of the North Adriatic basin, is characterized by its shallowness (mean depth 20 m), the significant impact of the hinterland and the extreme fluctuations of environmental parameters. Thermal and density stratification of the water column is developed in early summer (Tusnik, 1976) and towards the end of September isothermal conditions are established. The phytoplankton of the area is a typical neritic community (Fanuko, 1981), with an increased biomass and reduced species diversity as compared to the southern parts of the Adriatic.

2. MATERIAL AND METHODS

Four representative sites were chosen for the phytoplankton study:

i) a typical North-Adriatic off-shore station (station F, 22 m deep);

ii) the Bay of Koper known for its industrial activity (station K-1, 15 m deep);

iii) the Bay of Piran, centre of tourism (station MA, depth 15 m);

iv) a mussel-culturing area in the Bay of Piran (station D, depth 8 m).

In the first year of the investigation, samples were collected weekly at station F. Later, monthly samplings were taken at all sites. Living phytoplankton was enumerated according to Clark and Siegler (1963). Chlorophyll *a* was measured spectrophotometrically using the trichromatic equations (UNESCO, 1969). Phaeophytin *a* was determined in the acidified pigment extract (Lorenzen, 1967). The nutritive salts were measured spectrophotometrically (Strickland and Parsons, 1968).

3. RESULTS

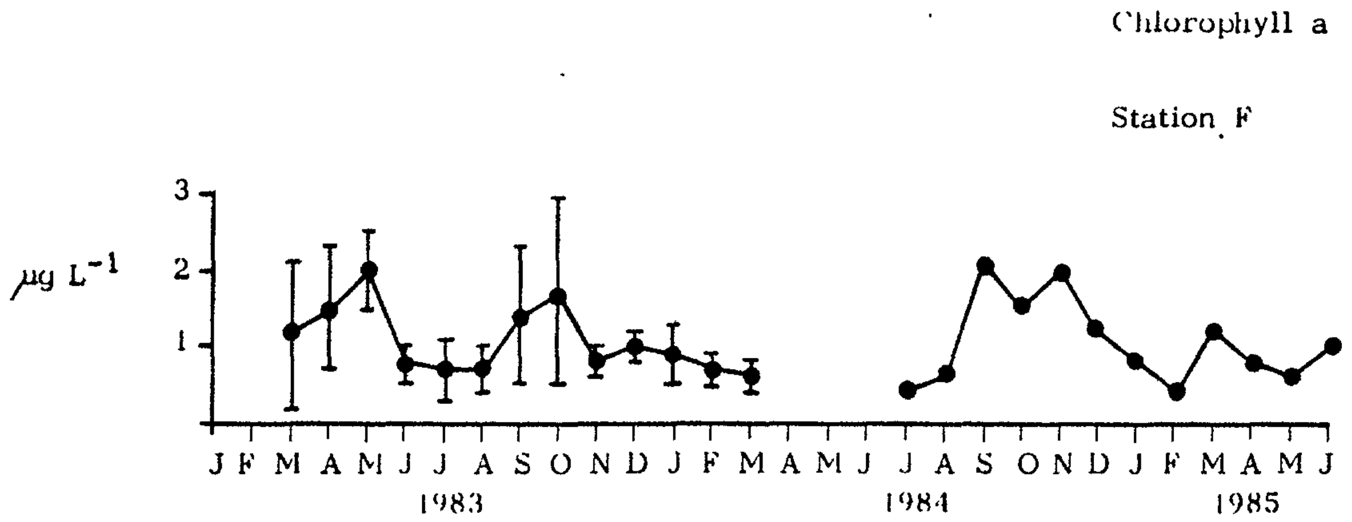
The phytoplankton of this area exhibited very intensive dynamics over the period of study. The chlorophyll a values showed high concentrations in the near-shore as well as in the off-shore waters (Fig. 1). Mean values are shown in Table I.

A statistical difference (t-test) was found between the off-shore chlorophyll biomass and that from the Bay of Koper ($p < .05$), which is considered as the most eutrophic bay in this area. Additionally a significantly increased biomass of annual chlorophyll a (t-test, $p < .05$) was found in off-shore waters in 1983 in comparison with 1982. The cell density of the open waters showed an even greater variability than the chlorophyll biomass. It reached 4 million cells l^{-1} in May 1983 and tended to be higher than the values recorded in the same area in previous years. Species successions occurred virtually every month in 1983. The weekly sampling at the off-shore station revealed that a phytoplankton bloom was developing month by month, always caused by different species (Table II).

The water column was populated by the same phytoplankton community (with the maximum abundance on the surface) throughout the year, except in summer. The differentiation of the phytoplankton in the column began in early summer and was preceded by the development of a vertical density gradient in the sea water (Table III).

A higher chlorophyll biomass was observed in the deeper layers throughout the summer (Fig. 2). Two prominent chlorophyll peaks were measured at 20 m depth: 3.15 µg l^{-1} and 6.93 µg l^{-1} in June and August, respectively. In June the dinoflagellate Prorocentrum micans co-dominated with microflagellates which bloomed in the upper layers. The large armoured dinoflagellates were in general more abundant in the bottom layer than above it. Ceratium fusus, C. furca and Gonyaulax polyedra were the most important species noted. In August during the other chlorophyll bottom maximum, an unusual bloom of the silicoflagellate Dictyocha speculum occurred (Fig. 3). This species is present only rarely in the Gulf in winter months. In August 1983, when the temperature of the bottom layer reached 18.48 °C, its concentrations were found to be 660,000 cells l^{-1}.

Lorenzen's index, that is the ratio of the integrated amount of phaeophytin a versus the integrated chlorophyll a concentration in the euphotic layer of the water column which gives a rough estimate of the rate of zooplankton grazing upon phytoplankton (Lorenzen, 1967), was lowest in August (Fig. 4), when the integrated chlorophyll biomass for the whole water column was at its maximum (42.05 mg m^{-2}). Thus a certain seasonal "excess" of phytoplankton biomass was established due to a low predation rate in that period. This unconsumed material sank towards the bottom, settled down and decomposed. Epifluorescent direct counts of heterotrophic bacteria in the Bay of Piran showed the highest values in August 1983 (Turk, 1984). The bottom oxygen demand from decaying organic matter both sedimented through the water column and of autochthonous benthic matter was sufficient to cause sulphate reduction, producing toxic H_2S (Faganeli et al., 1985) in some zones of the Gulf. On September 12, the first changes in the bottom fauna community were noted (Stachowitsch, 1984). Within a week virtually all organisms with the exception of some anemones and certain infauna forms had perished. Oxygen deficiency was the apparent cause of this catastrophe. At the end of September the pycnocline disappeared and the whole column became oxygenated.



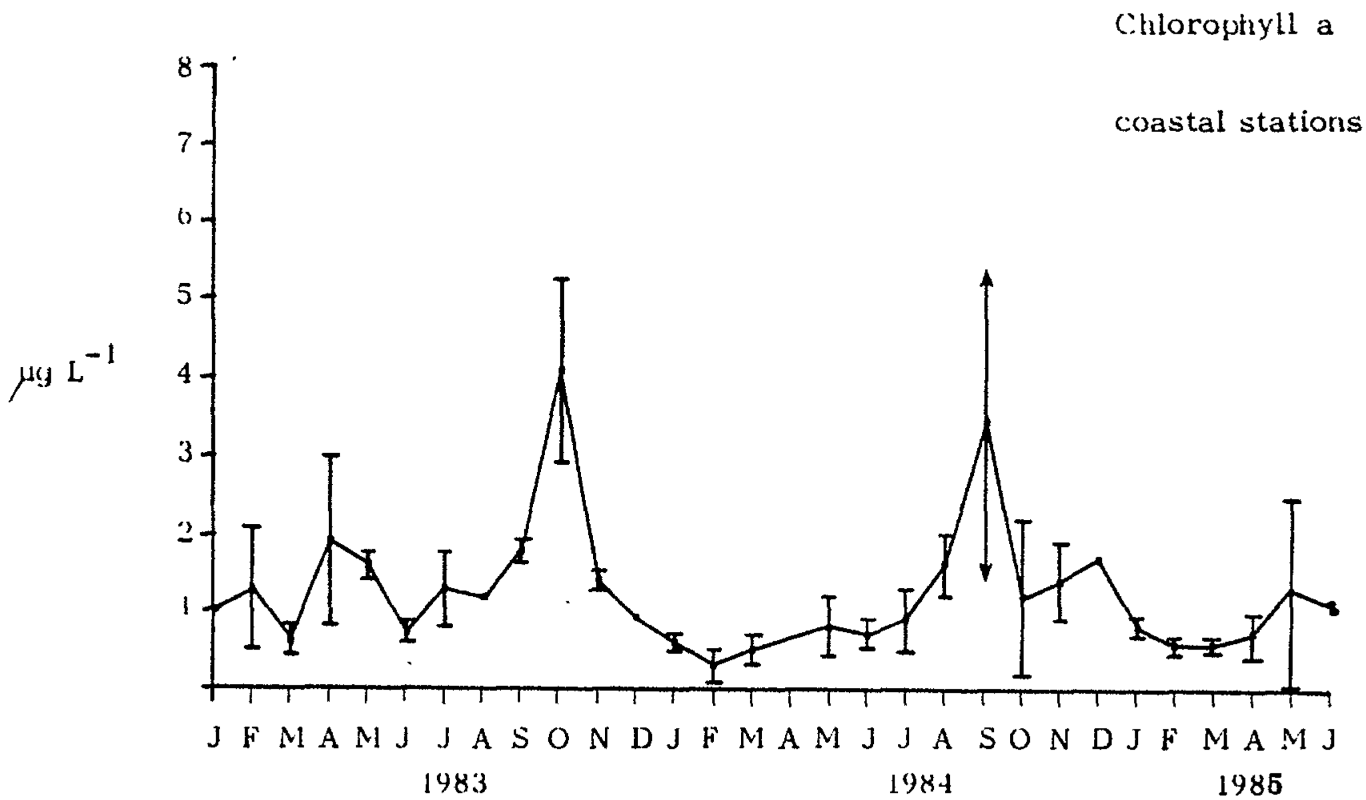


Fig. 1 Amount of chlorophyll a at offshore and coastal stations (surface) during the 1983-85 period

Table I

The mean chlorophyll *a* values ($\mu g\ L^{-1}$) in the period 1983-85 at the selected sites of the Gulf of Trieste on the surface (MV = mean value, SD = standard deviation, n = number of data, SE = standard error).

Station	MV	SD	n	SE
K-1	1.42	0.97	25	0.194
MA	1.27	1.6	28	0.3024
D	0.86	0.54	16	0.135
F	1.06	0.51	24	0.1041

Table II

Species causing blooms in 1983.

Species	Month	Species density x $10^3\ L^{-1}$	Total density x $10^3\ L^{-1}$
Prymnesium sp.	April	1,765	2,300
Chaetoceros simplex	May	2,552	4,320
Microflagellates	June	908	1,896
Meringosphaera triseta		670	
Cerataulina pelagica	July	794	1,724
Nitzschia delicatissima complex		390	
Dictyocha speculum	August	653	1,308 *
Rhizosolenia fragilissima	September	480	1,134
Microflagellates	October	940	1,745
Chaetoceros compressus		345	
Microflagellates	November	835	1,197
Leptocylindrus danicus		110	

* only in the bottom layer (20 m)

Table III

σ_t values and $\Delta \sigma_t$ (surface σ_t - bottom σ_t) in offshore waters of the Gulf of Trieste in 1983.

Date	24.5	1.6	9.6	15.6	23.6	30.6	6.7	14.7	20.7	2.8	10.8	18.8	24.8	31.8	14.9	20.9	29.9
Depth																	
Surface	23.98	23.77	27.37	25.46	26.09	25.88	24.03	24.22	22.63	20.86	24.04	23.57	23.16	23.32	25.08	25.20	25.57
5 m	25.23	25.29	27.89	26.26	26.16	25.87	25.24	26.04	25.00	21.58	24.22	25.29	24.19	25.07	25.31	24.98	25.68
10 m	25.83	27.29	27.89	27.72	27.12	26.98	24.58	26.37	26.39	21.47	25.74	24.52	25.44	25.80	25.27	25.14	25.62
20 m	28.62	28.07	28.16	27.83	28.27	28.60	27.47	27.92	27.02	26.67	27.08	27.00	26.76	27.19	24.95	25.28	26.17
$\Delta \sigma_t$	4.64	4.3	0.79	2.37	2.18	2.72	3.44	3.70	4.39	5.81	3.04	3.43	3.60	3.87	0.13	0.08	0.60

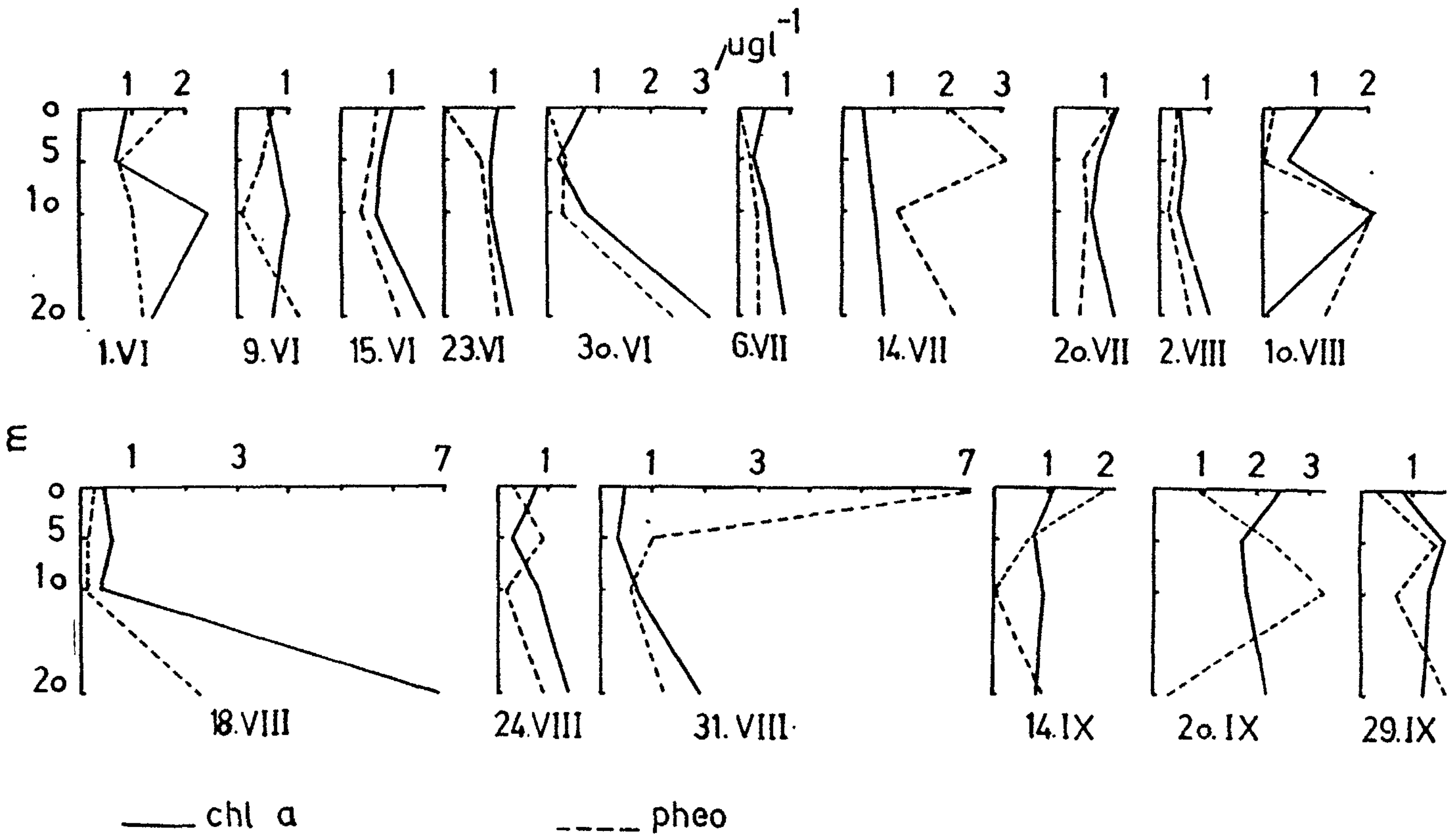


Fig. 2 Integrated algal pigments at offshore stations in summer 1983

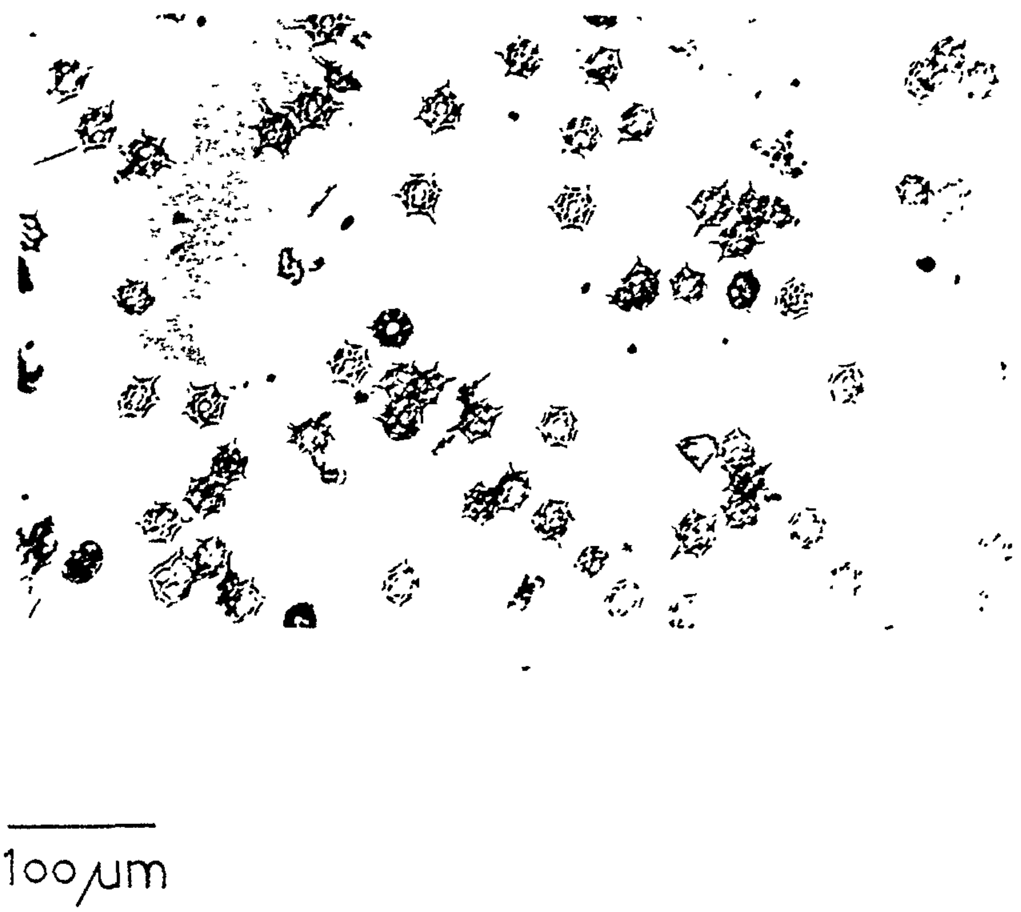


Fig. 3 Light micrograph of Dictyocha speculum blooming in summer 1983

In 1984 no anoxic conditions were observed in the Gulf. Again the phytoplankton exhibited monthly blooms rather than the classic spring and autumn blooms (Fig. 1). However, towards the end of September an irregular red tide occurred in the entire Gulf. The outbreak of the bloom caused discolouration of the seawater. Large green patches were seen offshore and were transported towards the shore and bays. Microscopic examination of the seawater samples revealed that, besides rare specimens of the diatom Chaetoceros affinis and of the dinoflagellates Protocentrum micans, P. triestinum, Gonyaulax polygramma, there was only one species flowering in excessive quantities (Fig. 5). This was a green unarmoured dinoflagellate, 26 um long, and 23 um wide. Scanning electron microscopy of the species (Fig. 6) revealed the fine external morphology of the body which resembled that of Gyrodinium pavillardi (Chatton, 1952).

The bloom was maintained for the whole month at the surface and afterwards the dinoflagellate was observed at 10 m depth for another month. At some points near the shore the phytoplankton biomass reached 360 $\mu g\ l^{-1}$ of chlorophyll a and 120 million cells per litre. This event was preceded by an abundant freshwater runoff that cooled the whole water column of the Gulf. Water temperature decreased by 3-4 ^{o}C compared with the previous month. Salinity decreased by 1-2 $^{o}/oo$ even in the bottom layer. Local rivers' discharges brought into the Gulf large quantities of nutrients, especially nitrates. Their concentration increased tenfold in some areas (Figs. 7 and 8).

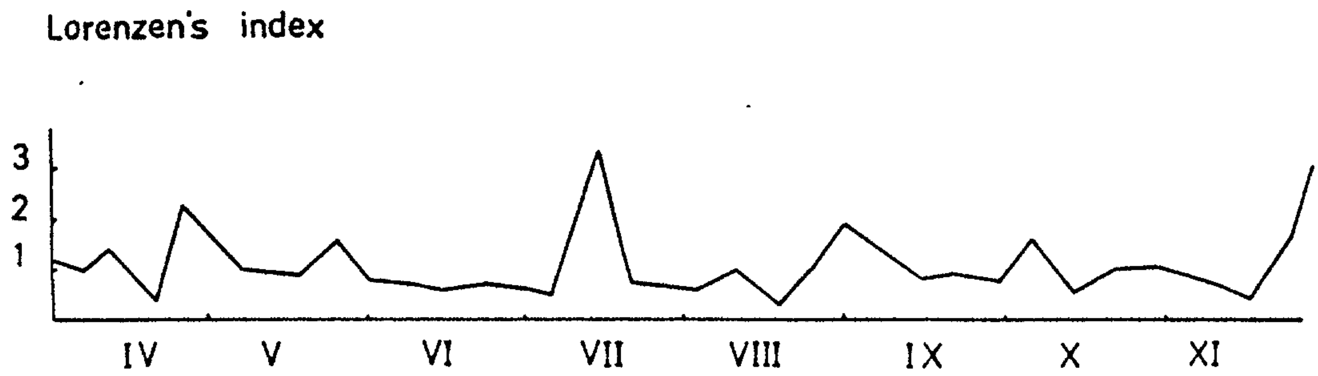


Fig. 4 Lorenzen's index at offshore stations in 1983

Bloom-forming dinoflagellates are often associated with the production of toxins and consequently may well cause large-scale mortality of fish and invertebrates (Cullen et al., 1982), as well as secondary poisoning of humans, if they eat organisms from the bloom-affected area (Oshima and Yasumoto, 1979). Up to now less than 20 dinoflagellate species are known to produce toxins (Steidinger, 1979) and all of these are photosynthetic. The green dinoflagellate flourishing in the Gulf during the study was an autotrophic species; this could be concluded from the morphological evidence of the cells and from the high chlorophyll data.

In the beginning of October some cases of gastro-intestinal disorders (diarrhoea, vomiting, sickness) were registered, concerning people who had consumed mussels grown in the bloom area. In order to assess the possible presence of dinoflagellate toxins in mussels (*Mytilus galloprovincialis*), mouse bio-assays were carried out (Fanuko et al., 1984). The mussel samples and the seawater containing the dinoflagellates were analysed. Then fat-soluble and water-soluble toxins were extracted from the mussel flesh, as well as fat-soluble toxins from the seawater. The toxicity of three extracts was tested on albino mice, strain NIH (Institute Rudjer Boskovic, Zagreb), 20-22 g weight. The mouse assay was carried out by intraperitoneal injection of a serially diluted solution of samples with a maximum amount of 75.6 mg dry weight of fat-soluble mussel extract, 57.5 mg DW of fat-soluble seawater extract and 25 mg DW butanol extract from the mussels. After 24 hours none of the tested mice showed any symptoms of intoxication. The potential quantity of toxins present was in any case below the concentration detectable by this method (McFarren et al., 1965).

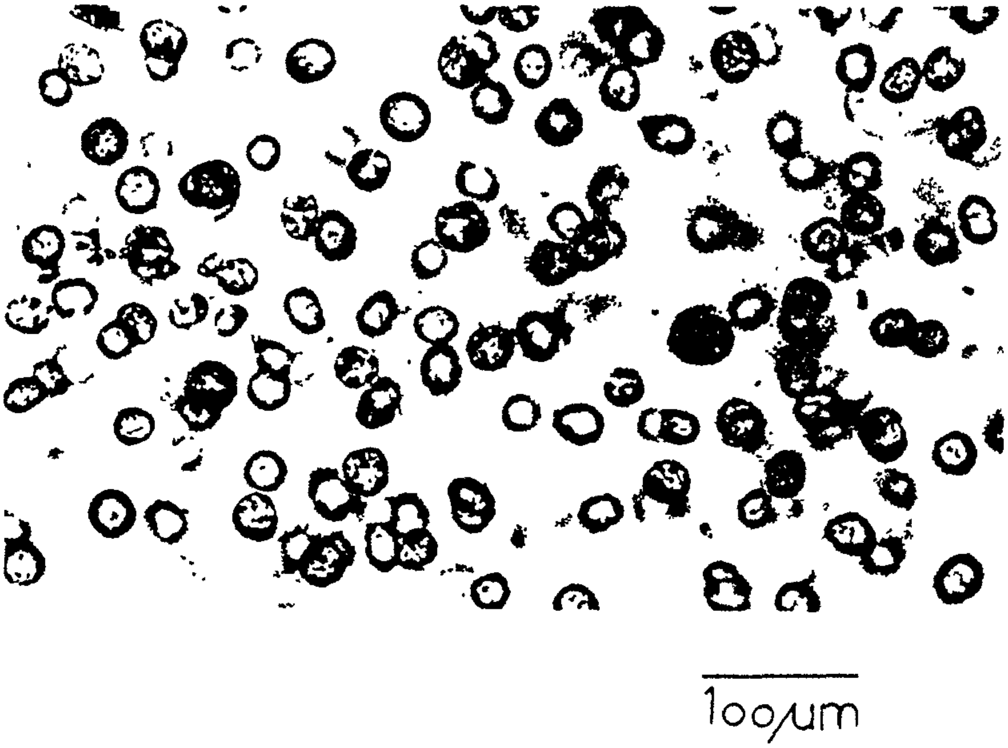


Fig. 5   Light micrograph of a red-tide dinoflagellate

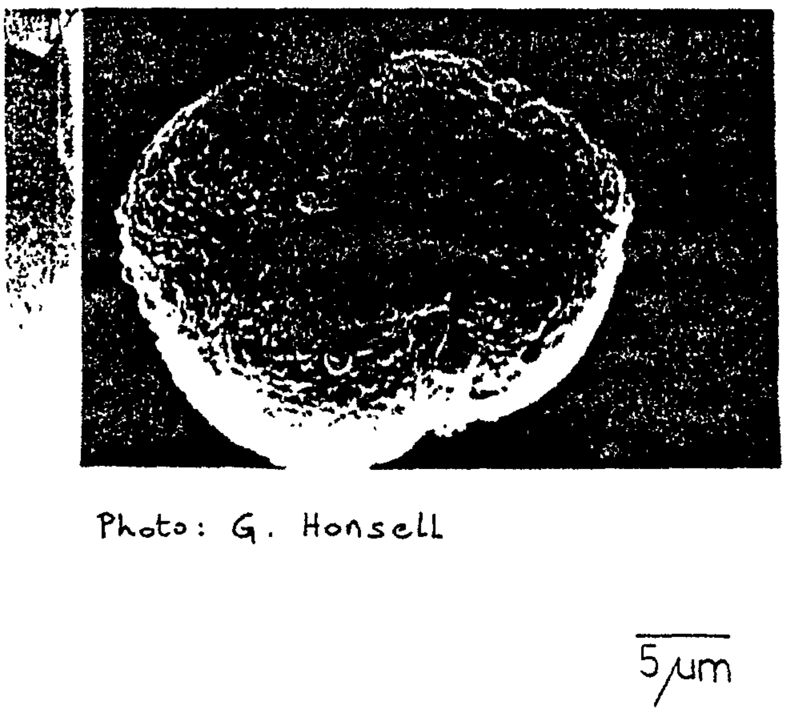


Photo: G. Honsell

Fig. 6   SEM micrograph of a red-tide dinoflagellate

Coastal stations

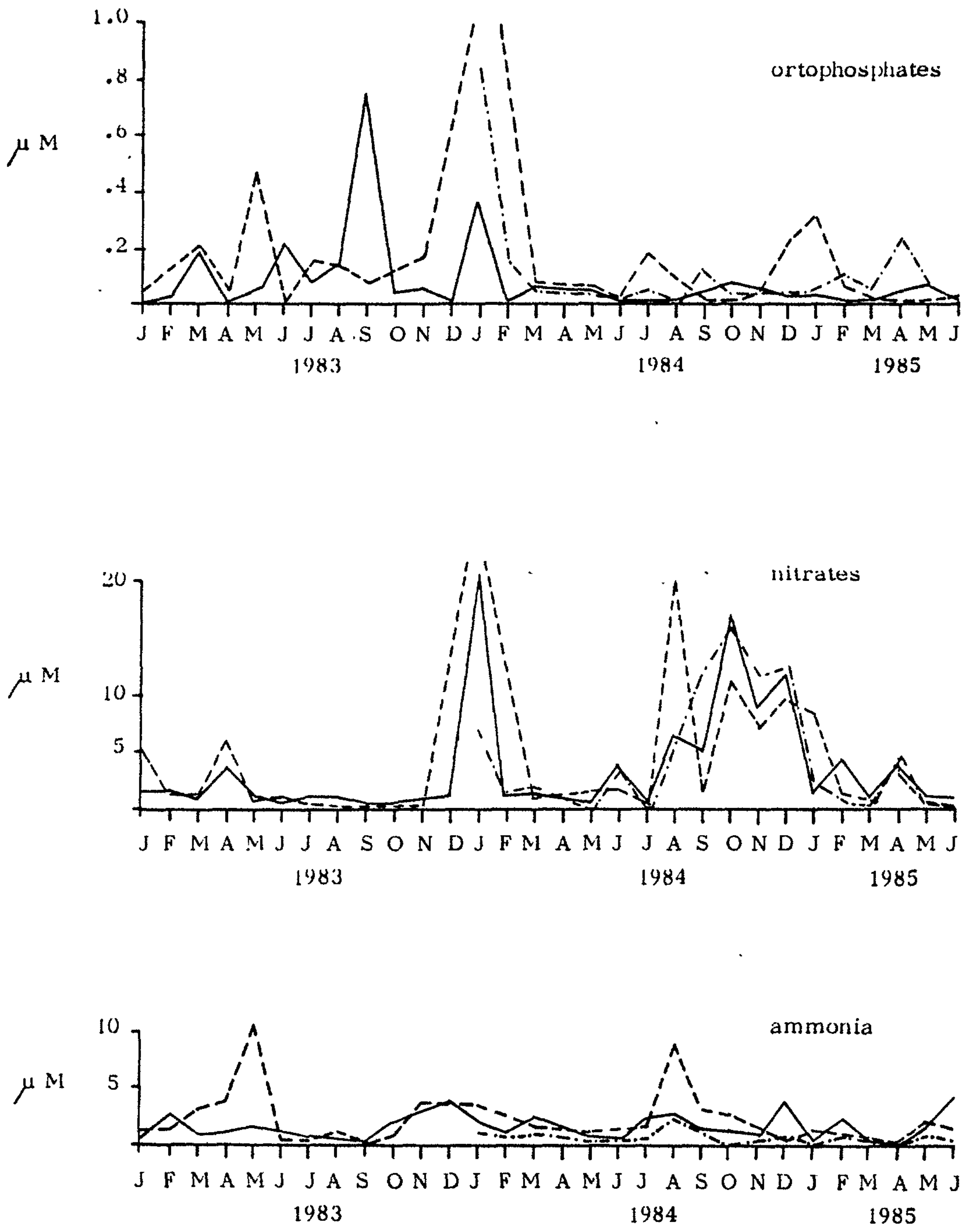


Fig. 7 Nutritive salts at coastal stations (surface)
______MA; _ _ _K-1; _·_·_D

Station F

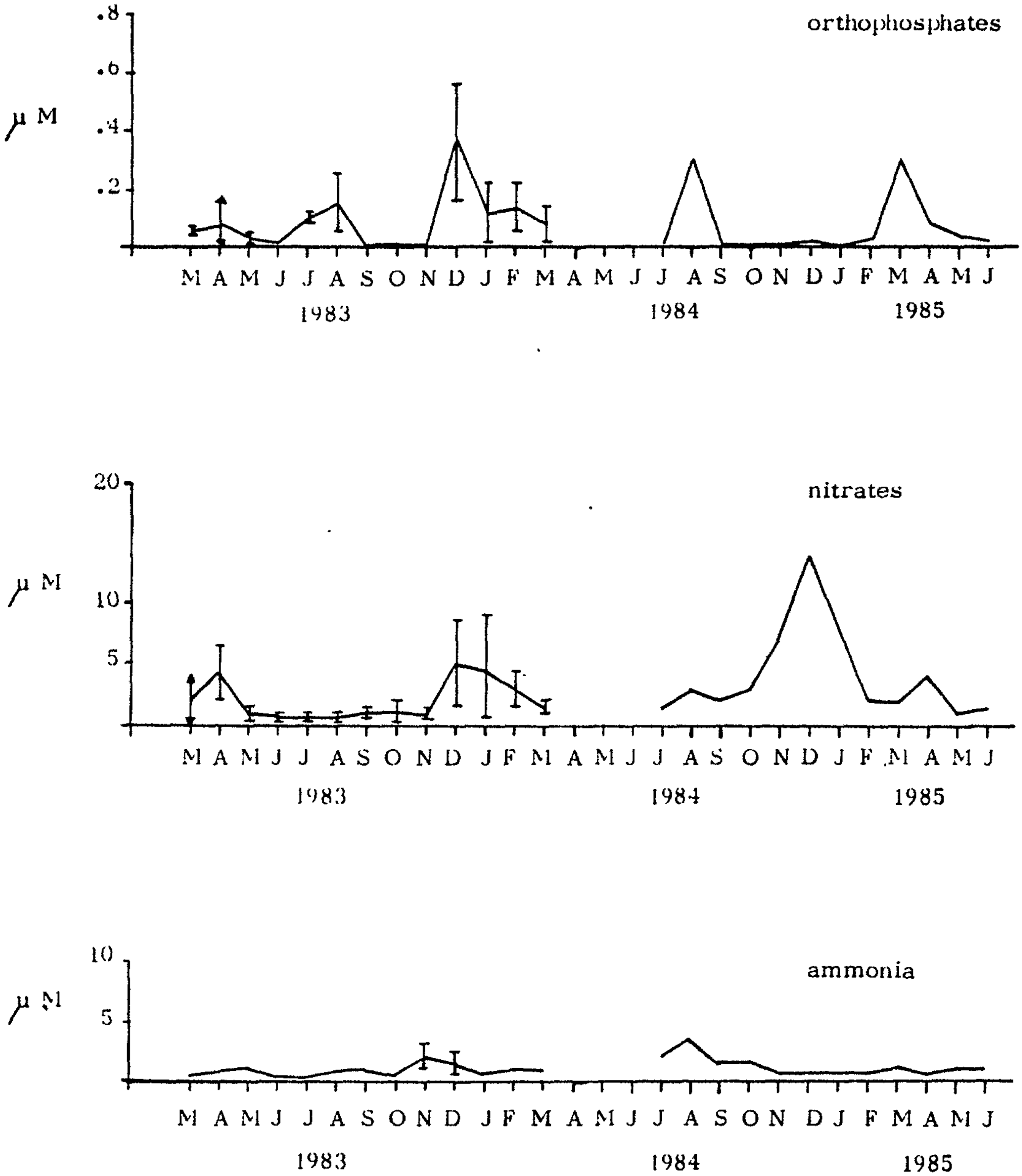


Fig. 8 Nutritive salts at offshore stations (surface)

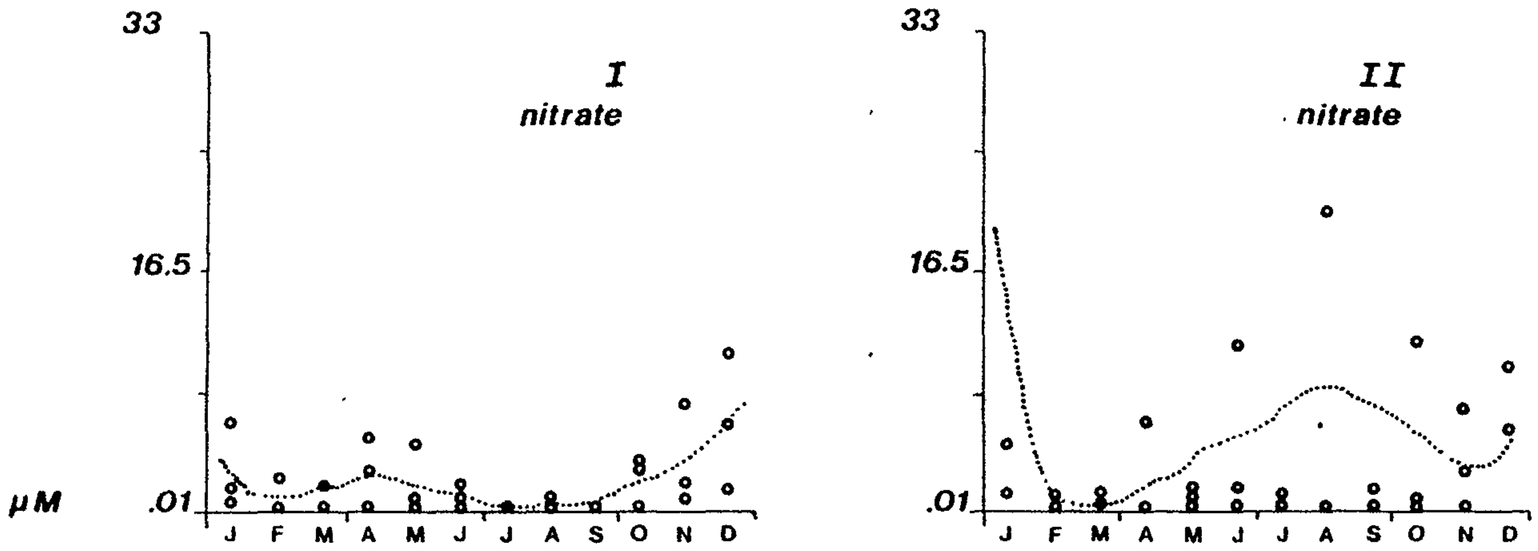
4. DISCUSSION

The Gulf of Trieste is subject, like all shallow marine ecosystems (Smayda, 1980), to numerous fluctuations of abiotic and biotic factors. Phytoplankton per se shows great changes even in the oligotrophic deep waters of the open Adriatic sea, showing a 60% variation in productivity over a nine-year average (Pucher-Petkovic, 1975). In our short-term period of investigation (1983-84) we could not provide any statistical evidence of increasing eutrophication in terms of either nutrients (Figs. 7 and 8) or algal biomass (Fig. 1). However, when the six-year data were considered, certain trends of increase emerged. Nutrients and chlorophyll a data from the Bay of Koper were divided into two groups (1979-1981 and 1982-1984 data) and compared. The results showed that although the nutrients did not increase significantly in the second period (Figs. 9 and 10), the chlorophyll biomass did (Fig. 11). Furthermore, the chlorophyll biomass changed its annual dynamics pattern (Fanuko and Justic, 1986). In autumn 1984 the monospecific bloom of a dinoflagellate held back the diatom flowering, normally occurring in this area in October (Fanuko, 1981).

It is assumed that the rich pelagic system of the Gulf influences the benthic community. The anoxic bottom conditions that occur every few years in this area (Fedra et al., 1976; Vukovic et al., 1984) and the consequent mass mortality of the bottom fauna (Stachowitsch, 1984), are associated with the metabolism of the adjoining pelagic system. A high algal crop from the upper layers sinking or actively swimming towards the bottom, the reduced grazing pressure and the active bacterial decomposition, the extraordinary bloom of silicoflagellates at the bottom layers, as well as the special hydrological summer regime of the Gulf, contributed to the oxygen depletion and H_2S formation. Similar conditions, where phytoplankton blooms are linked to bottom anoxia, have been registered in other shallow localities all over the world; the coastal waters of Florida (Steidinger, 1971), New York Bight (Mahoney and Steimle, 1979) and North European waters (Tangen, 1977; Boalch, 1979; Gillbricht, 1983). In all cases the organisms blooming are phytoflagellates whose respiration is more intense due to their mobility (Parsons et al., 1977) and is high enough to deplete the dissolved O_2 during the night (Smayda and Packard, 1979).

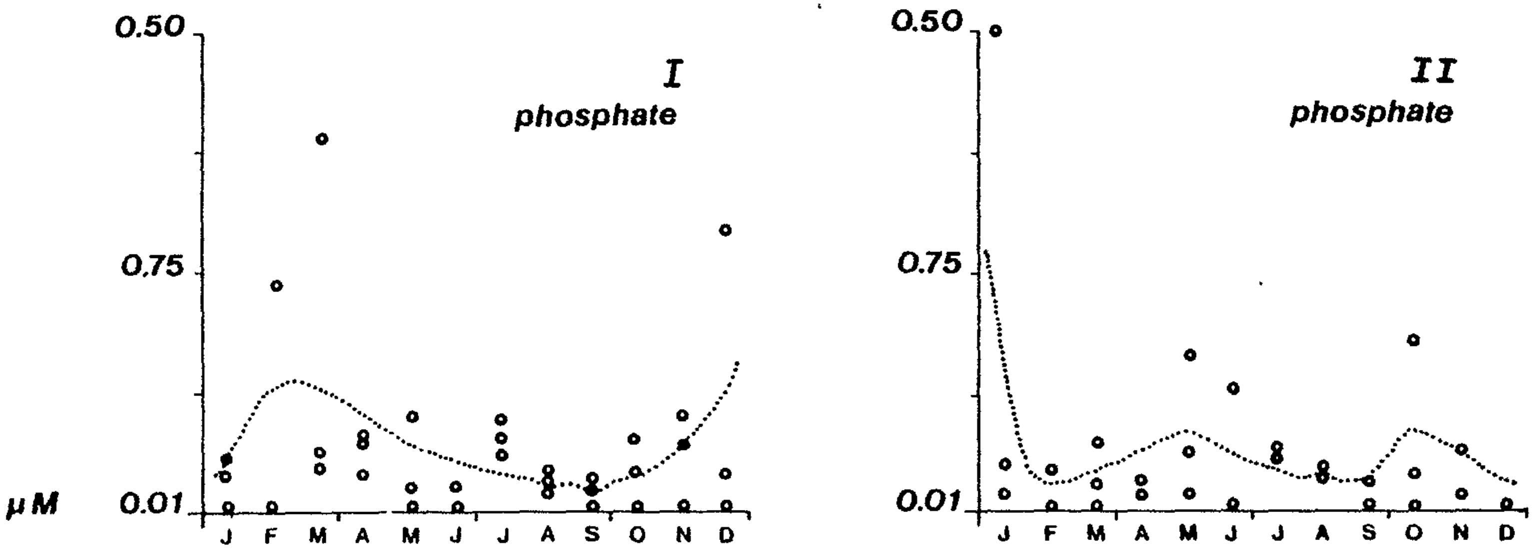
5. CONCLUSIONS

The significant increase of phytoplankton crop in some zones of the Gulf of Trieste and the irregular blooms of phytoflagellates that are associated either with bloom anoxia and concomitant mass mortality of benthic fauna or with red tide conditions confirms the fact that this area should be regarded as sensitive (Stachowitsch, 1984).



I 3-year mean in the period of 1979-81.   II 3-year mean in the period of 1982-84.

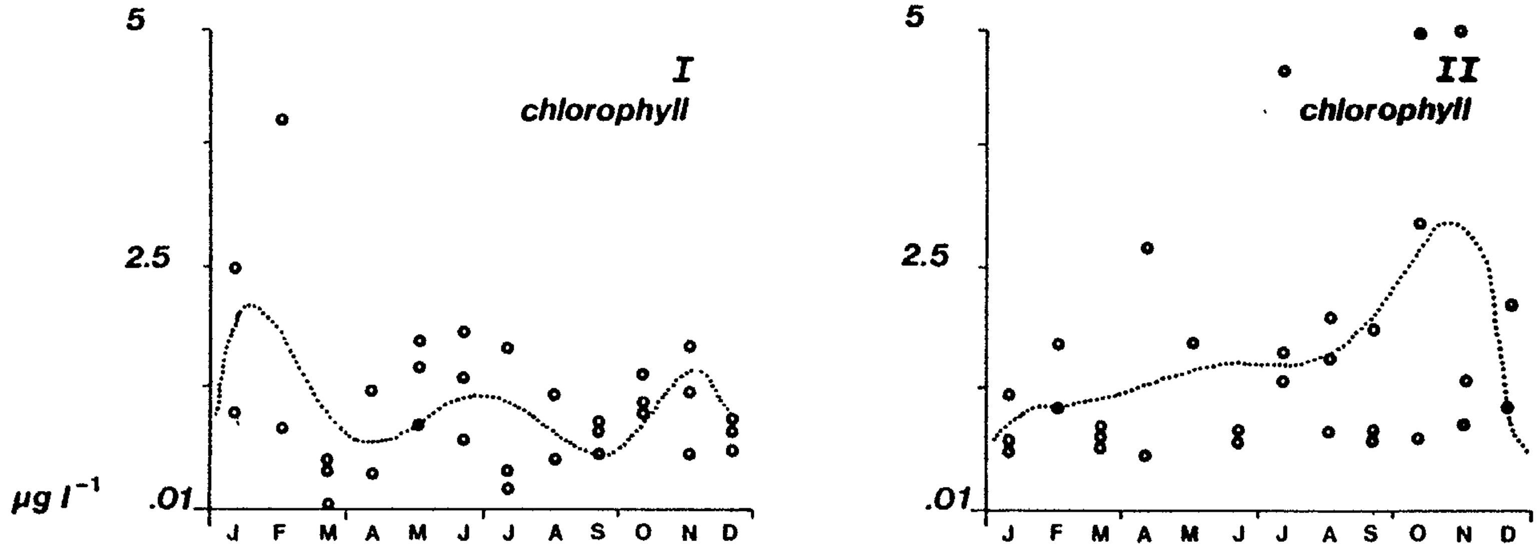
Fig. 9 Concentrations of nitrates in the Gulf of Trieste (station K-1/0 m)



I 3-year mean in the period of 1979-81.

II 3-year mean in the period of 1982-84.

Fig. 10 Concentrations of orthophosphates in the Gulf of Trieste (station K-1/0 m)



I 3-year mean in the period of 1979-81.

II 3-year mean in the period of 1982-84.

Fig. 11 Chlorophyll a biomass in the Gulf of Trieste (station K-1/0 m)

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EUTROPHISATION ET FLORAISON CONCOMITANTE DU PLANCTON : LAC DE TUNIS

par

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A B S T R A C T

Le present travail constitue une contribution à l'étude de l'évolution du peuplement planctonique caracteristique d'un ecosystème lagunaire lourdement affecté par l'eutrophisation et subissant une évolution imposée par l'homme; il y a lieu donc, d'un schéma déscriptif de l'impact des travaux d'amenagement sur l'écosystème lagunaire et d'une étude des eaux décolorées ménée conjointment à celle du phytoplancton et des mecanismes d'eutrophisation.

1. INTRODUCTION

Dans le cadre de ses activités sur l'eutrophisation des systèmes lagunaires et zones côtières marines, l'INSTOP mène depuis 1973, des recherches et des études, en matière de pollution marine par les substances organiques et leurs incidences sur les peuplements phytoplanctoniques et benthiques dans le lac de Tunis.

Une partie de ces études conduites sur le thème "Eutrophisation et floraison concomitante du plancton", a été realisée, en partie, avec le concours du PNUE/FAO; cette étude constitue une contribution aux projets pilotes d'étude et de surveillance continue de la pollution entreprise dans le cadre général des activités du Plan d'Action pour la Mediterranée (MEDPOL, phases I et II).

Situé au sud du 37ème parallèle, le lac de Tunis est une lagune côtière mediterranéenne eutrophe, d'origine marine; il s'étend depuis la ville de Tunis à l'ouest jusqu'au niveau du cordon littoral côtier à l'est. Avec une superficie de 48,6 km^2 et une profondeur moyenne de 1m, le lac de Tunis constitue un milieu presque ferme ne communiquant que faiblement avec la mer. Un canal de navigation d'une longueur supérieure à 10 km, d'une largeur de 200m et 6m de profondeur relie le port de Tunis à la Mediterranée; ce canal a été creusé vers 1985 et les déblais provenant du dragage séparent la lagune en deux bassins localement designés lac nord et lac sud. Le lac nord a une superficie de 29,5 km^2, le lac sud, 12,7 km^2; ils communiquent directement avec la mer respectivement, par le canal de Khereddine et par le canal de Rades.

A partir de l'année 1978, le lac nord de Tunis a été l'objet de plusieurs travaux, dont certains sont realisés dans le cadre du programme de son assainissement:

- construction d'une digue divisant le lac nord en deux parties, ouest (zone recevant toutes les eaux usées urbaines, de 7 km^2 de superficie) et,

- est (zone très riche en faune et flore, restant sous influence marine);

- dragage du sediment de fond pour approfondir, en vue de leur aération certaines zones très peu profondes gênant la navigation.

- installation de trois vannes au niveau de trois canaux de communication avec le canal de navigation, dits, Tunis marine, pont Chekly et Khereddine; ces vannes qui ne sont en fait que des portes metalliques ouvrables à volonté, ont été conçues pour orienter la circulation des courants dans une direction à sens unique schematisé par une entrée d'eau marine par le canal de Khereddine et une sortie d'eau lagunaire par Tunis marine et pont Chekly.

Par ailleurs, d'un canal longeant l'autoroute Tunis-Aeroport, pour véhiculer les eaux pluviales et provisoirement les eaux urbaines de la ville de Tunis vers le canal de navigation, donc, l'arrêt, depuis 1980, des rejets d'eaux usées dans la partie ouest du lac nord de Tunis, a eu des incidences plus ou moins directes sur la qualité des eaux et les biocenoses dans le nord et plus particulièrement, sur celles dans le canal de navigation et le lac sud de Tunis.

Afin d'évaluer l'impact de ces travaux d'aménagement sur l'ecosystème lagunaire, il a été procédé à une étude comparative de l'état de l'eutrophisation dans chacun des lacs, nord et sud et dans le canal de navigation, et cela, pendant les périodes se situant avant et au cours de l'assainissement (le début);

Par ailleurs, une étude des eaux décolorées menée conjointement à celle du phytoplancton et de l'eutrophisation constitue le second volet de ce rapport.

2. METHODES

Les stations sont choisies, en tenant compte des points de rejets des eaux usées, de la profondeur et de la biocenose dans certaines zones où l'état de la pollution organique diffère d'une zone à l'autre (Fig. 1). Les paramètres analysés et mentionnés dans ce rapport sont les suivants:

- la température de l'eau, prelevée à l'aide d'un thermomètre gradué au $^{1}/10$, la turbidité, le pH et la salinité sont respectivement determinés par l'emploi d'un disque de Secchi, d'un pH-mètre et d'un salinomètre;

- l'oxygène dissous est dosé par la méthode de Winkler, les sels nutritifs sont dosés par la méthode spectrophotométrique, utilisant pour les nitrites et les nitrates les méthodes énoncées dans FAO (1975) et pour les phosphates inorganiques, celle de Murphy et Riley (1962);

- l'étude taxonomique du plancton est faite, en partie par l'équipe du Pr. Aubert du CERBOM, à Nice, et l'indice de richesse phytoplanctonique (biomasse) est estimée par le dosage des pigments chlorophylliens selon la téchnique colorimètrique comme énoncée dans Strickland et Parsons (1968).

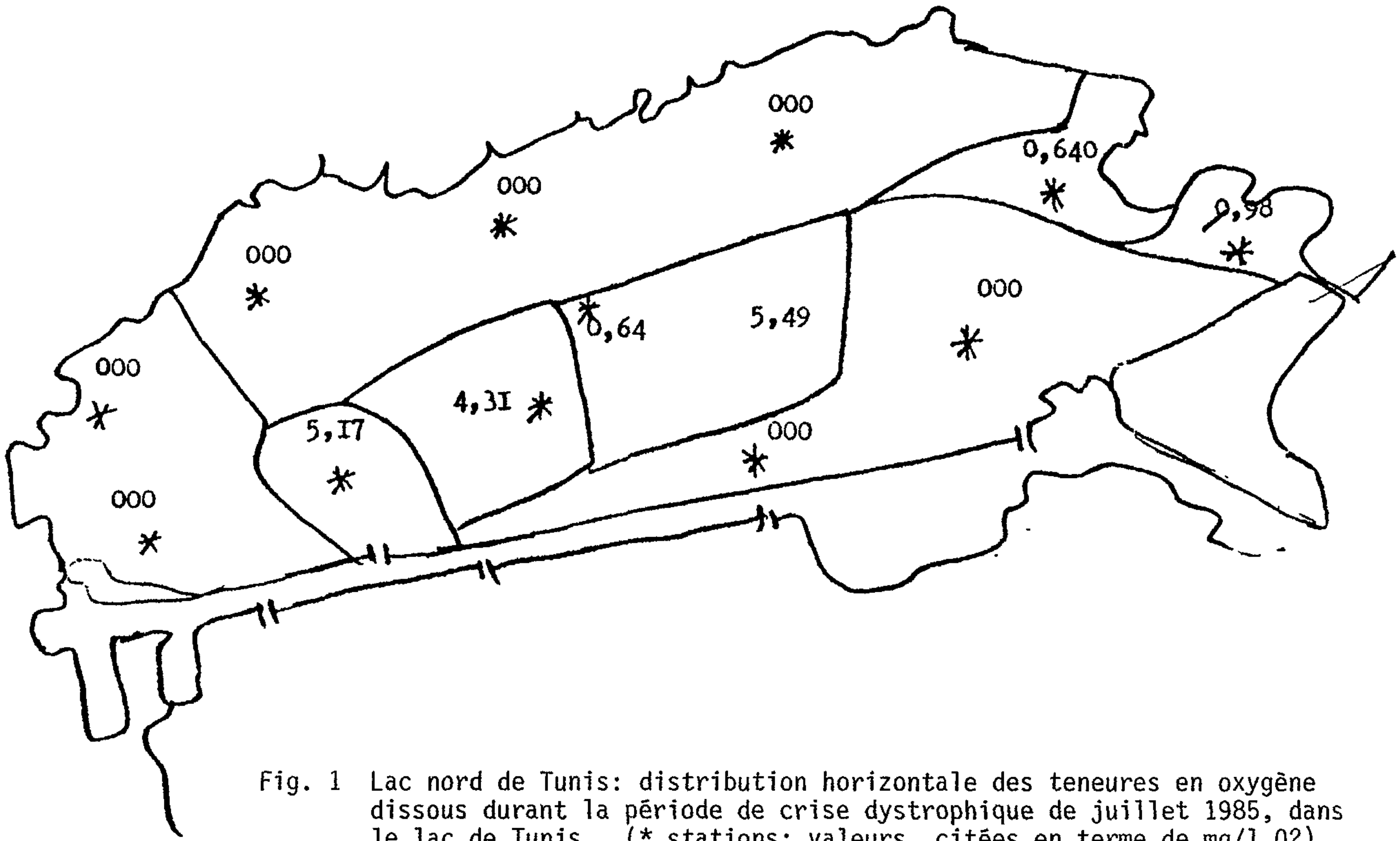

Fig. 1 Lac nord de Tunis: distribution horizontale des teneures en oxygêne dissous durant la pèriode de crise dystrophique de juillet 1985, dans le lac de Tunis. (* stations; valeurs, citées en terme de mg/l 02)

3. RESULTATS ET DISCUSSION

3.1 Eutrophisation comparée: periodes, avant et début assainissement

3.1.1 Lac nord

La construction de la digue séparant le lac nord de Tunis en deux bassins, a permis de noter un changement parfois très brutal de la qualité des eaux de chacun de ces deux ecosystèmes nouvellement crées de part et d'autre de cette digue, et dont reçoit la totalité des eaux usées urbaines (il sera dénommé, le bassin ouest), l'autre, reste sous l'influence marine (il sera dénommé, le bassin est). En effet, les teneurs des sels nutritifs, déjà élevées, avant la construction de la digue, le sont encore plus, après; dans le bassin ouest, les nitrites montrent, en septembre 1979 et en juin 1980 les valeurs respectives suivantes, 2,04 ug-at l^{-1} et 6,19 ug-at l^{-1}, valeurs qui sont 3 à 10 fois plus élevées que celles enregistrées en juillet 1976 (0,60 ug-at l^{-1}); les nitrates et les phosphates rappellent, en terme de concentration, celles des nitrites; leurs teneurs respectives sont (5,7 à 6,2 ug-at l^{-1}) et (0,7 à 5,1 ug-at l^{-1}), enregistrées respectivement en septembre 1979, soit 2 à 7 fois plus élevées que celles notées en juillet 1976 (Baier *et al.*, 1977).

Contrairement à la zone ouest, la zone est montre des valeurs relativement faibles, avec toutefois une amplitude plus élevée, pour les nitrites (0,01 à 0,58 ug-at l^{-1}) et pour les phosphates (0,25 à 0,85 ug-at l^{-1}); les teneurs en nitrates, par contre, variant, de 1,7 à 4,1 ug-at l^{-1}, notées en septembre 1979 sont deux fois plus élevées que celles de juillet 1976, (Baier *et al.*, 1977).

Suite à l'ouverture partielle de la digue, au mois de juin 1980, les échanges d'eaux se faisant dans les directions ouest-est, et reciproquement, donc, riches en matières fertilisantes (zone ouest) et moins riches (côté est), ont pour conséquences, une diminution légère des teneurs des éléments azotés, mais une élevation de celles des phosphates inorganiques dans les deux bassins, et plus particulièrement dans la zone est, où les concentrations rappellent la situation qui précède la construction de la digue (0,30 à 2,35 ug-at l^{-1} P-P04), (Belkhir et Hadj Ali Salem, 1982).

En ce qui concerne, l'oxygène dissous, son dosage a permis de noter des concentrations variant de 0,22 à 3,83 mg l^{-1} dans la zone ouest et, de 0,69 à 3,34 mg l^{-1} dans la zone est; et cela, au mois de septembre 1979 (Belkhir et Hadj Ali Salem, 1981); comparées aux teneurs d'oxygène enregistrées au mois de juillet 1976, on remarque que les concentrations précitées sont 4 fois moins élevées que après la construction de la digue, ceci est vrai, aussi bien pour la zone ouest que celle située à l'est, ce qui montre que malgré l'arrêt des rejets d'eaux usées dans la zone est, cette dernière continue à avoir les symptomes d'un milieu aussi confine que celui recevant des eaux domestiques.

En juin 1980, suite à l'ouverture partielle de la digue, les échanges quoique restreints des eaux, entre les deux bassins, semblent être bénefiques pour les deux systèmes situés de part et d'autre de la digue, et on assiste à une aération de ces deux zones: une croissance des teneurs d'oxygène dissous allant de 2,3 à 9,05 mg l^{-1} dans la zone est, et de 8,80 à 11,56 mg l^{-1} dans la zone ouest.

La salinité est le facteur le plus affecté à la suite de l'installation de la digue; si dans la zone ouest la salinité a diminué de 6 fois sa valeur enregistrée avant la digue, en juillet 1976 (salinité, variant de 36,6% à 42,8%) elle, par contre, augmente legèrement, dans la partie est, située sous influence marine, atteignant 42.1% et 44.2% en 1980, l'ouverture partielle de la digue a permis de retablir un certain equilibre dans la salure de chacune de deux masses d'eaux situées d'part et d'autre de la digue: la pénétration des eaux hypersalines dans la zone ouest, a entraîné une élévation de la salinité atteignant 37,6%, soit 5 fois plus que la salinité notée en 1979 (après la digue), par contre la zone est dont les se sont melangées aux eaux hyposalines de l'ouest, montre une salinité moins élevée (42,6%).

Par ailleurs, le phytoplancton qui a toujours montré une certaine homogeneité de point de vue biomasse et qualité, pendant une période donnée dans pratiquement tout le lac, a été largement affecté, par l'installation de la digue; en 1979, le phytoplancton a montré une diminution notable; sa biomasse a diminué de 2 à 13 fois sa biomasse notée en juillet 1976; et cela aussi bien dans la zone ouest que l'est. De point de vue qualitative, la zone recevant les eaux usées urbaines, a connu une très grande proliferation des algues cyanophycées: les spirulines, alors que la zone sous influence marine a connu une croissance parfois très intense des diatomées en période de faibles éclairements avec une dominance de dinoflagellés du genre Prorocentrum qui rendent très foncées à marron foncé les eaux de la zone est, pendant les périodes de fortes insolations.

Les variations des paramètres physico-chimiques et biologiques, qui illustrent bien un état de déstabilisation de la balance écologique dans le système lagunaire, ne sont pas dus seulement, à la construction de la digue qui a engendré l'établissement de deux milieux absolument différents sur tous les plans, mais aussi, à l'installation des vannes et surtout à la pratique des travaux de dragage, qui ont contribué à l'aggravement de la situation; donc les vannes qui sont installées au niveau des pêcheries ont eu pour conséquences nefastes, une restriction de la circulation des eaux dans le lac, donc une décélération des échanges hydriques entre le lac, la mer, le canal de navigation d'où l'obtention de deux milieux à eaux pratiquement stagnantes; l'étude courantologique pendant les périodes de stagnation des eaux, menée conjointement avec celle de la qualité physico-chimique et biologique montre que le lac est très confine; cet état de confinement est très avancé, par rapport aux années précédantes il est caracterisé par l'apparition avancée des eaux laiteuses anaerobies tuant, précocemment de très grandes quantités de poissons dans la partie est.

A l'effet de vannes s'ajoute celui du dragage entrepris en 1979-1980, d'une façon irréflechie, à cette période; ce dragage a, apparemment, une double répercussion: l'une immediate, definie par la libération puis la dissolution après mise en suspension, à chaque coup de benne, d'énormes quantités de matières fertilisantes qui, avec les sédiments remués du fond rendent le milieu très turbide; le second effet que peut avoir ce dragage, est ressenti plus tard en constatant une modification dans la biocenose dans la qualité des eaux et plus particulièrement dans l'apparition précoce des eaux laiteuses anoxiques.

Afin d'illustrer l'effet du dragage dans l'enrichissement des eaux en sels nutritifs et les repercussions sur les concentrations en oxygène dissous, nous avons prélevé en vue de leurs analyses des échantillons d'eaux, dans deux zones, l'une affectée par le dragage et l'autre non perturbée par ce dernier; dans la zone de dragage, nous avons constaté que les teneurs en oxygène dissous sont deux à trois moins élevées que celles trouvées dans la zone non draguée, et, respectivement, les nitrates sont 26 fois plus élevées, les nitrites le sont encore plus, soit 36 fois de plus, les phosphates rappellent celles des nitrates (25 fois plus), le pH est de 7,8, il est de 8,9 dans la zone non draguée, le disque de Secchi disparait à 28 cm sur une profondeur de 100 cm, alors que la zone éloignée du dragage laisse voir un eau prèsque limpide, donc à fond visible.

3.1.2 Lac sud et canal de navigation

Si le canal de navigation constitue actuellement, dans sa partie proche de la ville de Tunis (port de Tunis), le milieu récepteur de toutes les eaux usées et pluviales de la ville de Tunis et ses banlieues (debit variant entre 500m3 j^{-1} en periode d'étiage et 60.000 m3 j^{-1} en période de crue), le lac sud a toujours constitué, dans sa partie ouest, un lieu de rassemblement de toutes ces eaux usées urbaines qui, étant rejetées avant 1982 dans le lac nord, s'écoulent dans le canal de navigation puis penètrent par les canaux de communication dans le lac sud. L'installation dans le lac nord et le détournement des eaux usées pluviales et urbaines dans le canal de navigation ont entrainé l'extension du lieu de rassemblement de ces eaux sur presque toute la superficie du lac sud. Ainsi, les eaux du lac sud et du canal de navigation prennent des caractéristiques physico-chimiques et biologiques très avoisinantes, avec une variation d'amplitude généralement très faible au cours du temps et dans l'espace.

Etant donné une profondeur relativement élevée (une profondeur moyenne de 7m) dans le canal de navigation, il a été noté une stratification nette de la température et de la salinité, avec la superposition de couches: l'une mince superficielle du côté mer devenant plus épaisse et gagnant de volume au depens de la couche profonde au fur et à mésure qu'on s'approche de la ville de Tunis ou se rejettent les eaux usées domestiques. Au printemps, la couche d'eau superficielle associe les fortes temperatures aux faibles valeurs de la salinité, et celles de fond, les plus faibles températures aux plus fortes salinités. L'été, la description devient très simple et se limite à deux couches superposées dont l'une, en surface, jouit des valeurs de températures et de salinité plus faibles et celle en profondeur, les plus fortes.

En raison de la faible profondeur, cette stratification n'existe pas dans le lac sud; la salinité est relativement plus faible (33,6‰ à 36‰), les nitrites et les nitrates sont généralement faibles (de 0,5 à 4,11 ug-at l^{-1}), les phosphates, sont par contre très élevés, atteignant 18 à 34,6 ug-at l^{-1}; le maximum observé étant de 51,7 ug-at l^{-1} P-P04; le phytoplancton montre une biomasse très élevée allant de 38 à 407 mg m^{-3} de chla, avec une dominance sur le plan qualitatif, en dinoflagellés (Peridinium et Prorocentrum); Dans le canal de navigation, si la biomasse reste très élevée (120 à 188 mg m^{-3} de chla), le phytoplancton n'est pas homogène dans tout le canal; avec prédominance en diatomées dans la zone est (côté mer) devenant pauvre en diatomées qui sont remplacées par les cyanophycées au fur et à mesure qu'on s'approche de la ville de Tunis (zone de rejets d'eaux usées) les nitrites, les nitrates et les phosphates rappellent les teneurs enregistrées dans le lac sud et caracteristiques d'une eau brunâtre à vert marron foncé très chargée en sels nutritifs.

3.2 Eaux décolorées et phytoplancton

L'examen de la lagune de Tunis montre que les phenomènes d'eutrophisation se caracterisent par des variations de coloration des eaux qui peuvent devenir vertes, brunes, blanches ou rouges; ces colorations peuvent se succéder dans le temps mais elles peuvent se manifester simultanément mais séparement en certaines zones du lac (Fig. 2).

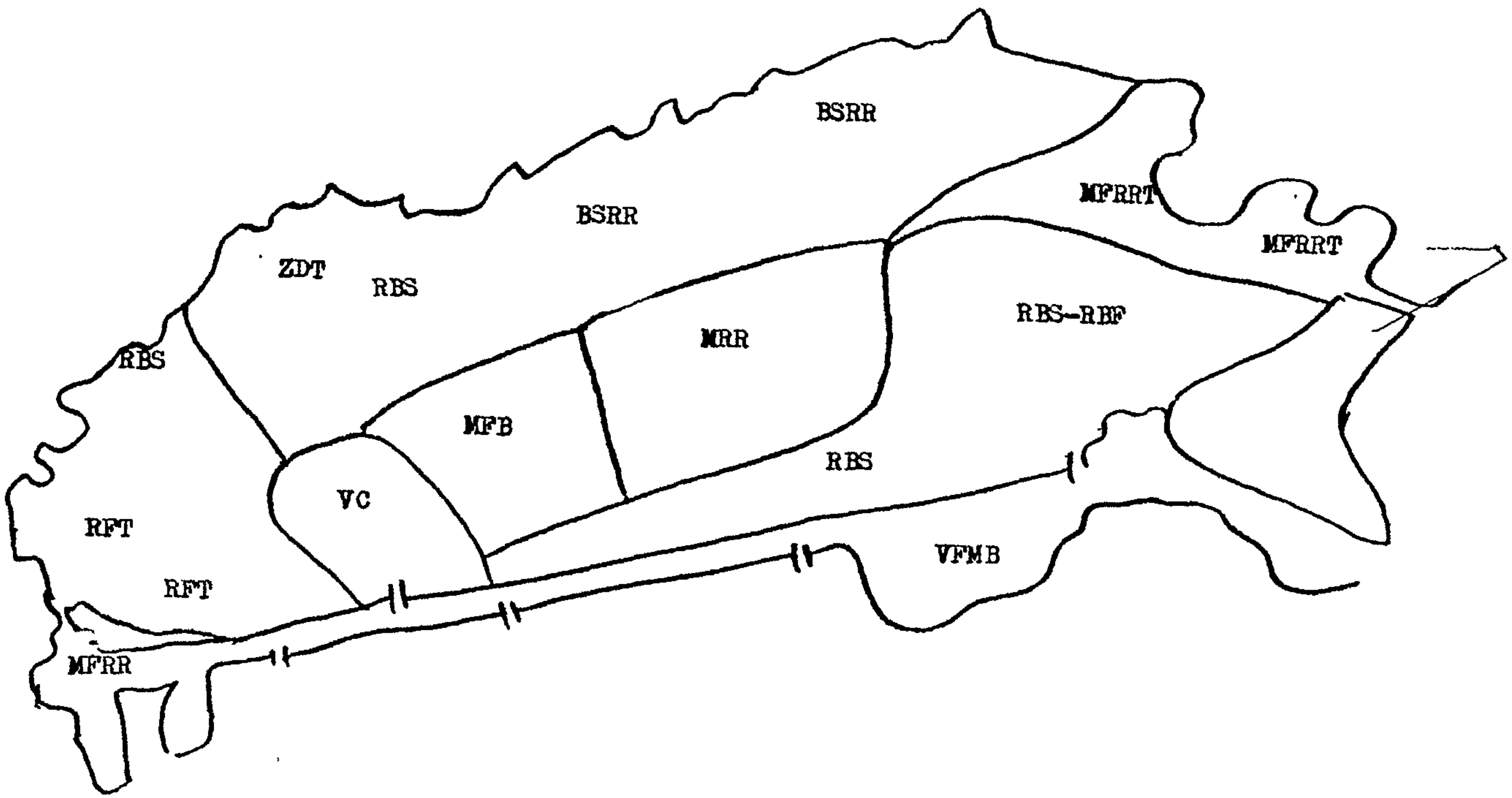

Fig. 2 Lac nord de Tunis: coloration des eaux durant la crise dystrophique de juillet 1985

Legendes:

VC	: vert citron	RBS	: rouge blanc salé
VFMB	: vert foncé à marron brunâtre	BSRR	: blanc sal à reflet rose
MFRR	: marron foncé à reflet rose	RBF	: rouge brique
MRR	: marron à reflet rose	MFRRT	: marron foncé à reflet rose turbide
RFT	: rouge foncé turbide	ZDT	: zone de dragage turbide

Les eaux vertes sont constituées en large partie par les Chlorophycées, les eaux brunes sont composées essentiellement par les Dinoflagellés, les eaux blanches comportent une microflore dense avec abondance de flagelles, il en est de même pour les eaux rouges, sauf que les bacteries thiorodacées sont les plus abondantes accompagnées d'une microflore non moins significative representée par les Cyanophycées qui semblent jouer un rôle important dans le rétablissement, par l'aération des eaux, dans l'équilibre de la balance écologique de la lagune.

A partir de nos résultats analytiques et de ceux publiés par d'autres auteurs, nous avons pu établir, en concertation avec M. Aubert, J. Aubert et S. Mathonnet, du CERBOM à Nice, un schéma de l'évolution des phenomènes d'eutrophisation du lac de Tunis; ce schéma proposé est assez original et devrait permettre de déboucher sur une conception étiologique pouvant être éventuellement utilisé dans un assainissement et un amenagement ultérieur de cette lagune (Aubert et al., 1985).

L'éxamen systématique des eaux a montré qu'il y avait au cours du temps et quelquefois simultanément en diverses zones du lac apparition d'eaux colorées qui évoluent selon un double cycle.

Le premier cycle que nous avons observé est le suivant: (Fig. 3)

Initialement, les eaux chargées en sels nutritifs accentuent leur coloration verte, en même temps que leur transparence diminue; on trouve alors une abondance de diatomées (Rhizosolenia, Cyclotella, Nitschia, Synedra) et le taux d'oxygène est élevé. Au bout de quelques jours elles deviennent plus claires et le taux de nutrilites deçroit rapidement en même temps que la transparence augmente et que les formes phytoplanctoniques se rarefient. Dans les petits fonds, on voit alors se developper une fine couche blanchâtre et l'eau devient quelque temps plus tard laiteuse. En même temps que le taux d'oxygène deçroit rapidement, se produit un dégagement d'hydrogène sulfuré; on peut constater alors une mortalité importante des poissons, ayant lieu généralement entre une heure et trois heures du matin.

Sur la pellicule blanchâtre du fond apparaissent des tâches rouges qui s'étendent rapidement, plus particulièrement sur les bords du lac et l'eau se colore à son tour en rouge vif.

L'examen microbiologique montre la prolifération de bacteries sulfo-oxydantes qui succèdent aux bacteries sulfato-reductrices se développant aux dépens des composés soufres qui ont precipité. Le taux d'oxygène s'accroit alors, et les eaux redeviennent claires et transparentes.

La durée de ce cycle est de quelques jours; sa durée est fonction de la température et diminue lorsque cette dernière augmente.

Le deuxième type de cycle que l'on peut observer est généralement plus long puisqu'il dure de quelques jours à quelques semaines (Fig. 4).

Comme précédemment, on commence par observer un accroissement de la coloration verte des eaux avec perte de transparence, liée à une prolifération de diatomées. Le taux de nutrilites est élevé ainsi que le taux d'oxygène. Puis la diminution des sels nutritifs entrainent en quelques jours une diminution de cette flore qui est remplacée par une brutale efflorescence de dinoflagellés, principalement Prorocentrum micans et des cyanophycées composées essentiellement par Anabaema et Oscillatoria.

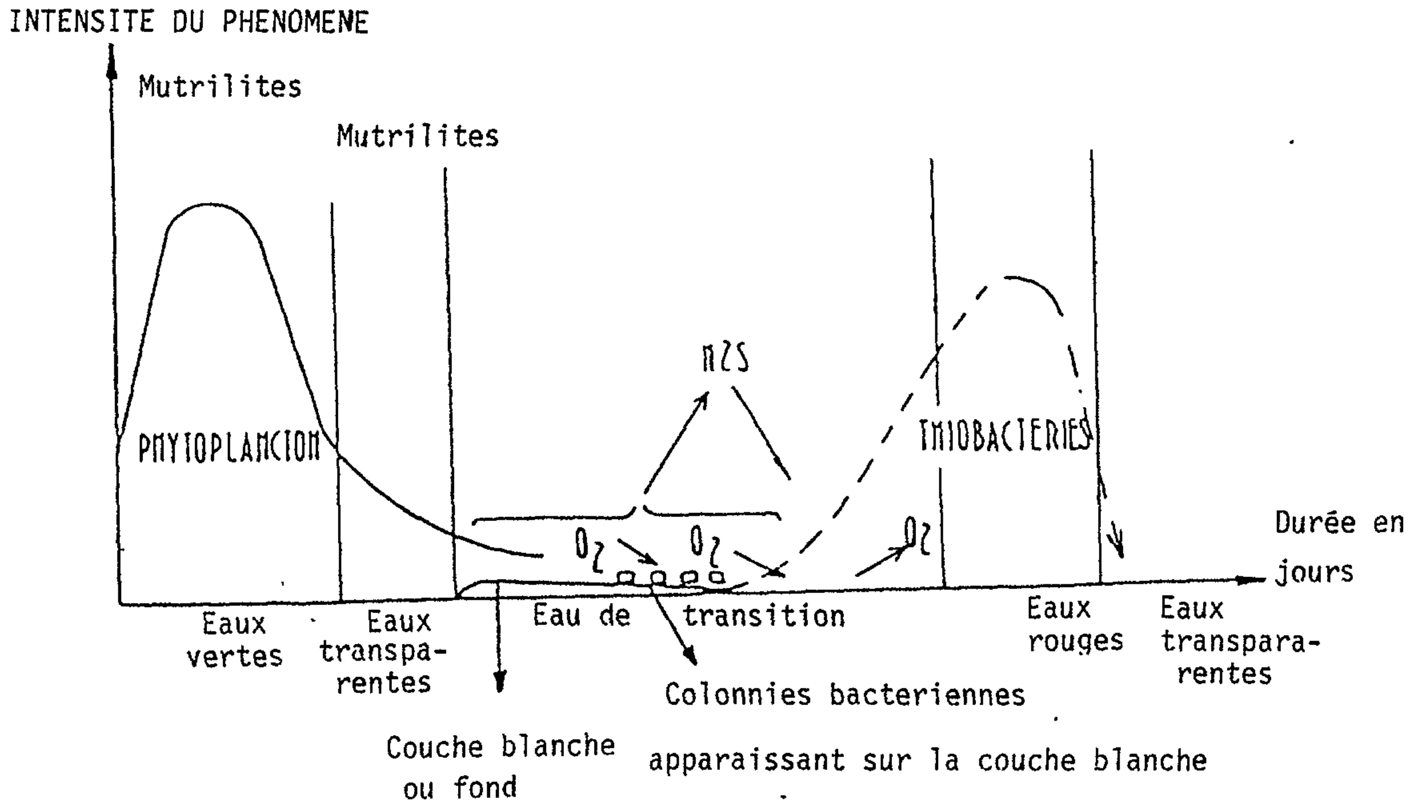

Fig. 3 Eaux rouges d'origine bactériennes (Thiobactéries)

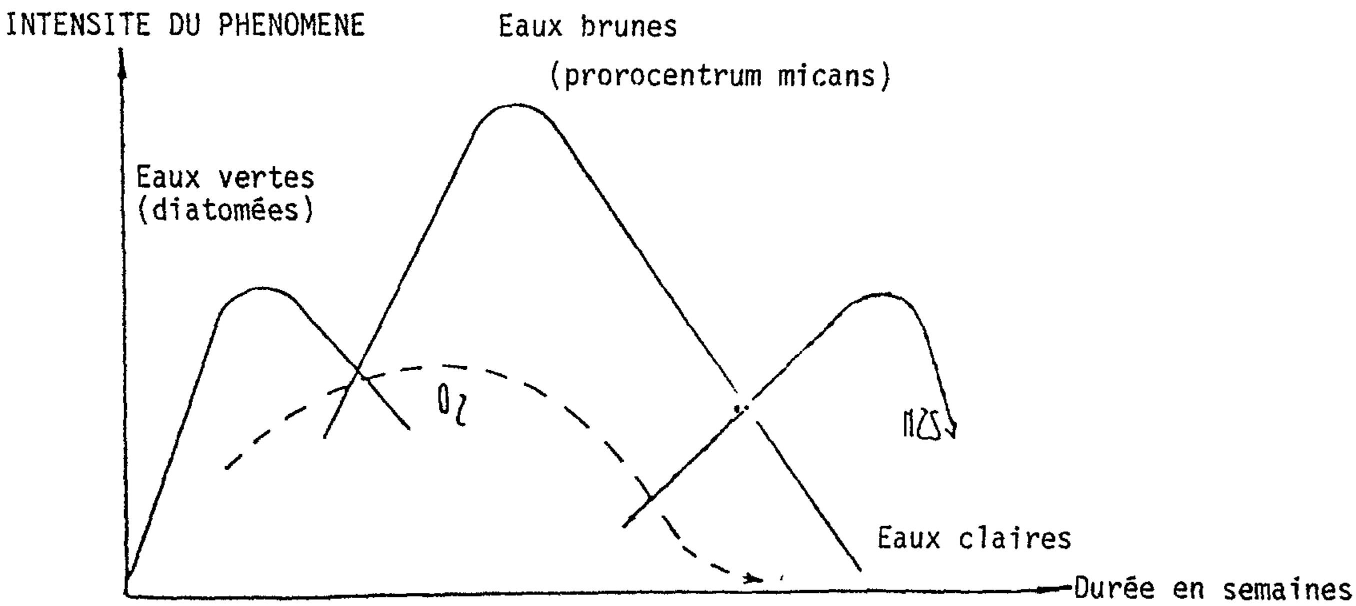

Fig. 4 Eaux rouges (brunes à phytoplancton)

Les eaux deviennent alors de couleur brune et sont peu transparentes; puis progressivement l'efflorescence des dinoflagelles deçroit d'intensite. Le taux d'oxygène diminue; un dégagement sulfure se manifeste mais son intensite et sa durée sont moins importantes que dans le cycle à sulfobacteries. Au bout de quelques jours les eaux redeviennet claires. Il est à noter que dans certains circonstances, et plus particulièrement à proximité des rejets d'eaux residuaires, la prolifération planctonique responsable d'eaux brunes a porté sur d'autres espèces avec une large prépondérance de Spirulines, mais l'évolution et les caractéristiques hydrologiques ont été semblables.

Ainsi on assiste donc à deux processus cycliques qui débutent, se poursuivent et se terminent d'une manière systématique.

Leur début correspond plus particulièrement à des conditions climatiques estivales: une température élevée et des eaux immobiles sont des causes favorisantes d'un processus qui s'établit dans un milieu riche en substance nutritives.

Mais comme il a été montré dans les travaux antérieures du Pr. Aubert et son équipe, travaux concernant l'étiologie des processus de l'eutrophisation, ces conditions ne sont pas suffisantes et necéssaires pour que de tels phenomènes se manifestent: il est connu que des processus eutrophisantes dans les mers froides et leur développement n'est pas concomitant avec des teneurs élevées de nutrilites.

Il est probable qu'il existe des mécanismes induits par des médiateurs issus des espèces en cause dont la prolifération cyclique induit ou bloque ces développements avec plus ou moins de brutalité.

L'équipe du Pr. Aubert, lors de sa visite en Tunisie en juillet 1985 a essayé de comparer les spectres des eaux recueillies dans le lac de Tunis avec ceux obtenus au cours de leurs travaux antérieurs sur les milieux de culture d'espèces analogues en élevage monospecifique, et cela pour pouvoir "in vitro" mettre en evidence certaines phases de ces mécanismes et isoler les médiateurs qui règlent l'équilibre entre Diatomées et Dinoflagelles.

S'il est difficile de retrouver une parfaite concordance entre ces images spectrales du fait des mélanges secrétoires existant dans un milieu d'une telle richesse biologique, on peut remarquer entre elles une certaine analogie. Celle-ci permet de penser qu'à l'origine de ces développements successifs et des cycles d'apparition de ces phénomènes d'eutrophisation existent des actions liées aux télémediateurs secrètes par certaines espèces induisant la prolifération puis l'arrêt total de ces processus que les seules conditions nutritionnelles ne peuvent induire.

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DISTRIBUTION OF CHLOROPHYLL-A DURING SUMMER IN RIJEKA BAY (NORTHERN ADRIATIC) FOLLOWING AN INCREASE IN PHOSPHORUS LOAD

by

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A B S T R A C T

Ratios of nutrients in the water further from the coast show that the nutrient most likely to limit phytoplankton growth during summer is phosphorus. At this stage of eutrophication there is a clear relationship between total phosphorus load and chlorophyll a. Distribution of chlorophyll a during summer is obtained for an increased total phosphorus load. Using a mathematical interpolation model, the case of one and two outfall inputs has been computed.

1. INTRODUCTION

Over the past fifty years, areas of pronounced eutrophication have been expanding in the northern Adriatic. Ecological studies are being carried out in order to provide baseline data for assessing the present state of eutrophication. Such data typically consist of lists of concentrations of chemicals and biological species, of meteorological conditions and occasionally of measurements of sea currents. Although data from ecological studies are appropriate for the assessment of the present state of eutrophication, as a rule they do not include extensive experiments in the sea which would provide a basis for constructing dynamic models capable of predicting the ecological effects of various management scenarios. Since there is a need to relate management options to their potential ecological effects, the data collected during ecological studies may therefore be used to reconstruct some aspects of the typical stationary situation in which the data were obtained, for instance the situation in winter or summer. Then, assuming considered management actions and the same underlying physical, chemical and biological processes, one is able to construct the corresponding projections. As is customary with all mathematical models, such projections must be accompanied by explicit specifications of conditions under which the projections are expected to hold. It is also advisable to test the projections on an independent set of data and to perform sensitivity analysis in order to judge the merits of projections.

2. METHODOLOGICAL APPROACH

In this work, eutrophication is taken to mean an increase in concentration of chlorophyll a. The increase in chlorophyll a depends on the concentration of the limiting nutrient and the latter depends on the input from the coast. Hence the first step consists of determining which nutrient was the most likely to be limiting. Secondly, an attempt was made to assess the input of the nutrient to the coastal area. Next, the stationary field of sea currents was reconstructed. Fourthly, a reconstruction of the transport equation was attempted, and finally the nutrient concentration field was linked to chlorophyll a. Initial sensitivity analyses for the last three steps were also carried out.

3. RESULTS

3.1 Phosphorus as the limiting nutrient

Apart from temperature and light, both of which limit growth during winter, three potentially limiting nutrients were measured (Degobbis, 1981; 1983): nitrogen, phosphorus and silica. In waters further from the coast these nutrients show similar characteristics above the thermocline (Fig. 1). During winter, higher concentrations were found throughout the water column. As the thermocline is established, the layer above the thermocline is depleted while higher concentrations are found below. Examination of the dynamics of the nutrients in isolation, will not allow conclusions to be reached as to which of the nutrients effectively limits phytoplankton growth.

We compared P/N and P/Si ratios in water for winter and summer above and below the thermocline (Table I) to ratios in controlled growth experiments where the limiting nutrients are varied, using the results of experiments with Skeletonema costatum (Harrison et al., 1976) and Thalassiosira pseudonana (Perry, 1976).

In Si limited environment, composition of S. costatum is: P/Si = 1/2, P/N = 1/10.5. In N (NH_4) limited medium the composition is: P/Si = 1/8.4, P/N = 1/5.6. T. pseudonana has less than twice the amount of nitrogen per phosphorus in N limited medium than S. costatum (P/N is from 1/6.4 to 1/8.3). In P limited medium where the division rate is μ = 0.98 day^{-1}, T. pseudonana had P/N = 1/39. Stronger P limitation gives P/N = 1/62 (with u = 0.408).

Disappearance experiments regularly show that at low nutrient concentration the flux into cells is proportional to concentration in water. Uptake ratios of nutrients in the above experiments also show values close to the composition ratios. Hence, if at low concentrations, P/N and P/Si in the water is significantly smaller than the ratios of uptake requirements, then it may be concluded that, of the three given nutrients, phosphorus is in the shortest supply. A comparison of ratios from Table I and ratios for T. pseudonana grown in P-limited medium indeed suggests that phosphorus is the limiting nutrient in the open waters of Rijeka Bay.

In order to discover which of the nutrients comes second in limiting phytoplankton growth, the N/Si ratio in Rijeka Bay waters and in phytoplankton cultures grown under Si and N limitation must be investigated. In Si limited medium, S. costatum had N/Si = 5, while in N limited medium N/Si = 1/1.5. From Table I it can be concluded that in Rijeka Bay surface waters there was N/Si = 1/1.6 in winter and N/Si = 1/1.3 in summer, while for bottom waters the situation was N/Si = 1.86 during winter and N/Si = 1/5.6 during summer. It follows that nitrogen is far more limiting than silica. This result stands regardless of the fact that nitrogen regenerates faster than silica.

A previous study of the limitation of phytoplankton production using enrichment experiments in the northern Adriatic (Pojed and Kveder, 1977), south-west of Rijeka Bay showed that phytoplankton is mainly limited by phosphate and less by nitrate.

Table I

P:N and P:Si ratios for open waters of Rijeka Bay above the thermocline (termed: "above") and below the thermocline (termed "below") (Data from Jeftic, 1977, 1978).

Rijeka Bay

	above		below	
	winter	summer	winter	summer
P:N	1:71.25	1:39	1:43	1:38
P:Si	1:112.5	1:50	1:80	1:213

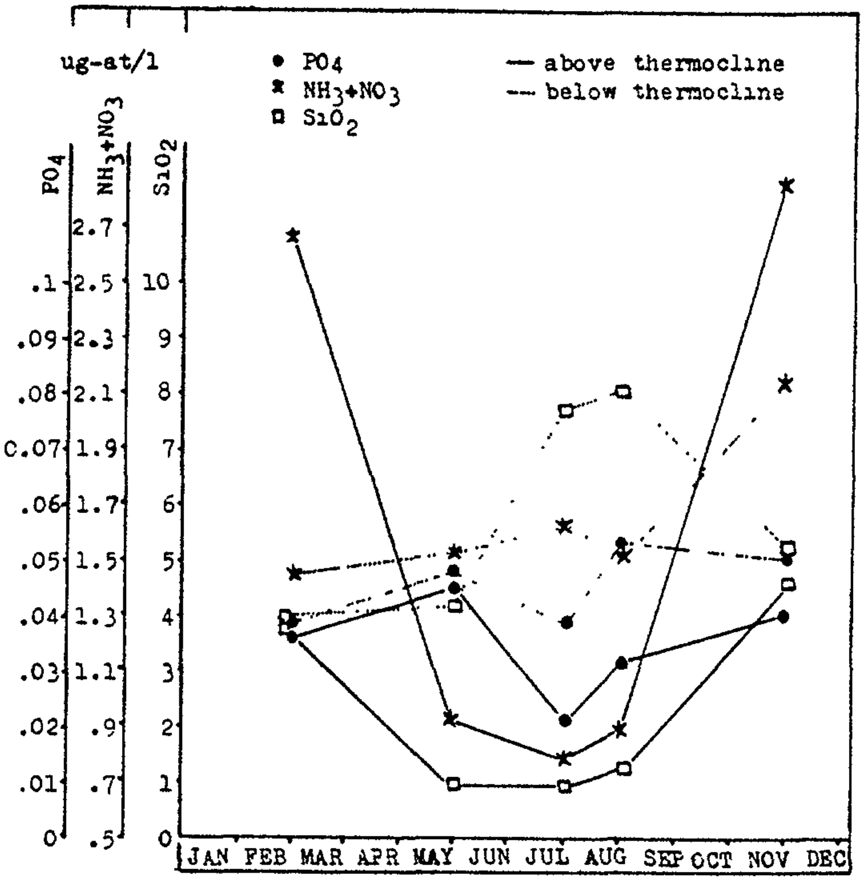

Fig. 1 Concentrations of nutrients in open waters of Rijeka Bay (Data from Jeftic, 1977, 1978)

To summarize, given P, N and Si as potentially limiting nutrients, the above results show that (i) P is the limiting nutrient; (ii) N is the first potentially limiting nutrient, and (iii) Si is the next potentially limiting nutrient.

3.2 Distribution of chlorophyll a

The distribution of chlorophyll *a* as a result of either one or two inputs can be described in three steps: (i) development of a model describing total phosphorus distribution, (ii) establishment of a relationship between total phosphorus and phosphate and (iii) relating chlorophyll *a* to phosphate.

Let us denote the concentration of total phosphorus by c. The distribution of total phosphorus is sought as a solution to the equation:

$$\Delta c + \vec{v}\,\vec{\nabla} c + kc = 0 \qquad (1)$$

where sources are at the boundary. c is given at the open boundary of the area (Fig. 2) as $c = c_b$; $\partial c/\partial n = Q$ at the source and $\partial c/\partial n = 0$ along the rest of the coast. If the source is inside the area, then the right hand side of equation 1 is equal to the influx Q. The coefficient of turbulent dispersion has been determined (Legovic, *et al.*, 1989) as being equal to 1.45 10^4 cm^2 s^{-1}. The quantity of total phosphorus in the area is estimated as $\int_{\Omega} c\, dx\, dy = 60.6 \times 10^3$ kg. The extinction constant k is determined by integrating equation (1) over the whole area. Given the influx $Q = 2.7\ 10^3$ kg day^{-1}, one finds that $k = 1.10^{-4}$. To solve numerically equation (1), an approximation of current field is needed. The current field is given by the equation:

$$v(x,y) = \text{grad}\ \phi\ (x,y) + \text{rot}\ \Psi\ (x,y) \qquad (2)$$

where $\Delta\phi = 0$ and $\Delta\Psi = Q$. However, the vortex field is unknown. Using a condition of the minimum square error between model results and field measurements (Smircic and Ilic, 1981) the vortex field may be found (Limic, 1984). The resultant current field is shown in Fig. 3. By using the model and estimating the total phosphorus input, the distribution of total phosphorus is found. Furthermore, the total phosphorus may be related to PO_4 by the equation:

$$(PO_4) = a_1 c + a_2. \qquad (3)$$

while chlorophyll *a* may be related to PO_4 by the equation:

$$(\text{Chl}\ \underline{a}) = a_3(PO_4)^2 + a_4(PO_4) + a_5 \qquad (4)$$

This means that one may relate Chl *a* directly to total phosphorus by the equation:

$$(\text{Chl}\ \underline{a}) = b_1 c^2 + b_2 c + b_3 \qquad (5)$$

where b_1, b_2 and b_3 are constants.

Using an input of total phosphorus that is roughly three times larger than the present-day input, two cases have been computed, one where there is a single outfall and a second in which there are two outfalls. The resulting Chl *a* distributions are shown in Figs. 4 and 5, respectively.

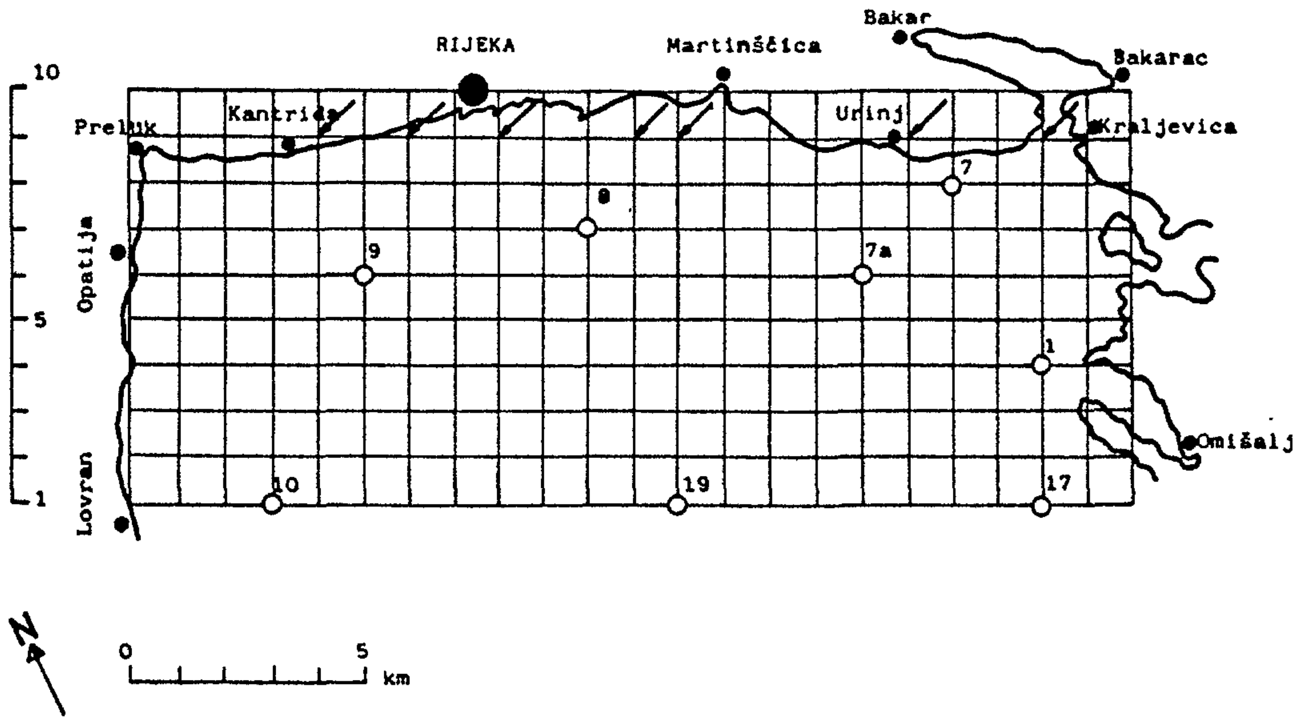

Fig. 2 The study area. Grid squares 1km x 1km. O indicates position of stations. Arrows represent inputs from the coast

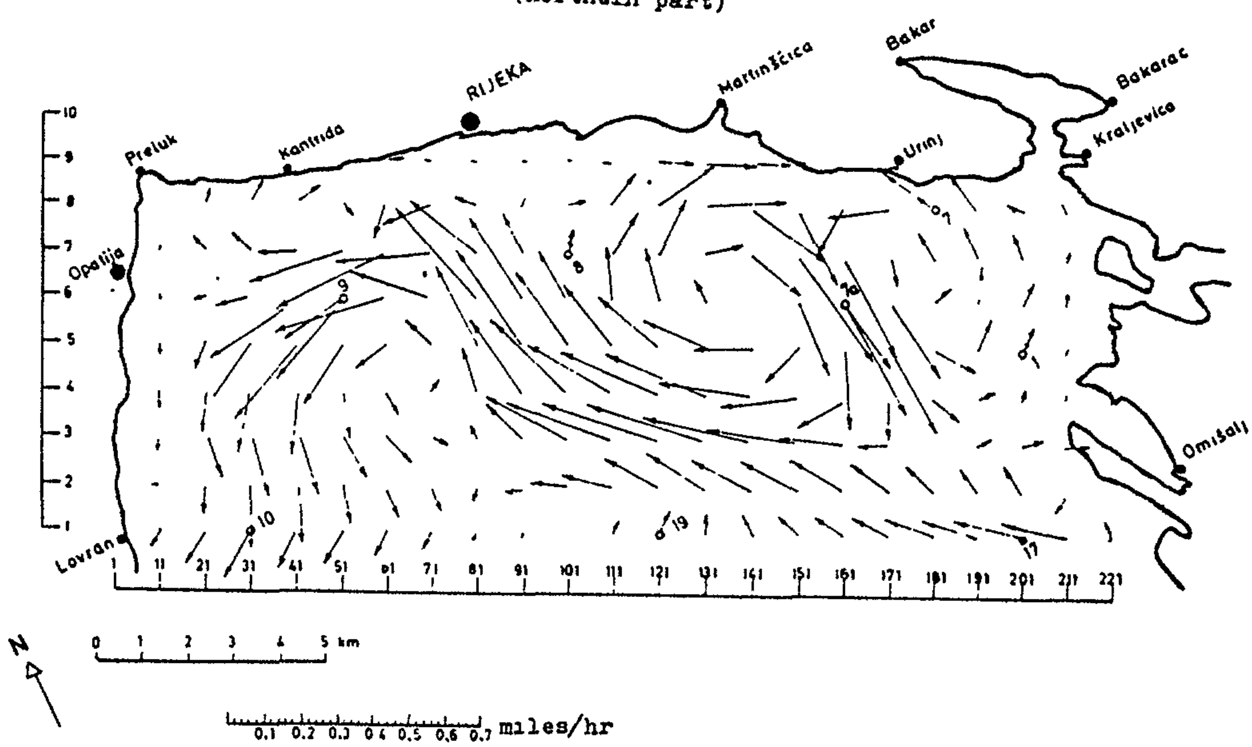

Fig. 3 Reconstructed current field

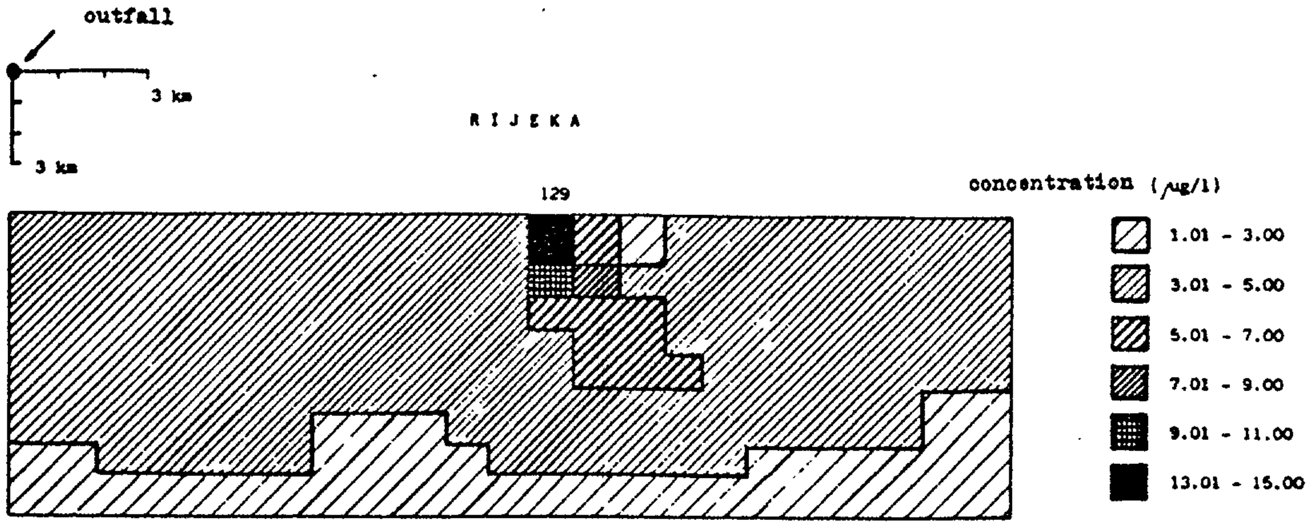

Fig. 4 Distribution of chlorophyll a for one outfall (input Q = 11.3 X 10^3 kg day^{-1})

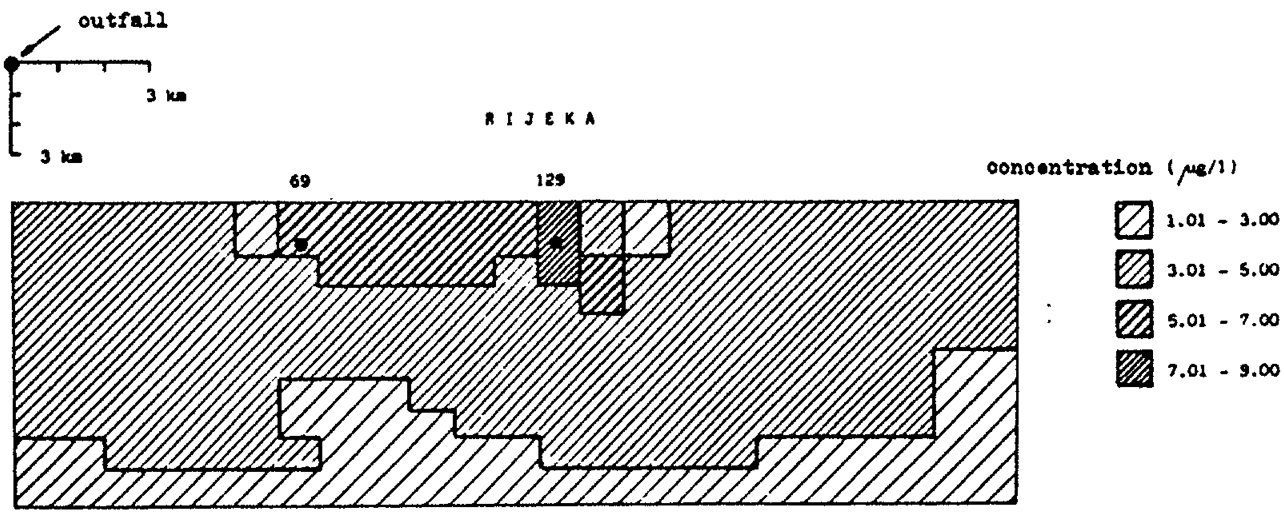

Fig. 5 Distribution of chlorophyll a for two outfalls. (Total input Q = 11.3 X 10^3 kg day^{-1})

4. DISCUSSION AND CONCLUSION

The results presented above indicate that the nutrient which actually limits phytoplankton growth is phosphorus, while potentially-limiting nutrients are nitrogen and silica.

Since concentration of nutrients and species composition of phytoplankton in the open waters of the Adriatic are similar to those in the open waters of Rijeka Bay, it is expected that the results presented here may be applicable to the larger region of the Adriatic Sea. This however excludes places very near sewage outfalls, where other factors (significant sources of total phosphorus and influences in the vicinity which diminish accessibility of phosphorus) are dominant.

Using a mathematical model, the residual current field during summer is reconstructed. The first attempt to represent the current field by an irrotational plus a rotational part was not unique. The non-uniqueness came from the rotational part; however the recent results guarantee that as the number of data points increases, the unique current field is approached. Using the representation for a current field, a concentration field has been obtained. Finally, total phosphorus is related to phosphate, and phosphate to chlorophyll a. By keeping the total flux constant, the field of chlorophyll a is estimated for two important cases: a) one outfall and b) two outfalls of total phosphorus. These results could serve as a guide to decision-makers when place and number of outfalls are considered. The same methodology may be applied to other areas of the Mediterranean Sea.

3. ACKNOWLEDGEMENTS

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RELATIONSHIP BETWEEN PHYTOPLANKTON BLOOMS AND DISSOLVED ORGANIC MATTER IN THE NORTHERN ADRIATIC

by

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ABSTRACT

The Northern Adriatic is the most productive basin of the Mediterranean, with a trend of increasing eutrophication. Except for the surfactant activity measurements, little has been done on monitoring the levels of dissolved organic matter and its sources.

The work done under MED POL - PHASE II forms part of the complex investigation started by the Research Centre in 1973.

Spatial and seasonal changes in surfactant activity, as a measure of dissolved organic matter, were analyzed in the period 1976-1986.

The content of dissolved organic matter (DOM) in the surface layer of the northern Adriatic is significantly higher than in the open waters of the rest of the Adriatic and Mediterranean sea. A significant correlation was found between surface active DOM and other parameters of primary production with decreasing salinity in the surface layer for the salinity range 30-38^{o}/oo.

Phytoplankton is the major source of dissolved organic matter; anthropogenic and terrestrial plant contributions were found to be less important for the marine environment as a whole.

The input of nutrients by the river Po, primarily of phosphorus, appears to be a major factor in the determination of the increased levels of DOM in the Northern Adriatic.

The increased levels of DOM affect the form and fate of toxic metals and their entry into marine food chain. The fate of radionuclides and hydrophobic organic pollutants is probably also affected. In addition, at higher concentrations, the decomposition of DOM causes excessive oxygen consumption. Finally, changes in the distribution of some biological species in the area may be expected.

1. INTRODUCTION

The Northern Adriatic Sea, extending from the Gulf of Trieste southward to the line Ancona - Pula, is a shallow, semi-enclosed basin with a mean depth of about 30 metres (Fig. 1). Several rivers flow into the north Adriatic along its northwestern coast generating a continuous supply of nutrients and freshwater which, mixing with the oligotrophic waters coming from the Mediterranean, make the productivity of this basin one of the highest in the whole Mediterranean Sea (Faganelli, 1961; Stirn *et al.*, 1974). The Po river, the major river system of northern Italy (650 km long, average annual

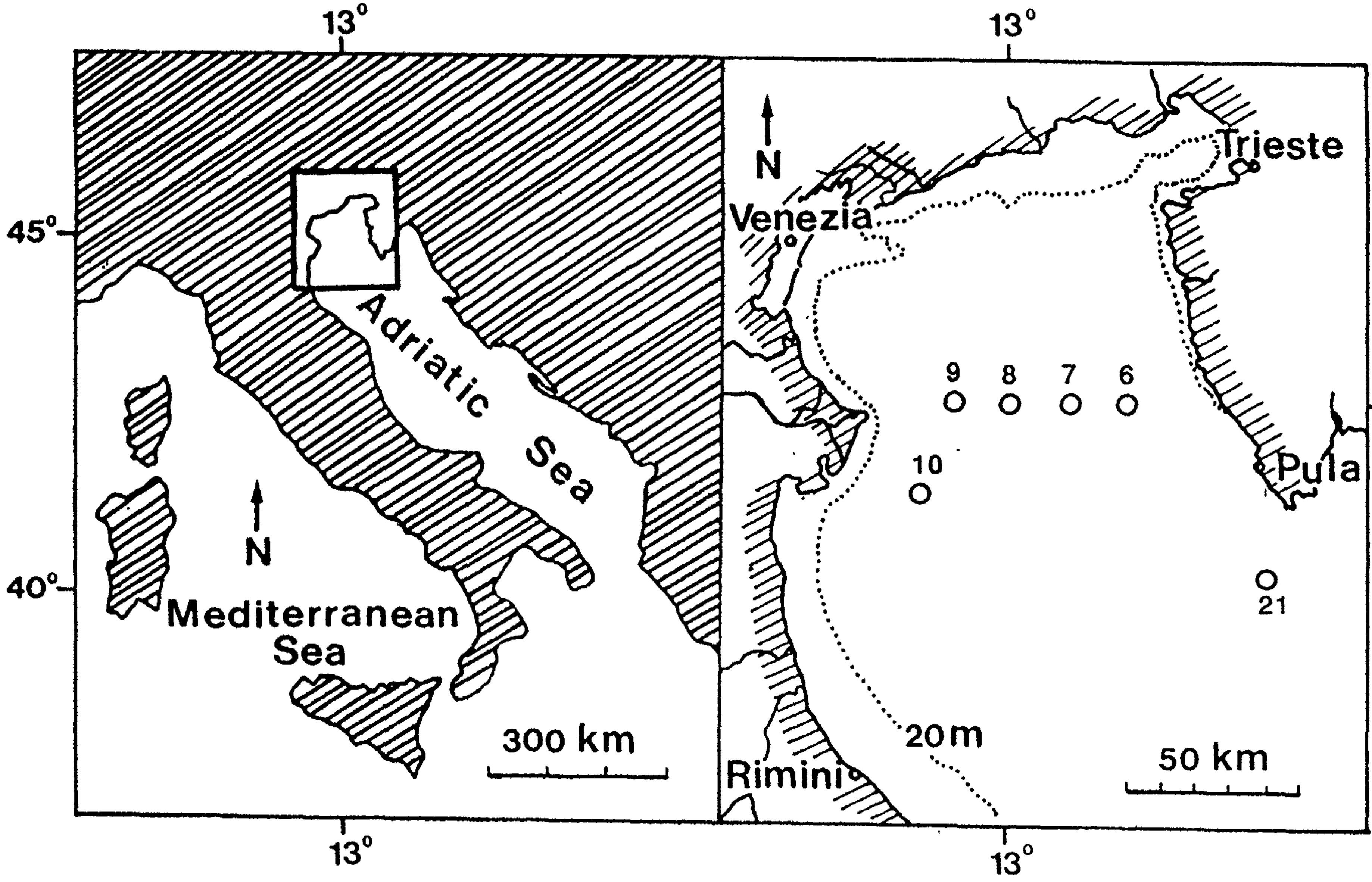


Fig. 1 The investigated area of the northern Adriatic Sea. Stations are indicated where characterization of organic matter by biogeochemical markers has been performed (Marty <u>et al.</u>, 1987)

discharge 1,500 m^3 s^{-1}), plays a dominant role in the distribution of the hydrographic and biological properties of the Northern Adriatic (Grancini and Cescon, 1973). In addition to the natural inputs, nutrients and organic detritus, the Po river drains a densely-populated region with intensive industrial and agricultural activities. Intensive autumn and spring phytoplankton blooms were found to appear regularly in the part of the basin under the direct influence of the Po river (Revelante and Gilmartin, 1976).

On the basis of the analysis of a long-term series of oxygen data, a continuous trend of increasing primary productivity, starting from the early sixties, has recently been identified (Justic et al., 1987).

Phytoplankton blooms are known to have occurred in the shallow North Adriatic from time to time for centuries (Fonda-Umani, 1985). Moreover, during the last 20 years several investigators have observed that anoxic conditions in the near-bottom layer occur during summer in certain areas of the Northern Adriatic Sea. Extensive blooming has been reported as occurring more frequently and an increased eutrophication has been indicated (Degobbis et al. 1979).

Increased concentrations of dissolved organic matter (DOM), measured as surfactant activity, were recorded in the whole northern Adriatic during the phytoplankton bloom in early summer 1977 (Fig. 2) and a close correlation of surfactant activity and phytoplankton density was indicated (Zutic et al., 1981).

Except for the surfactant activity measurements (Cosovic and Zutic, 1979; Zutic et al., 1981; Cosovic and Vojvodic, 1982), little work was carried out on the characterization of organic matter in the Northern Adriatic, and its sources.

A preliminary characterization of the main classes of organic matter in the sea surface microlayer and subsurface water (Julien, 1982) has indicated a predominance of carbohydrates and a relatively high concentration of lipids both in dissolved and particulate fraction.

2. EXPERIMENTAL METHODS

Efficient electrochemical methods have been developed for the characterization of surface active DOM in the sea, phytoplankton cultures and estuaries.

DOM was characterized as surfactant activity (S.A.), by two electrochemical methods: method of polarographic maximum (method A) and capacity current measurement by AC polarography (method B) (Cosovic et al., 1985). No pretreatment of water samples such as filtration is needed. Surfactant activity is expressed in terms of surfactant equivalents of the nonionic surfactant Triton-X-100, in mg l^{-1} seawater. Methods A and B differ in the type of electrical excitation, the response measured and the electrode charge (positive for method A, and slightly negative for method B), which results in different sensitivities to various classes of organics.

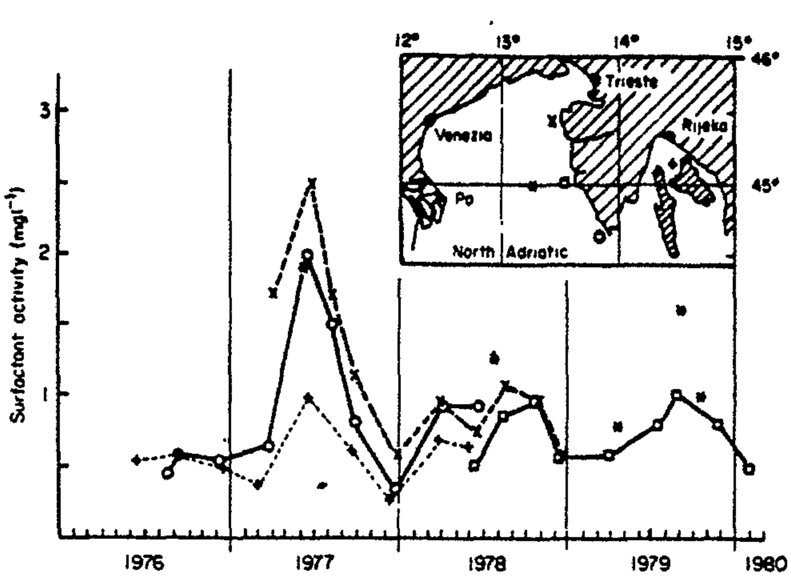


Fig. 2a DOM measured as surfactant activity at 3 offshore stations (surface samples, 0.5m) in the northern Adriatic and in Rijeka Bay in the period 1976-1978

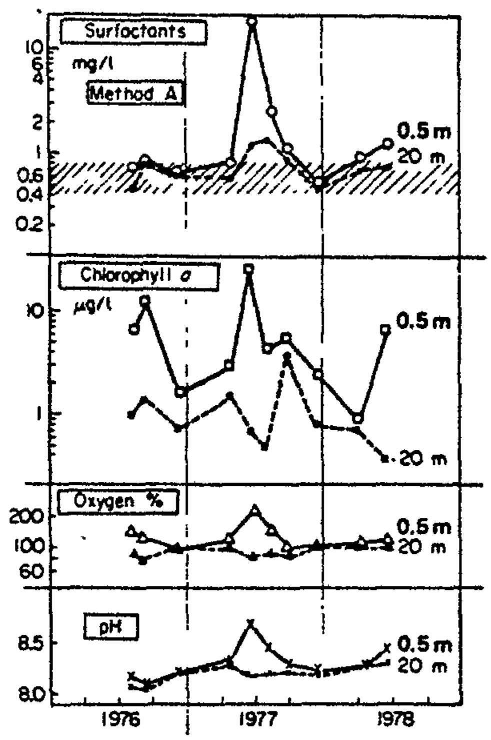


Fig. 2b Surfactant activity, chlorophyll a, oxygen saturation and pH values at a station in the Pula harbour (east coast) during the same period, (Zutic et al., 1981)

The method of polarographic maximum makes it possible to distinguish betweeen "dissolved" organic matter and surface active aggregates (Zutic _et al._, 1984; Tomaic _et al._, 1989). The property of surfactant activity is rather generally distributed throughout the range of DOM found in fresh, marine and estuarine waters. A systematic comparison of dissolved organic carbon (DOC) and surfactant activity of marine and estuarine samples (Hunter and Liss, 1981) showed a linear relationship between the two quantities that may be expressed as: S.A. (mg l^{-1}) = 1.3 DOC (mg l^{-1}).

Method B is specifically sensitive to the hydrophobic fraction of DOM (lipids in particular).

The concentration of anionic detergents (determined as methylene blue active substances, Kozarac _et al._, 1975) was selected as a pollution marker (Cosovic _et al._, 1985; Marty _et al._, 1988).

The relationship between phytoplankton and DOM has been studied in laboratory cultures of _Dunaliella tertiolecta_ and natural Adriatic populations (Plese _et al._, 1985).

3. RESULTS

Data on surface active DOM measured in seawater samples of the Northern Adriatic in coastal waters and offshore stations at various depths (including sea surface microlayer), transects and stations were analysed and compared with other Mediterranean regions of lower biological activity, such as the open waters of the western Mediterranean (Fig. 3) and Rijeka Bay (Fig. 4).

DOM content in the surface layer in the Northern Adriatic is significantly higher than in the open waters of the rest of the Adriatic and Mediterranean Sea.

Organic pollutants do not contribute significantly to the total pool of DOM in the aquatorium as a whole. To illustrate this, concentrations of anionic detergents and total (method A) and hydrophobic surface active organic matter (method B), measured in the open waters of the Northern Adriatic during the two cruises in 1986, are presented in Fig. 5 together with the plot of the two parameters indicating no correlation.

However, significant correlations were obtained between surfactant activity and chlorophyll _a_, and between surfactant activity and oxygen saturation in the $\leq$ 5 m surface layer. The correlation, exemplified in Fig. 6, using the set of data for a coastal station in the period 1976-1978, indicates that the phytoplankton is the major source of DOM. Moreover, forms of the electrochemical response measured in surface microlayer samples and in the surface water during periods of intensive primary production, during blooms in particular, closely resembled signals of phytoplankton culture suspensions (Fig. 7), most frequently those of diatoms.

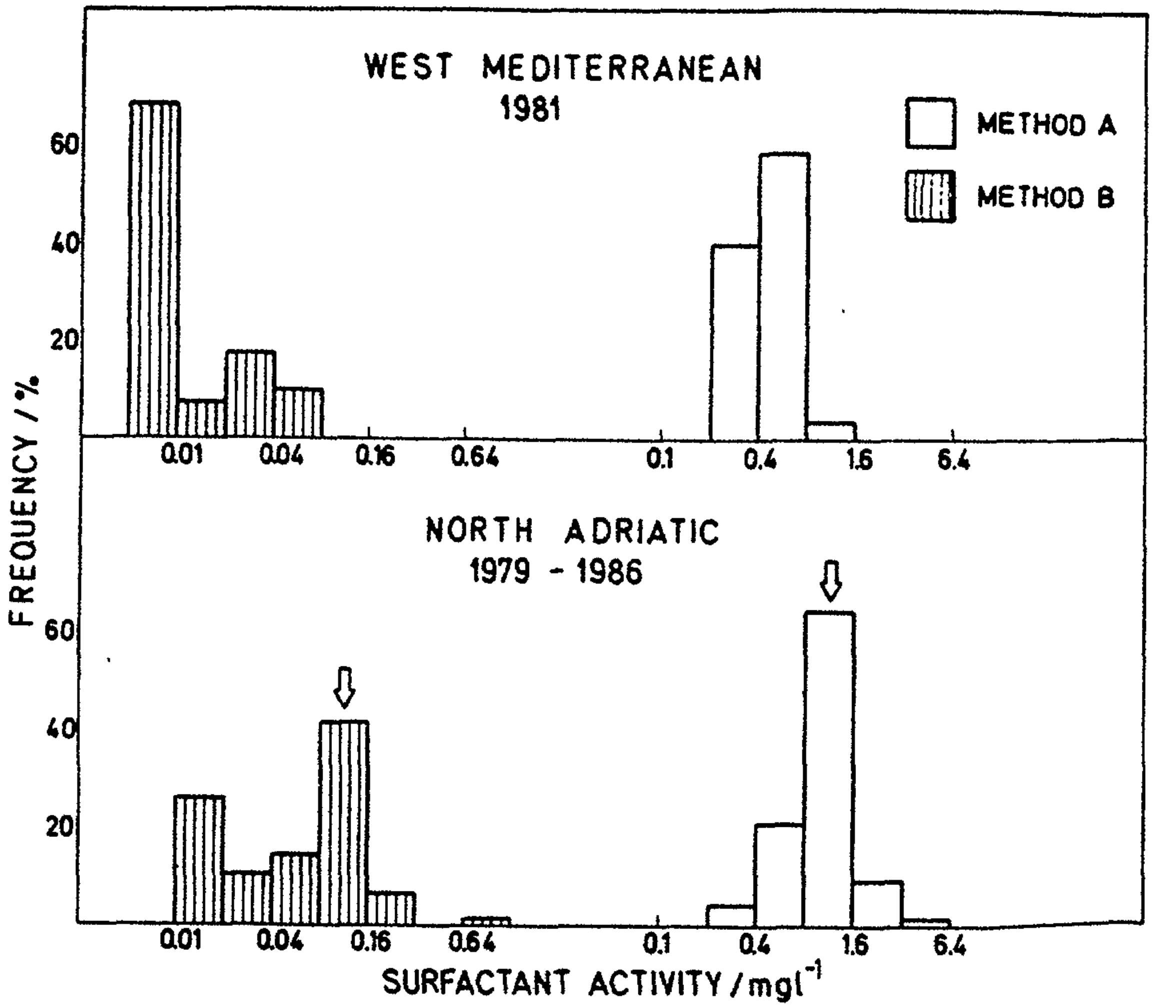


Fig. 3 Frequency distribution of surfactant activiy of seawater samples collected in the open waters of western Mediterranean and northern Adriatic (Marty et al., 1988)

The form of the electrochemical response, as well as the chemical analysis of various classes of DOM showed that polar polymeric material of the carbohydrate type predominates. The content of hydrophobic material (lipids) is highly variable and seems to depend heavily on the type of phytoplankton population. Unsaturated lipid- like surface active aggregates- were also detected in the surface layer (Novakovic and Zutic, 1983). In general, the concentration of unsaturated lipids (freshly produced by active populations) is higher than that reported in the literature for other Mediterranean areas (Julien, 1982; Marty et al., 1988).

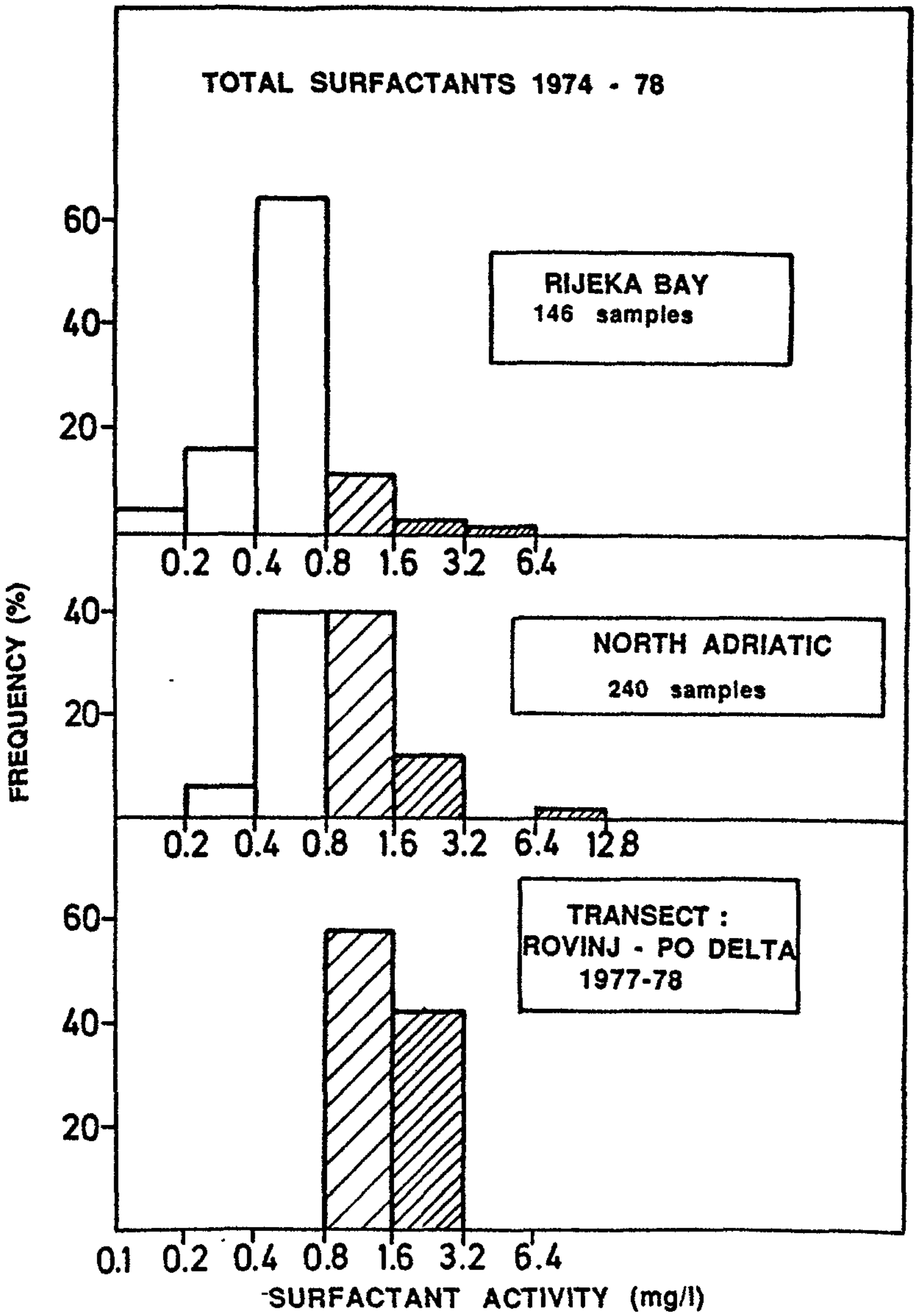


Fig. 4 Comparison of distributions of surfactant activity values, measured by method A in Rijeka Bay, the northern Adriatic (including the coastal stations) and the northern Adriatic open waters along the transect Rovinj - Po delta

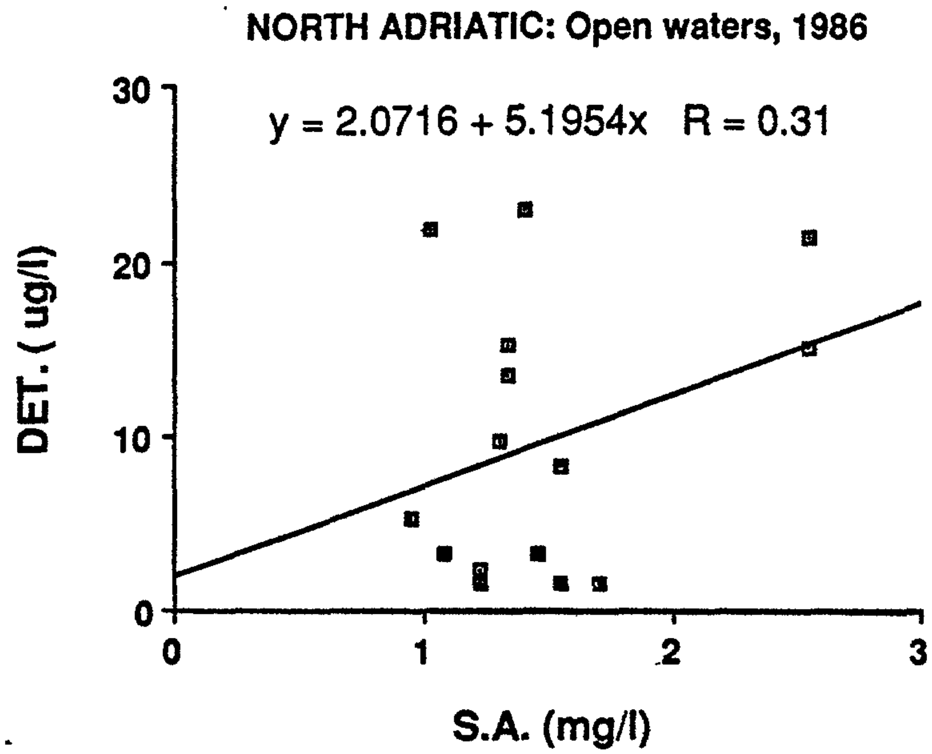
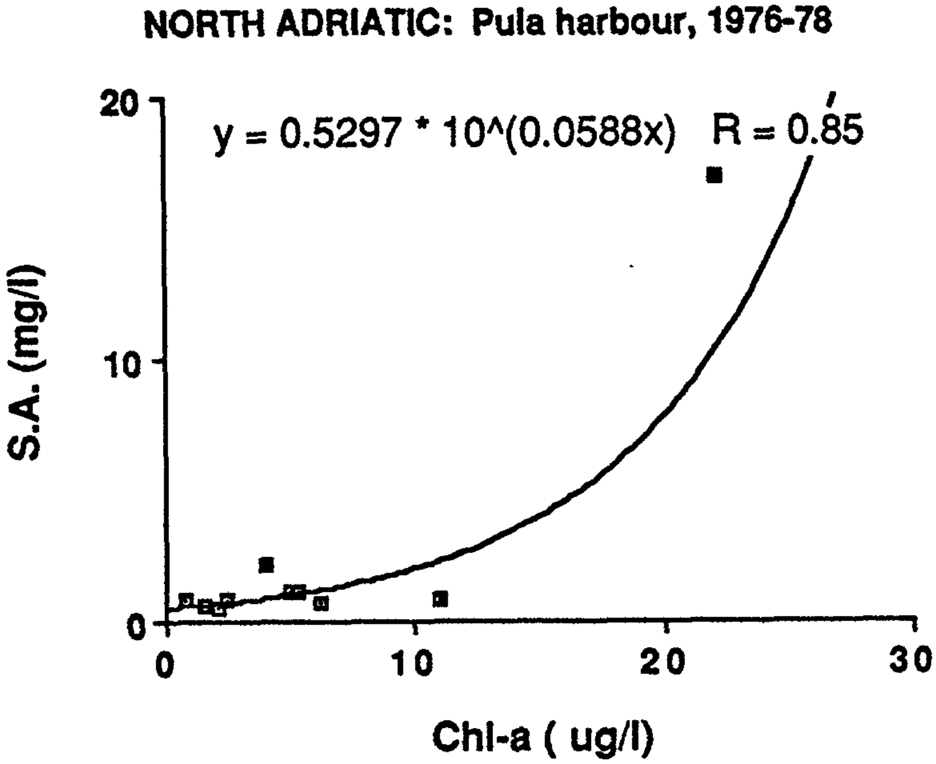


Fig. 5 Regression line for surfactant activity (method A) and anionic detergent concentration. Data obtained during the two cruises in the open waters of northern Adriatic, in May/June and December 1986, (Cosovic, 1987)

A comparison with the results of the molecular approach (Marty et al., 1988), using biogeochemical markers (fatty acids and hydrocarbons) to identify various sources and the degradation state of the organic matter, supports the above finding, that the measured DOM originates in phytoplankton. The analysis of surface water and sea surface microlayer samples collected in the open waters of the northern Adriatic (at stations indicated in Fig. 1) in the summer of 1980 and the autumn of 1982, showed: (i) low anthropogenic and terrestrial plant contribution and (ii) autochthonous, phytoplankton and bacteria, the source both of dissolved and particulate fractions of organic matter. However, a fine distinction of bacterial contribution to DOM and its mechanism has still to be determined, since a parallel series of measurements of heterotrophic activity of bacteria has not yet been undertaken.



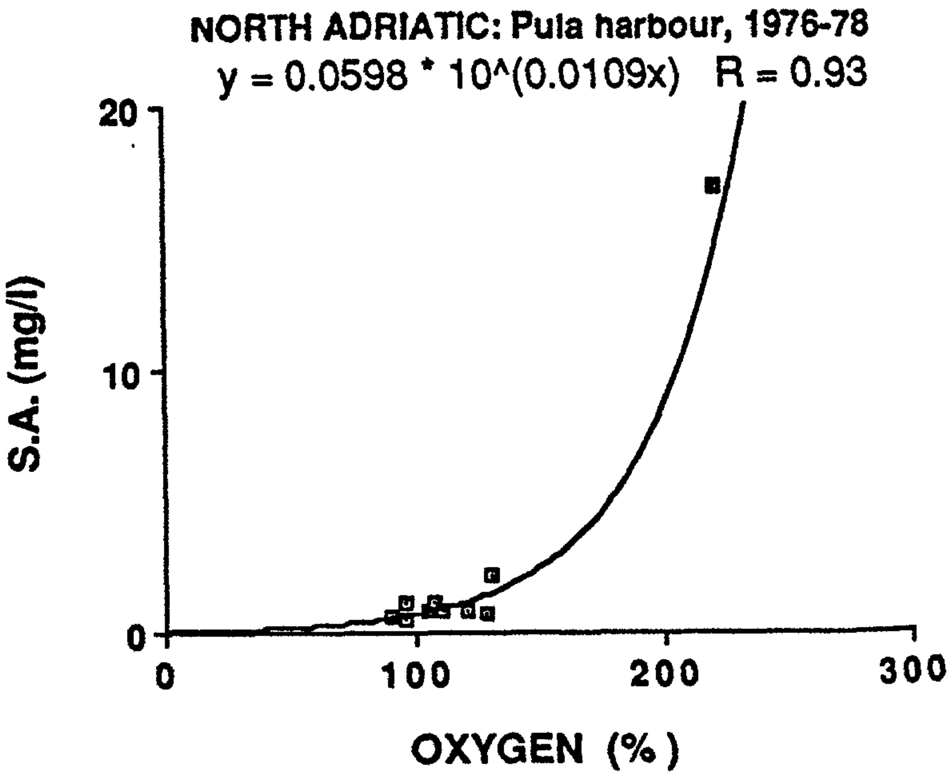


Fig. 6 Plot of surfactant activity (method A) values and Chlorophyll a (a) and oxygen saturation (b) measured in the same samples (surface samples: 0.5m) seasonally in Pula harbour (east coast)

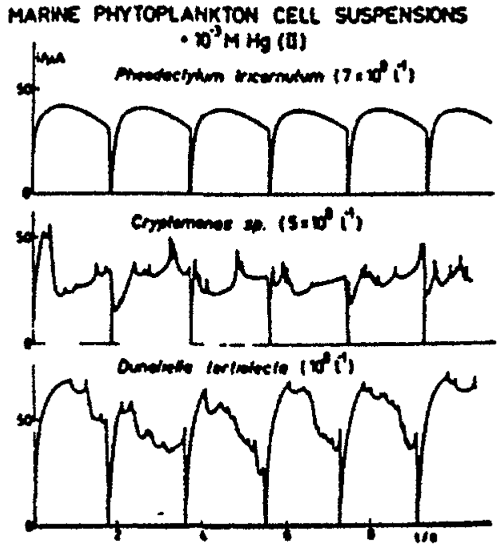


Fig. 7 Electrochemical response (current-time curves, method A) in the marine phytoplankton cell suspensions. Comparison of a typical response in diatom culture (Pheodactylum tricornutum) with two microflagellates (Dunaliella tertiolecta and Cryptomonas sp.), where the irregular perturbations are caused by fluid surface-active aggregates

The high levels of surfactant activity measured in the surface layer are negatively correlated with salinity (Fig. 8). The decrease in salinity is an indication of the influence of the Po river. A significant and unique regression line seems to hold for the range of higher salinities (between 30°/oo and 38°/oo) (Fig. 9). However, the relationship is probably not valid for salinities lower than 30°/oo, i.e. for those sites closer to the Po delta.

4. CONCLUSIONS

Measurements of surfactant activity are particularly suited to the characterization of DOM in marine environments.

The significantly higher DOM levels in the northern Adriatic (compared to the rest of the Adriatic and open Mediterranean waters) are directly related to phytoplankton production: excretion and decay products.

During periods of higher primary production, a relatively high fraction of unsaturated lipids was identified in the sea surface microlayer and in the surface layer.

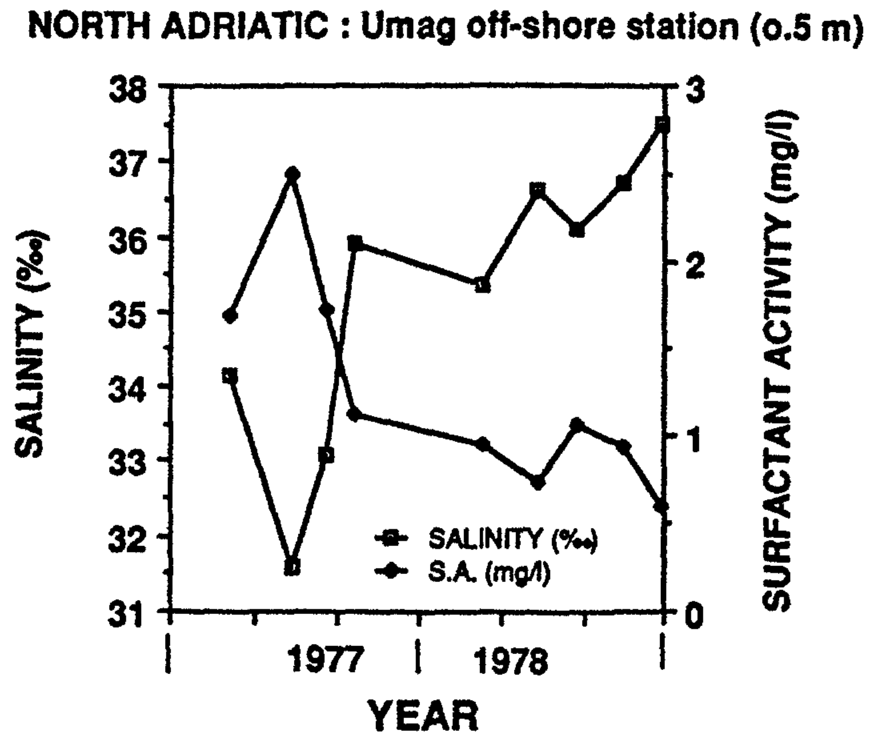


Fig. 8 Comparison of surfactant activity values (method A) and salinity in surface samples at the east coast

The input of nutrients by the river Po, primarily of phosphorus, appears to be a major factor in the determination of the increased levels of DOM in the Northern Adriatic.

The increased levels of DOM affect the form and fate of toxic metals and their entry into marine food chains (Zutic et al., 1985). The fate of radionuclides and hydrophobic organic pollutants is probably also affected. In addition, at higher concentrations, the decomposition of DOM causes excessive oxygen consumption. Finally, changes in the distribution of some biological species in the area may be expected (Legovic, 1988).

5. ACKNOWLEDGEMENTS

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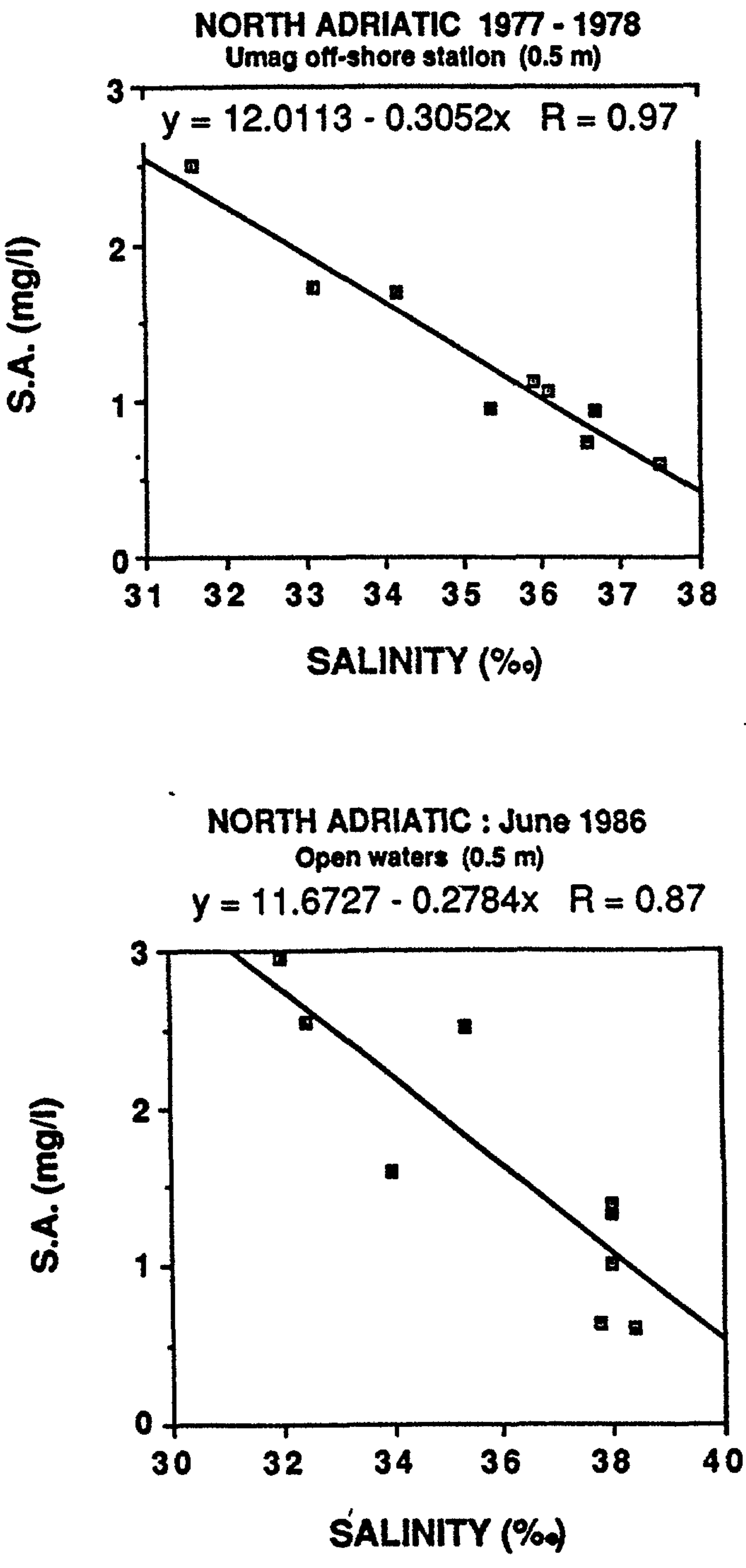

Fig. 9 Regression line for surfactant activity (method A) and salinity: the surface samples: (a) at the Umag offshore station (data from Fig. 8) and (b) at the transect Istrian peninsula - the Po delta

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