MEDITERRANEAN ACTION PLAN
MED POL

UNEP

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

# FINAL REPORTS OF RESEARCH PROJECTS ON TRANSPORT AND DISPERSION (RESEARCH AREA II)

## Modelling of eutrophication and algal blooms in the Thermaikos Gulf (Greece) and along the Emilia Romagna Coast (Italy)

**MAP Technical Reports Series No. 113**

UNEP
Athens, 1996

**ISBN 92-807-1624-7**



For bibliographic purposes this volume may be cited as:

UNEP/IOC: Final reports of research projects on transport and dispersion (Research Area II) - Modelling of eutrophication and algal blooms in the Thermaikos Gulf (Greece) and along the Emilia Romagna Coast (Italy). MAP Technical Reports Series No. 113. UNEP, Athens, 1996.

*Pour des fins bibliographiques, citer le présent volume comme suit:*

PNUE/IOC: Rapports finaux des projets de recherche sur le transfert et la dispersion (Domaine de Recherche II) - Modélisation de l'eutrophisation et des efflorescences algales dans le golfe Thermaïque (Grèce) et le long du littoral de l'Emilie-Romagne (Italie) . MAP Technical Reports Series No. 113. UNEP, Athens, 1996.

This volume is the one hundred-and-thirteenth issue of the Mediterranean Action Plan Technical Reports 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 Marine Pollution Emergency Response Centre for the Mediterranean.

Ce volume constitue le cent-treizième 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 méditerranéen pour l'intervention d'urgence contre la pollution marine accidentelle.

**PREFACE**

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 and 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 and appropriate allocations of resources.

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.

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.

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);

The Contracting Parties at their 6th Ordinary Meeting (Athens, October 1989) agreed to:

(a) Re-orient the research activities within MED POL in order to generate information which will also be useful for the technical implementation of the LBS protocol in addition to supporting monitoring activities;

(b) replace as from 1990 research activities A-L by the following five new research areas:

Research area I - Characterization and measurement

This area will include projects which cover the characterization (identification of chemical or microbiological components) and measurement development and testing of methodologies of specified contaminants;

Research area II - Transport and dispersion

This area will include projects which aim at improving the understanding of the physical, chemical and biological mechanisms that transport potential pollutants from their sources to their ultimate repositories. Typical topics will be atmospheric transport and deposition, water movements and mixing, transport of contaminants by sedimentation and their incorporation in biogeochemical cycles. Priority will be given to the provision of quantitative information ultimately useful for modelling the system and contributing to regional assessments;

Research area III - Effects

This area will include projects relevant to the effects of selected contaminants, listed in Annexes I and II of the LBS and Dumping protocols, to marine organisms, communities and ecosystems or man and human populations. Priority will be given to effects and techniques providing information useful for establishing environmental quality criteria;

Research area IV - Fates/Environmental transformation

This area will include projects studying the fate of contaminants (including microorganisms) in the marine environment such as persistence or survival, degradation, transformation, bioaccumulation etc. but excluding transport and dispersion which is dealt in area II;

Research area V - Prevention and control

This area will include projects dealing with the determination of the factors affecting the efficiency of waste treatment and disposal methods under specific local conditions as well as the development of environmental quality criteria and common measures for pollution abatement;

(c) define target contaminants or toher variables at periodic intervals depending on the progress of implementation of the LBS protocol;

(d) select project proposals on the basis of their intrinsic scientific validity, their Mediterranean specificity, and encourage whenever possible bilateral and multilateral projects among Mediterranean countries from the north and the south of the basin.

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 contains the final reports of research projects dealing with transport and dispersion of pollution. Final editing and compilation of this volume was done by Mr A. Bousoulengas, IOC Consultant on Marine Pollution Research and Monitoring.

**Thermaikos Gulf Case Study**
**Modelling Eutrophication and Plankton Blooms**

by
J. Ganoulis, L. Rossis and I. Krestenitis

**Hydrodynamic Effects on Nutrients Diffusion and Algal Blooms Along the Emilia Romagna Coast**

by
G. Montanari, P. Reic, A. Rinaldi and E. Todini

# TABLE OF CONTENTS

# THERMAIKOS GULF CASE STUDY : MODELLING EUTROPHICATION AND PLANKTON BLOOMS

by
J. Ganoulis, L. Rorris and I. Krestenitis
Hydraulics Laboratory, Dept. of Civil Engineering,
Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

## 1. INTRODUCTION

### 1.1 Definition of the Problem

In the Mediterranean region, particularly during the last two decades, the need has been felt to combat environmental pollution caused by the discharge into the sea of various pollutants from land-based sources. The ever-increasing quantities of such pollutants discharged into the sea have caused concern, which has led to a number of studies and research projects. In order to reach the long-term objective of defining the conditions under which wastewater containing various types of pollutants could be discharged without damage to the marine environment, it is necessary to understand the relationship between the pollutant loads and the resulting negative effects on the marine environment.

With regard to liquid wastes originating on land and discharged into the sea, one important category refers to nutrients. Nutrients are mainly composed of nitrogen and phosphorus substances and are the key factors for algal growth and eutrophication. Phytoplankton exists in many different forms (*e.g.*, diatoms, green algae, blue-green algae, dinoflagellates, etc.) and is an important part of the water ecosystem, determining eventual water quality. Algae are primarily responsible for the uptake of nutrients, which are then recycled through algal respiration and decay. Photosynthesis by algae in the euphotic zone produces oxygen; this is reversed at night due to respiration.

Algae settling in deeper, oligophotic waters, on the other hand, contribute to oxygen depletion there. Algae either take up dissolved $CO_2$ or respire $CO_2$, thus changing water pH and the subsequent chemical interactions in the water. Their presence increases water turbidity, reducing the euphotic depth in the column. On the other hand, phytoplankton constitutes the foundation of the food chain of higher species, virtually supporting the marine animal biota. Because of the variety of different algae, it is customary to consider algal concentrations in terms of chlorophyll-a concentrations. Algal growth is a function of temperature, solar radiation and concentrations of nutrients (phosphorus, nitrogen, carbon, and silicon substances for diatoms).

In this report, a mathematical model of eutrophication is presented following three main steps:

a) The particular Mediterranean conditions are briefly reviewed as far as the circulation and the mechanisms of dispersion and decay of pollutants are concerned; a classification of the bays in the Mediterranean is reported based mainly on morphological and water circulation considerations;

b) the various characteristics of the Gulf of Thermaikos, which is the study area of the project, are summarized; and

c) the mathematical model for eutrophication is presented together with some main results of simulation.

## 1.2 Aim of the Research Project

Many semi-enclosed bays and coastal areas in the Mediterranean are actually heavily polluted, mainly from domestic sewage and inputs from rivers and drainage ditches. Collection and analysis of water quality data is the basis for assessing the environmental situation and the risk of pollution. Mathematical models based on physical variables are useful tools to quantify the risk of pollution and explore the efficiency of different remedial measures to restore coastal ecosystems. In this report, the use of such models is illustrated for the case of eutrophication in the Thermaikos Gulf (NE Mediterranean Sea).

Water drained by rivers carries pollutant substances such as organics, nutrients, fertilizers and pesticides, its ultimate destination being coastal waters in estuaries. Major rivers discharging into the Mediterranean, such as the rivers Po, Rhone, Ebro and the Nile are heavily polluted. It has been recognised that coastal eutrophication from rivers is nowadays one of the most crucial environmental problems.

Pollution in river estuaries and deltas originates, apart from local sources discharging wastewaters into the river, mainly from diffuse sources, scattered within the entire river basin. Agricultural activities may overload soils with fertilizers and pesticides. Washing off the soil by rainfall produces large concentrations of nitrates, phosphorus and toxic chemicals in rivers and coastal waters. Time series data of pollutant concentrations in rivers show high variability both in time and space. Uncertainties related to various kinds of variability in data should be analysed and then quantified by means of adequate mathematical tools. This is shown for the case of the Axios River , which is discharging into the Bay of Thermaikos.

Recognizing that nutrients transported from rivers and sewage are the key factor for algal growth and eutrophication phenomena, the aim of the project is to analyse, understand and model eutrophication in coastal areas of the Mediterranean. As a case study, the Thermaikos Gulf, NW Aegean Sea, has been selected. The long-term objective was to propose measures and actions to efficiently combat eutrophication. More precisely, this project deals with the development and application of adequate mathematical models that can simulate eutrophication in the Mediterranean.

The present report aims to provide some basic information on mechanisms which regulate eutrophication in Mediterranean coastal areas, by use of mathematical modelling. All the computations and applications refer to a case study from the Thermaikos Gulf, NW Aegean Sea, Greece.

The main objective of the project is to couple an ecological mathematical model with a three-dimensional hydrodynamic one, in order to simulate eutrophication phenomena in the Mediterranean. Because of different space and time scales involved in the circulation and in ecological processes, the above objective has been achieved following two main tasks:

a) development of appropriate software to allow the ecological model to use results from the hydrodynamic model; and

b) development of computer codes to simulate eutrophication in Mediterranean coastal areas.

## 2. MEDITERRANEAN CONDITIONS

### 2.1 General Conditions

The following conditions in the Mediterranean may be important in order to understand and model eutrophication:

a) tideless sea: good weather during the summer and weak currents;

b) oligotrophic conditions in most open areas allow relatively high loads of domestic wastes if sufficient dilution is assured;

c) solar exposure and transparency of waters result in important apparent die-off of bacterial indicators and quick photolytic degradation of some non-persistent organic substances; and

d) the general absence of strong tidal currents and the subsequent lack of dispersion in the Mediterranean give great importance to attaining a high degree of eutrophication.

Because of these reasons, for most situations in the Mediterranean, eutrophication is mainly developed in semi-enclosed bays and gulfs, where the degree of water renewal is relatively small.

## 2.2 Classification of Bays and Gulfs in the Mediterranean

The morphology and openness of the coast is one of the main characteristics to be considered when studying eutrophication, as it defines the renovation capacity of a given gulf. The currents field clearly depends on the degree of openness or enclosure of a certain coastal zone. In semi-enclosed areas, the actual effective length is greatly reduced, so that pollutant discharges do not reach the open sea and remain inside the semi-enclosed areas.

As shown in Fig. 1, two different cases may be distinguished

a) semi-enclosed gulfs and bays; and

b) open gulfs.

There are also intermediate situations with morphologies between semi-enclosed and open gulf or bay.

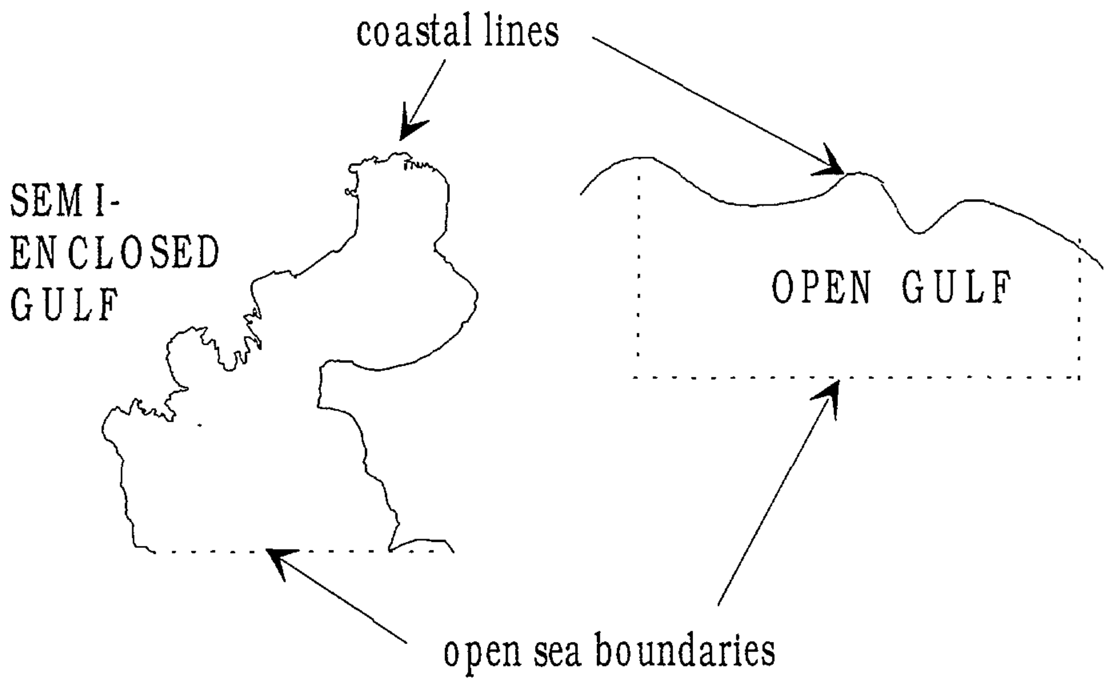



Fig. 1 Types of marine coastal areas.

## 2.3 Water Quality Standards

Water quality standards for the protection of freshwater and marine environment have been developed in several countries. However, these standards do not explicitly refer to eutrophication and similar phenomena related to algal growth. Freshwater, bathing water and, to a lesser extent, shellfish-growing water quality criteria have been issued by states, the European Union and also International Organizations.

To be useful in practical problems, water quality criteria need to fulfil the following basic characteristics:

a) the criteria have to be expressed in terms of parameters and values which may be easily measured;

b) criteria and parameters should be relevant to the beneficial uses in the water body; they have to be associated with sanitary and ecological consequences, either through a direct cause-effect relationship or through a clearly-stated statistical relationship;

c) criteria should be attainable by normal technical procedures and should take into account the natural base-line concentrations in regional waters; and
d) although only average values are mainly used for the design, in order to take into account the natural variability and changes in environmental parameters, water quality criteria should be defined in a statistical form.

To preserve *fisheries* in freshwater, such as rivers and lakes, recommended water quality criteria are given in Table 1, according to the EC directives. Only nitrites, ammonia and phosphorus are implicitly related to eutrophication.

In 1985, Mediterranean countries have adopted interim criteria for bathing waters, based mainly on faecal coliforms, though faecal streptococci constitute also an important additional parameter. Recommended *bathing water quality criteria* are listed in Table 2.

Table 1

Recommended Freshwater Water Quality Criteria for Fisheries Protection.
(EC Directive 18/7/78- 78/659/CEE-JO 14/8/78))

| Quality Criteria | Unit | Desirable Limit | Higher Allowable Limit |
|---|---|---|---|
| Dissolved oxygen | ppm | 50%>=8<br>100%>=5 | 50%>=7<br>100%>=4 |
| Suspended solids | ppm | 25 | |
| $BOD_5$ | ppm | 6 | |
| Total ammonia ($NH_4+$) | ppm | 0.2<br>(0.16)** | 1<br>(0.78)** |
| Nitrites($NO_2$-) | ppm | 0.03 | |
| Total phosphorus (P) | ppm | 3 | |
| Dissolved copper (Cu) | ppm | 0.04 | |

** Nitrogen-Ammonia ratio N/$NH_4$+

Table 2

Recommended Bathing Water Quality Criteria for Design Purposes
(UNEP, 1985; 1994).

| Parameter | Unit | Percentages | | Remarks |
|---|---|---|---|---|
| | | 50% | 90% | |
| A. Bacteriological | | | | |
| 1. Faecal coliforms | n/100 ml | 100 | 1,000 | Bathing |
| 2. Faecal Streptococci | n/100 ml | 100 | 1,000 | Bathing |
| B. Physical | | | | |
| 3. Colour | mg Pt-Col/l | 10 | 30 | * |
| 4. Suspended solids | mg/l | 1.3NV | 1.5NV | ** |
| C. Chemical | | | | |
| 5. Dissolved oxygen | mg/l | 6 | 5 | Surface |
| 6. Nitrogen ammonia | mg N/l | 0.05 | 0.12 | |
| 7. Dissolved ortho-phosphate | mg P/l | 0.02 | 0.05 | |

* To be observed at the plume surfacing point
** NV = Background (normal) value in the area before the discharge

In case of *shellfish farming*, criteria and standards in current use are based on bacterial concentrations in the shellfish themselves, as opposed to the actual waters (Table 3).

Table 3

Water Quality Criteria for Oyster Farming Waters
(EC Directive 30/10/79-79/923/CEE-JO 10/11/79).

| Quality Criteria | Unit | Desirable Limit | Higher Allowable Limit |
|---|---|---|---|
| Dissolved oxygen | % of saturation | >=80% | 70-110% |
| Faecal coliforms<br>(waters)<br>*(in the flesh)* | n/100ml<br>n/100ml | <70/100*ml*<br><=300/100*ml* | |

Because of the concentration factor and uptake variations, no definite correlation has been established so far between concentrations in the actual shellfish and the surrounding water. A recommendation made by WHO and UNEP in 1986 proposed a maximum concentration of 10 faecal coliforms per 100 ml in, at least, 80% of the samples, and a maximum concentration of 100 faecal coliforms per 100 ml, in 100% of the samples. The quality criteria adopted on a joint basis by Mediterranean states in 1987 impose a maximum concentration of 300 faecal coliforms per 100 ml of shellfish (flesh + intervalvular fluid) in at least 75% of the samples.

For the calculation and control of the impact from wastewater disposal, faecal coliforms and faecal streptococci can be taken as non-conservative pollutants subject to exponential bacterial decay. Dissolved oxygen should be evaluated taking into account the oxygen consumption due to bacterial degradation of organic matter. Nitrogen ammonia and dissolved ortho-phosphate should finally be considered as conservative pollutants, while colour, suspended solids and pH criteria are applied in the upper parts of the rising plume. All these criteria are presented in Tables 1, 2 and 3, mainly as technical recommendations.

Water quality criteria can also be used as a tool for monitoring domestic wastewater discharges, coastal and freshwater areas and also for the control and evaluation of the efficiency of sanitary engineering works. They are included here only as reference and in any case they don't explicitly refer to eutrophication.

## 3. CHARACTERISTICS OF THE GULF OF THERMAIKOS

Information on pollutant loads is essential in analysing the long-term quality characteristics of coastal waters. More specifically, with respect to eutrophication, it is useful to see the likely effect of the pollutant loads on coastal water quality. This can be studied by simulation, as presented below for a typical case in the Mediterranean; the Thermaikos Gulf, north Aegean Sea. The question is: what would the consequences be on the water quality of the Thermaikos Gulf from any variation on the amount of pollutants entering the Gulf? In the case study, only the direct influence of load changes on water quality will be considered. Indirect effects, caused by variations in the amount of runoff or rainfall precipitation entering the water body, have not been included.

Using the results of monitoring at twelve stations over the time period 1984-1990, the water quality in the Thermaikos Bay area is first presented. In all these stations temperature, salinity, pH, dissolved oxygen, nitrites, nitrates, ammonia, phosphates, silicates, heavy metals, total coliforms and E-coli have been measured in the water column with seasonal frequency. There is a general trend in water pollution to increase from south to north and from the open sea to the river estuaries. This reflects the effect of pollutant loads from human population in the northern region and from river flow. Mathematical modelling of the transport and fate of pollutants in the bay are used to assess the risk of pollution. Models are very useful in analysing various combinations between the choice of the disposal site and the effects on eutrophication.

### 3.1 Description of the Thermaikos Gulf

The Thermaikos Gulf is located at the north-west corner of the Aegean Sea with a width of 15 km at its maximum opening between Aherada Peninsula, on the west, and Epanomi on the east (Figs. 2 and 3). The maximum "height" of the gulf, from north to south, is 45 km and its total surface 473 $km^2$; Fig. 3 sketches its bathymetry. Thermaikos is open only on the south side. It constitutes the discharge basin for one major river (Axios) and three minor in terms of flowrate (Aliakmon, Loudias, Gallikos) (Fig. 2). All three carry water year-round, with flow rates varying between 10 $m^3/s$ and 400 $m^3/s$ from summer to winter. The flow rates vary greatly also due to irregular drainage from agricultural irrigation (Ganoulis, 1988, 1990, 1991a). In addition, the sewage from the town of Thessaloniki (1,000,000 inhabitants) is also discharged into the gulf.

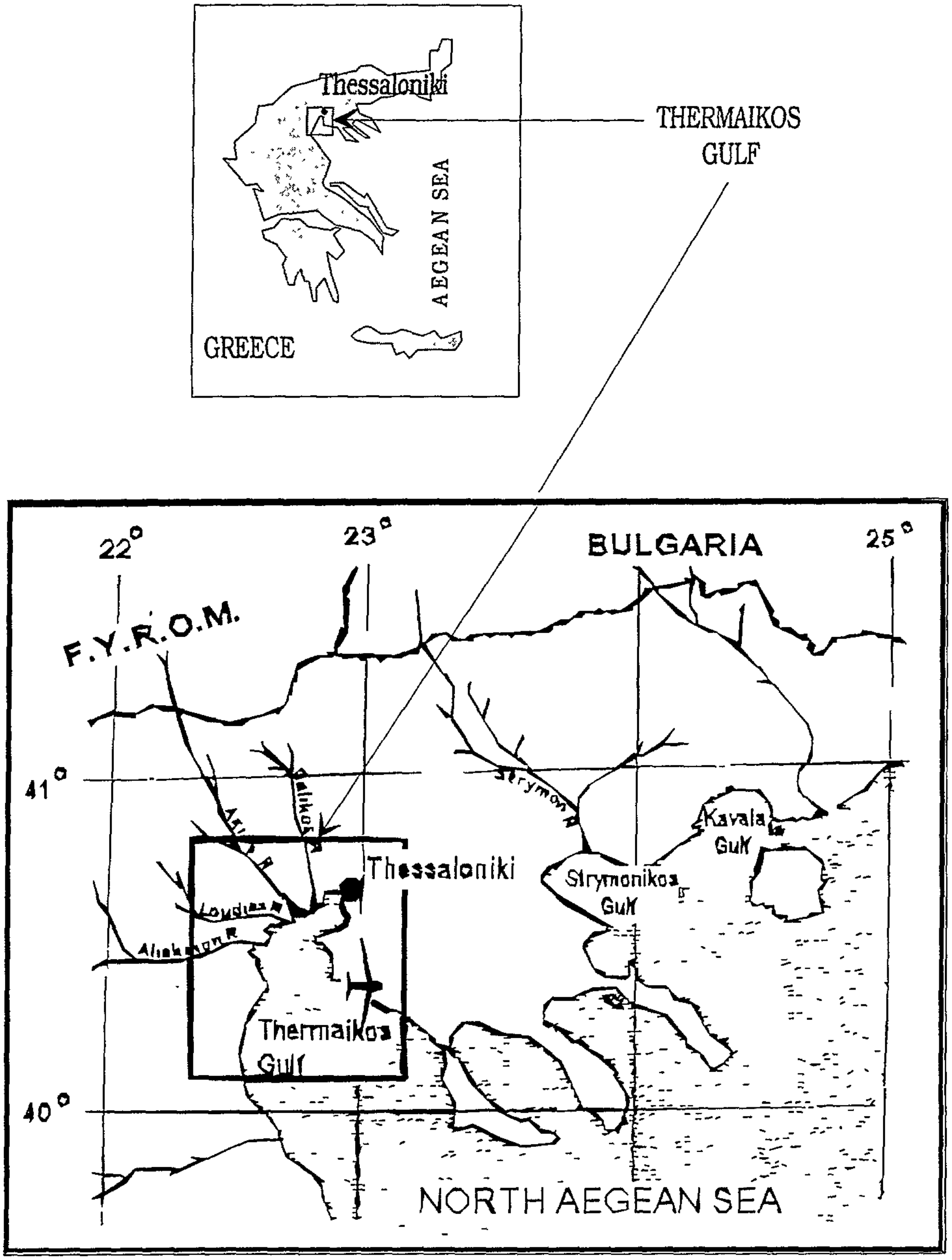



Fig. 2 Geographic location of Thermaikos Gulf.

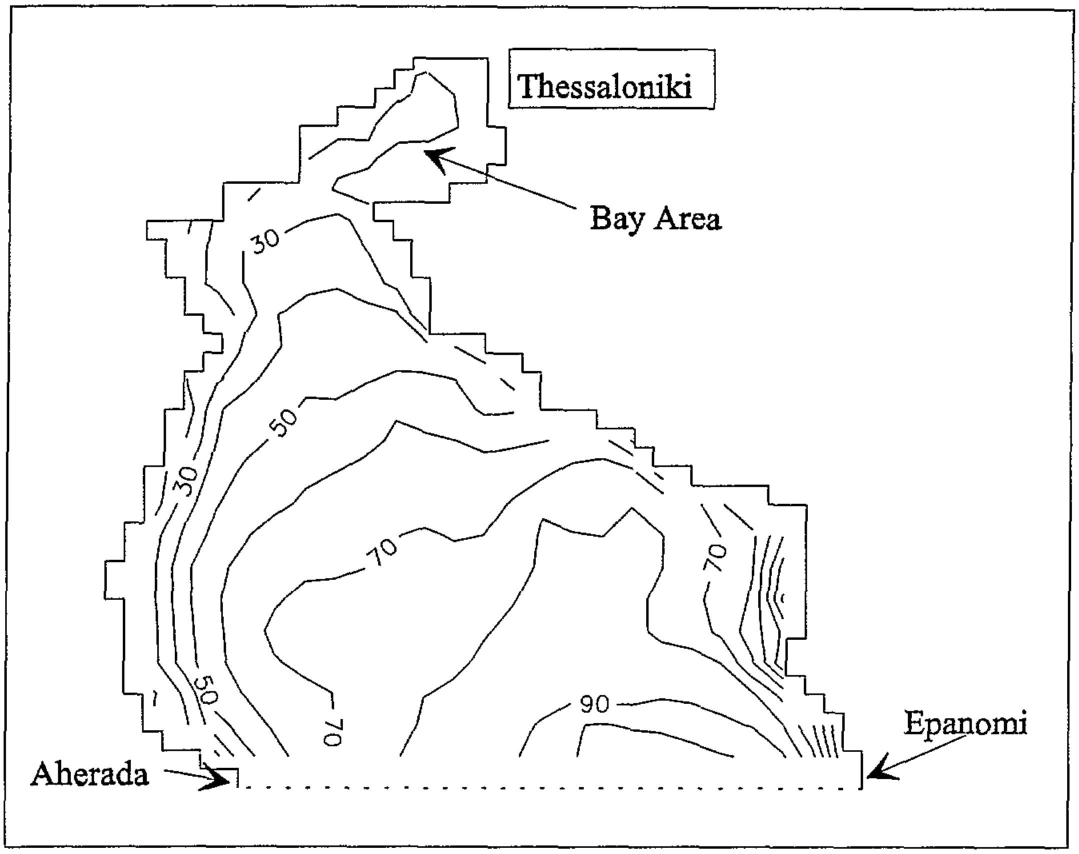



Fig. 3 Bathymetry of Thermaikos Gulf (in [*m*]).

## 3.2 Hydro-meteorological Characteristics

The main climatological data in the region are shown in Tables 4 and 5. The prevailing winds are S-SE, during summer, and N-NW during winter (Fig. 4). Strong winds (>15 m/s) are infrequent and of short duration, lasting one or two days and arising usually during winter.

Table 4

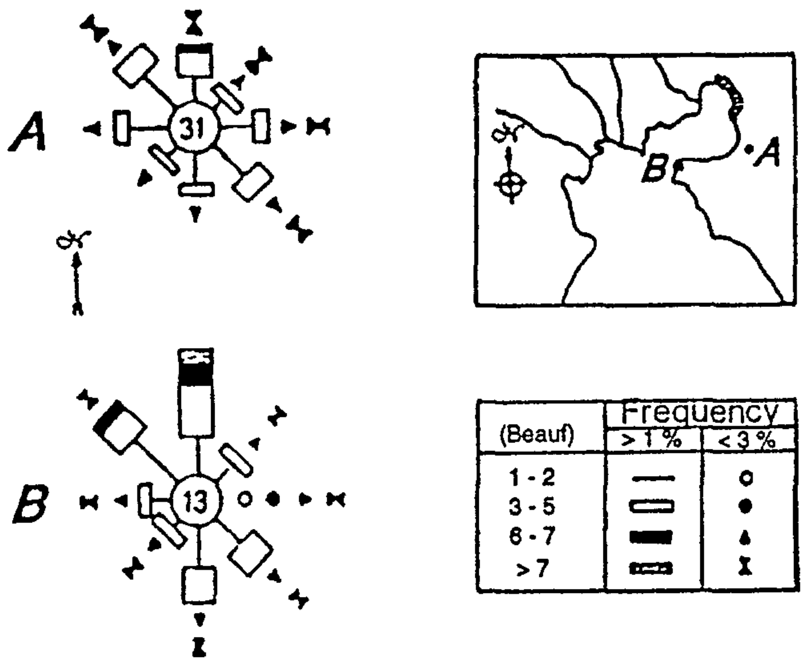
Meteorological characteristics in the Thermaikos Gulf: temperature during the period 1930-75 (from Ganoulis, 1988).

| Temp [$^oC$] | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min | 3.0 | 2.9 | 6.3 | 12.1 | 17.5 | 22.6 | 25.4 | 25.4 | 20 2 | 14.2 | 9.5 | 5.2 | 15.3 |
| Max | 10.5 | 11.3 | 13.7 | 17.4 | 22.3 | 25.4 | 28.3 | 28.4 | 25 4 | 21 5 | 14.5 | 11.5 | 17.5 |
| Ave | 6.0 | 7.3 | 10.0 | 14.8 | 19.6 | 24 0 | 26.8 | 26.5 | 22.4 | 17.2 | 12.4 | 8 0 | 16.2 |

Table 5

Meteorological characteristics in the Thermaikos Gulf: precipitation during period 1930-75 (from Ganoulis, 1988).

| Month | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation[$mm$] | 41 | 35 | 40 | 41 | 49 | 37 | 27 | 20 | 31 | 51 | 56 | 55 | 483 |




| Beaufort strength | 1-2 | 3-5 | 6-7 | >=8 |
|---|---|---|---|---|
| [m/s] | 1-3 | 3-10 | 10-17 | >=17 |

Fig. 4 Meteorological characteristics in the region of Thermaikos Gulf: average yearly wind roses at two locations (A=Thessaloniki Mikra airport, B=Epanomi) during 1950-68 (from Ganoulis, 1988).

### 3.3 Sewage Works

The initial design of the sewage system of the city of Thessaloniki is shown in Fig. (5). The Figure focuses on the upper part of the gulf, known as the Bay of Thessaloniki. The main sewer collector (SC) is a tunnel of 2m in diameter, located at an average depth of 20m. This pipe collects all the sewage of the city from the eastern to the western part of the greater Thessaloniki metropolitan area. It ends in the sewage treatment plant (TP), located close to the river Gallikos (Fig. 5). An advanced treatment of sewage has been decided, including bio-oxidation of wastewater. After this treatment, the disposal of wastewater was initially into the river Axios using a twin-pipe system between the sewage treatment station and the river Axios (Fig. 5). Because of the environmental concern about the water quality in the river and estuary, the design has been modified. This is due to the fact that the flow rate of the river Axios has been constantly decreasing during the last few years, leading to lower wastewater dilution. In the same time, for the protection of river and coastal waters, the new water quality standards should be applied, according to the directives issued by the European Union. The coastal area close to the river mouth is considered as a protected area of very great importance from the ecological point of view. According to the RAMSAR convention this area is a special protected estuary. An estimation of the pollutant loads discharging into the bay is given in Table 6.

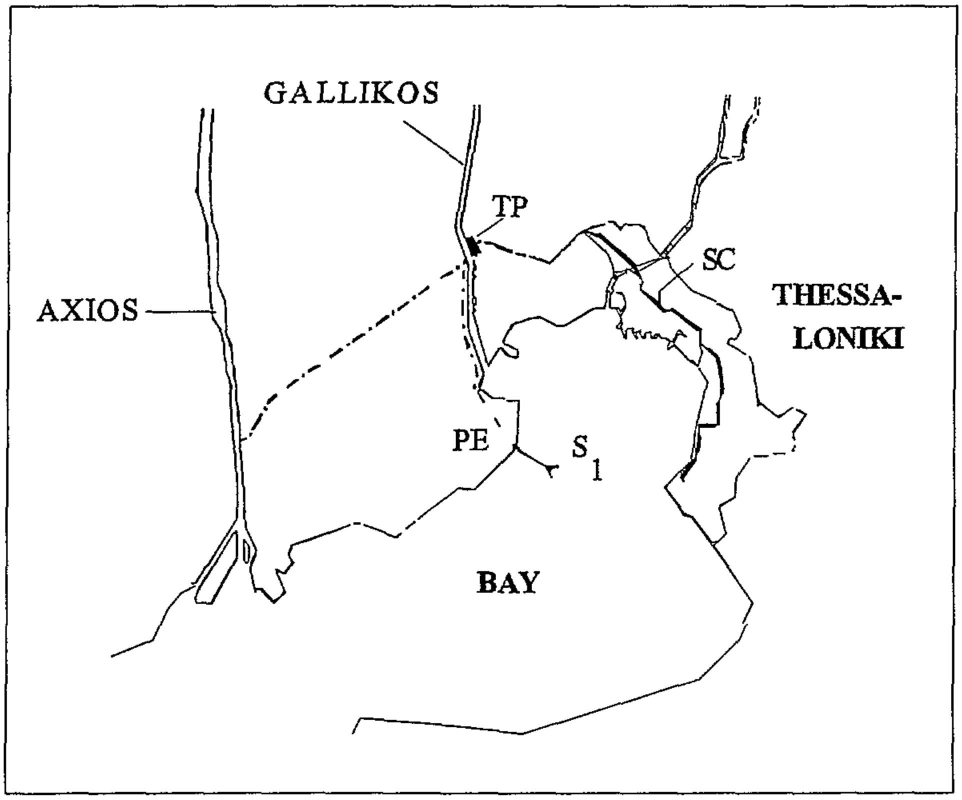



Fig. 5 Sewage collection and treatment plant in the city of Thessaloniki.

Until biological treatment of all wastewater is implemented in the near future, a preliminary operation of the treatment plant is provided since 1992. During this transitional period, wastewater disposal occurs in the upper part of the bay (point PE), by using a ditch parallel to the bed of the river Gallikos (Fig. 5). The local environmental impact in this area and especially the concentrations in coliforms have been studied by application of risk assessment and mathematical modelling techniques (Ganoulis, 1991b; 1992).

### 3.4 Pollutant Loads from Land-Based Sources

Estimation on the amount of pollutant loads entering daily the Gulf of Thessaloniki from land based sources is summarized in Tab. 6. Concerning the nutrients it may be noted that the most important source is Axios River.

Table 6

Pollutant loads in the Gulf of Thessaloniki

| Pollutant Sources | Flowrate ($m^3$/day) | $BOD_5$ (kg/day) | N (kg/day) | P (kg/day) |
|---|---|---|---|---|
| Sewage | 150,000 | 60,000 | 10,000 | 4,000 |
| Industrial waste-waters | 60,000 | 10,000 | 5,000 | ? |
| Axios | Winter 170 $m^3$/s<br>Summer 20 $m^3$/s | 50,000 | 16,000 | 4,000 |
| Aliakmon | Winter 80 $m^3$/s<br>Summer 10 $m^3$/s | 20,000 | 3,000 | 900 |
| Loudias | Winter 30 $m^3$/s<br>Summer 10 $m^3$/s | 20,000 | 3,000 | 900 |
| Pumping stations | Winter 15 $m^3$/s<br>Summer 2 $m^3$/s | 20,000 | 4,000 | 400 |

The case of Axios River has been studied in relation with the more general problem of the systematic increase of nitrates in surface waters in Greece and other European countries. This increase in concentrations constitutes a potential danger of eutrophication in the Gulf of Thermaikos.

Although the nitrate concentration in surface waters does not exceed generally the critical values fixed by the EU standards, there are many cases of local water contamination by nitrates. These refer to rivers, lagoons and semi-enclosed coastal areas, where surface waters drain large quantities of nitrates (Giannakopoulou, 1990). In these areas the water renewal is very small and high nitrate concentrations enhance eutrophication phenomena.

Data of nitrate concentration available from monitoring in Axios River show in many cases a systematic trend to an increase in nitrate content. This trend is to be taken into consideration together with farming, particularly the increasing use of fertilizers, which are among the principal sources for nitrate contamination. There is also use of septic tanks in urban areas, where the sewer system is also an important source of nitrate pollution.

In this section, an overview of the present situation is summarised. It refers to Axios River (Makedonia, Northern Greece), where monthly sampling of nitrate concentration is made and related water quality parameters have been analysed during the last few years. To prevent water pollution by nitrates, many technical alternatives are possible. They can be efficient, depending on the degree of knowledge of the existing environmental situation as well as of the relation between the pollutant loads from external sources and the level of nitrate concentration in waters.

As shown in Fig. (6) Axios River has a partial length of approximately 75 km between the international border and the sea. This corresponds only to 10% of the total basin area of 23.750 $km^2$, the remainder being located in F.Y.R.O.M.

The mean flow rate of the river is about 170 $m^3/s$ and the minimum, during the summer, 37 $m^3/s$. Samples have been collected on a monthly basis at monitoring station III starting from April 1988 (Fig. 6). The following water quality parameters have been analysed: temperature, pH, dissolved oxygen, BOD, COD, suspended solids, salinity, conductivity, nitrites, nitrates, ammonia, total organic nitrogen (NK), phosphates, silicates and heavy metals.

The time series of the nitrogen related parameters are shown in Fig. 7. All these values (in ppm) are rather low and especially are far below the prescribed values by the standards for drinking water. By comparing the mean values of the nitrate-nitrogen concentrations with the corresponding values in the period 1981-82 (Tab. 7) it is seen that in 7 years the increase in nitrate-nitrogen is about 50%.

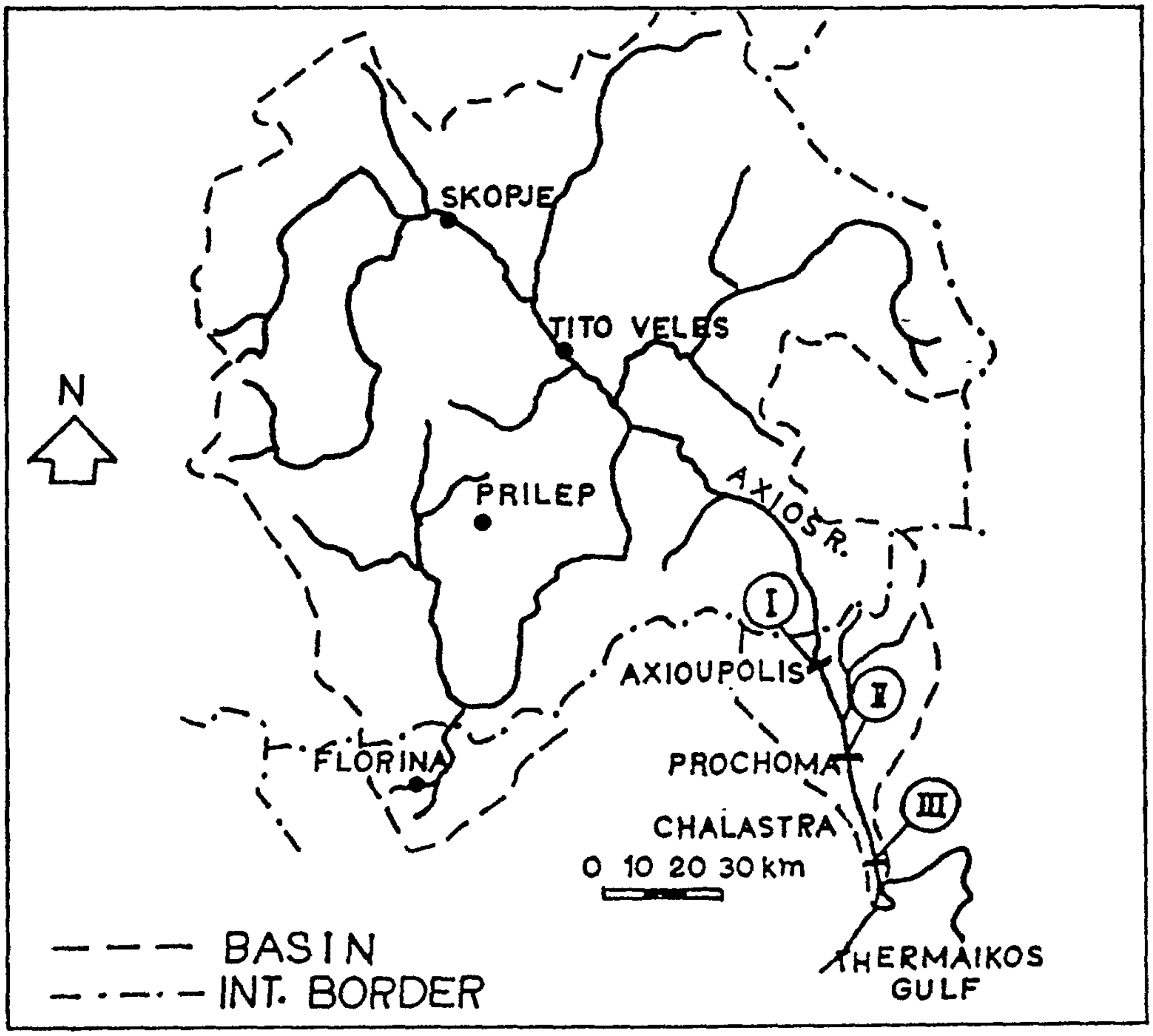



Fig. 6 Monitoring stations at Axios River.

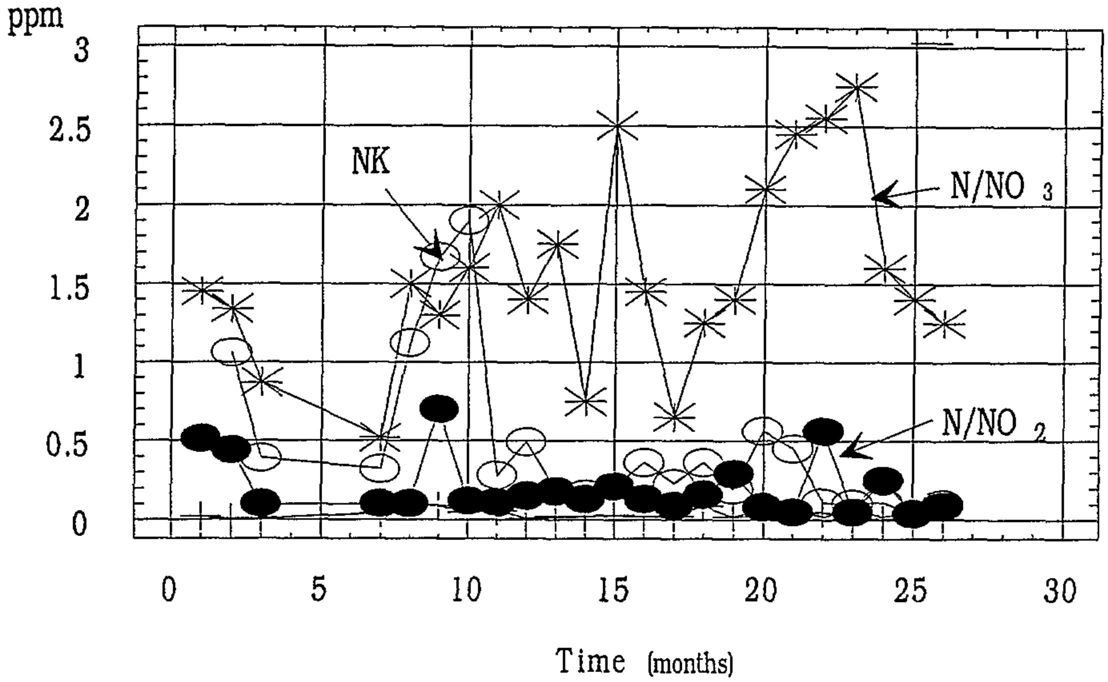



Fig. 7 Time series of nitrogen related parameters at station III (Axios River).

Table 7

Values of N-NO3 concentrations (in ppm) in the Axios River.

| Period | min | mean | max |
|---|---|---|---|
| 1981-82 | 0.50 | 1.05 | 1.76 |
| 1988-90 | 0.52 | 1.56 | 2.75 |

This trend is confirmed during the time period 1988-1990 by the linear regression shown in Fig. (8). Exploring possible sources for nitrate pollution in Axios River, a seasonal analysis of the existing data has been made. First, by computing the autocorrelation coefficient of the nitrate time series it has been found that no significant correlation exists for a time period greater than three months. By plotting the seasonal subseries of N-NO3 concentrations over one year, it is seen in Fig. (9) that the increase of nitrates is systematic between November and February each year. This corresponds to the rain period and the washing off the soil by the drainage water.

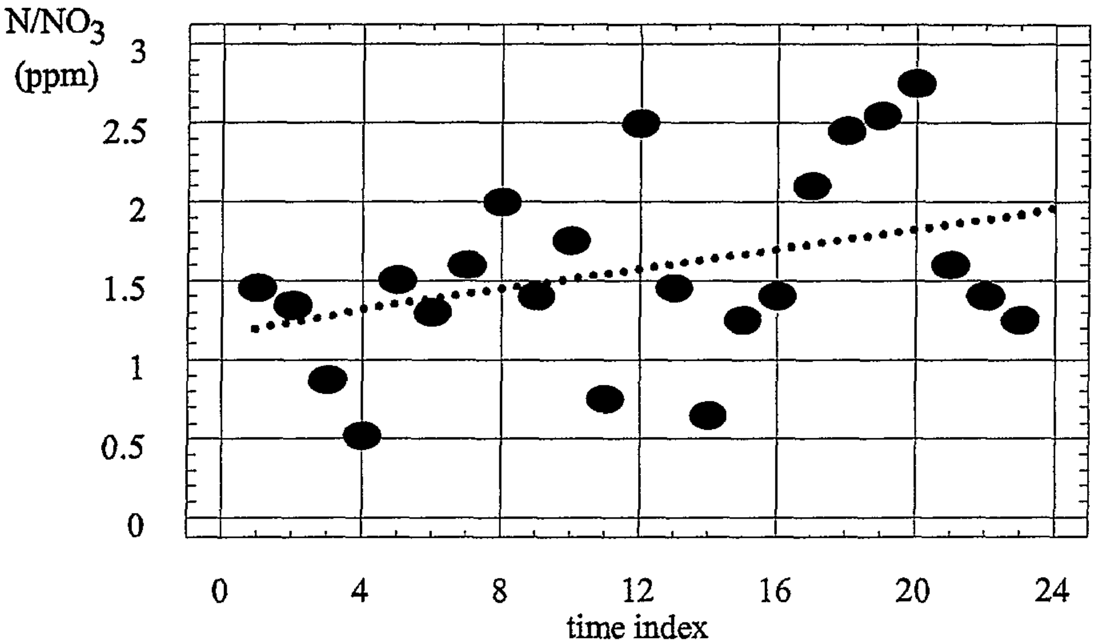



Fig. 8 Linear trend for N-$NO_3$ concentrations at station III (1988-90) (Axios River).

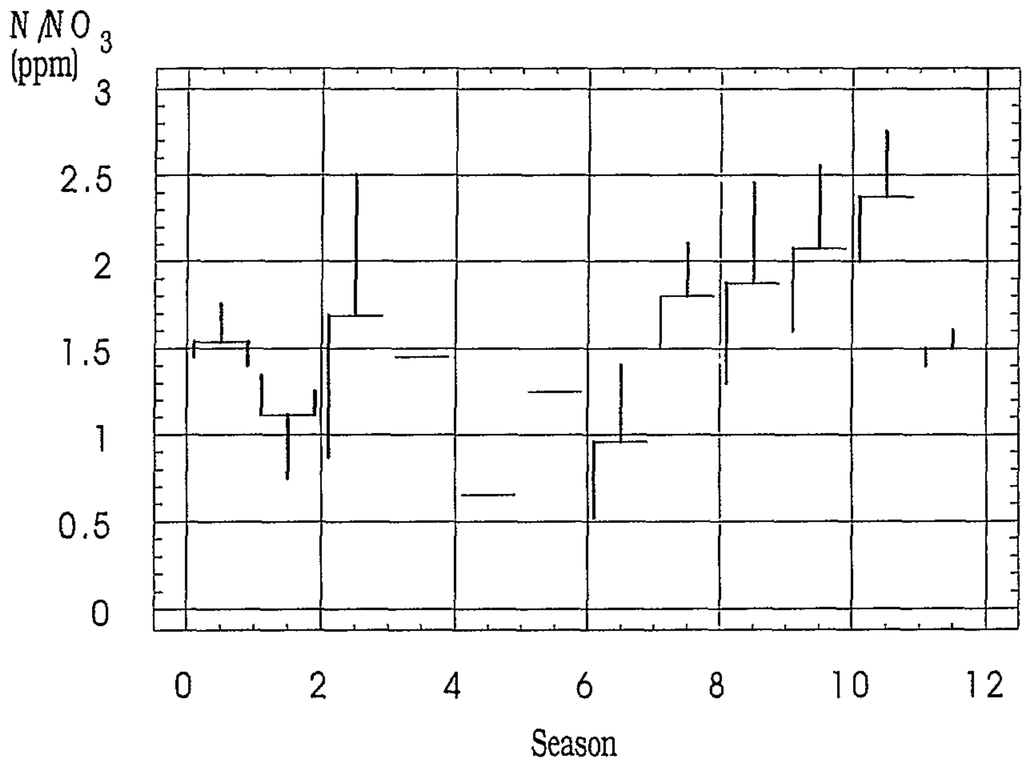



Fig. 9 Seasonal subseries of N-$NO_3$ concentrations at station III (Axios River).

## 3.5 Assessment of the Water Quality in the Gulf

Monitoring of water quality characteristics and data processing is the basis for formulating computerized mathematical models in order to decide on the appropriate remedial measures for environmental protection. The main objective of a previous study was the assessment of the present environmental situation in the bay of Thermaikos and the environmental impact analysis of the sewage works, currently under completion in the city of Thessaloniki. As shown in Fig. (10), appropriate sampling stations non-uniformly distributed in space have been selected. Using the research vessel "THETIS" (13m long) during the period 1984-1990, more than 2,500 water samples were collected and analysed. Apart from the currents and winds, the following parameters were monitored with seasonal frequency near the surface, the mean depth and near the bottom of the water column

(a) Temperature, salinity, density, dissolved oxygen, pH;

(b) Nutrients as $NO_2^-$, $NO_3^-$, $NH_4^+$, $PO_4^{3-}$, $SiO_4^{4-}$

(c) Total coliforms and E-coli; and

(d) Heavy metals as Cd, Pb and Cu.

Heavy metals have been also analysed in sediments. Variations of the water quality parameters are very large both in time and space. As an example, the time series of nitrates at station 1, located near the city of Thessaloniki is shown in Fig. (11). These variations are due to the irregular physical conditions which prevail in the Mediterranean. In fact, the tides are very low and the wind induced circulation is strongly unsteady and variable in space. In view of the large variations of the data a statistical analysis has been performed. The contour lines of equal dissolved oxygen concentrations are shown in Fig. (12). These are mean values over the time period 1984-1989 near the seafloor.

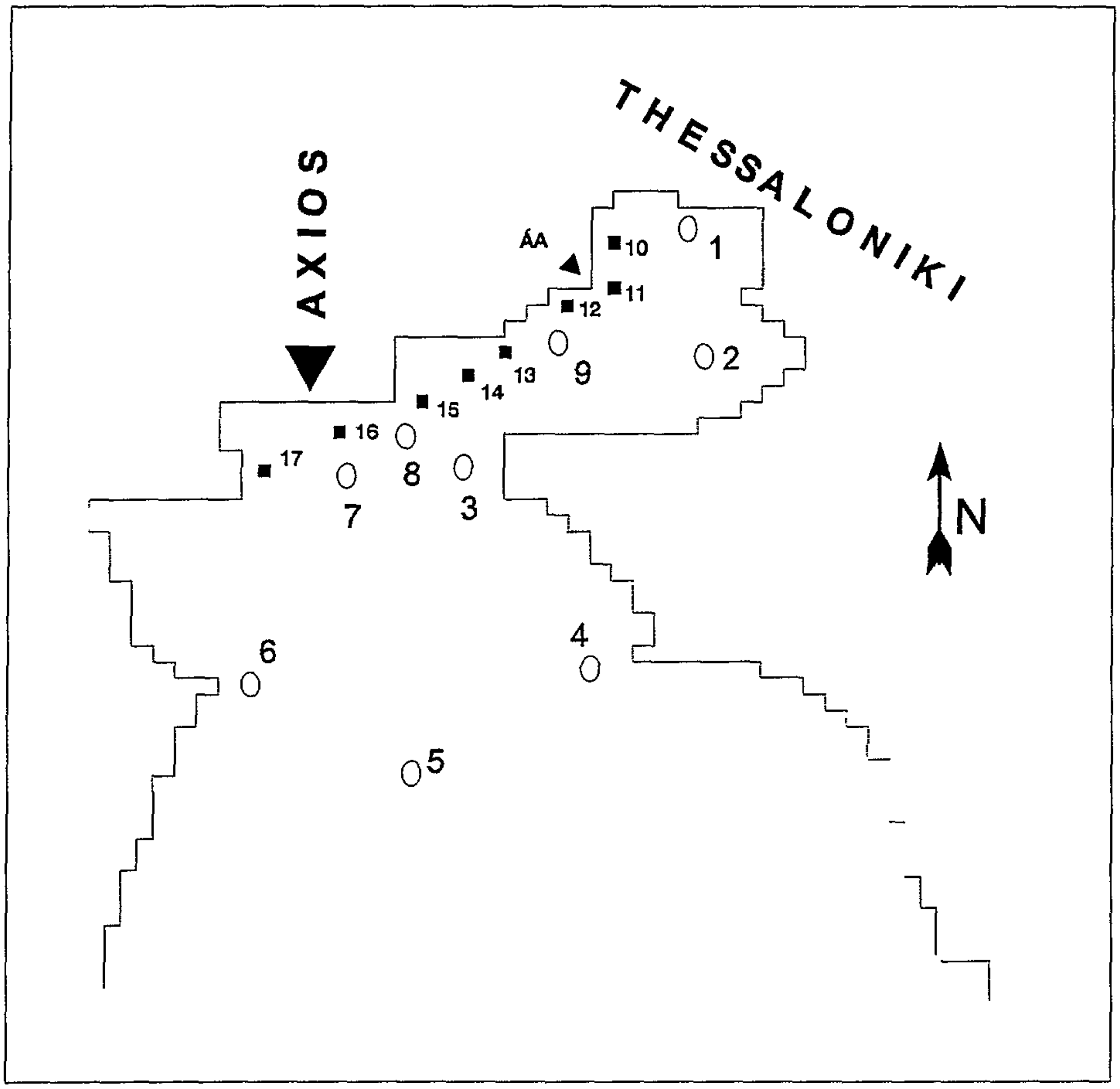



*Fig. 10* Location of sampling stations in Thessaloniki Bay.

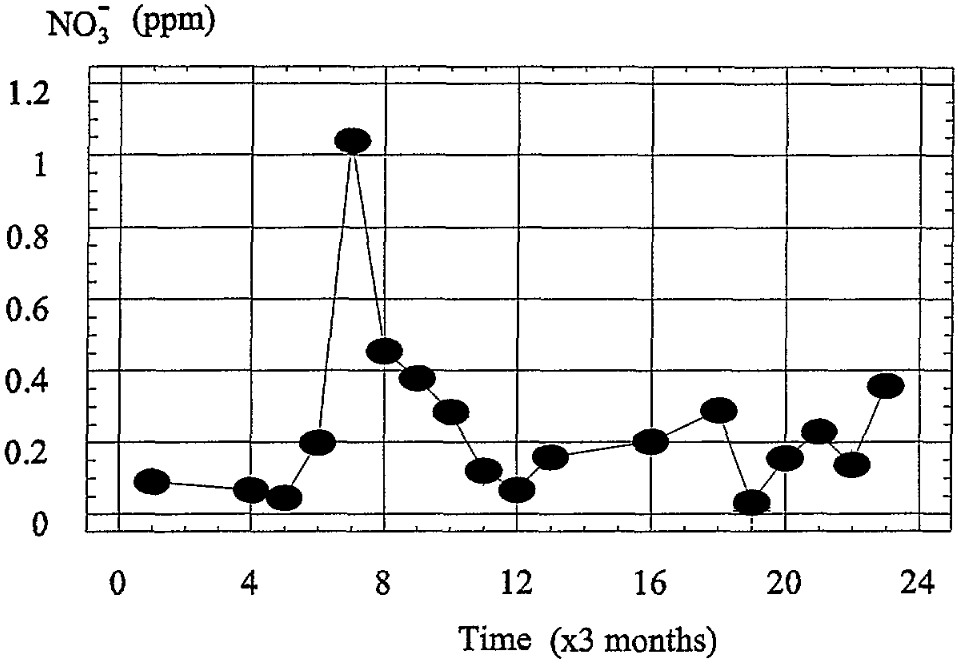



Fig.11 Time series of nitrates $NO_3^-$ recorded at station 1, near the surface.

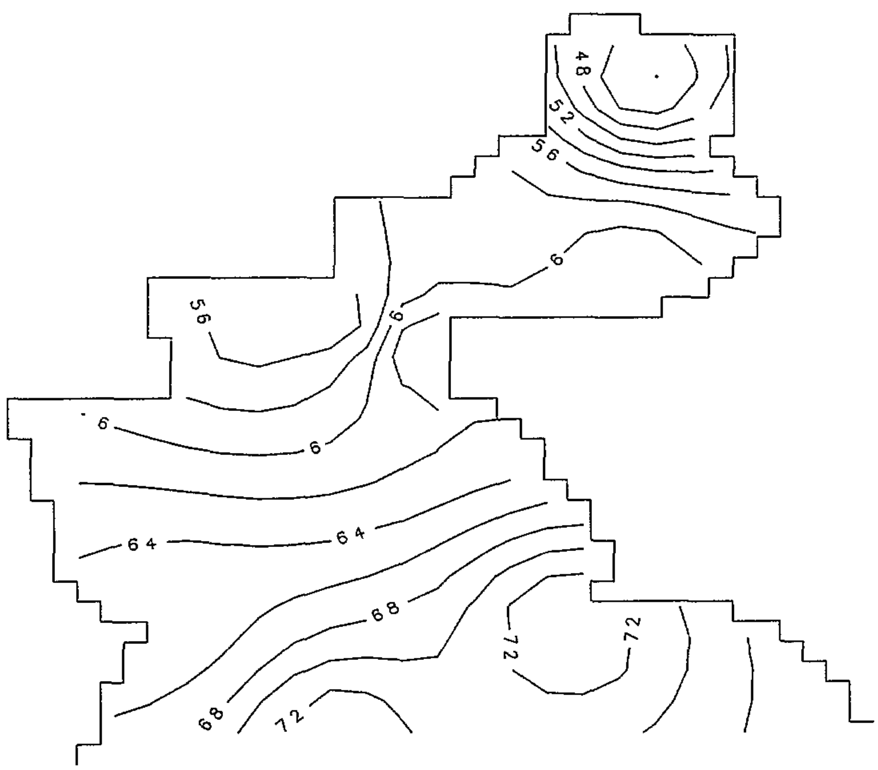
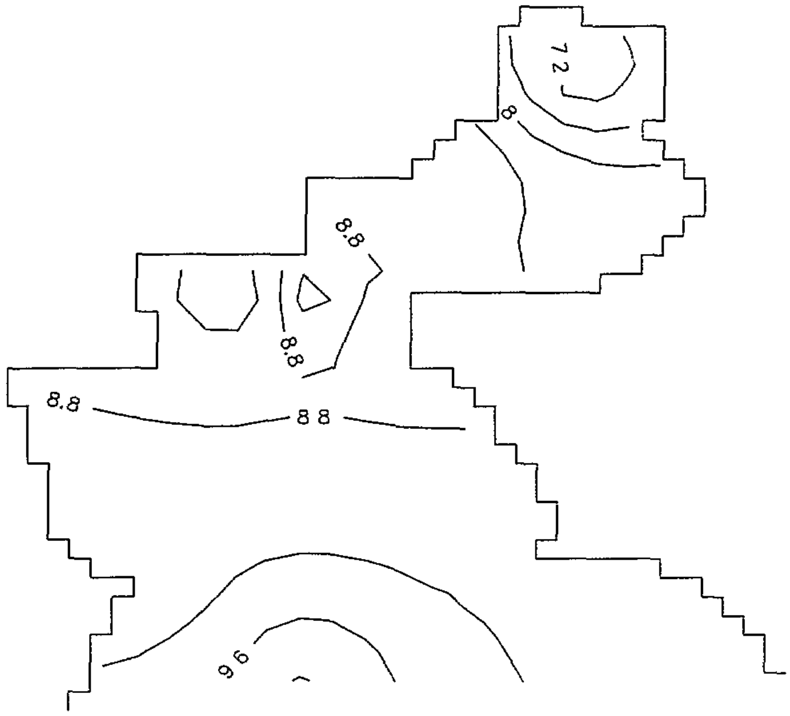
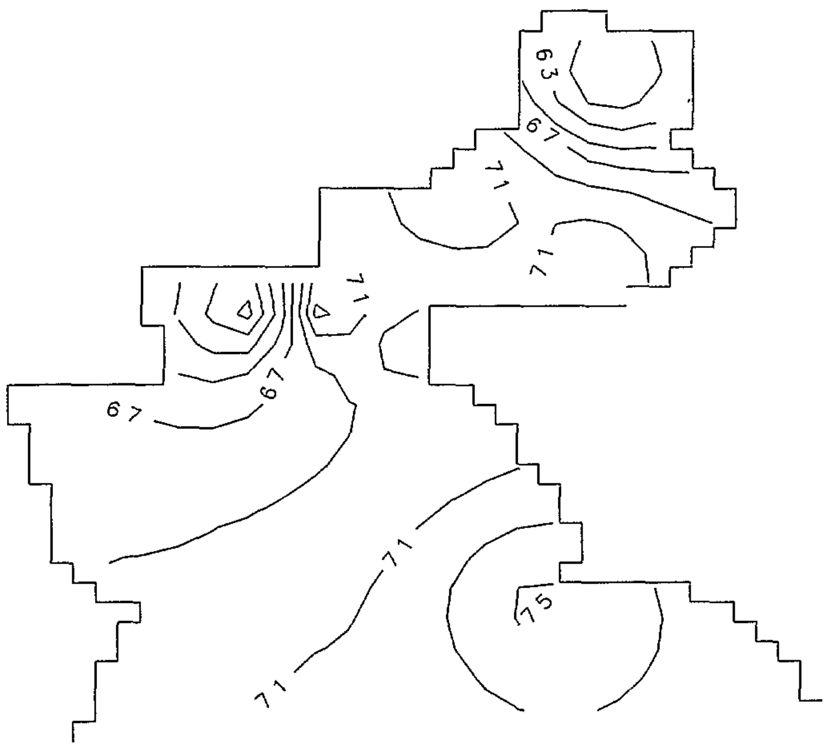



Fig. 12 Distribution of dissolved oxygen (DO) in Thermaikos Gulf (mean values over 1984-1989 measured near the seafloor).




(a)




(b)

Fig. 13 Experimental results for the distribution of DO near the bottom of Thermaikos Gulf (averaged annual values(a) 1992 and (b) 1991) (from Ganoulis, 1988; 1990).

From these data a statistical trend is deduced to increase water pollution from south to north (high population density) and to the river estuaries (high pollutant loads). In fact four different zones are distinguished, ranging from very bad to excellent water quality situation (Ganoulis, 1988).

It should be noted (Figs. 12 and 13) that mean annual values of dissolved oxygen are not constant, especially for the years 1991 and 1992. A general improvement can be observed in 1992, possibly due to the operation of the wastewater treatment plant (started beginning 1992). Ecologically sensitive coastal zones in the bay area, requiring special protection measures, are shown in Fig. 14. These include the major part of the western coast near the rivers, where the water depth is small and large quantities of nutrients are discharged from the rivers.

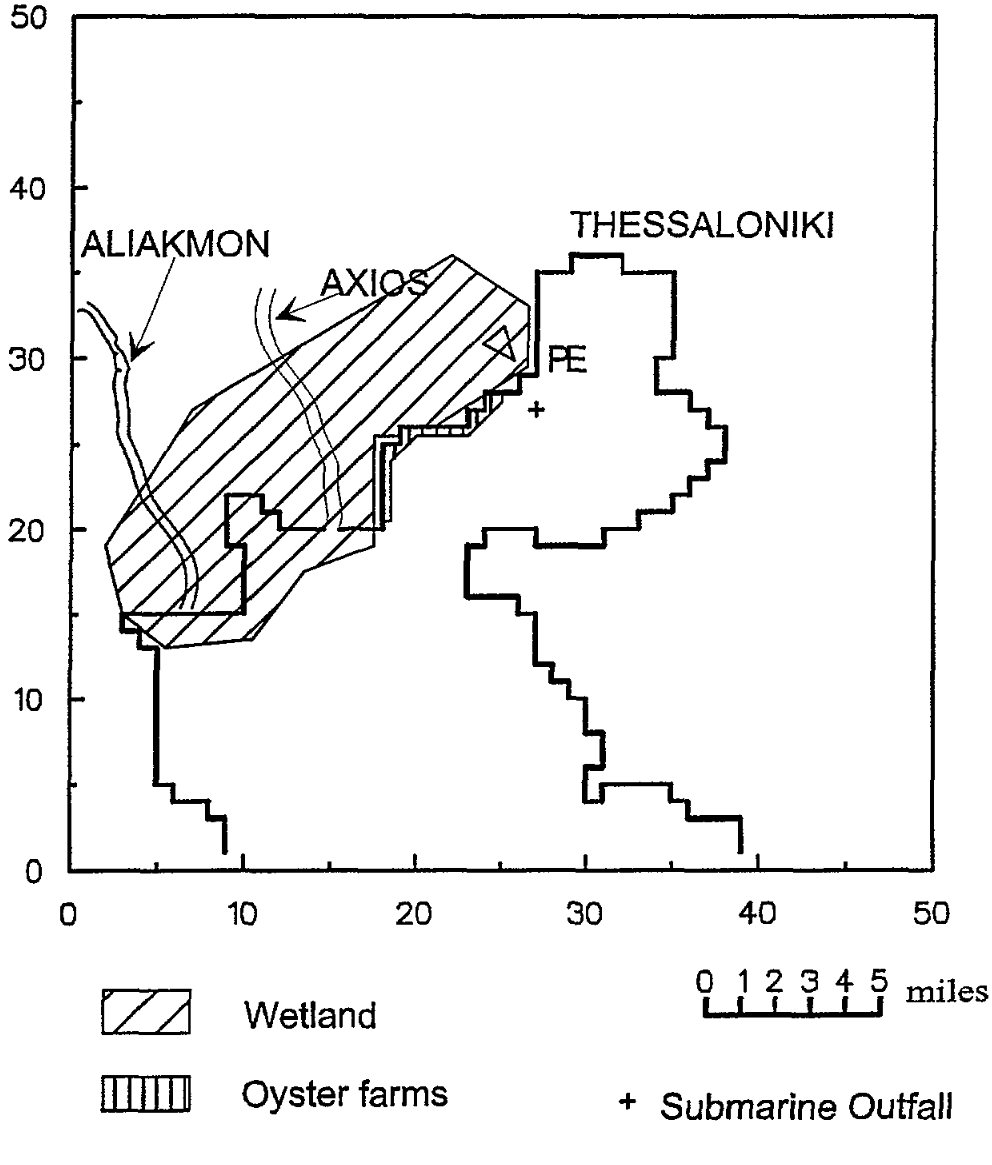



Fig. 14 Sensitive zones in Thessaloniki Bay.

In this part of the bay, oyster farms have been developed, producing several millions of tonnes of oysters every year. With the new operation of the wastewater treatment plant, the risk of contamination of shellfish by coliform bacteria should be evaluated. Chlorination for sewage disinfection has to be used very carefully (Ben Amor et al., 1990) in order to avoid formation of THM (Tri-Halo-Methanes) in coastal waters.

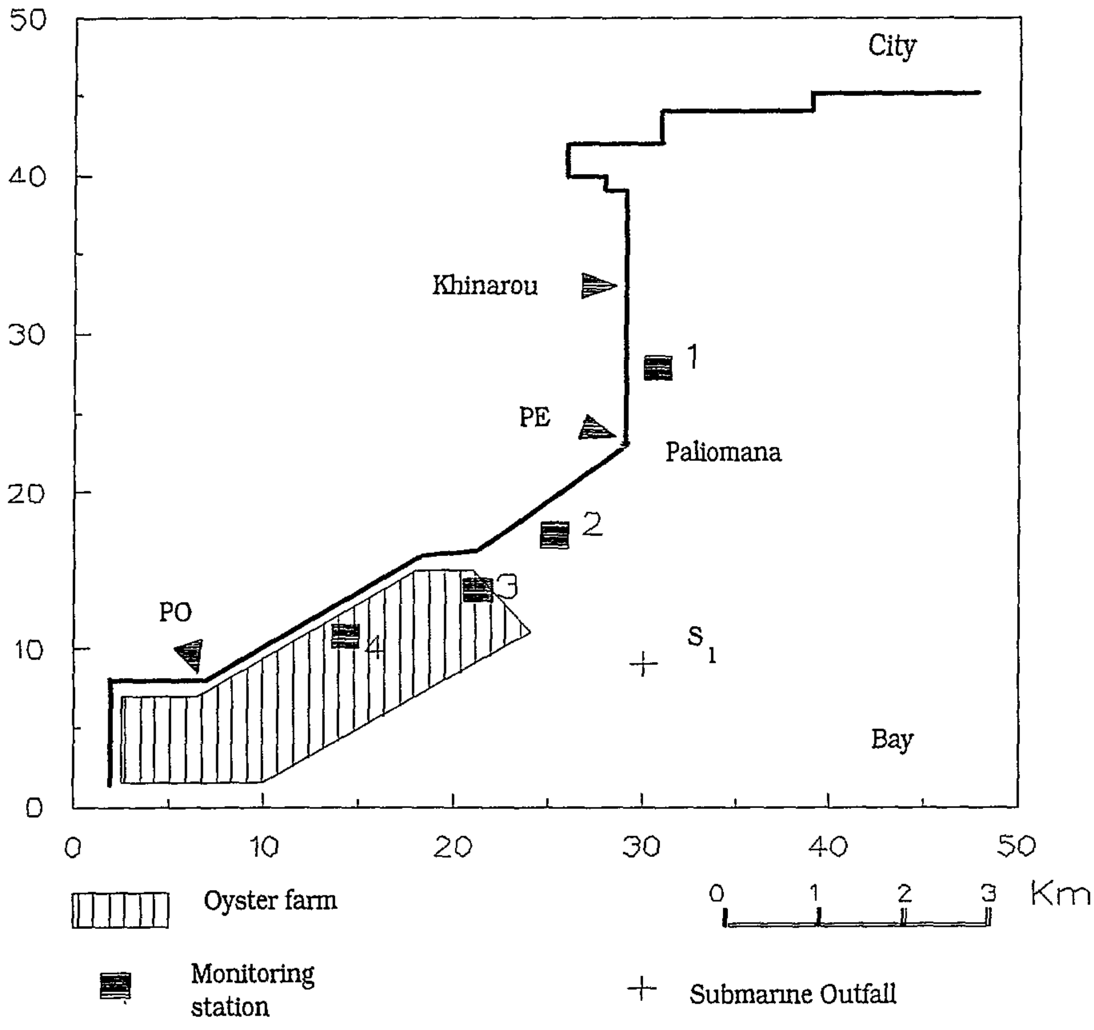



Fig. 15 Sensitive zones near Paliomana.

# 4. MATHEMATICAL MODELLING

## 4.1 Hydrodynamics

A 3-D hydrodynamic model, which simulates the wind-induced circulation at various depths has been developed. The hydrodynamic model integrates the Navier-Stokes equations in the finite-difference grid of Fig. 16; this is described on a regular Cartesian co-ordinate system, in the x-y plane, and the transformed coordinate $\sigma = (z - \eta)/H$ along the vertical -z. H is the water depth and $\eta$ the surface elevation. Neglecting the vertical velocity components, the Navier-Stokes equations may be combined with the continuity equation to yield

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial x} + v_{Th}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + v_{Tv}\frac{\partial^2 u}{\partial z^2} \tag{4.1}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - fu = -\frac{1}{\rho}\frac{\partial p}{\partial y} + v_{Th}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + v_{Tv}\frac{\partial^2 v}{\partial z^2} \tag{4.2}$$

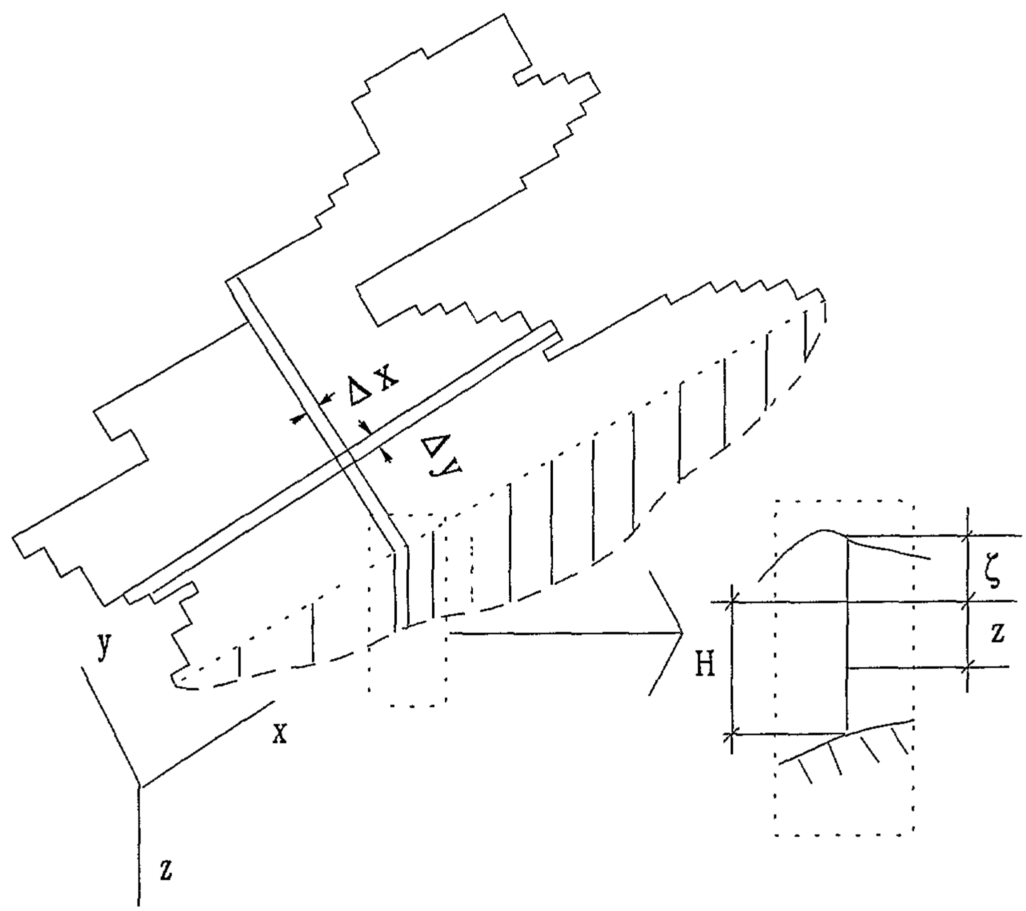



Fig. 16 The 3-D grid used in hydrodynamic computations.

In these equations the terms $\nu_{Th}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)$ and $\nu_{Th}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)$ represent the horizontal dispersion of momentum due to turbulence and are usually negligible, compared with the terms $\nu_{Tv}\frac{\partial^2 u}{\partial z^2}$ and $\nu_{Th}\frac{\partial^2 v}{\partial z^2}$ which represent the respective momentum gradients in the vertical direction. Furthermore, we may assume as a first approximation that the vertical pressure distribution is hydrostatic. We may then write

$$p = p_\alpha + \rho g(n - z)$$

where $p_a$ is the atmospheric pressure. From Eqs. (4.1, 4.2) the final forms of equations arise as

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv=-g\frac{\partial n}{\partial x}+\frac{\partial}{\partial z}\left(\nu_{Tz}\frac{\partial u}{\partial z}\right) \quad (4.3)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu=-g\frac{\partial n}{\partial y}+\frac{\partial}{\partial z}\left(\nu_{Tz}\frac{\partial v}{\partial z}\right) \quad (4.4)$$

In summary it may be said that Eqs. (4.3 , 4.4) are based on the assumptions of

- incompressible fluid;
- horizontal flow;
- negligible horizontal dispersion of momentum; and
- hydrostatic pressure distribution.

To determine the functions u(x,y,z,t), v(x,y,z,t) and n(x,y,t) another equation should be added; this represents the mass concentration in integral form. Thus, the excess mass per unit volume during dt equals

$$-\rho\left(\frac{\partial}{\partial x}\int_{-h}^{n} u\,dz+\frac{\partial}{\partial y}\int_{-h}^{n} v\,dz\right)dt \quad (4.5)$$

This mass equals the change of the volume of the element due to changes in free surface elevation. Per unit volume and in time dt we have

$$\rho\frac{\partial H}{\partial t}dt=\rho\frac{\partial n}{\partial t}dt \quad (4.6)$$

Equating the two expressions (4.5) and (4.6), we obtain the integral continuity equation

$$\frac{\partial n}{\partial t}+\frac{\partial}{\partial x}\int_{-h}^{n} udz+\frac{\partial}{\partial y}\int_{-h}^{n} vdz=0 \tag{4.7}$$

In the deterministic approach, the velocity field is obtained by using hydrodynamic models. The development of such models both in 2-D and 3-D space has been used to predict the current fields generated by tides and winds (Baines and Knapp, 1965; Fischer et al., 1979; Churchill and Csanady, 1982; Ganoulis and Krestenitis, 1982; ibid, 1984). Numerical algorithms based on finite differences or finite elements have been introduced for the numerical integration of the hydrodynamic equations. The model which has been developed here is based on coordinate transformations in the 3-D space (Krestenitis, 1987; Krestenitis and Ganoulis, 1987).

However, significant errors may be induced in numerical simulations. These are due to the fact that only a limited number of terms in the Taylor series expansions are taken into account. Explicit algorithms suffer from the so-called numerical diffusion. This is an artificial diffusion related to the truncation errors. It is superimposed on physical diffusion and leads to an excessive attenuation of the input signals. Implicit finite difference algorithms introduce trailing effects, because the initial signals propagate with celerities different than the physical ones. Minimization of numerical errors is related to the amount of data available. For the Gulf of Thessaloniki time series of wind generated currents have been registered in various locations. as an example the time variation of the u component is given in Fig. 17.

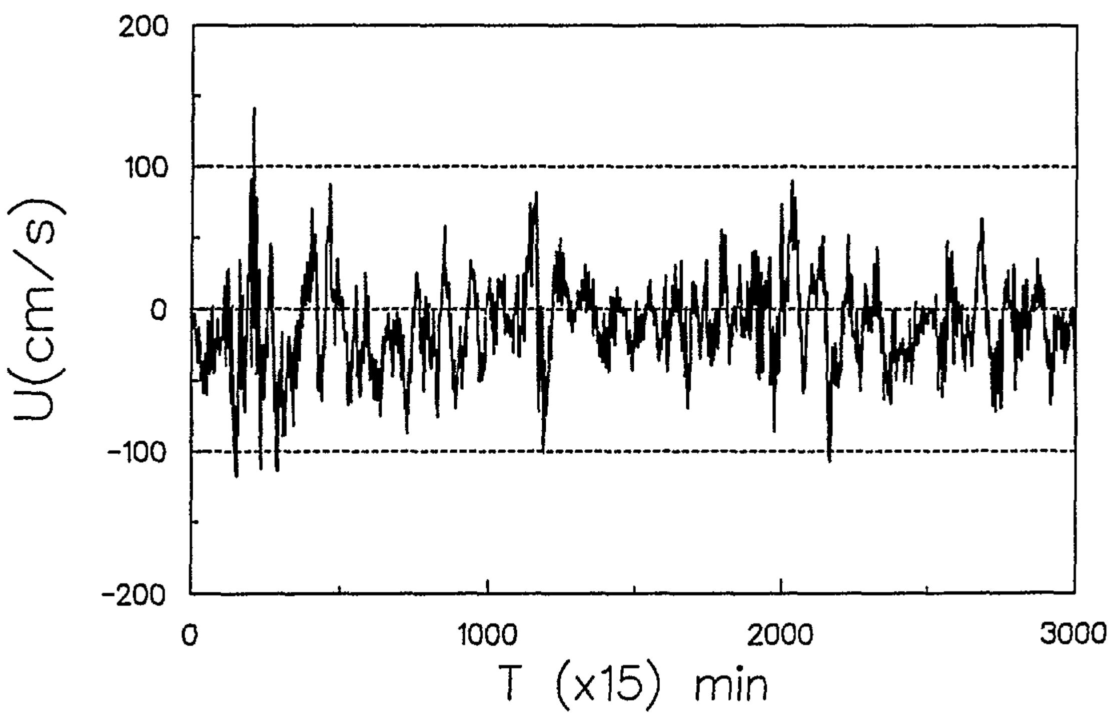



Fig. 17 Time series of current velocity u.

## 4.2 Phytoplankton Kinetics

The 3-D hydro-ecological model which has been developed, describes water quality and eutrophication in coastal areas by taking into account three main processes

(a) convection by currents;

(b) dispersion due to turbulence; and

(c) variation of phytoplankton biomass due to biochemical interactions with other physical and chemical systems.

Phytoplankton exists in many different forms of algae and it is customary to consider algal concentrations in terms of chlorophyll-a concentrations.

As shown in Figs. 18 and 19 the chlorophyll-a growth rate $S_A$=dA/dt reflects the uptake of nutrients such as $NH_3$, $NO_3$ and $PO_4$.

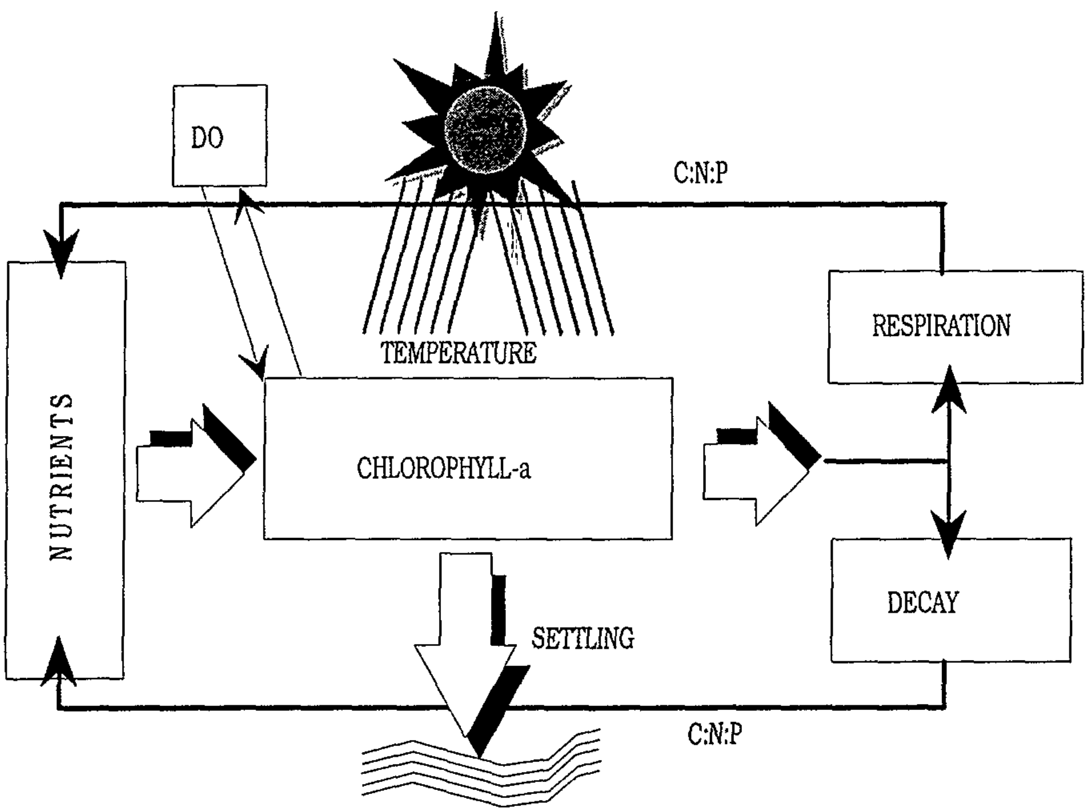
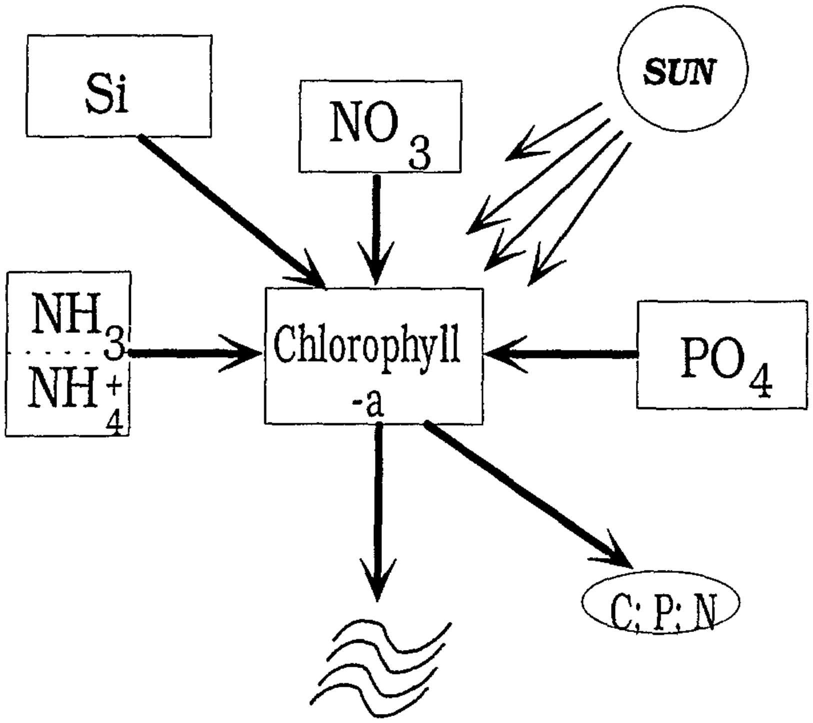



Fig. 18 Phytoplankton kinetics: physical mechanisms.




(b)

*Fig 19* Phytoplankton kinetics: interaction between chemical systems.

Under the influence of solar insulation and temperature, chlorophyll is recycled by

(i) respiration;
(ii) decay (non-predatory); and
(iii) settling.

Inorganic nutrients are reproduced from phytoplankton biomass back into the system through respiration and non-predatory mortality. Organic matter is converted to dissolved inorganic substances at a temperature-dependent rate.

Concerning interactions with dissolved oxygen, although algae produce oxygen by photosynthesis in the euphotic zone, this is reversed at night due to respiration. Furthermore, algae settling at the bottom, contribute to oxygen uptake by bio-degradation. In terms of chlorophyll-a concentration A, the phytoplankton kinetics may be described as

$$\frac{dA}{dt} = (\mu - r_A - e_x - s - m_A)\,A - G_A \qquad (4.8)$$

where

A: chlorophyll-a concentration (mass/volume)
$\mu$: phytoplankton growth rate ($T^{-1}$)
$r_A$: respiration rate ($T^{-1}$)
$e_x$: excretion rate ($T^{-1}$)
S: settling rate ($T^{-1}$)
$m_A$: non-predatory mortality ($T^{-1}$)
$G_A$: loss rate by grazing (mass/volume/time).

Temperature plays a key role in all bio-chemical transformations. Constants involved in usually first-order kinetic relations (i.e. oxidation, nitrification, denitrification) are related to temperature according to an Arrhenius-type relationship

$$\mu = \mu_{20^0C} \cdot T^{(t-20^oC)} \quad (4.9)$$

The growth rate $S_A$=dA/dt in chlorophyll-a expressed in Eq. (4.1) should be incorporated in the advective-dispersion balance equation (Fischer et al., 1979), which has the form

$$\frac{\partial A}{\partial t}+\frac{u\partial A}{\partial x}+\frac{v\partial A}{\partial y}+\frac{w\partial A}{\partial z}-\frac{\partial}{\partial x}\left(K_x\frac{\partial A}{\partial x}\right)-\frac{\partial}{\partial y}\left(K_y\frac{\partial A}{\partial y}\right)-\frac{\partial}{\partial z}\left(K_z\frac{\partial A}{\partial z}\right)=S_A \quad (4.10)$$

where

A: phytoplankton concentration (mass/volume)
u, v, w: velocity components (length/time)
$S_A$=dA/dt: rate of change of phytoplankton concentrations due to bio-chemical interactions given by (Eq. 4.8) (mass/volume/time).

The ecological model expressed by Eqs. (4.8) and (4.10) is linked with a 3-D hydrodynamic model, which simulates the wind-induced circulation at various depths.

Water quality in the gulf is determined as follows. First, on the basis of prevailing winds (summer, winter), the water circulation in the gulf is found using the three-dimensional hydrodynamic model. The gulf is divided horizontally in a rectangular 2x2 *km* grid. The water circulation velocities may be found everywhere in the gulf to be fed into a suitable ecological model. The model is based on a link-node representation of the flow field, divided into interconnected segments. Using the flow exchanges between neighbouring segments, it solves the transport and diffusion equations for each pollutant. Different programme modules deal with different pollutants, separately.

A less refined discretization is needed for the ecological model than for the hydrodynamic one. The spatial relation between the two grids on the horizontal plane is shown in Fig. 20. The same segmentation is replicated along the vertical direction, following the transformed depth coordinate $\eta$. A software assuring the automatic linkage between hydrodynamic and ecological computations has been developed specially for the purpose.

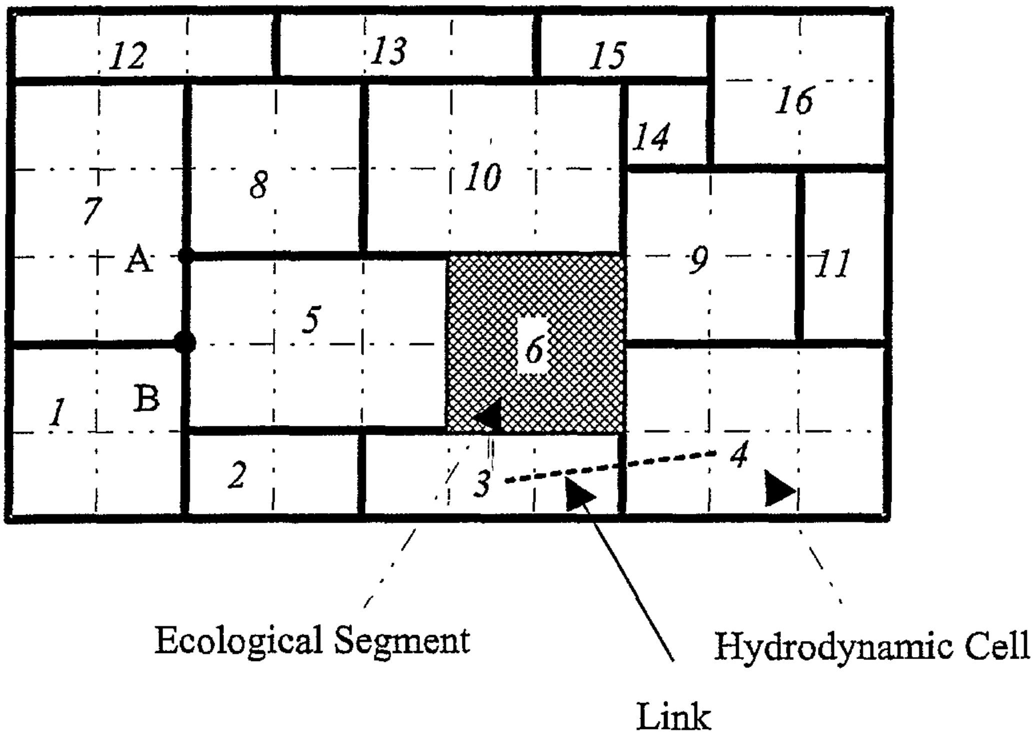



Fig. 20 Relationship between the hydrodynamic (fine lines) and ecological grids (thick lines) on the horizontal plane.

# 5. RESULTS OF SIMULATION

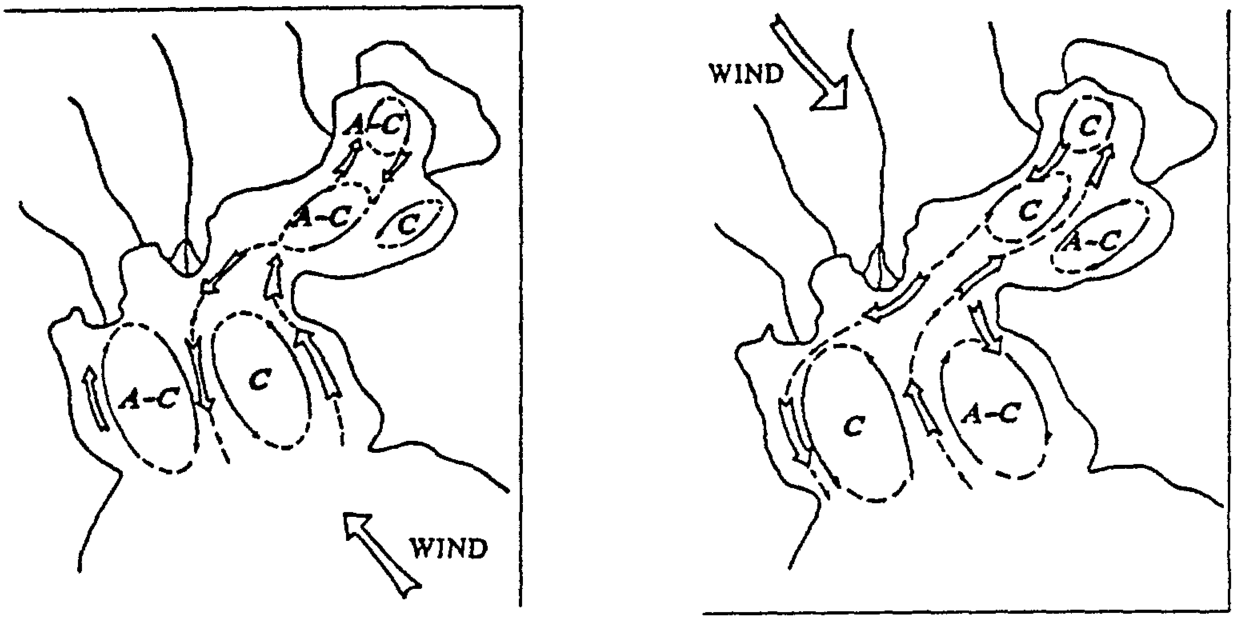
## 5.1 Water Circulation Patterns

The understanding of the water circulation is of great importance. Previous measurements of currents using drogues, driftcards and currentmeters (Balopoulos and James, 1984; Ganoulis and Koutitas, 1981) and the application of hydrodynamic models (Ganoulis and Koutitas, 1981; Krestenitis and Ganoulis, 1987) have led to the following conclusions: (a) tidal currents are very low(< 5 cm/s); (b) external circulation from the N. Aegean sea creates a current entering the bay along the eastern coast and creating a cyclonic circulation; and (c) currents are mainly due to the winds.

On the basis of mathematical simulation work and *in situ* measurements the average water circulation patterns during winter and summer have been determined and are shown in Fig. 21 (Ganoulis, 1988; 1990). Tidal currents are insignificant; total tidal elevation in the inner bay do not exceed 30 cm. The measurements show that, during summer, strong stratification of the water occurs with the warmer surface layers remaining stable over the colder depth layers; this leads to relatively anoxic conditions at the bottom. In contrast, during winter, the colder and denser surface layers destroy the stratification and satisfactory vertical mixing in the water column results. Consequently, the worst conditions for pollution occur during summer.

During the summer, sea breezes create a residual water circulation, which is very characteristic for the pollutant transport. In fact, this is the most critical circulation state for the pollutant advection because, as the currents are small, an increase in pollutant concentration is observed. In the present development of mathematical modelling, steady state hydrodynamic conditions corresponding to the prevailing winds are used.

To assess the risk of pollution in the gulf, the convective dispersion model has been used. For the numerical integration of the equations involved, various numerical algorithms have been developed during the last decade. Algorithms based on finite differences or finite elements suffer from numerical diffusion and trailing effects. Lagrangian models based on random walk simulation or using a mixed Eulerian-Lagrangian approach have been found reliable to simulate the fate of pollutants in the Thermaikos Gulf (Ganoulis, 1990; 1991a). These models have been tested in simple cases where analytical solutions are available and validated by using the data collected. They have been adopted as tools for studying the environmental impacts from several alternatives of remedial measures aiming to protect the water quality in the gulf.




a) b)

Fig. 21 The prevailing water circulation patterns in inner Thermaikos gulf during *a)* summer and *b)* winter.
(*A*: Anticyclonic, *C*: Cyclonic circulation)

Results of model simulation include circulation patterns, pollutant concentrations at various positions and depths, including phytoplankton or chlorophyll-a concentrations. They are used either to validate the model by comparing simulation results with available measured data (Ganoulis et al., 1994; Ganoulis, 1988; 1992), or to predict future- impacts on water quality and eutrophication.

## 5.2 Chemical Species Distributions

A NORTHERN WIND

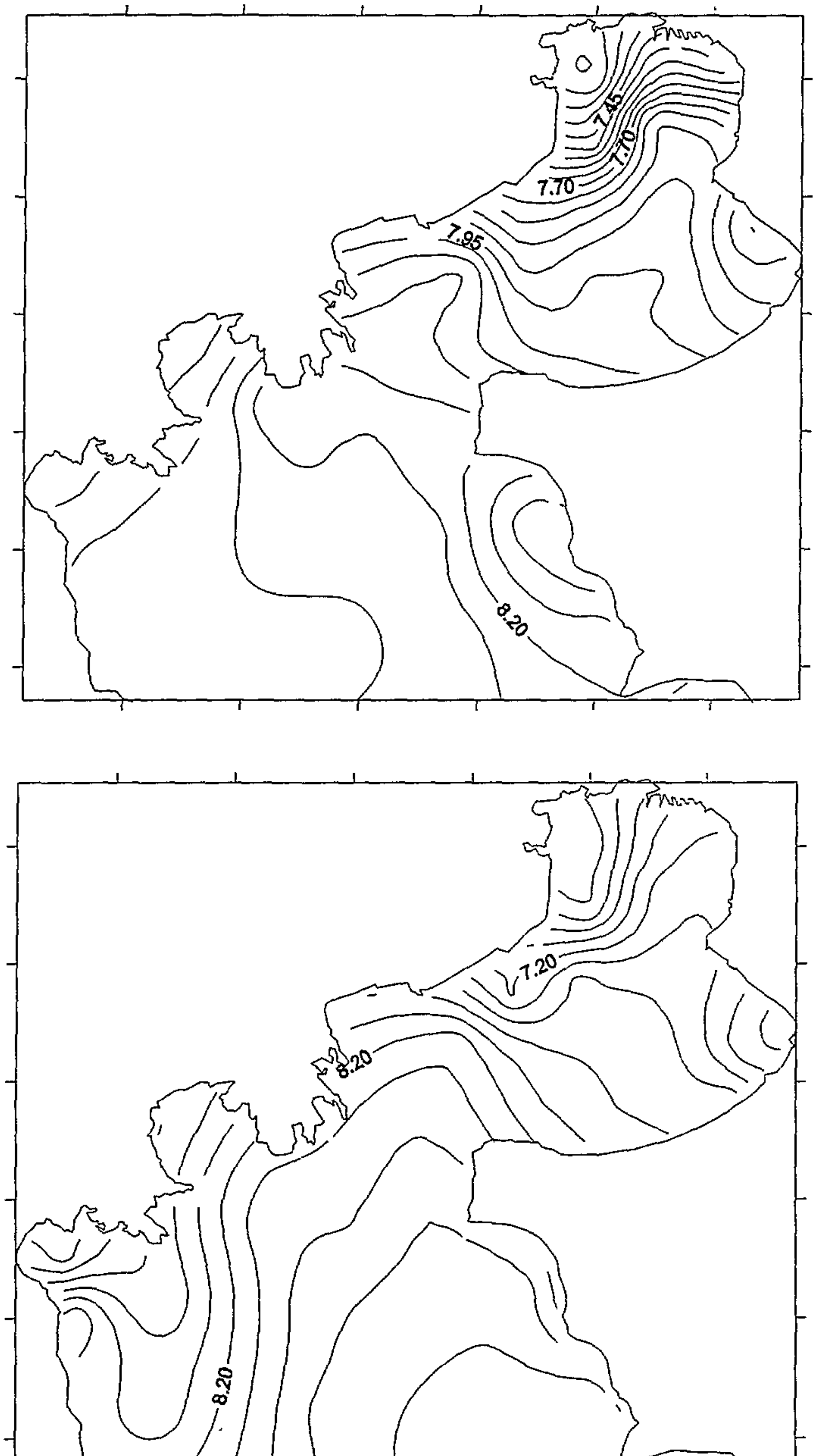



Fig. 25 DO concentration for Northern Wind (10 m/s). Top and Bottom Layers.

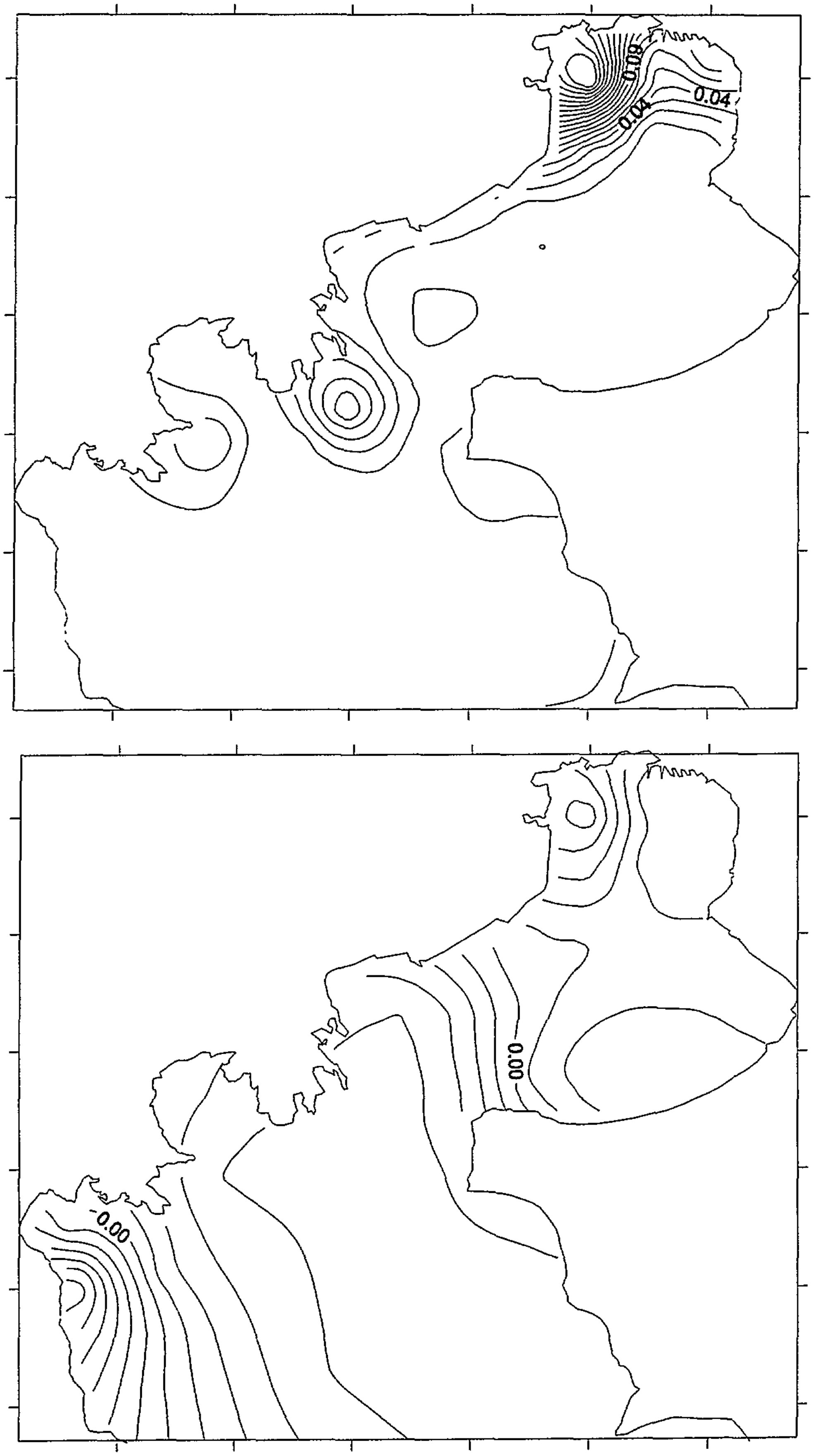



Fig. 26 CBOD Concentration for Northern Wind (10 m/s). Top and Bottom Layers.

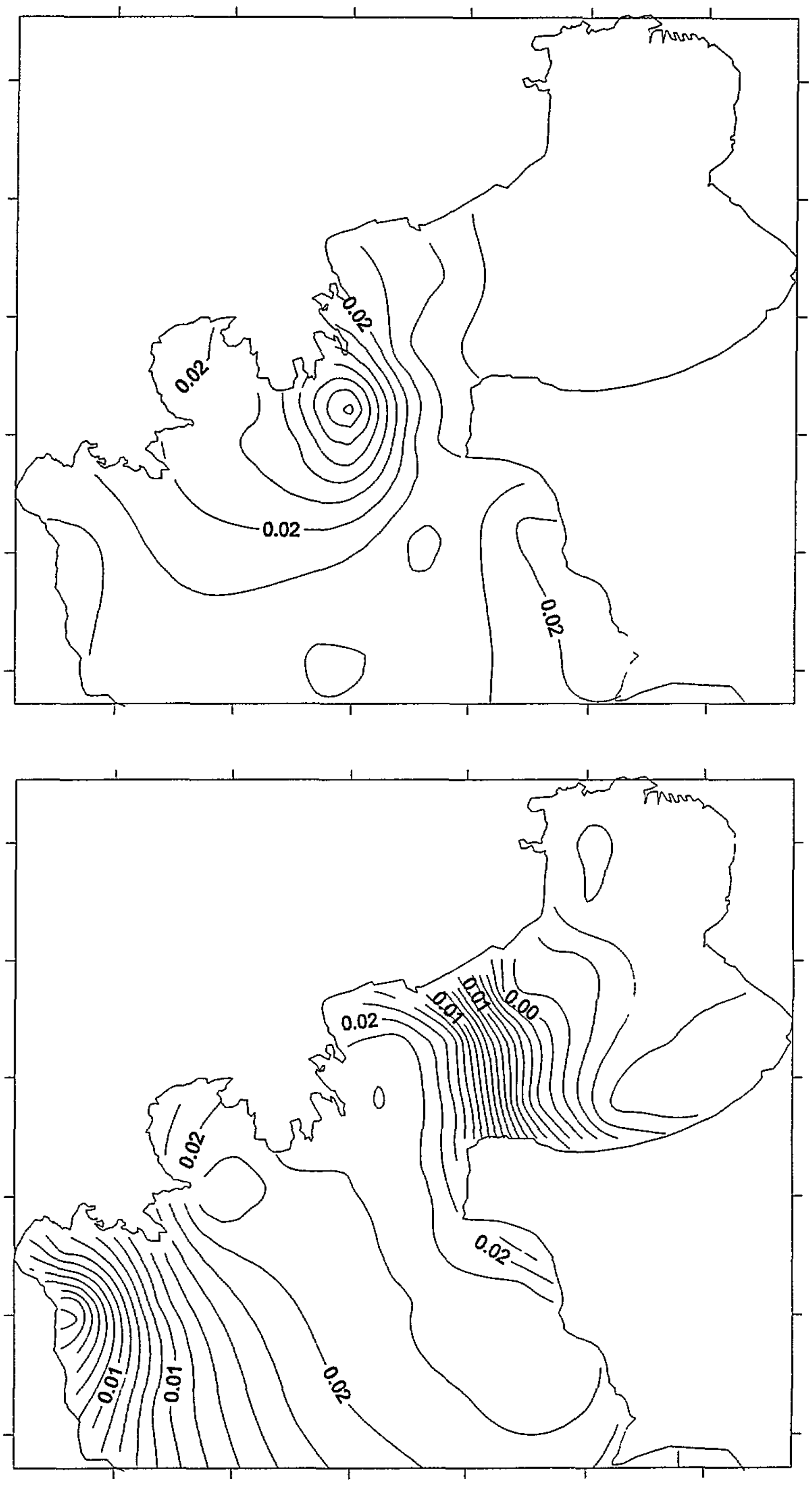



Fig. 27 $NO_3$ Concentration for Northern Wind (10 m/s). Top and Bottom Layers.

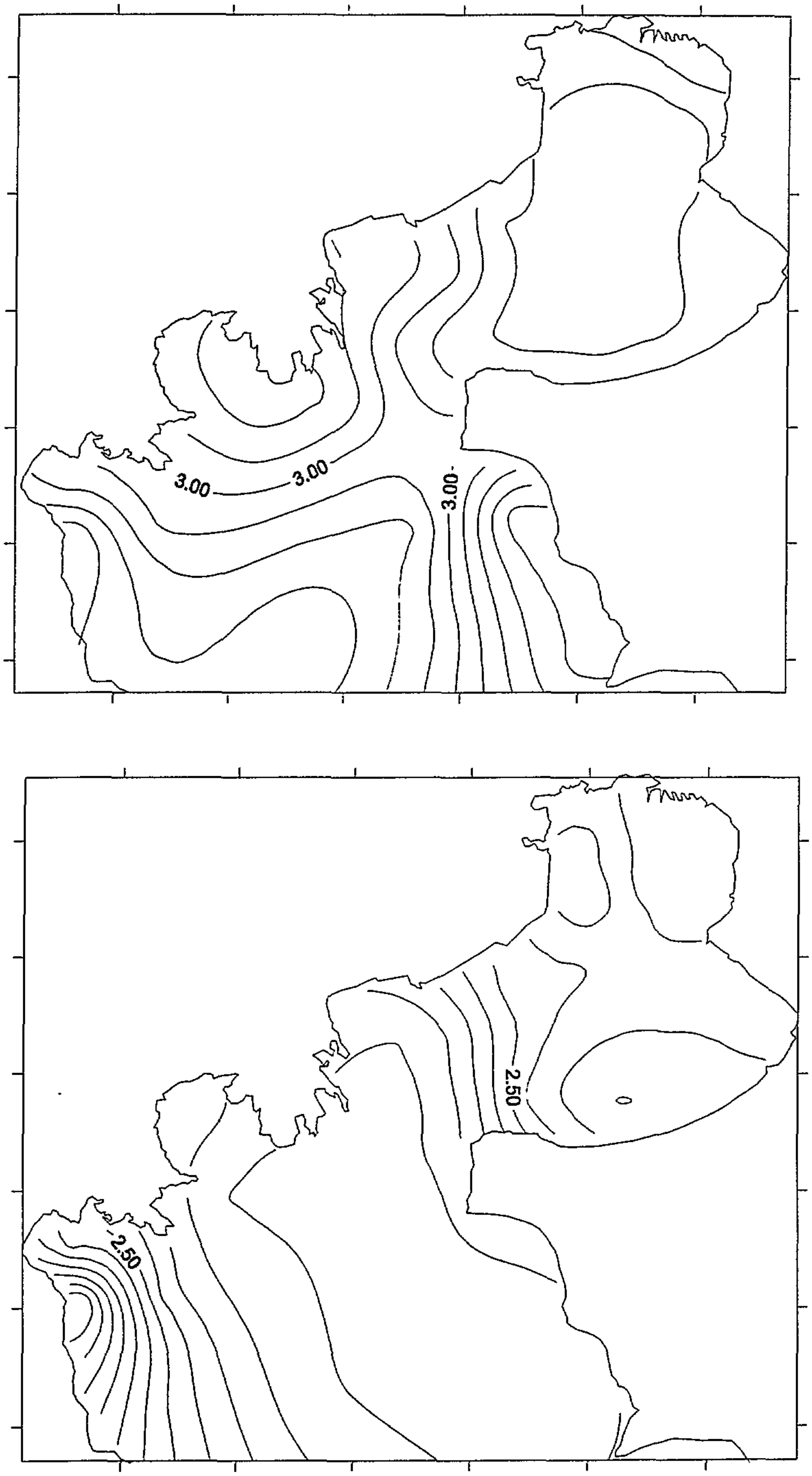



Fig. 28 Chl-a Concentration for Northern Wind (10 m/s). Top and Bottom Layers.

B SOUTHERN WIND

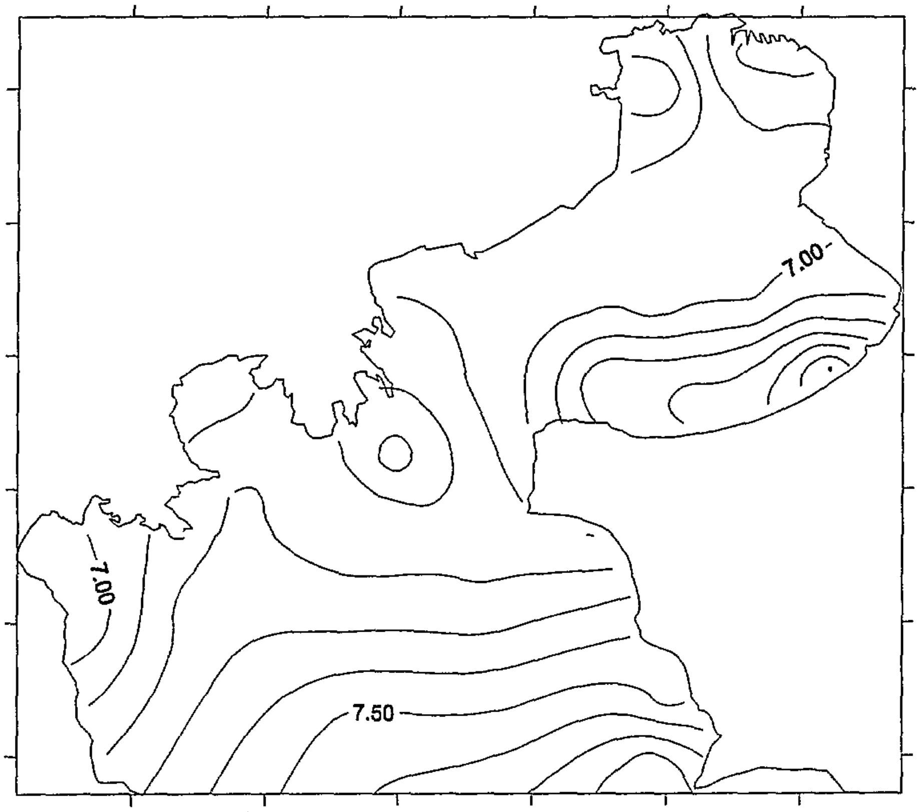




Fig. 29 DO Concentration for Southern Wind (3 m/s). Top and Bottom Layers.

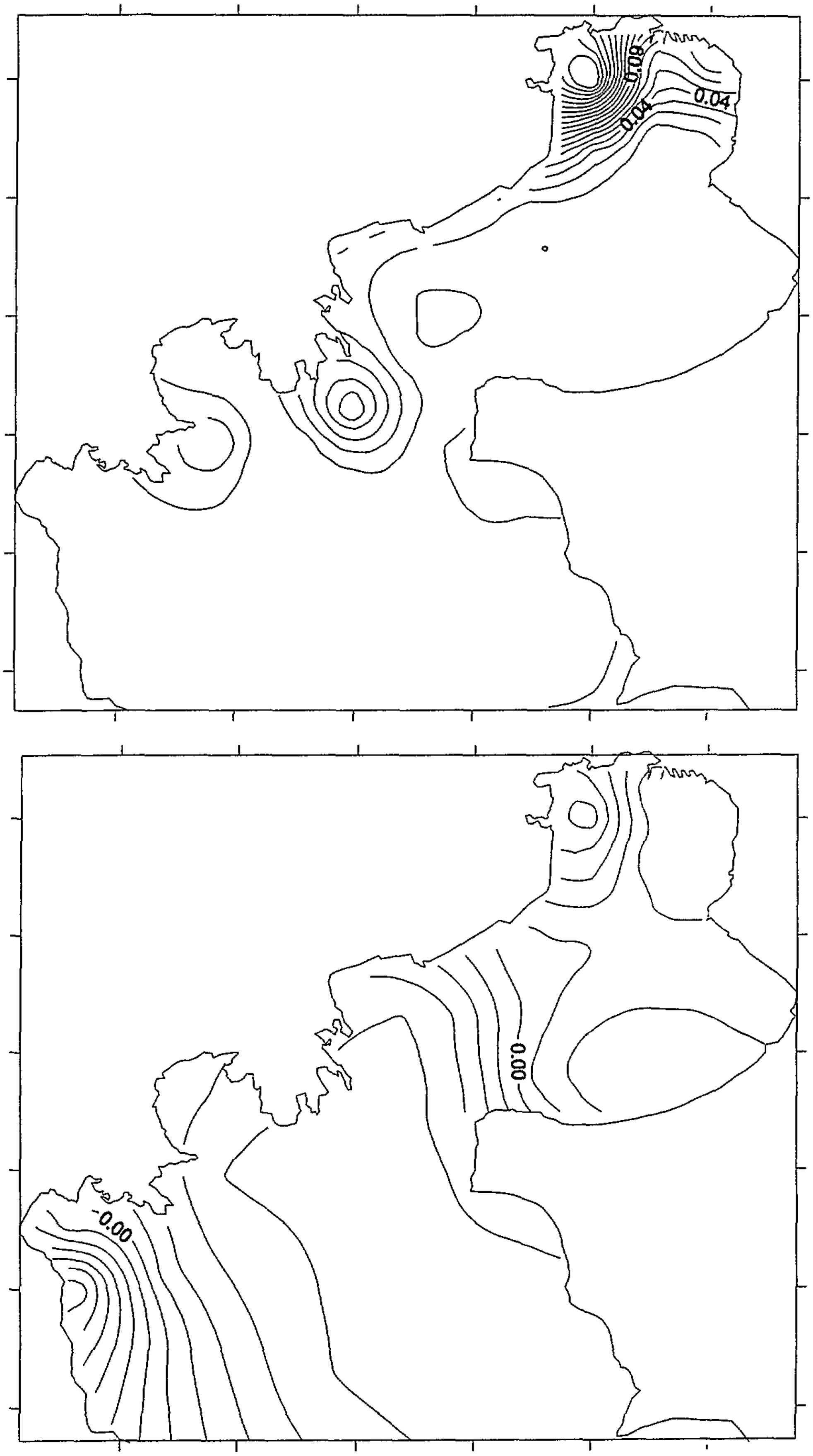



Fig. 30 CBOD Concentration for Southern Wind (3 m/s). Top and Bottom Layers.

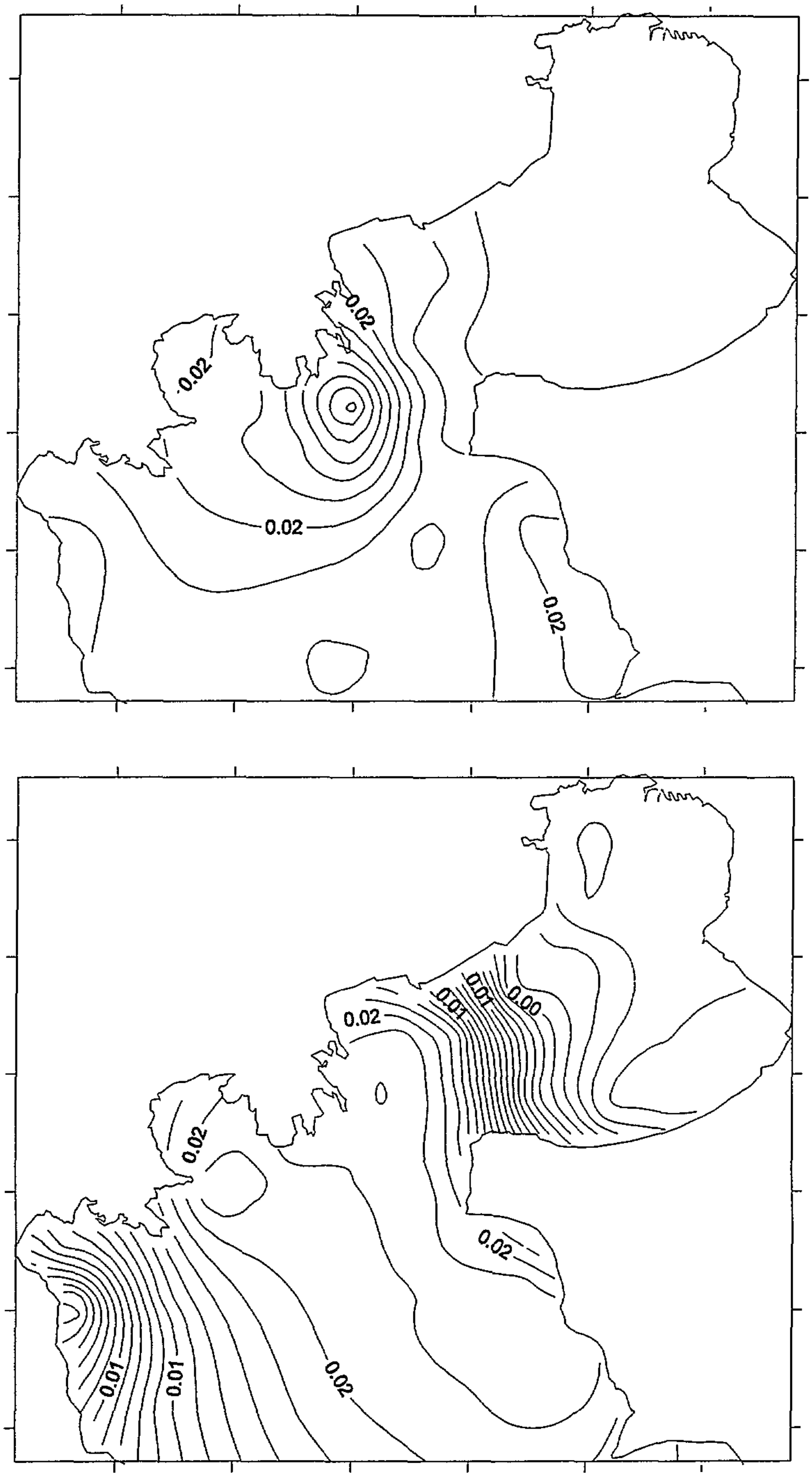



Fig. 31 $NO_3$ Concentration for Southern Wind (3 m/s). Top and Bottom Layers.

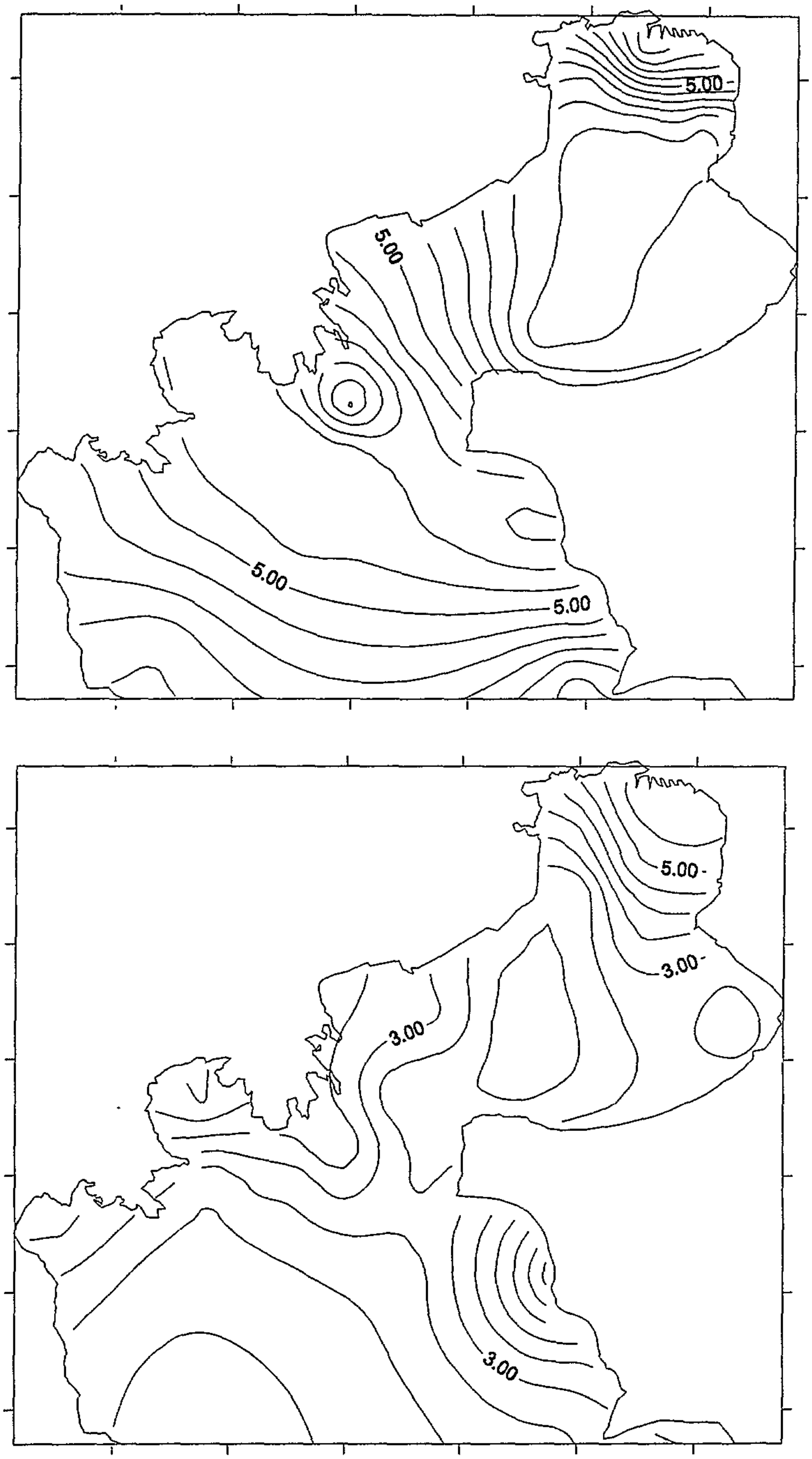
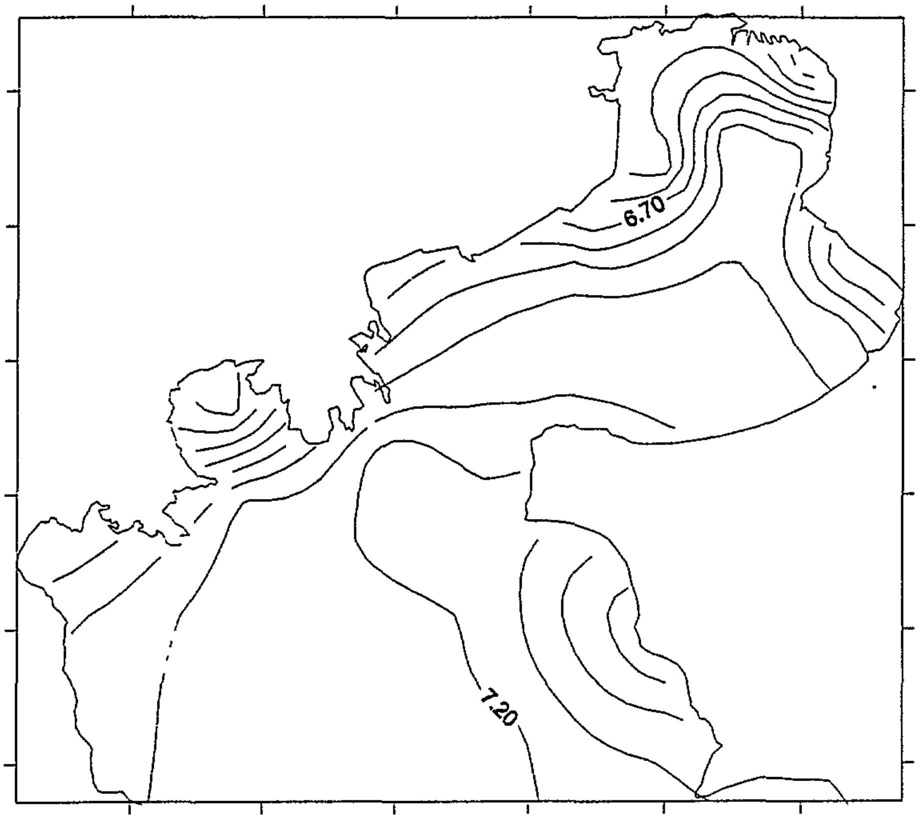



Fig. 32 Chl-a Concentration for Southern Wind (3 m/s). Top and Bottom Layers.

C RESIDUAL CIRCULATION (SUMMER)



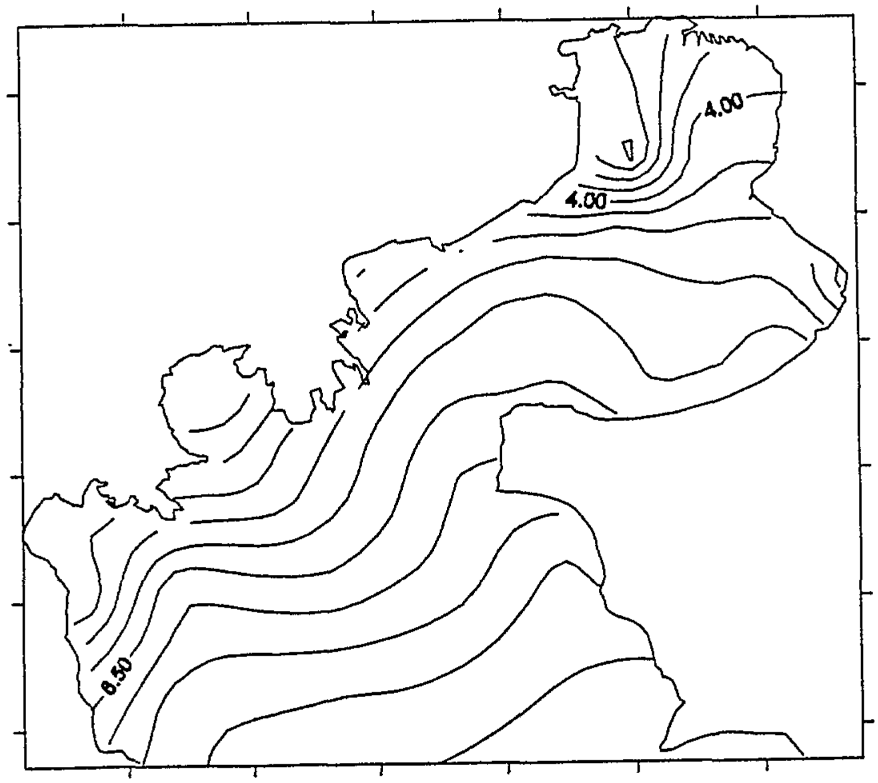




Fig. 33 DO Concentration for Summer Conditions. Top and Bottom Layers.

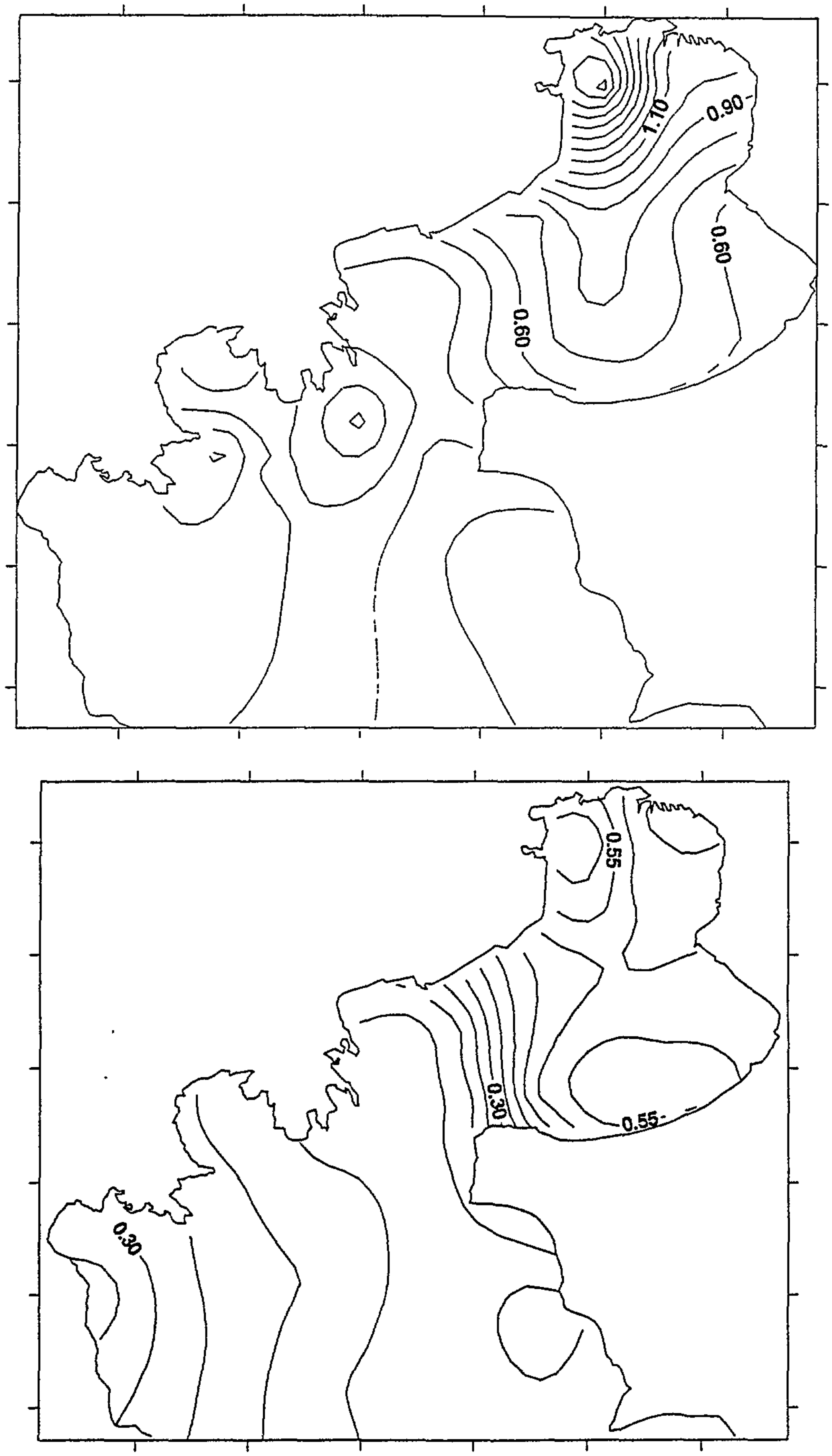



Fig. 34 CBDO Concentration for summer conditions. Top and Bottom Layers.

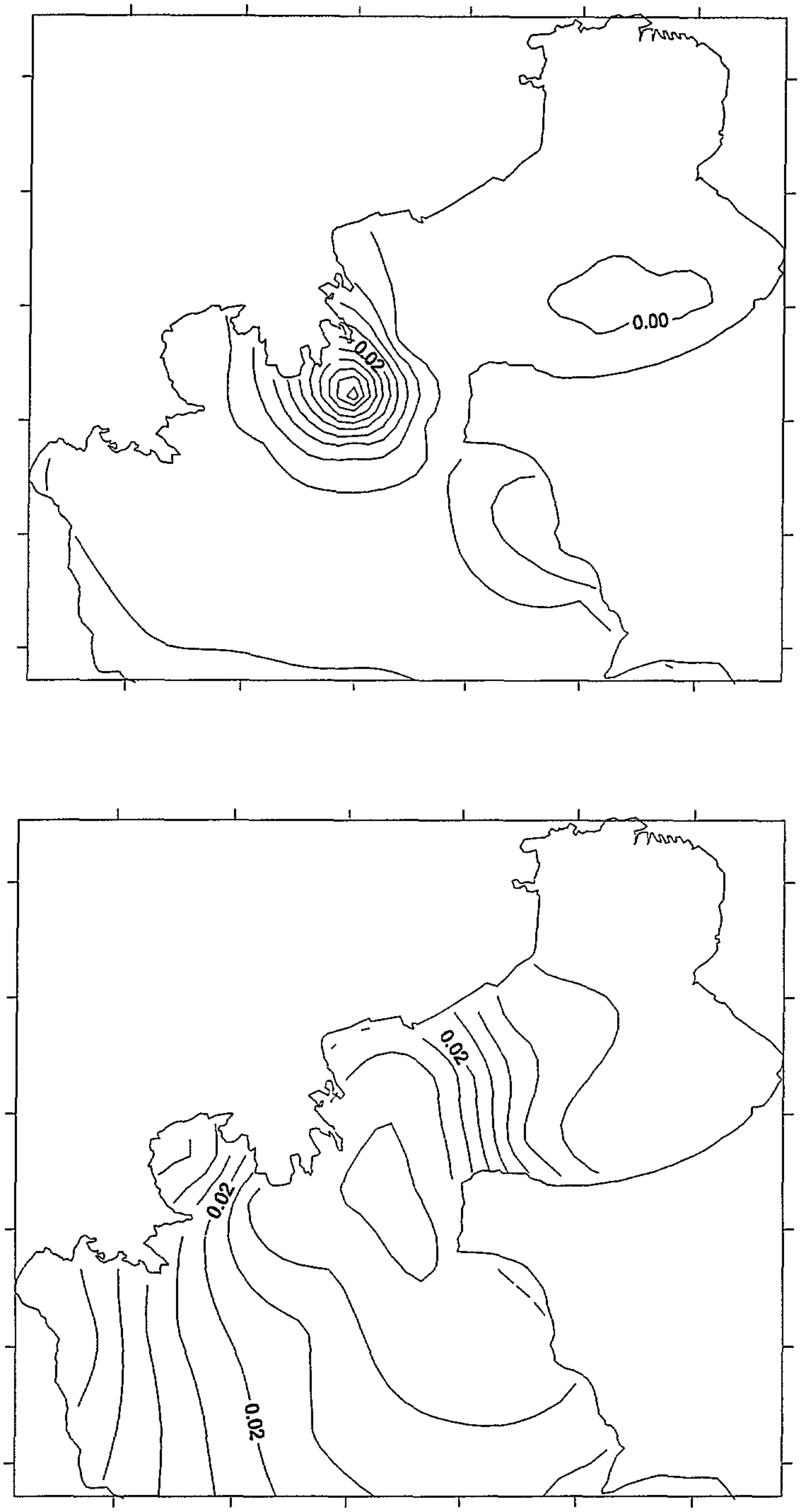



Fig. 35 $NO_3$ Concentration for summer conditions. Top and Bottom Layers.

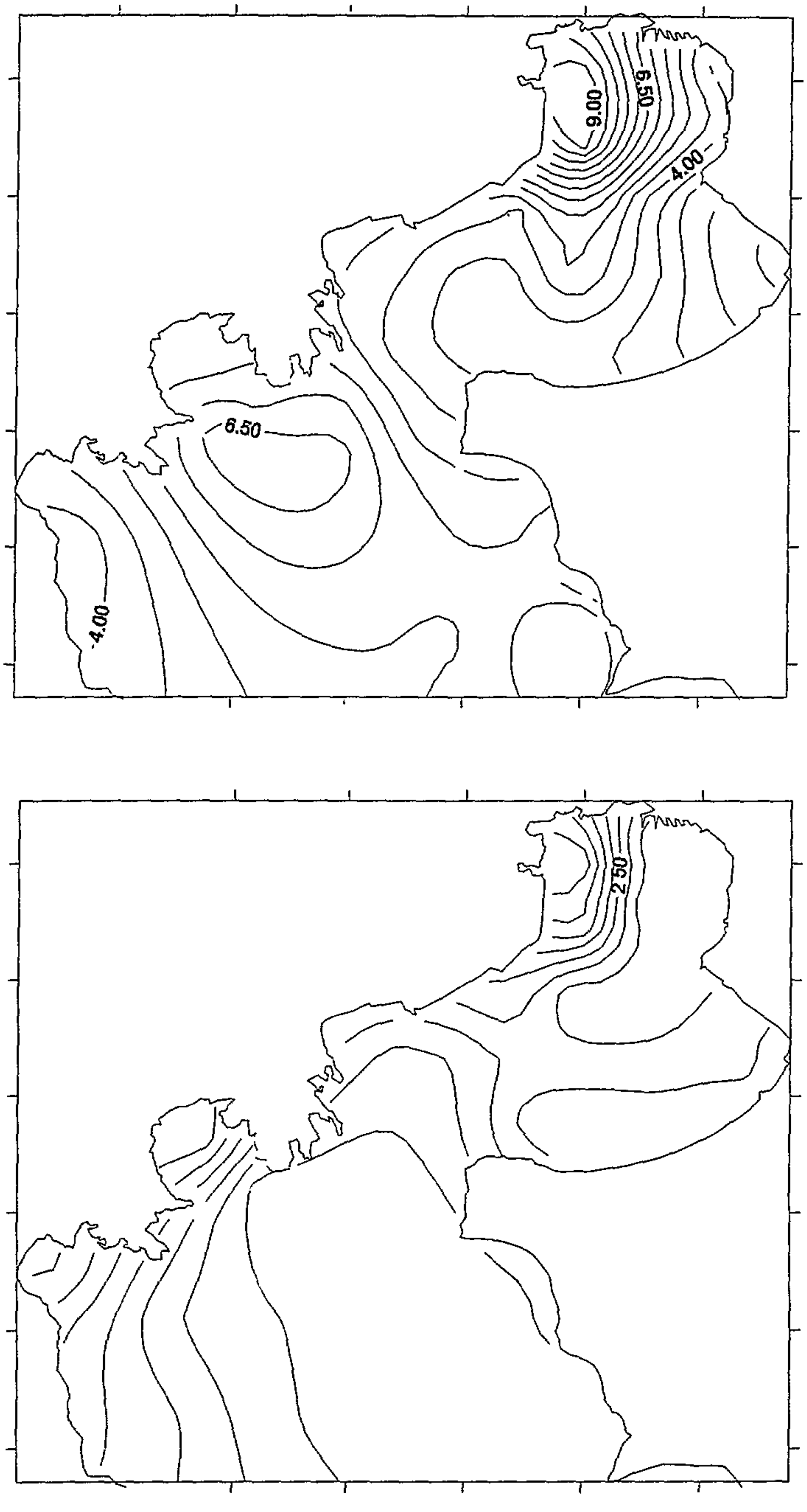



Fig. 5 16 Chl-a Concentration for summer conditions. Top and Bottom Layers.

## 7. CONCLUSIONS

A 3-D hydro-ecological model has been developed to simulate the impact of nutrient loads from land-based sources on coastal water quality and eutrophication. First, data of coastal circulation and water quality have been utilized to test the global performance of the model. Then, different scenarios of characteristic water circulation patterns have been used to simulate eutrophication.

Both historical and future pollutant loads have been introduced as inputs to the hydro-ecological model to simulate coastal water quality and eutrophication. Subject to model validation with more data, the case study in the bay of Thessaloniki, NW Aegean Sea, indicates that the model may predict the risk of enhancing eutrophication and oxygen depletion in coastal areas due to inputs from land-based sources.

Further research work for simulating eutrophication in coastal areas, should concentrate on the effect of water stratification, especially near the river deltas and during the summer period.. Simulation of algal blooms may require closer cooperation between marine biologists and environmental engineers.

## REFERENCES

Abraham, G. and Brolsma, A.A. (1965) Diffusers for Disposal of Sewage in Shallow Tidal Water. Delft Hydraulics Lab. Pub. No. 37.

Baines, W.D. and D.J. Knapp (1965) Wind driven water currents. J. Hydr. Div., ASCE, HY **2**: 205-221.

Balopoulos, E. and A.E. James (1984) Drogue measurements of the upper layer circulation in Thermaikos Gulf (Greece). Thalassographika **7**: 73.

Ben Amor, H., J. De Laat and M. Dore (1990) Oxydation d' un acide humique aquatique par le bioxyde de chlore. Revue des Sciences de l' Eau **3**: 83-105.

Churchill, L.H., and G.T. Csanady (1982) Nearsurface measurements of quasi-lagrangian velocities in open water. J. Physical Oceanography

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J. and Brooks N.H.(1979) Mixing in Inland and Coastal Waters, Academic Press, New York.

Ganoulis, J. and C. Koutitas (1981) Utilisation de données hydrographiques et modèles mathematiques pour l' étude hydrodynamique du Golfe de Thessaloniki, Rapp. Comm. int. Mer Medit. **27**: 41.

Ganoulis, J. and J. Krestenitis (1982) Choix du site optimum d' evacuation des eaux usées dans une region côtière. XVII èmes Journées de l' Hydraulique, Soc. Hydrotechnique France, Nantes.

Ganoulis, J. and J. Krestenitis (1984) Modelisation numerique du transport côtier des pollutants en Mediterranée. XVIII èmes Journées de l' Hydraulique, Soc. Hydrotechnique France, Marseille.

Ganoulis, J. (1988) Oceanographic Conditions and Environmental Impact from the Sewage Works of Thessaloniki. Report to the Greek Ministry of the Environment, Town Planning and Public Works, Thessaloniki (in Greek), 244 pp.

Ganoulis, J. (1990). Environmental Impacts from sewage works in the Bay of Thessaloniki. Report to the Ministry of Environment, Town Planning and Public Works (in Greek)

Ganoulis, J. (ed.) (1991) Water Resources Engineering Risk Assessment, NATO ASI Series, Vol. G29, Springer-Verlag, Heidelberg, 539 pp.

Ganoulis, J. (1991a) Water quality assessment and protection measures of a semi-enclosed coastal area: the Bay of Thermaikos (NE Mediterranean Sea). Mar. Poll. Bull. **23**:83-87

Ganoulis, J. (1991b) Risk in coastal pollution. In: Ganoulis, J. (ed.) Water Resources Engineering Risk Assessment. NATO ASI Series, Vol. G29, Springer-Verlag, Heidelberg, pp. 167-188

Ganoulis, J. (1992) Dispersion et disparition des bactéries coliformes dans la baie de Thessaloniki. Revue des Sciences de l'Eau, **5**, 541-554.

Krestenitis, J. (1987). Numerical study of three-dimensional circulation using coordinate transformations. Ph.D. Thesis, Aristotle University of Thessaloniki (in Greek)

Krestenitis, J. and J. Ganoulis (1987) Forecasting coastal currents using curvilinear coordinates. Technica Chronica, A **7**(4): 33.

UNEP/WHO (1985) Guidelines for the Computations Concerning Marine Outfall Systems for Liquid Effluents. Athens

UNEP/WHO (1994) Guidelines for Submarine Outfall Structures for Mediterranean Small and Medium-Sized Coastal Communities. EUR/ICP/CEH/047, Athens

# HYDRODYNAMICAL EFFECTS ON NUTRIENTS DIFFUSION AND ALGAL BLOOMS ALONG THE EMILIA ROMAGNA COAST

**by**

**G. Montanari[a], P. Reic[b], A. Rinaldi[a] and E. Todini[c]**

*a Laboratory "DAPHNE", Emilia Romagna Region, Cesenatico, Italy*
*b Centro IDEA of the University of Bologna, Italy*
*c Dept. of Earth and Geo-Environmental Sciences University of Bologna - Italy*

## 1. INTRODUCTION

In the last decade the attention of the international scientific community and of central and local authorities has been increasingly focused on the ecological degradation of the Northern Adriatic.

Recurrent spring and autumn algal bloomings appear with wider spread on the water surface: from the Po Delta to Ancona and sometimes further south to the Manfredonia Gulf. This situation seriously affects both, the aquatic life, with the death of different species of fish, and the tourism activity of the entire coast, where summer resorts usually accommodate millions of tourists.

After a number of years, scientific research, more analytic than synthetic, has not yet provided the identification of the most important factors affecting the eutrophication phenomena in the upper Adriatic sea. All the studies were carried out in a very deep and interesting manner, by analyzing in detail many of the single phenomena that concur to the overall eutrophication mechanism, such as the hydrodynamical circulation, the dispersion of pollutants, the biological evolution, etc... Unfortunately each single phenomenon was regarded as "the important" phenomenon by the scientists and no attempt to prioritize the importance of the different phenomena, or to establish a good balance in the spatial or temporal description of the different phenomena, was ever made. The scientific information was not compiled with the management purpose in mind. Putting together the pieces of the puzzle can be greatly assisted by a comprehensive framework such as an ecological model, which can integrate and synthesize available information, identify gaps in our knowledge and understanding of important phenomena, and finally, it can be used as a decision-support tool.

Numerous models exist applicable to the coastal marine environment, that describe primary production, trophic relationships from phytoplankton to zooplankton and fish. But only few of them provide for a satisfactory coupling of physical transport phenomena and the biological processes.

Given the extreme importance of the transport phenomena on the formation and dispersion of the algal mass. Scope of this research is to establish a hydrodynamical model of the Emilia-Romagna coastal zone and to include in it a biological cycle.

Such a model may provide significant support for:

- co-ordinating the work of multidisciplinary teams of physical, chemical and biological specialists in the interpretation of the phenomenon;
- improving the design and operation of monitoring networks;
- testing control techniques.

However, mathematical modelling should not be regarded as a substitute for the scientific approach; an integrated programme of data collection, field and laboratory experimentation and modelling which addresses specific and concrete questions, is the best way forward.

## 2. THE PROBLEM OF WATER QUALITY ALONG THE EMILIA-ROMAGNA COAST

The part of the northwest Adriatic Sea most seriously affected by eutrophication is the coastal region of Emilia-Romagna south of the River Po delta, extending some 150 km south, and some 20 km offshore.

This section of the Adriatic Sea shows some geomorphological and hydrodynamical features which are of importance for the process of eutrophication. While the North Adriatic Sea is generally shallow (the maximum depth on a line between Rimini and Pola, Croatia, is only 50 m), the mean inclination of the seafloor of the region south of the Po delta is only about 1m/km up to 20 km offshore, except inshore where the 5 m bathymetric line parallels the coast at 1 km from the shore. Inshore the sea floor is sandy, becoming more muddy offshore. The geomorphological traits of the northwest Adriatic Sea are given in Fig. 1.

Until the end of the 1960s algal blooms in the Adriatic Sea occurred only occasionally alternating with prolonged periods of clear water phases. No particular location of the coastal area seemed to exhibit particularly favourable conditions for the onset of blooms. Since 1975 algal blooms along the Emilia-Romagna coast have no longer been occasional and have become important enough to cause serious problems to the environment, tourism and fishery. The now chronic state of hypertrophy of the northwest Adriatic Sea shore causes recurrent crises of anoxia involving vast benthic zones. In addition to frequent fish mortality, change in water colour, alteration of the organoleptic characteristics of the waters and emissions of unpleasant smells into the air, are now a common disturbance. Over the last decade these conditions have caused a rarefaction, and in certain cases the disappearance of organisms sensitive to dystrophy.

The regular survey and research programs covering a fixed station grid along the coast of Emilia-Romagna have been carried out since 1977. Nineteen double stations, inshore at 500 m and offshore at 3 km from shore, evenly distributed between Goro in the north and Cattolica in the south, have been selected for weekly coverage. In addition to these, five transects perpendicular to the shore to 20 km offshore have been surveyed at least monthly during the growing season of each year (Fig. 2).

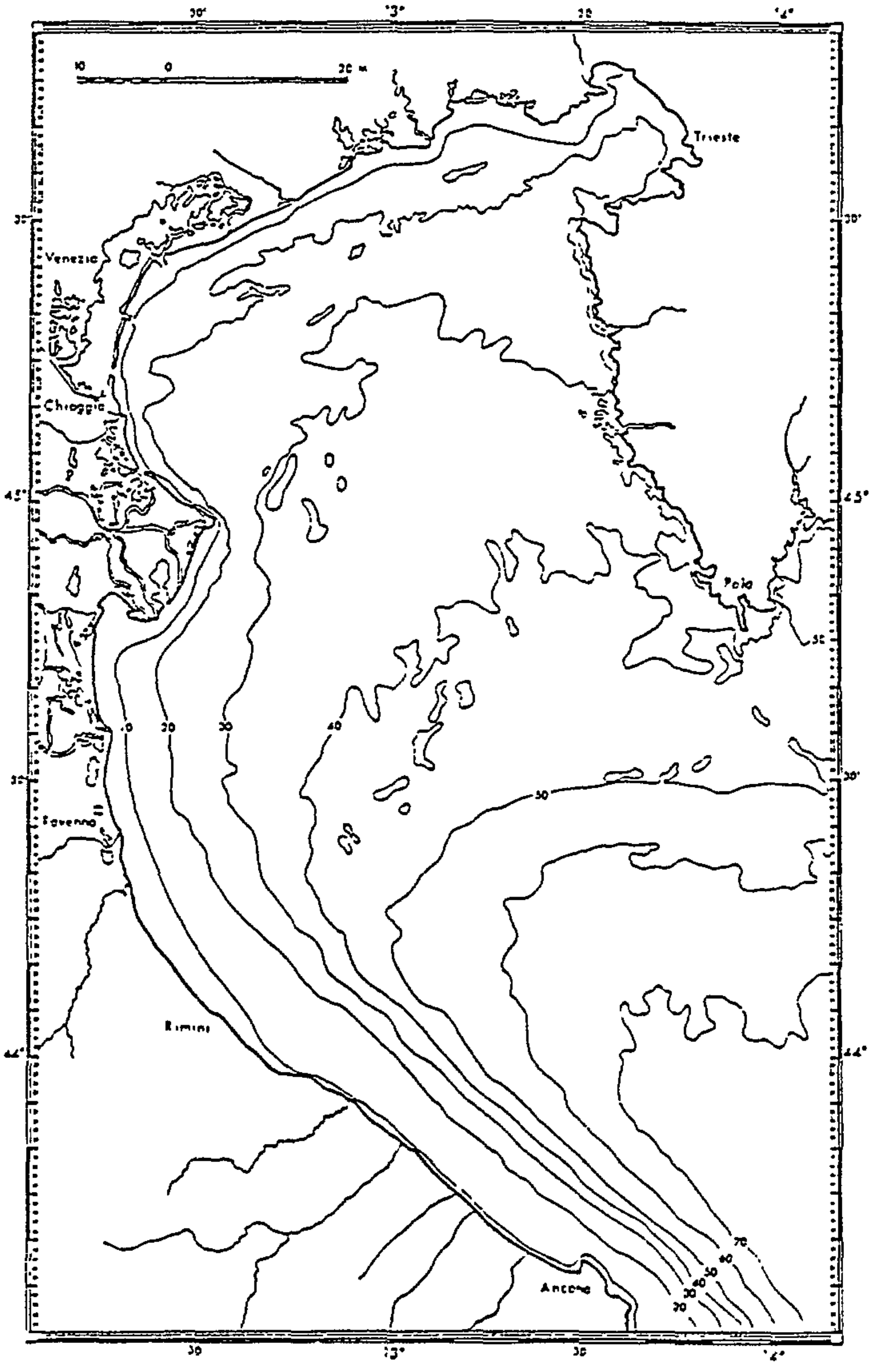



Fig. 1. Northern Adriatic Sea: bathymetry in meters. Map by the Istituto Idrografico della Marina.

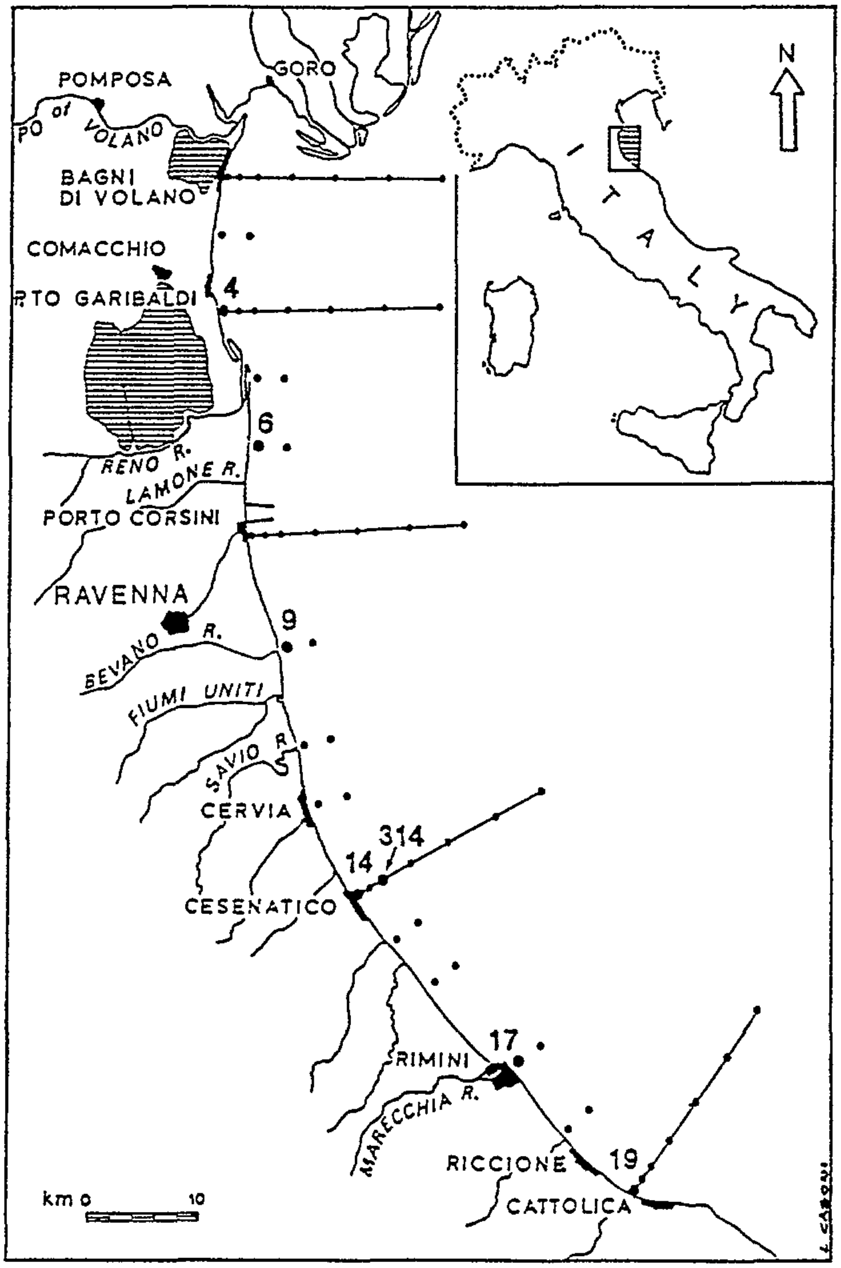



Fig 2. Monitoring stations grid of the coastal waters of the Emilia-Romagna Region.

## 3. HYDROGRAPHICAL AND HYDROLOGICAL SITUATION

From the hydrological point of view, the coastal region of Emilia-Romagna south of the delta receives a substantial fraction of the waters of the River Po. Mean yearly discharge is around 1,500 $m^3$/sec, but with considerable seasonal variations from 400 to 8,000 $m^3$/sec (Marchetti et al., 1989); minor coastal rivers contribute some 220 $m^3$/sec as a mean. During periods of intense supply these waters do not become well mixed with offshore waters, creating situations of high density stratification in bands or lenses parallel to the shore. Conversely, during periods of low supply, the north-south currents tend to slow down due to the effects of bottom friction and the presence of numerous artificial structures built for the protection of beaches and harbours. At the height of summer stratification water masses tend to be stagnant. These features have an essential bearing on the temporal development and spatial distribution of algal blooms.

It is clear (Table 1, Fig. 3) that most of the rivers flowing into the sea south of the Po are not very important from a hydrographical and hydrological point of view. The only exceptions are the Po di Volano, the Reno and the Fiumi Uniti river, each of which has a catchement basin of over 1,000 $km^2$. The other rivers, although small in size, are often responsible for a high, or even a very high, amount of contamination. It should be noted that the two rivers Montone and Ronco converge shortly before reaching the sea, resulting in what is called the Fiumi Uniti river. It should be also noted that the Savio River (with a basin of 625 $km^2$) includes the harbour-canal of Cesenatico (179 $km^2$). The flow data are not available for some of the rivers.

Table 1

Principal hydrological and hydrographical characteristics of the sixteen rivers flowing into the sea of the Emilia-Romagna.

| | Basin area | Length | Flow ($m^3$/s) | | |
|---|---|---|---|---|---|
| | ($km^2$) | (km) | mean annual | monthly minimum | monthly maximum |
| Po di Volano | 2735 | 72 | | | |
| Reno | 4597 | 211 | 59.00 | 6.66 | 119 |
| Destra Reno | 733 | | | | |
| Lamone | 515 | 88 | 8.33 | 0.91 | 17 |
| Candiano | 334 | 11 | | | |
| Fiumi Uniti | 1253 | 90 | 20.52 | 1.95 | 39 |
| Bevano | 308 | 33 | 1.96 | 0.14 | 5 |
| Savio | 804 | 96 | 10.78 | 1.04 | 21 |
| Rubicone | 191 | 28 | 2.05 | 0.13 | 5 |
| Uso | 149 | 32 | 1.54 | 0.90 | 3 |
| Marecchia | 574 | 67 | 9.12 | 0.84 | 17 |
| Marano | 59 | | | | |
| Melo | 51 | | | | |
| Conca | 152 | 44 | 2.14 | 0.16 | 4 |
| Ventena | 41 | 30 | 0.40 | 0.02 | 1 |
| Tavollo | 75 | 21 | | | |

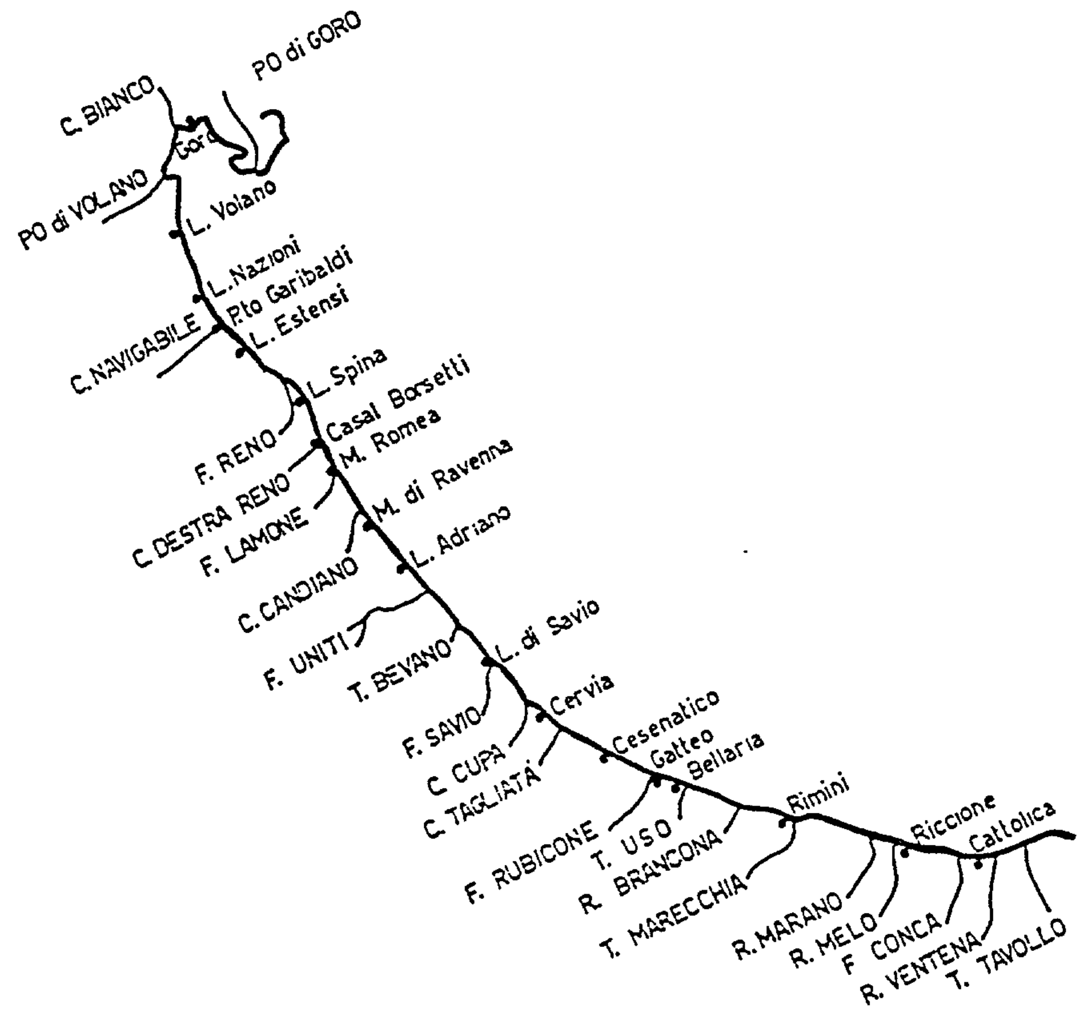



Fig. 3. Geographic position of the sixteen rivers considered in the present study in relation to the Adriatic Sea.

Phosphorus and nitrogen loads are shown in Figures 4 and 5. In the course of one year, the total load (in tons per year) carried to the sea from the sixteen basins is: phosphorus = 2,158; nitrogen = 30,115. To a great extent, this load is produced in the northern part of the coast, where the first two basins, Po di Volano and Reno, together account for more than 56% of the total load. If one considers that this northern coastal area also receives nutritive salts from the southern branches of the Po River Delta, it is not surprising that higher frequency of algal blooms occurs here. Description of nutrient loads as well as eutrophication in the coastal zone of Emilia Romagna can be found among others in Todini and Bizzarri (1988), UNESCO (1988), Rinaldi (1989) and Vollenweider et al. (1990).

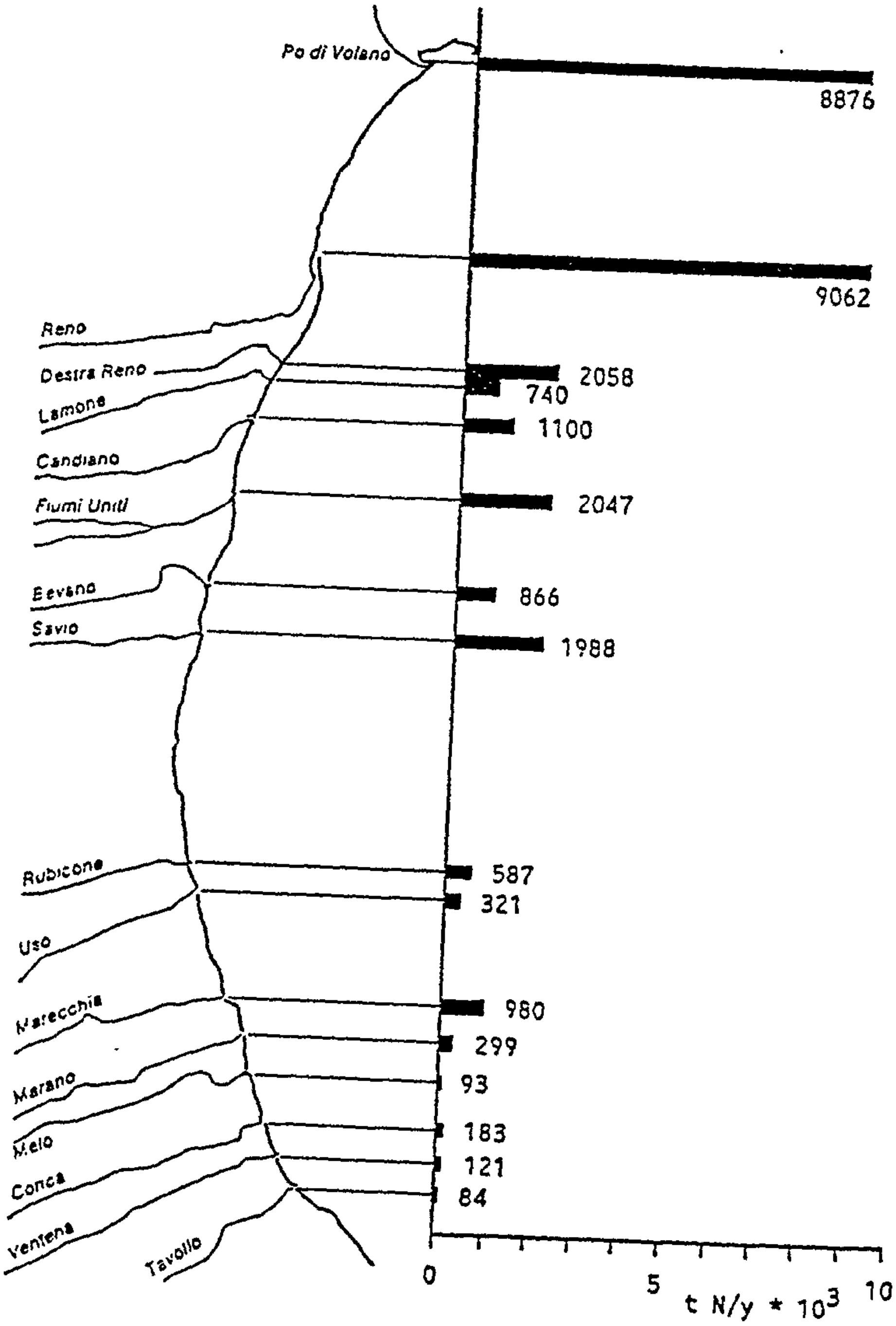



Fig. 4. Nitrogen loads carried to the sea by the 16 rivers (after Marchetti and Verna, 1990).

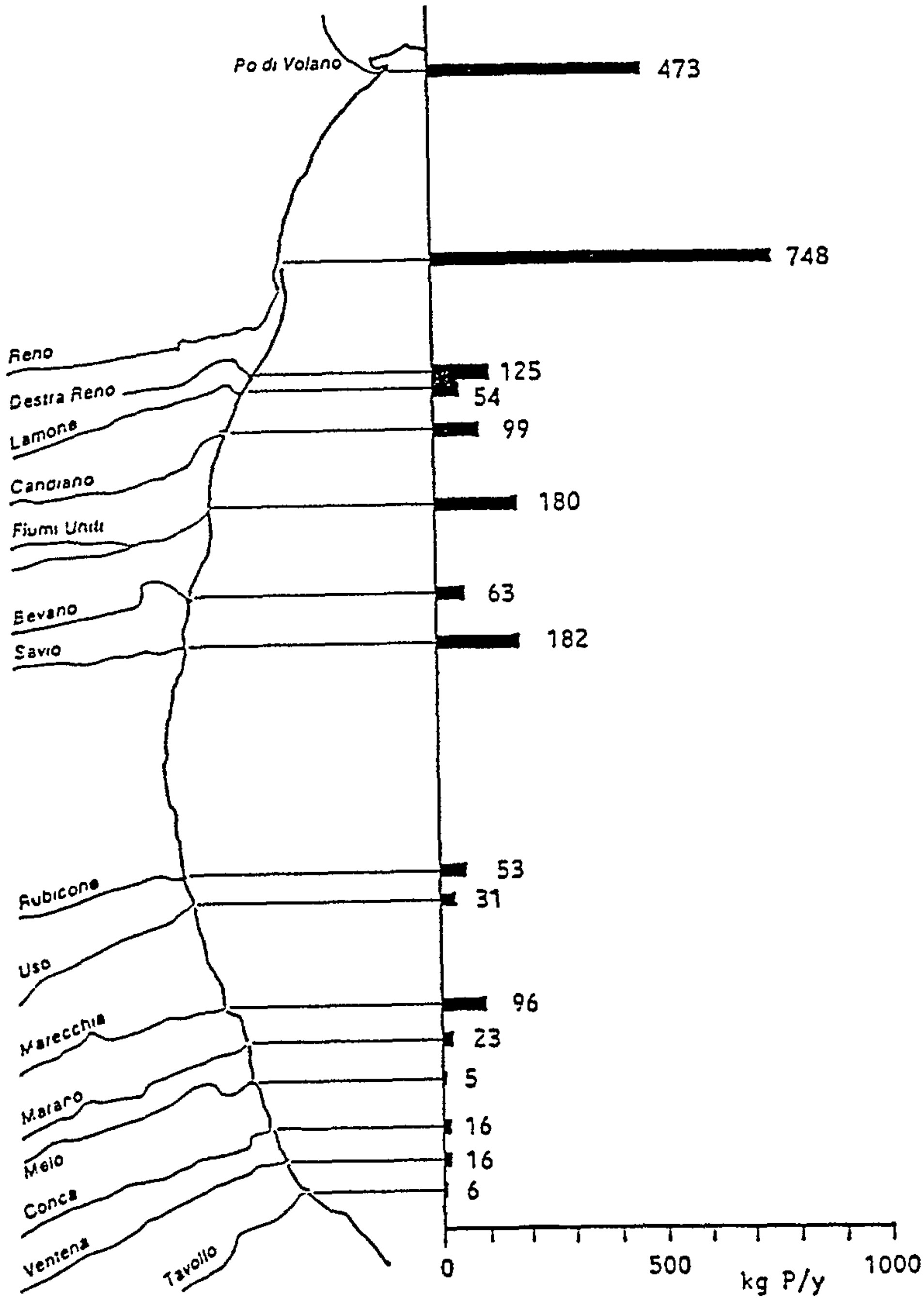



Fig. 5. Phosphorus loads carried to the sea by the 16 rivers (after Marchetti and Verna, 1990).

## 4. THE MATHEMATICAL MODEL

This section describes the system of differential equations used to represent the turbulent field along the coastal areas which constitues the basis of the three-dimensional mathematical model. The model used is a modification of Leendertse's three dimensional model for coastal seas and estuaries (Leendertse et al, 1973 and 1977), which was extensively tested in various studies dealing with the Emilia Romagna coastal zone (O'Kane et al., 1990; Reic, 1992).

The finite difference numerical scheme is described in detail in Leendertse et al, 1973 and 1977. An explicit scheme is used in the horizontal and an implicit scheme in the vertical. The scheme uses a space staggered grid with equidistant points in each horizontal direction. The uniform spacing may differ in each direction. A concept of layers is used in the vertical direction. The governing equations are integrated over the layer thickness to give an average value. A variable grid is possible in the vertical direction.

The finite difference equations are obtained, from the differential equations valid in the continuum, by means of an integrated difference scheme; i.e., by analytically integrating the equations valid in one point, along the vertical depth of the individual layer, to then arrive at the formulation of the differences in discrete terms.

The basic equations used in the model contain nine state variables: the height of the water surface above the reference level (average sea level); the three velocity components in the directions of the reference axes; the temperature and salinity (and their effect upon the density); the eddy kinetic energy, the concentration of one nutrient and the concentration of the phytoplankton.

The mesurements shown in the equations below are : $x,y,z$ = Cartesian coordinates, positive eastwards, northwards and upwards, respectively; $u,v,w$ = velocity components in the directions $x,y,z$; $t$ = time; $p$ = pressure; $f$ = Coriolis parameter; $T$ = temperature; $s$ = salinity; $\rho$ = density; $\kappa$ = vertical mass diffusion coefficient; $\kappa'$ = vertical heat diffusion coefficient; $\tau_{xx}, \tau_{xy}, \tau_{yx}, \tau_{yy}, \tau_{xz}, \tau_{yz}$ = Reynolds tensor components; $D_x, D_y$ = horizontal turbulent diffusion coefficients.

The equations of conservation of momentum inserted into the model, within the hypothesis of non-compressible fluid in a horizontal field of motion, taking into account the effect caused by the Earth's rotation, are as follows:

$$\frac{\partial u}{\partial t}+\frac{\partial (uu)}{\partial x}+\frac{\partial (uv)}{\partial y}+\frac{\partial (uw)}{\partial z}-fv+\frac{1}{\rho}\frac{\partial p}{\partial x}-\frac{1}{\rho}\left[\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right]=0$$

$$\frac{\partial v}{\partial t}+\frac{\partial (vu)}{\partial x}+\frac{\partial (vv)}{\partial y}+\frac{\partial (vw)}{\partial z}+fu+\frac{1}{\rho}\frac{\partial p}{\partial y}-\frac{1}{\rho}\left[\frac{\partial \tau_{yx}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right]=0$$

The vertical water acceleration value due to the action of the tide and wind is extremely small compared with the acceleration due to the gravity. Short-period waves are excluded and the vertical momentum equation is replaced by the hydrostatic pressure equation, where the density of the sea water is expressed through an empirical state equation:

$$\frac{\partial p}{\partial z} + \rho(S,T)g = 0$$

Considering the water as non-compressible, the equation of continuity in terms of volume results as being:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

The equations for the dynamic equilibrium of salinity and heat are, respectively:

$$\frac{\partial s}{\partial t} + \frac{\partial (us)}{\partial x} + \frac{\partial (vs)}{\partial y} + \frac{\partial (ws)}{\partial z} - \frac{\partial \left( D_x \frac{\partial s}{\partial x} \right)}{\partial x} - \frac{\partial \left( D_y \frac{\partial s}{\partial y} \right)}{\partial y} - \frac{\partial \left( \kappa \frac{\partial s}{\partial z} \right)}{\partial z} = 0$$

$$\frac{\partial T}{\partial t} + \frac{\partial (uT)}{\partial x} + \frac{\partial (vT)}{\partial y} + \frac{\partial (wT)}{\partial z} - \frac{\partial \left( D_x \frac{\partial T}{\partial x} \right)}{\partial x} - \frac{\partial \left( D_y \frac{\partial T}{\partial y} \right)}{\partial y} - \frac{\partial \left( \kappa' \frac{\partial T}{\partial z} \right)}{\partial z} = 0$$

In the heat balance equation, the same diffusion coefficient was used as in the salinity balance, i.e., the flow of heat by conduction was not considered; only the flow exchanges caused by turbulence.

The horizontal Reynolds stresses present in the dynamic equation are considered to be proportional to the horizontal velocity gradients.

$$\tau_{xx} = A_x \frac{\partial u}{\partial x}, \tau_{xy} = A_x \frac{\partial u}{\partial y}, \tau_{yx} = A_y \frac{\partial v}{\partial x}, \tau_{yy} = A_y \frac{\partial v}{\partial y}$$

As the finite difference equations derived from the differential equations described above and used for the numerical solution of the model do not allow for the resolution of the flow field at length scales of less than twice the discretization size, a proportion coefficient A is introduced. This coefficient, called non-linear horizontal eddy viscosity is:

$$A = \gamma \left| \left( \frac{\partial w}{\partial x} + \frac{\partial w}{\partial y} \right) \right| (\Delta l)^3$$

where

$$\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \Delta l = \sqrt{\Delta x^2 + \Delta y^2}$$

where $\omega$ is the vorticity of the velocity field *(u-v)*, $\Delta x$ and $\Delta y$ are the horizontal dimensions of the grid, and $\gamma$ is a proportionality factor.

A vertical momentum exchange term, or eddy viscosity exchange coefficient *E*, is also introduced, which connects the vertical Reynolds stresses to the vertical gradients of the horizontal velocity components.

$$\tau_{xz} = E_x \frac{\partial u}{\partial z}, \tau_{yz} = E_y \frac{\partial v}{\partial z}$$

The vertical momentum exchange coefficient $E$ is defined as:

$$E = \rho L \sqrt{e} \exp(-mRi)$$

where m is a parameter, $Ri$ the Richardson number expressed in terms of the vertical gradient of the density $\rho$ and the eddy kinetic energy *(e)*, relative to vortices smaller than the size of the grid:

$$Ri = -\frac{g}{\rho e} \frac{\partial \rho}{\partial z} L^2$$

In this equation the characteristics length scale $L$ is defined, based on the Von Karman constant $\chi$, as:

$$L = \chi z \sqrt{1 - z/d}$$

where

$z$ = vertical distance from the bottom to the point considered

$d$ = vertical distance from surface to the bottom

It the Leendertse formulation, both the vertical exchange of mass and momentum for three-dimensional turbulence and the horizontal exchange of mass and momentum for the two-dimensional turbulent eddies, are determined by means of a reduced number of parameters, constant over time and space.

This significant simplification, however, brings about the introduction of an additional state variable: the eddy kinetic energy, which requires the addition of a new equation to represent its dynamics.

The preservation of eddy kinetic energy, and thus the energetic balance of momentum within the grid, is thus given by:

$$\frac{\partial e}{\partial t} + \frac{\partial (ue)}{\partial x} + \frac{\partial (ve)}{\partial y} + \frac{\partial (we)}{\partial z} - \frac{\partial \left( D_x \frac{\partial e}{\partial x} \right)}{\partial x} - \frac{\partial \left( D_y \frac{\partial e}{\partial y} \right)}{\partial y} - \frac{\partial \left( E_e \frac{\partial e}{\partial z} \right)}{\partial z} + S - D_e = 0$$

The horizontal and vertical energy exchange coefficients $D_x, D_y$ and $E_e$ are specified in a similar way to the corresponding mass exchange coefficients. The generation of energy $S$ within the grid is a function of the shear stress induced by vertical velocity:

$$S = L\sqrt{e}\left(\frac{\partial \overline{u}}{\partial z}\right)^2$$

where $\overline{u}$ is the mean velocity. The dissipation factor $D_e$ is made to depend on the energy transfer rate from larger to smaller eddies according to the expression:

$$D_e = a_2 \frac{e^{3/2}}{L}$$

with $a_2$ a constant.

The term which takes into account the energy subtracted from the tension on the bottom is expressed as:

$$S = g\frac{U^3}{C^2}$$

with $U$ the energy in the lower layer in the flow direction and $C$ as the Chézy friction coefficient.

On the surface, instead, it is considered that the wind generates surface waves which, in turn, induce a turbulence in the upper portion of the water column. The characteristics of the wave depend on the intensity and duration of the wind and on the section of the sea considered.

Considering the sea to be in fully-developed movement, with a moderate wind velocity $u_w$, the total wave energy per unit of surface will be equal to:

$$E_t = 5.6 * 10^{-9} u_w^4$$

with a limit on the velocity of the wind $u_w$, in order to achieve a reasonable approximation:

$$u_w < 21.8\sqrt{h_1}$$

with $h_1$ the depth of the upper layer.

Finally, a mass balance equation was added for nutrient substance $N$, and for phytoplankton, $Ph$.

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}+\frac{\partial (wN)}{\partial z}-\frac{\partial\left(D_x\frac{\partial N}{\partial x}\right)}{\partial x}-\frac{\partial\left(D_y\frac{\partial N}{\partial y}\right)}{\partial y}-\frac{\partial\left(\kappa\frac{\partial N}{\partial z}\right)}{\partial z}=0$$

$$\frac{\partial Ph}{\partial t}+\frac{\partial (uPh)}{\partial x}+\frac{\partial (vPh)}{\partial y}+\frac{\partial (wPh)}{\partial z}-\frac{\partial\left(D_x\frac{\partial Ph}{\partial x}\right)}{\partial x}-\frac{\partial\left(D_y\frac{\partial Ph}{\partial y}\right)}{\partial y}-\frac{\partial\left(\kappa\frac{\partial Ph}{\partial z}\right)}{\partial z}=0$$

# 5. THE MARINE ECOLOGICAL SYSTEMS

## Introduction

An overview of a subset of the marine ecosystem will be presented with the aim to describe certain concepts which form the basis of the model used in this study. Some of the concepts are the simplifications of reality and others have much debate surrounding them.

The main concepts and definitions in this chapter are taken from the following references: Barnes and Hughes (1988); Fenchel (1987); Mann and Lazier (1991); Buckley (1995).

## Ecosystems

An ecosystem is a community of organisms and their physical environment interacting as an ecological unit.

## Communities

A community is defined as a body of individuals or an assemblage of species. The individuals of the community interact with one another. An important consideration is the existence, importance, looseness, transience and contingency of interactions. One of the ways of analysing these interactions is by using the important principle of food chain and food cycles. The interactions or links can be separated into a) vertical or trophic links and b) horizontal links between species. The trophic links are predation parasitism, herbivory and scavenging. The horizontal links is competition. Progressively fewer animals occupy the upper levels of the food chain.

## Pelagic Community

Marine organisms can be placed into two large categories: the pelagic community refer to those organisms which are found in the water column; those found in the bottom sediments are referred to as the benthic community. The pelagic community is subdivided into two large groupings. The species which are distributed at the mercy of water currents are called plankton, while those which can swim against water currents are called nekton. Nekton are the top predators of the pelagic community.

Plankton range in size from bacteria which are about 1 µm in diameter to larger jellyfish which are approximately 0.5 m in diameter. Plankton are classified according to logarithmic size: ultraplankton or picoplankton (< 2 µm); nanoplankton (2-20 µm), macroplankton (200-2,000 µm); and megaplankton (>2,000 µm). Ultra plankton are mainly bacteria, the nano- and microplankton are protists and the macro- megaplankton are animal.

## Production

Production is the increase in biomass in the water column. Biomass is organic matter or energy accumulated by a population or trophic unit. It can be divided into primary and secondary production. Primary production is much greater than the secondary production. Barnes et al. (1988) estimate that secondary production is between 10 to 12% of primary production.

## Primary Production

Primary production is the increase in biomass in the water column due to organisms which carryout phytosynthesis. Phytosynthesis is a biochemical process that utilises radiant energy from sunlight to synthesise/fix carbohydrates from carbon dioxide and water in the presence of chlorophyll. The group of organisms which carry out photosynthesis are called phytoplankton. The total quantity of carbon or energy fixed is called gross primary production. Net primary production is that portion of gross primary production incorporated into the body of the phytoplankton. The difference between gros primary production and net primary production is community respiration, the utilisation of synthesised organic compounds to release energy. Net production also includes the loss of organic substances from primary producers to the water which is utilised by bacteria and some zooplankton. The term primary production can be assumed to mean net primary production.

## Secondary production

Secondary production is the increase in biomass due to the grazing of phytoplankton by other organisms which in turn are grazed by other organisms. These organisms are called zooplankton. Mann and Lazier (1991) state that zooplankton has two important functions; firstly they convert the organic matter of phytoplankton into larger particles which facilitates the movement of energy and materials along the marine food chains and secondly they excrete inorganic substances such as ammonia and phosphorous thereby returning nutrients to the water column for use by phytoplankton.

## Marine food chains

Food chains consist of a sequence of organisms on successive trophic levels within a community, through which energy is transferred by feeding; energy enters the food chain during fixation by primary producers, passes to the herbivores and then to the carnivores. Food chains are often called food pyramids because they take the form of a pyramid of numbers, biomass or energy. Food chains are a subset of food webs which are a network of interconnected food chains of a community.

The basic marine food chain has phytoplankton at its base and various species of zooplankton in the middle trophic levels. At the top of the food chain are the nekton species. Energy flows up through the system. Food chains cannot include more than about five trophic levels because of the limited efficiency in the transfer of organic carbon from one trophic level to the next. The transfer of energy between trophic levels has been estimate at 20 % for the phytoplankton herbivore interface and between 10 to

15% further up the food web. The food chain assumes that living primary producers are the main source of food for zooplankton.

Food chains are the cornerstone of ecological models because they simplify the complicated interconnecting relationship which exists between organisms. Fenchel (1987) states that the classical picture of phytoplankton food chains remains essentially correct, the fact that bacteria and protist typically make up about half the total biomass suggests that this description is incomplete., The microbial loop has been suggested to complete the description of the marine food web.

Microbial loop

Traditional primary producers which form the base of the food chain were thought to consist mainly of diatoms and dinoflagellates. Diatoms and dinoflagellates are microplankton. Three important discoveries have changed this perception of the marine ecosystem:

a) It was discovered that there are a large number of smaller organism present in the water column;

b) Bacteria and protists make up typically about half of the total biomass; and

c) It has been found that photosynthetic nano- and picoplankton are responsible for a large proportion of the entire primary production especially in oligotrophic oceanic waters.

Phytoplankton releases about 10 to 15 % of its photosynthesis as dissolved organic matter which is utilised by bacteria. Bacteria may have generation times ranging from a few hours to a few days and may have production rates equivalent to 20 % of the total primary production. Since bacterial growth efficiency is not likely to exceed 50%, about half of the primary production is consumed by bacteria.

There is some evidence which suggest that small heterotrophs are also likely to excrete dissolved organic compounds. If this is the case, then the fraction of primary production directly utilised by bacteria may not be as large as suggested above. Bacterial numbers are relatively constant in the water column.

Traditional filter feeding zooplankton appear not to be able to ratain bacterial particles. However heterotrophic nanoflagellates which are nanoplankton consume these bacterial particles. These nanoplankton in turn fall prey to phagotrophic microplankton which then enter the classical food chain.

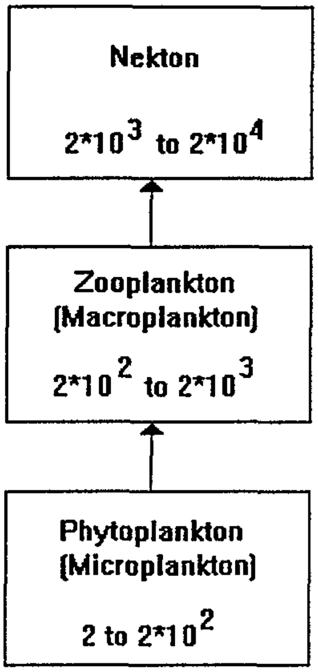



Fig. 6. A schematic representation of traditional marine plankton food chain. The dimensions are the size range of the organisms in µm.

## Population structure

Photosynthetic organisms depend on the uptake of dissolved compounds which often occur in an extremely diluted form. In oligotrophic waters where concentrations are low, pico- and nanoplankton predominate.

The base of the food chains in these waters is composed of very small cells, the microbial loop dominates the pelagic food web and unicellular organisms are responsible for almost the entire energy flow and the mineralisation processes in the water column.

Where there is an input of "new" nutrients, large phytoplankton such as diatoms and dinoflagellates are an important contribution to the phytoplankton biomass, and are the base of the food chain. They are eaten by copepods or they sink as sediment on the bottom. This food chain consists of fewer levels and a much larger part of the primary production is channelled to larger organisms and/or exported to the benthos.

## Phytoplankton

Phytoplankton concentration is affected by light, temperature, nutrient concentration, zooplankton grazing and phytoplankton concentration.

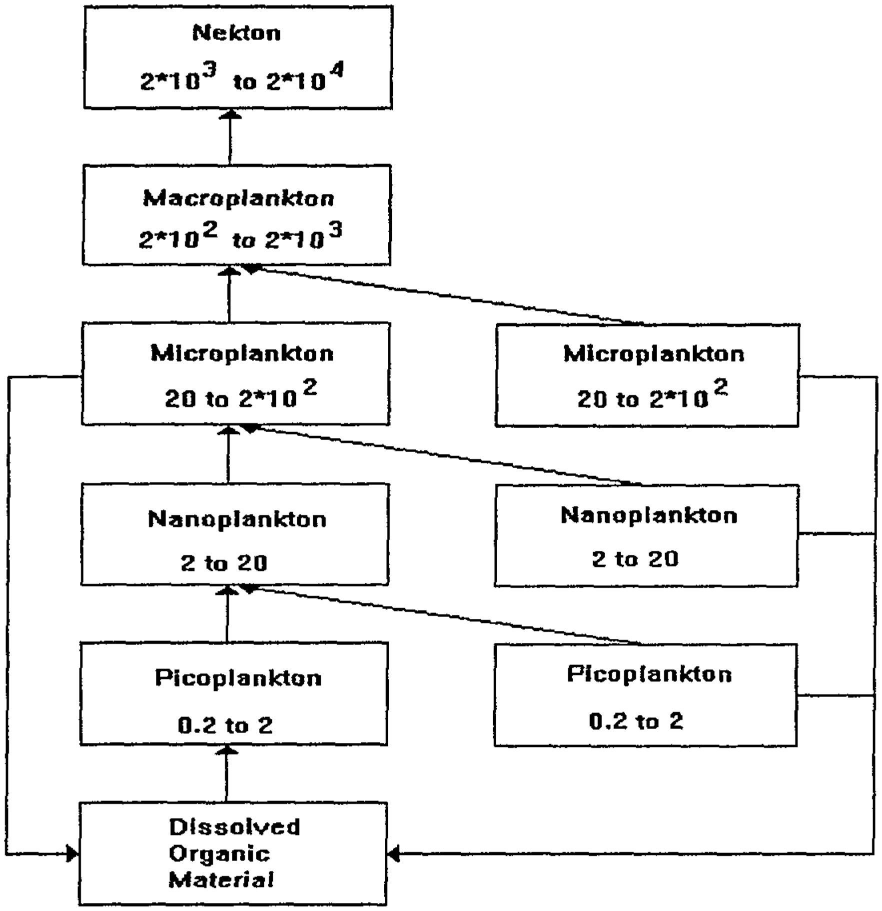



Fig. 7. A schematic representation of the microbial loop and its relation to the classical plankton food chain. The left column represents heterotrophs and the right column photoautrophs.

## The role of light

Light is the main source of energy which drives in the ocean. Light intensity strongly affects the rate of photosynthesis, and varies over time and space. Photosynthesis increases with increasing light intensity, up to an optimum light intensity value, then begins to decrease. Optimum light intensity values vary for different species of phytoplankton. Respiration is also thought to increase with light intensity but the relationship is unknown.

The role of nutrients

Phytoplankton require certain compounds or elements for their growth. Some elements such as Carbon, Hydrogen, Oxygen, Nitrogen, Silicon, Potassium, Magnesium, Phosphorus and Calcium are needed in relatively large amounts and are known as "Macro nutrients". Other elements such as Manganese, Copper, Zinc, Boron, Sodium, Chlorine and Cobalt are required in very small amounts and are referred as "Micro nutrients" or "trace elements". Most of these elements are in sufficient quantity for phytoplankton growth. However at certain times of the year, some of the elements, especially nitrogen, are not present in sufficient quantity and limit phytoplankton growth.

Nutrient concentration in the water column affects the growth rate of phytoplankton in an indirect way. This effect has been broken into three sets of relationships:

a) Nutrient uptake by cells take place at discrete sites on cell membranes. When concentrations are low, uptake rates increase with increasing nutrient concentration. As nutrient concentrations increase the uptake sites become saturated and the rate of increase of the uptake rate decreases and goes to zero (Fig. 8).

b) The amount of the nutrient that is stored within cells is in turn controlled by the rate of uptake of cells (Fig. 9). Although cells may store nutrients in excess of current needs, there seems to be a feedback between cell content of nutrients and the rate with which a given nutrient may be taken up by the cells (Barnes and Hughes 1988).

c) The internal pool of nutrients control the rate at which a phytoplankton population may grow (Fig. 10). When the internal pool of nutrients are small growth rates increase with increasing size of the internal pool nutrients. As the size of the internal pool of nutrients increase, the growth rate decreases and goes to zero (Fig. 10).

The three relationships described above can be simplified to one relationship. When concentrations are low, growth rates increase with increasing nutrient concentration. As nutrient concentrations increase the rate of increase of the growth rate decreases and goes to zero (Fig. 11).

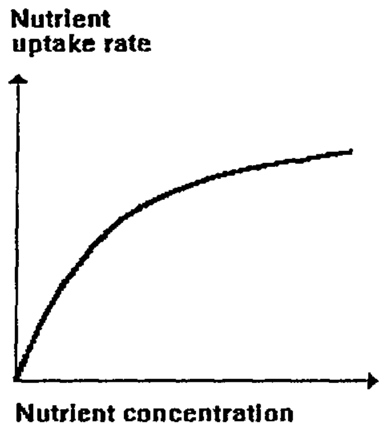


Fig. 8.

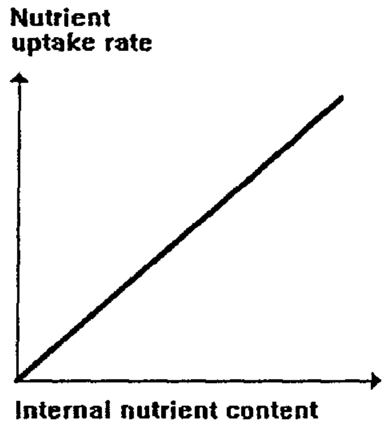


Fig. 9.

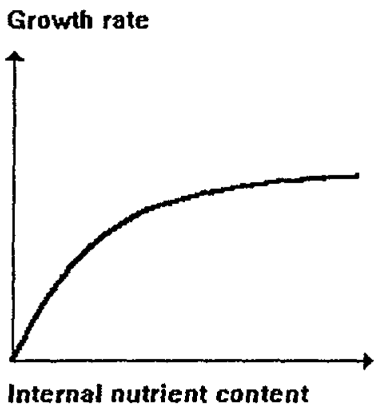


Fig. 10.

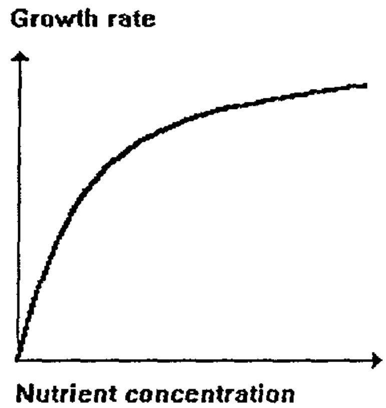


Fig. 11.

The role of the temperature

Temperature variations effect the growth of phytoplankton. The major temperature variation is seasonal, although some diel and spatial fluctuation occur. For most species of phytoplankton growth rates increase with increasing temperature up to an optimum value and then begins to decrease. Temperature is generally not considered a limiting factor for growth.

The role of self shading

As phytoplankton concentrations increase, the absorbtion of light by cells themselves, reduces the energy available to the phytoplankton lower in the water column.

Zooplankton

Zooplankton can be subdivided into carnivores and herbivores. The herbivorous zooplankton concentration depends on phytoplankton concentration and carnivorous zooplankton concentration. The carnivorous zooplankton concentration depend on the herbivorous zooplankton concentration and other carnivorous zooplankton concentration.

Zooplankton grazing

Zooplankton in the water column consume particles of appropriate size and nutritional quality. The ratio of zooplankton to particle size is usually 1:10 (Fenchel, 1987). Zooplankton have two methods of feeding which are filter feeding and raptorial feeding. These two methods are appropriate for different sizes of prey although some zooplankton use both methods for catching prey. The smaller size particles pico-, nano- and microplankton are removed by various forms of felter feeder. The larger size particles macroplankton are consumed by raptorial predators.

Zooplankton require a minimum concentration of prey before grazing commences. When prey concentration is low but above the threshold concentration, ingestion rates increase with increasing prey concentration. As prey concentration increases the rate of increase of the ingestion decreases and falls to zero.

Zooplankton assimilates only a portion of the total amount grazed. The assimilation efficiency of different species of zooplankton vary widely from between 10-90%. Assimilation rates are difficult to measure and a great deal of uncertainty is attached to specific values. Some species od zooplankton have different assimilation rates depending on age. Assimilation efficiency is much higher for carnivorous zooplankton than herbivorous zooplankton. The remainder portion not assimilated is excreted.

The energy assimilated is used for two purposes, growth and metabolism. Growth efficiency has been put between 10-60%. High assimilation efficiency corresponds to low growth efficiency. Growth rates and assimilation rates can be simplified given the uncertainty to one rate term and are set equal to a constant rate in ecological models.

## 6. SIMPLE MODEL OF MARINE ECOLOGICAL SYSTEM

The goal of an ecological model is to depict the main features of both the spatial variations throughout the region of interest and the temporal changes during the year of the planktonic ecosystem.

The ecological model used is the simplified version of the model developed by Valerie Andersen (1986) for the Bay of Villefranche. The main equations are:

$$\frac{dPh}{dt} = (\mu_m l_N l_T l_E - m_{Ph})Ph$$

$$\frac{dN}{dt} = -\mu_m l_N l_T l_E Ph + N_e$$

*Ph* - Phytoplankton
*N* - Inorganic nitrogen

**Growth of Phytoplankton**

The growth and assimilation of nitrogen by the phytoplankton is $\mu_m l_N l_T l_E$ where:
$\mu_m$ = the maximum growth rate

$l_N = \frac{N}{k_N + N}$ is the limitation of growth due to nitrogen

$N$ = concentration of inorganic nitrogen

$k\ k_N$ = half saturation constant for inorganic nitrogen

$l_E = 2(1+\beta_E)\frac{x_E}{x_E^2 + 2\beta_E x_E + 1}$ is the limitation due to the light intensity

$x_E = \frac{E}{E_s}$ where

$E$ = light intensity at time t

$E_s$ = optimal light intensity

$\beta_E$ = the slope of the light limitation curve

$l_T = 2(1+\beta_T)\frac{x_T}{x_T^2 + 2\beta_T x_T + 1}$ is the limitation due to temperature

$x_T = \frac{T - T_0}{T_S - T_0}$

$T$ = temperature at time t

$T_0$ = temperature where there is no growth

$T_s$ = optimal temperature for growth

$\beta_T$ = slope of the temperature limitation curve

$E$ and $T$ values are generated by a sine wave and for a depth of 20 meters are:

$$E(t) = 67.8 sin\left(\frac{2\pi t}{365} - \frac{\pi}{2}\right) + 640$$

$$T(t) = 6.25 sin\left(\frac{2\pi t}{365} - 0.74\pi\right) + 19.25$$

**Phytoplankton mortality**

The mortality rate depends on the nourishment concentration. There is a threshold concentration below which the death rate is a maximum.

for $B \leq B_{min}$ $\quad m = m_{\max}$

for $B \geq B_{min}$ $$m = \frac{a_m}{B} + m_0$$

$m$ = mortality rate
$B_{min}$ = threshold concentration
$B$ = nourishment concentration
$m_{max}$ = maximum mortality rate
$m_0$ = minimum mortality rate
$a_m$ = slope of the mortality curve

Table 2

Parameter values for growth of phytoplankton

| growth of phytoplankton | symbols | units | values |
|---|---|---|---|
| specific growth rate | $\mu$ | $d^{-1}$ | 2.16 |
| half saturation constant | $k_N$ | $\mu$ mol N/l | 1.0 |
| optimal light intensity | $E_S$ | ly/d | 82.24 |
| shape factor for light curve | $\beta_E$ | unitless | -0.6 |
| optimal temperature for growth | $T_S$ | °C | 15.5 |
| temperature where there is no growth | $T_0$ | °C | 11.0 |
| shape factor for temperature curve | $\beta_T$ | unitless | -0.8 |

Table 3

Parameter values for death of phytoplankton

| phytoplankton mortality | symbols | units | values |
|---|---|---|---|
| maximum mortality rate | $m_{max}$ | $d^{-1}$ | 0.067 |
| minimum mortality rate | $m_0$ | $d^{-1}$ | 0.03 |
| shape factor for the mortality curve | $a_m$ | $\mu$ mol N/ld | 0.012 |
| Threshold concentration | $B_{min}$ | $\mu$ mol N/l | 0.31 |

## 7. THE STUDY

The study, which led to the calibration of the hydrodynamic and water quality model along the Emilia-Romagna coast, was based on the following data:

a) Geographical data (profile of coast and bathymetries printed by Istituto Idrografico della Marina): The finite difference mesh of the area examined was divided into 109 grid points in the $y$ direction and 30 grid points in the $x$ direction. The distance between each grid point is 1.0 km. The adopted model has six levels in the vertical direction, based on the sea bottom's bathymetric trend, three of which are 2 m deep, one is at 3 m, one at 9m and one on the bottom at 11 meters.

b) Marine meteorological data (currents, winds,tides): The boundary conditions due to currents and tide levels were introduced into the boundary meshes, at present the shear stress caused by the wind have not been introduced.

c) Initial state: The initial conditions were obtained by assigning to each element at time zero the values of salinity, temperature, concentrations of pollutants, nitrogen and phytoplankton, and carrying out a simulation for a congruous number of time increments until a dynamical equilibrium was reached.

d) Polluting loads: The data regarding salinity, temperature, concentrations of phytoplankton, nitrogen and pollutants were introduced qualitatively and quantitatively, for the time being, in the different locations identified along the coast (see Fig. 3, Fig. 4, Fig. 5 and Table 1).

The time integration interval adopted is 21 seconds and with this increment, simulations for over 45 days were carried out without numerical instabilities.

Calibration of the mathematical model was based on a series of discrete measurements in space and in time, carried out efficiently by the laboratory vessel "Daphne II" from Cesenatico. The vessel is supplied with automatic instruments for measuring on-the-spot temperature, salinity, PH, oxygen and chlorophyll. For this special case results were used from observations during the campaign of August 1991.

The results were verified through a comparison with the measured data, and salinity was considered as the most significant variable for the calibration as far as the diffusion factors concerned, since it summarizes the general hydrodynamic situation and it enables to verify the consistency of the values used for diffusivity and convectivity coefficients.

In order to obtain a good graphic display of the results, several post-processing programmes were developed for the compaction and graphic management of the numerical data archives obtained from the main computer programme. Using suitable colours, it was possible to illustrate the trend of dependent variables in time and in space by disaggregating the results on the considered discretization levels ($x,y$ planes for $z$ = constant).

## 8. THE RESULTS

### River and estuarine plumes on the continental shelves

In the situations where river flow heavily predominates over any tidal effects, the surface outflow onto the continental shelf is mainly of fresh water from the river itself, and this is called a river plume. In other situations there is strong penetration of salt water into the river valley to form an estuary, and the outflow onto the continental shelf is of river water mixed with considerable quantities of salt water. This constitues an estuarine plume.

When the light upper water from an estuary or a river flows out into the open ocean it leaves behind a narrow region where the flow is predominantly two dimensional and enters a less-confined world where the Coriolis force can change the direction of the flow.

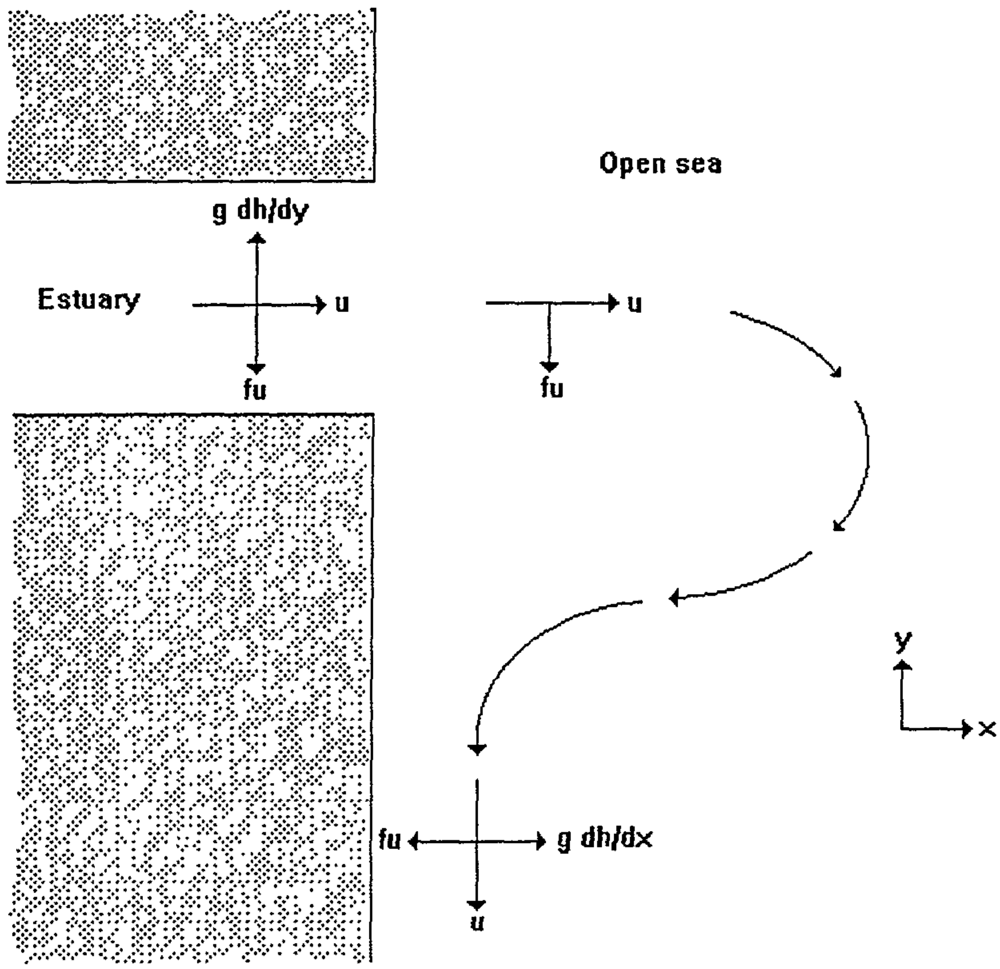



Fig. 12. Water moving down the estuary at the velocity $u$ is in geostrophic balance. The Coriolis force balances the pressure gradient. In the open ocean the flow is not in geostrophic balance and in the northern hemisphere the Coriolis force causes the flow to turn to the right and flow along the coast.

In the illustration in Fig. 12 the water moves down the estuary at a velocity $u$. Because this motion is relative to the earth there is a Coriolis effect directing water to the right of the flow. The water, however, is not able to change direction because of the side boundaries of the estuary but the water does move to the right causing a slight tilt to the sea surface and a pressure gradient in the direction opposite to the Coriolis force. The flow is therefore in geostrophic balance and the slope of the sea surface can be easily estimated.

When the water flows out of the estuary this surface slope is missing, so it cannot provide the pressure force to balance the Coriolis force. Being unopposed, the Coriolis force causes the flow to turn to the right but it comes under the influence of the shoreline again and sets up a situation similar to the one found within the estuary. As the Coriolis force pushes the water to the right, the blocking of the coast causes an opposing pressure gradient in the form of a slight slope in the sea level to be generated against the coast, and the plume of fresh water continues on its way as a coastal current in geostrophic balance parallel to the coast.

When the water leaving a river or estuary flows into a region where there is already a current, the movement of the fresh water plume is not as simple as in the case described above. The position of the plume in these cases will be the result of the ralative strengths of the background flow in the ocean and the flow will overwhelm a weak outflow and the plume may turn in an unexpected direction. In most cases the flows are tide dependent and the plume changes position over the tidal cycle.

Figures 13a,b,c,d,e,f show the residual discharge at the different levels of the hydrodinamical model after 7 days of simulation, while Figures 14a,b,c,d,e,f show the same residual discharge after 15 days. It clearly emetges that the residual discharge tends to move the inflowing substances from North to South and the resulting combined effect is shown in the simulation results, thus affecting all the bio-chemical processes.

The evolution in time of the spatial pattern of the computed concentration of a hypothetical conservative pollutant is shown in Figures 15a,b,c,d,e,f for the different layers of the model while the patterns of Nitrogen and Phytoplankton are given, for the same layers in Figures 16a,b,c,d,e,f and 17a,b,c,d,e,f respectively.

**Biological effects of river and estuarine plumes**

The biological effects of fresh water discharge may be considered under three headings:

a) direct effects of the materials carried by the river on biological production in the plume;

b) entrainment and consequent upwelling of nutrient-rich water, which is likely to enhance primary and secondary production;

c) enhancement of the stability of the water column, which may be expected to increase productivity at the time of a spring bloom, but which may inhibit vertical mixing and hence reduce primary productivity at other times of year.

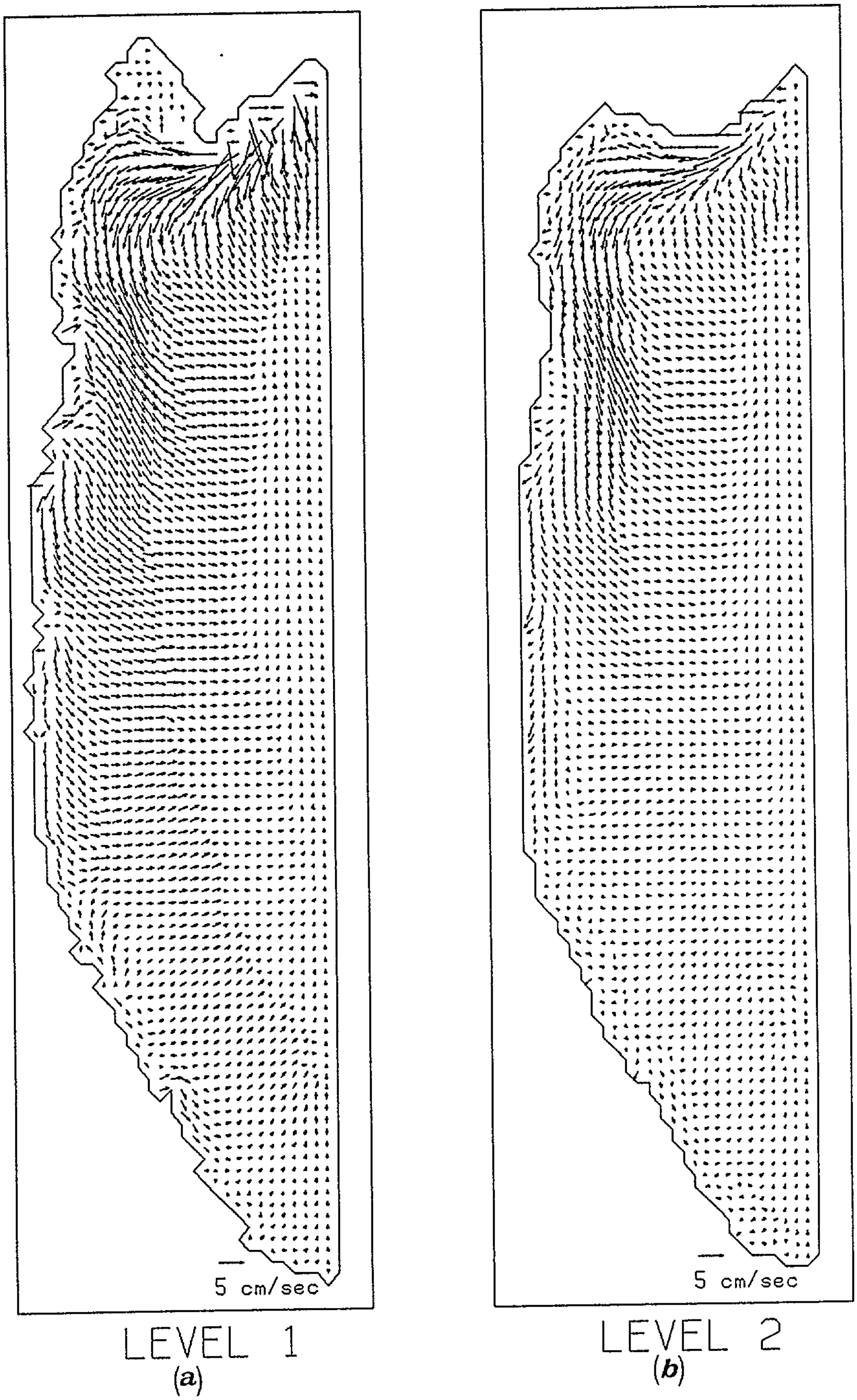



Fig. 13(a),(b). Computer simulated residual circulation patterns along Emilia-Romagna coast after 7 days. Sea current speeds are shown by the lenghts and directions of arrows.

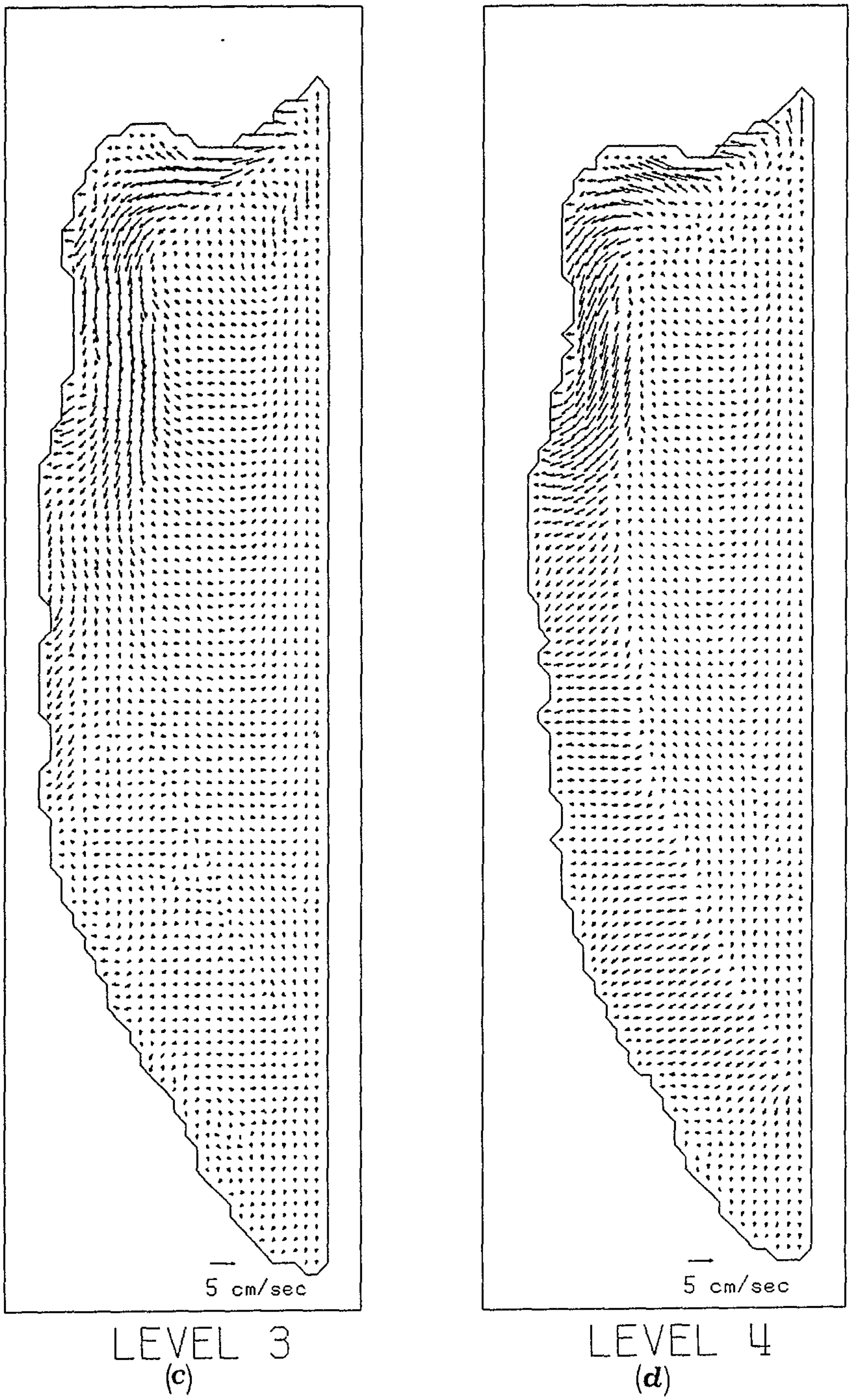



Fig. 13(c),(d). Computer simulated residual circulation patterns along Emilia-Romagna coast after 7 days. Sea current speeds are shown by the lenghts and directions of arrows.

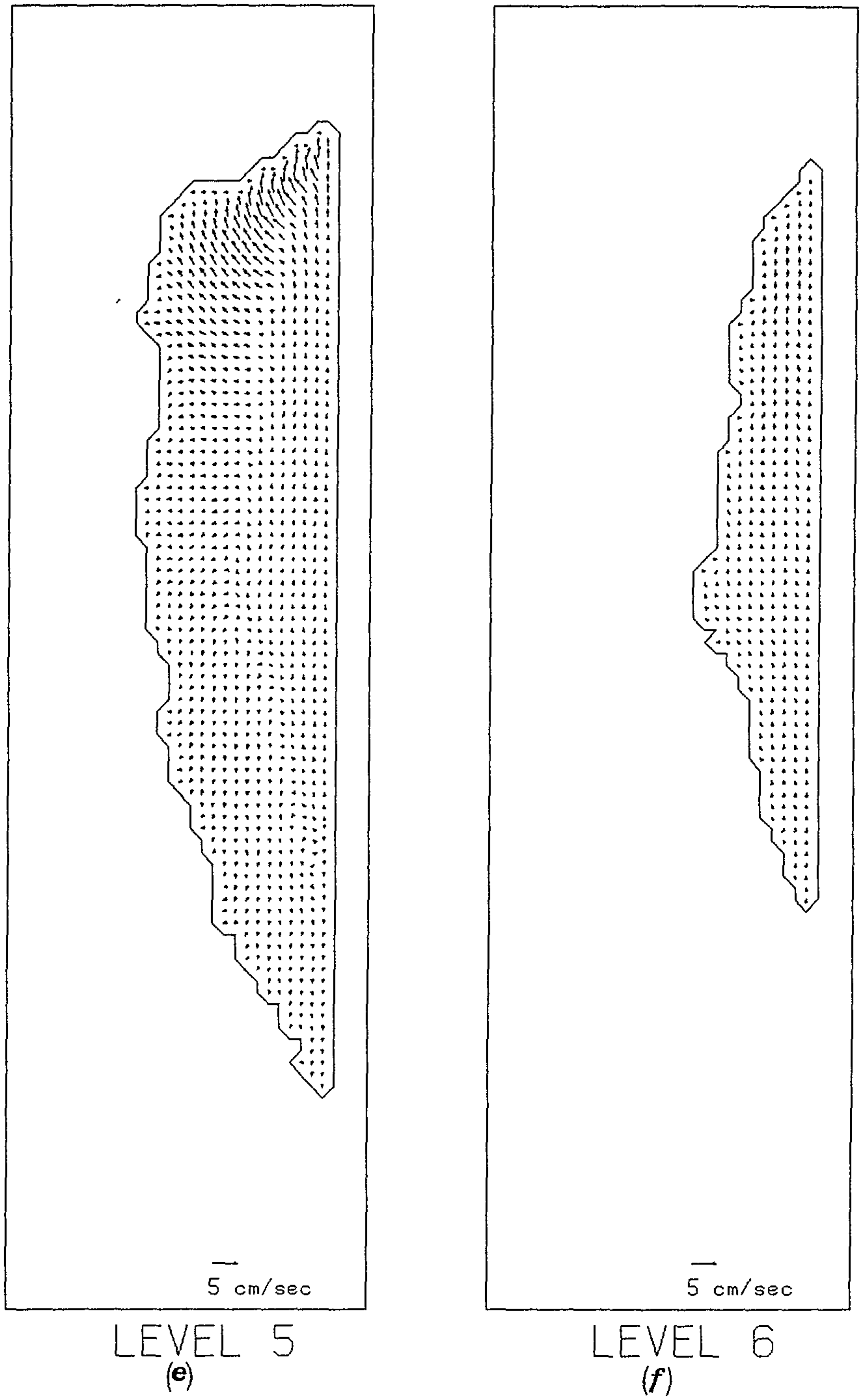



Fig. 13(e),(f). Computer simulated residual circulation patterns along Emilia-Romagna coast after 7 days. Sea current speeds are shown by the lenghts and directions of arrows.

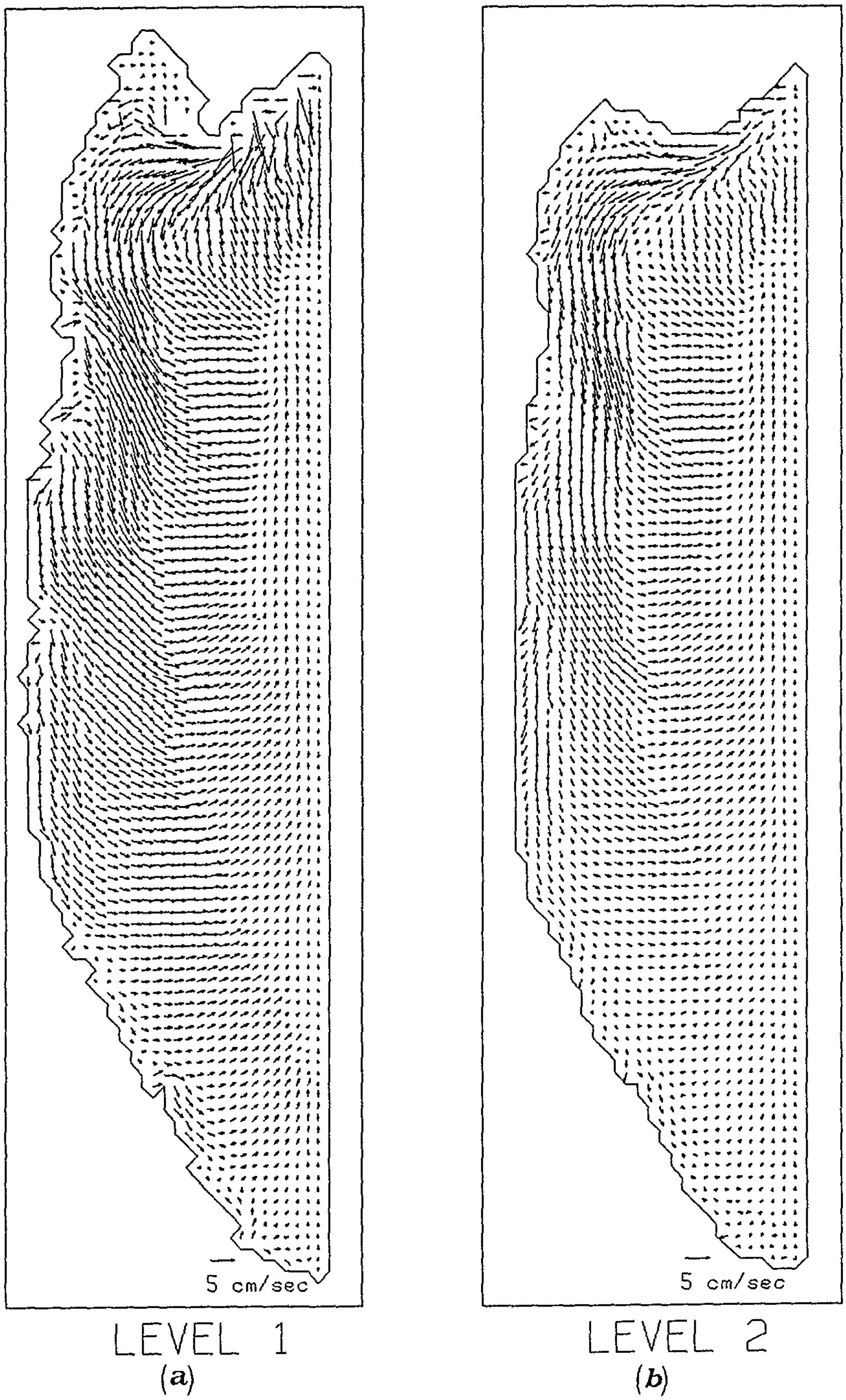



Fig. 14(a),(b). Computer simulated residual circulation patterns along Emilia-Romagna coast after 15 days. Sea current speeds are shown by the lenghts and directions of arrows.

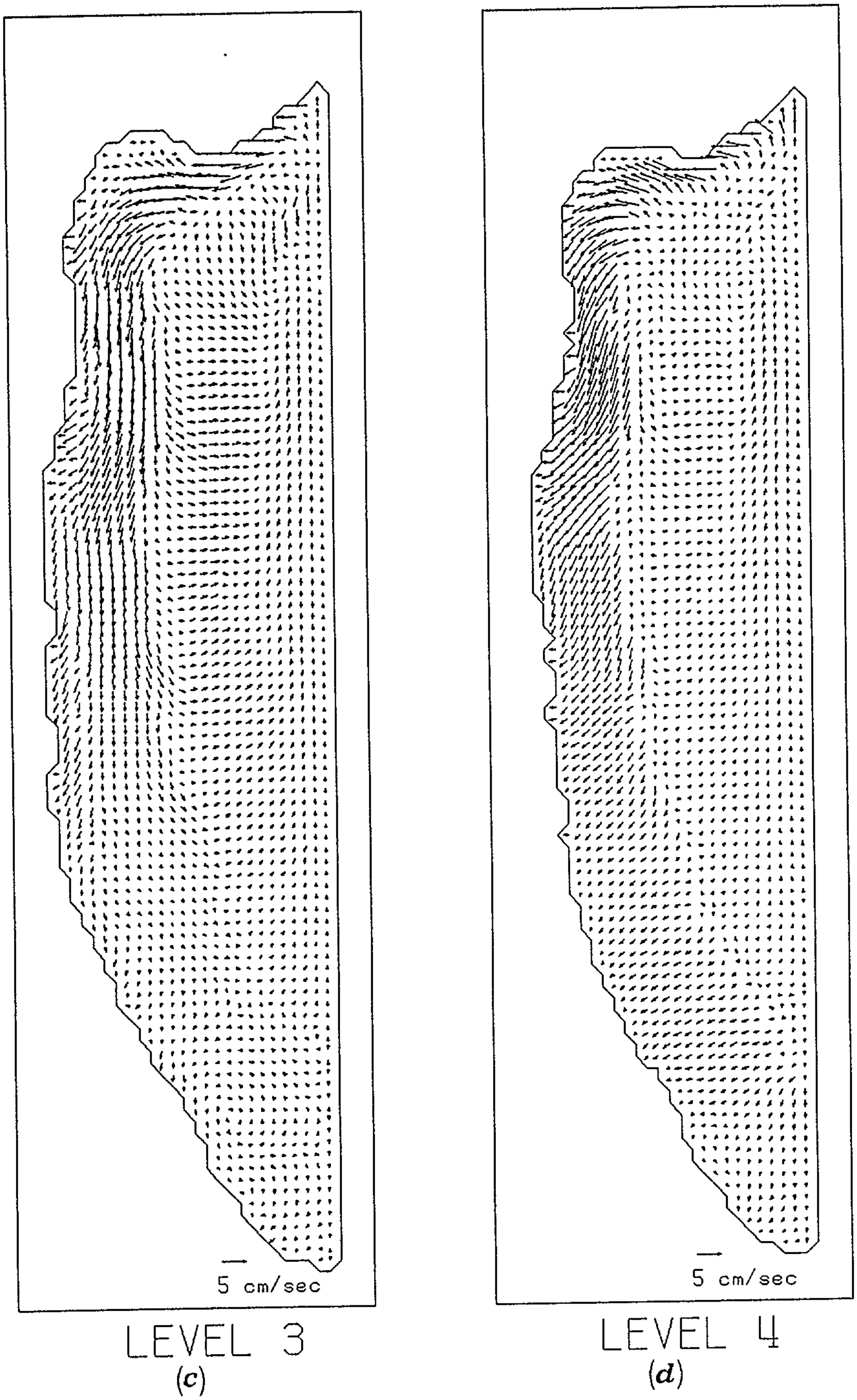
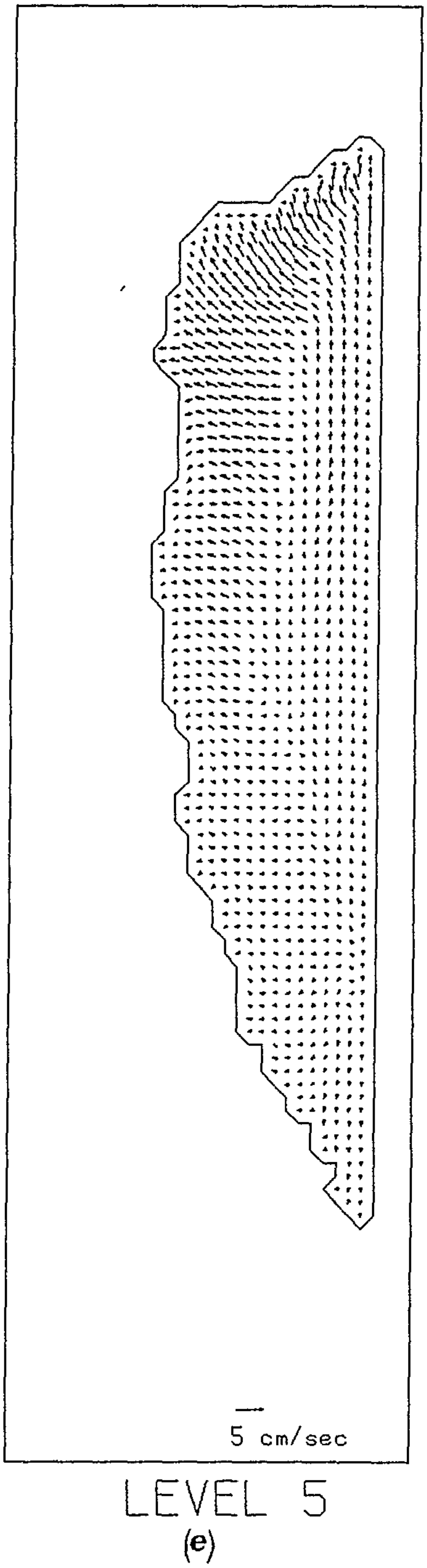



Fig. 14(c),(d). Computer simulated residual circulation patterns along Emilia-Romagna coast after 15 days. Sea current speeds are shown by the lenghts and directions of arrows.



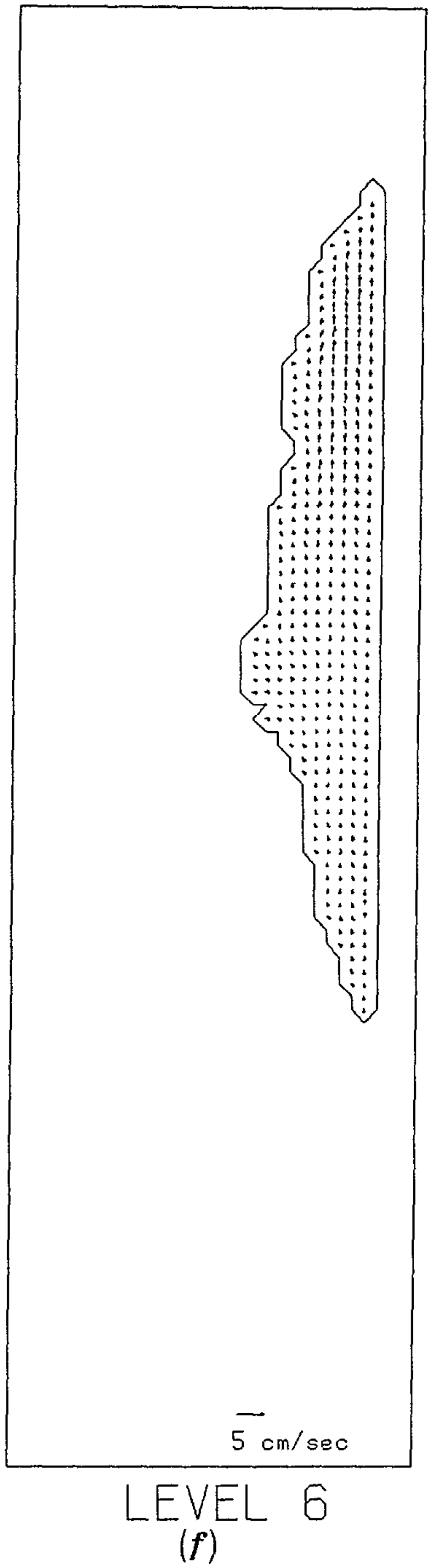




Fig. 14(e),(f). Computer simulated residual circulation patterns along Emilia-Romagna coast after 15 days. Sea current speeds are shown by the lenghts and directions of arrows.

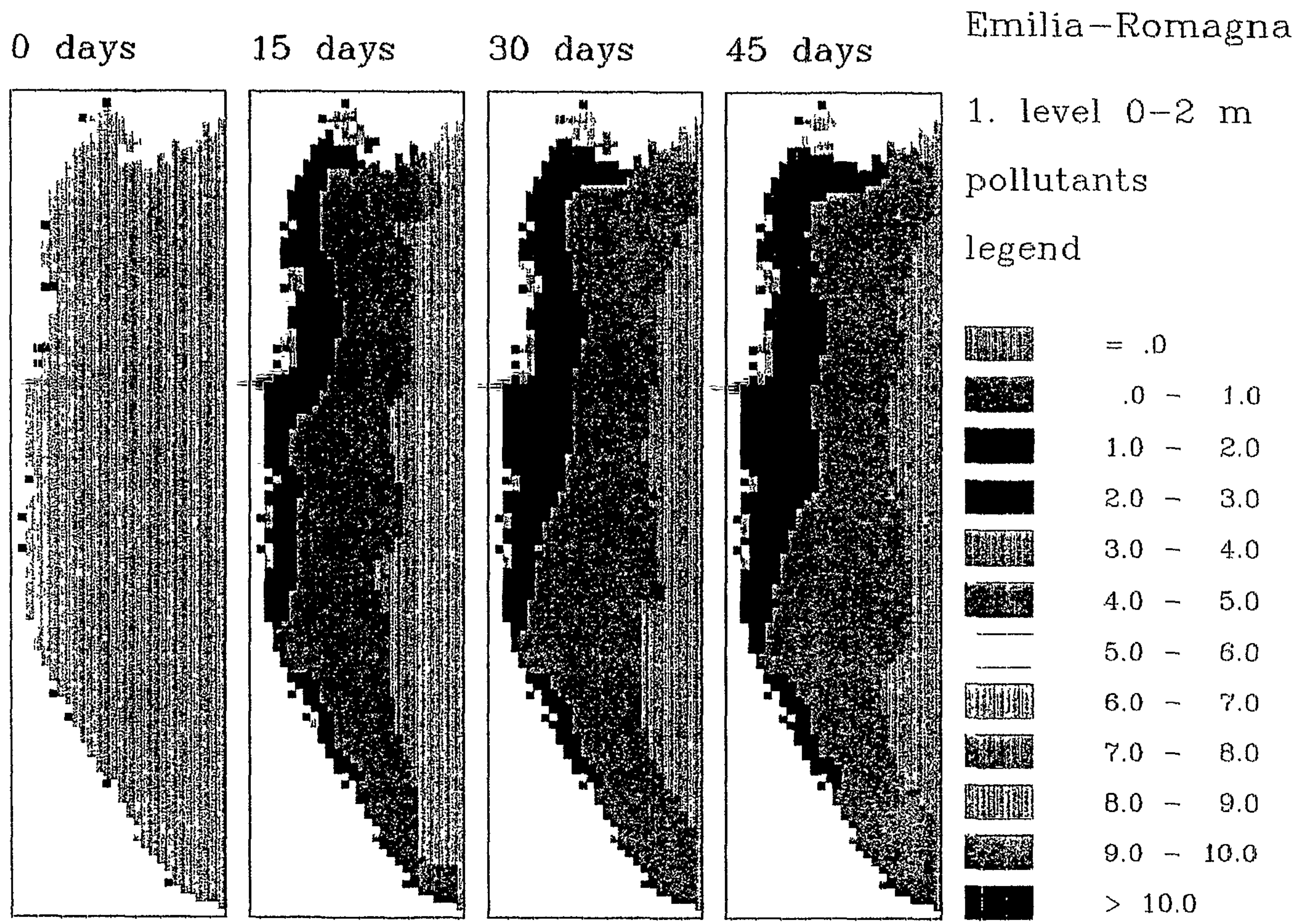



Figure 15(a). Simulated concentration of a conservative pollutant in the first layer (0-2m)

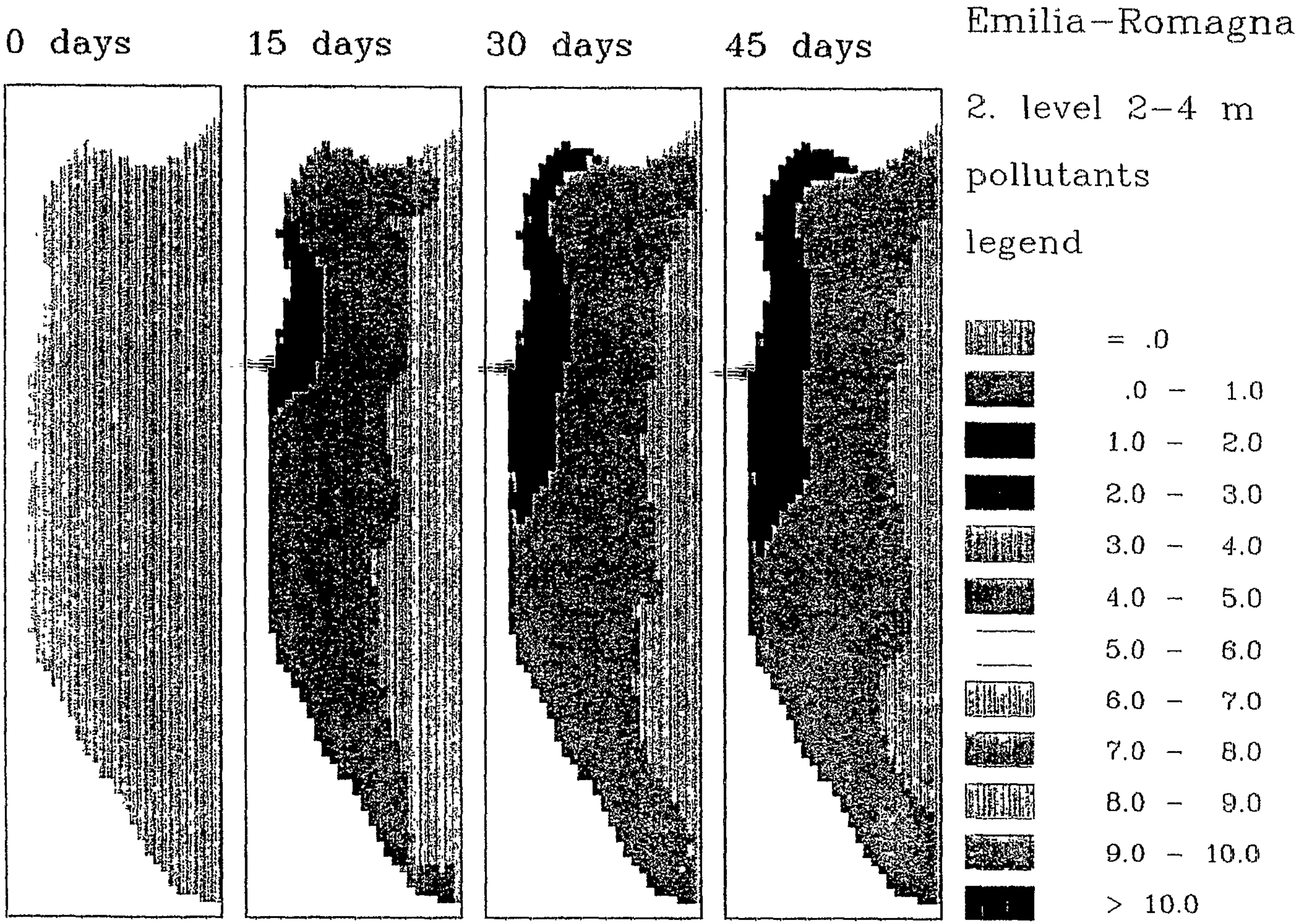



Figure 15(b). Simulated concentration of a conservative pollutant in the second layer (2-4m)

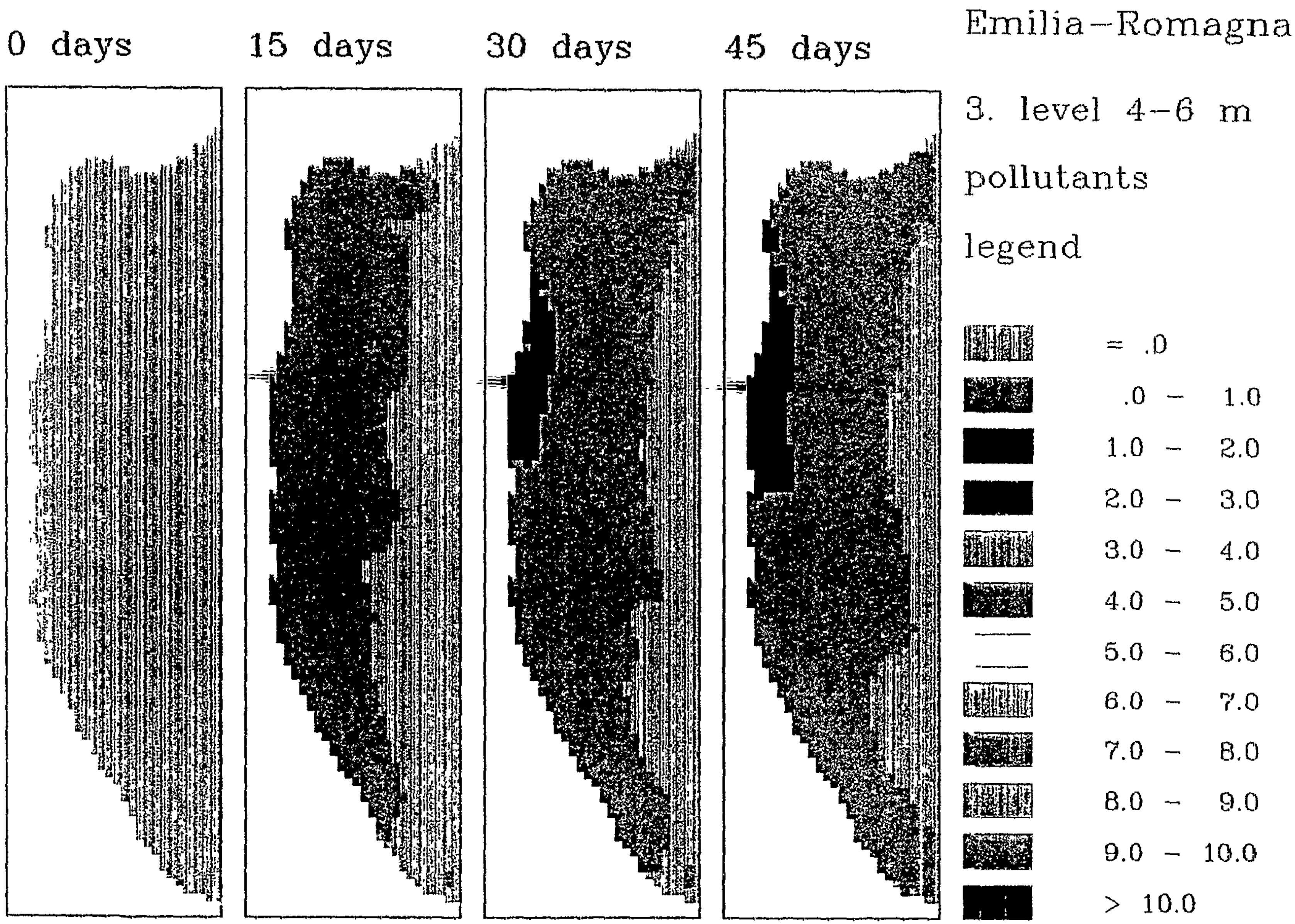



Figure 15(c). Simulated concentration of a conservative pollutant in the third layer (4-6m)

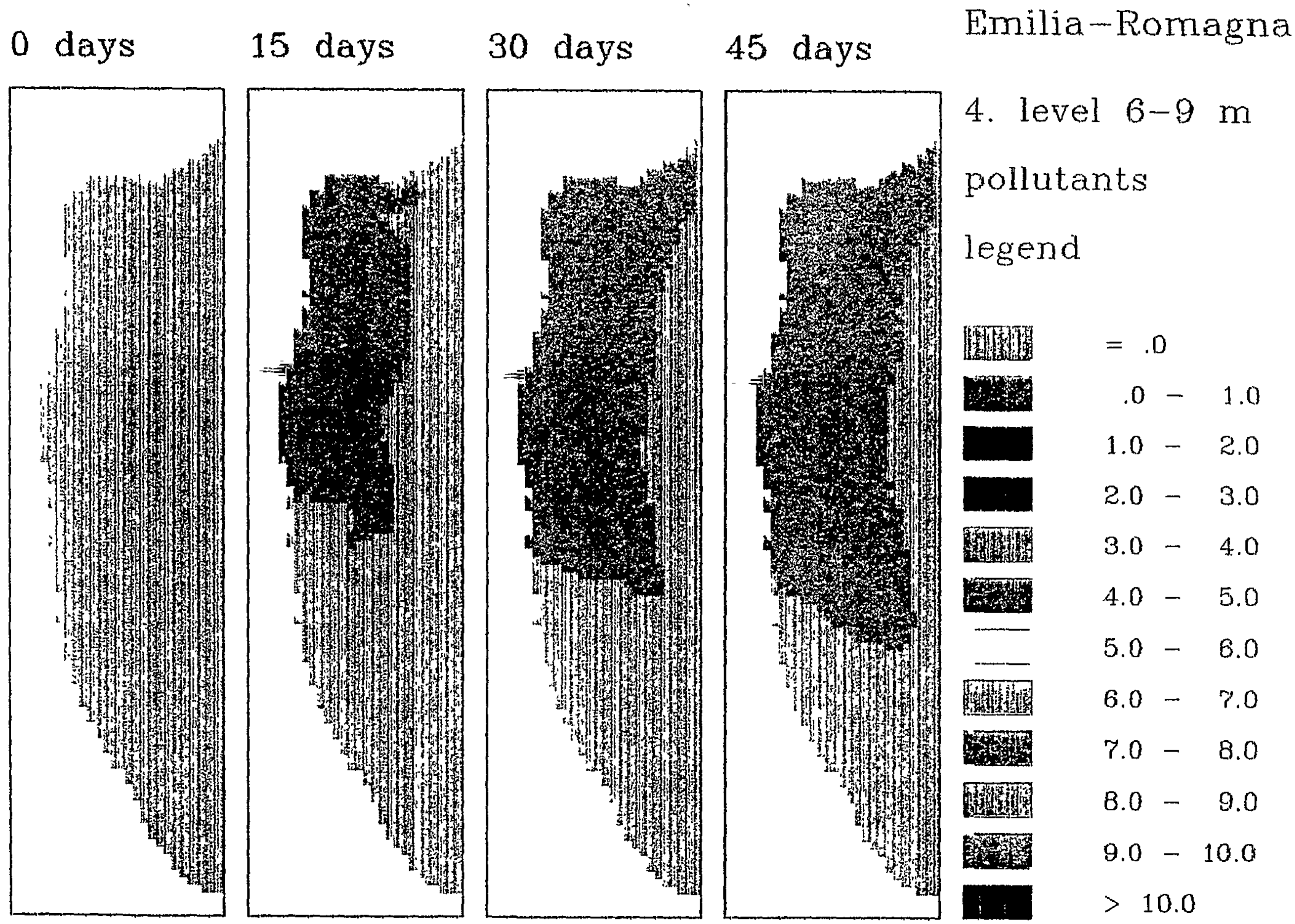



Figure 15(d). Simulated concentration of a conservative pollutant in the fourth layer (6-9m)

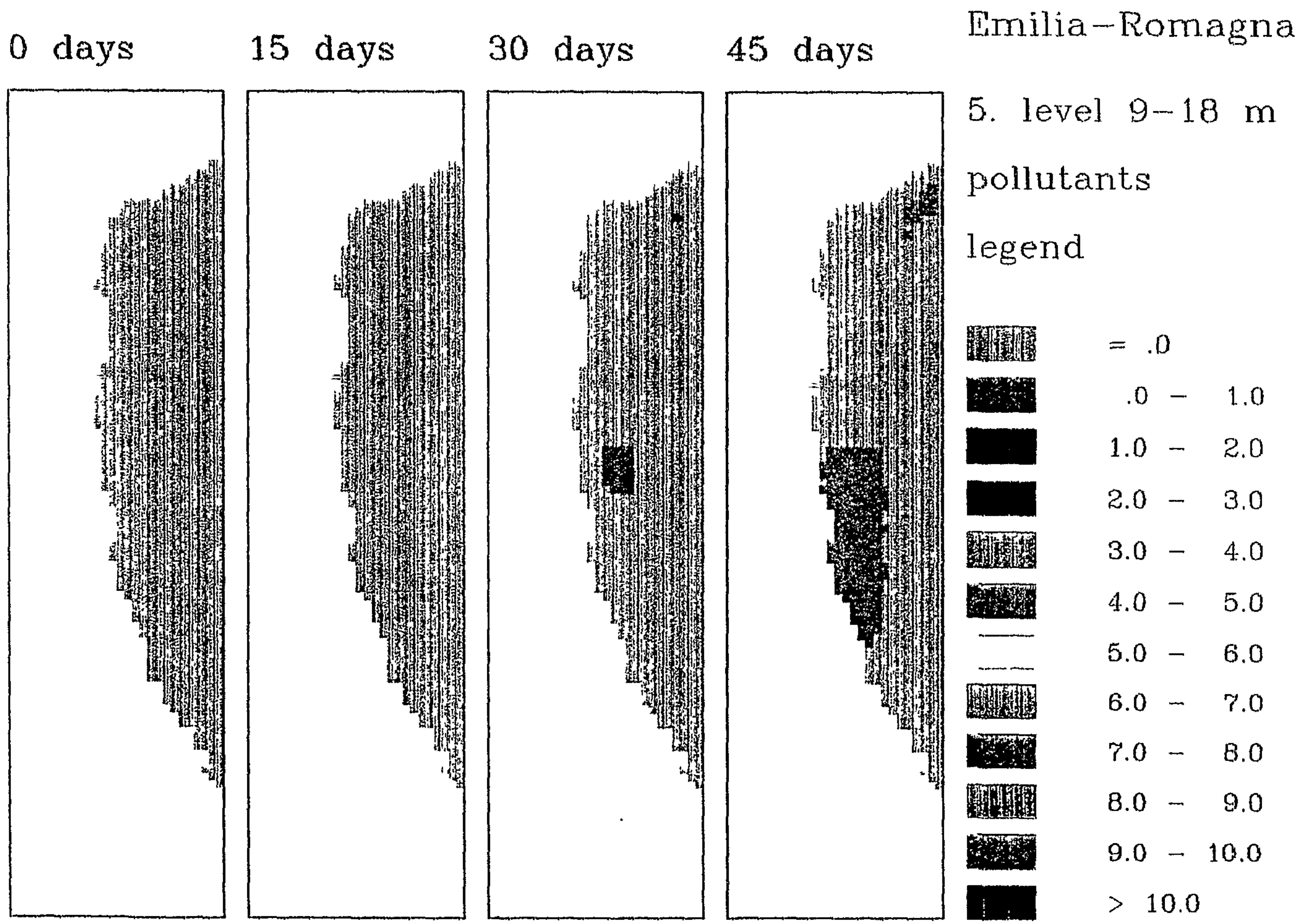



Figure 15(e). Simulated concentration of a conservative pollutant in the fifth layer (9-18m)

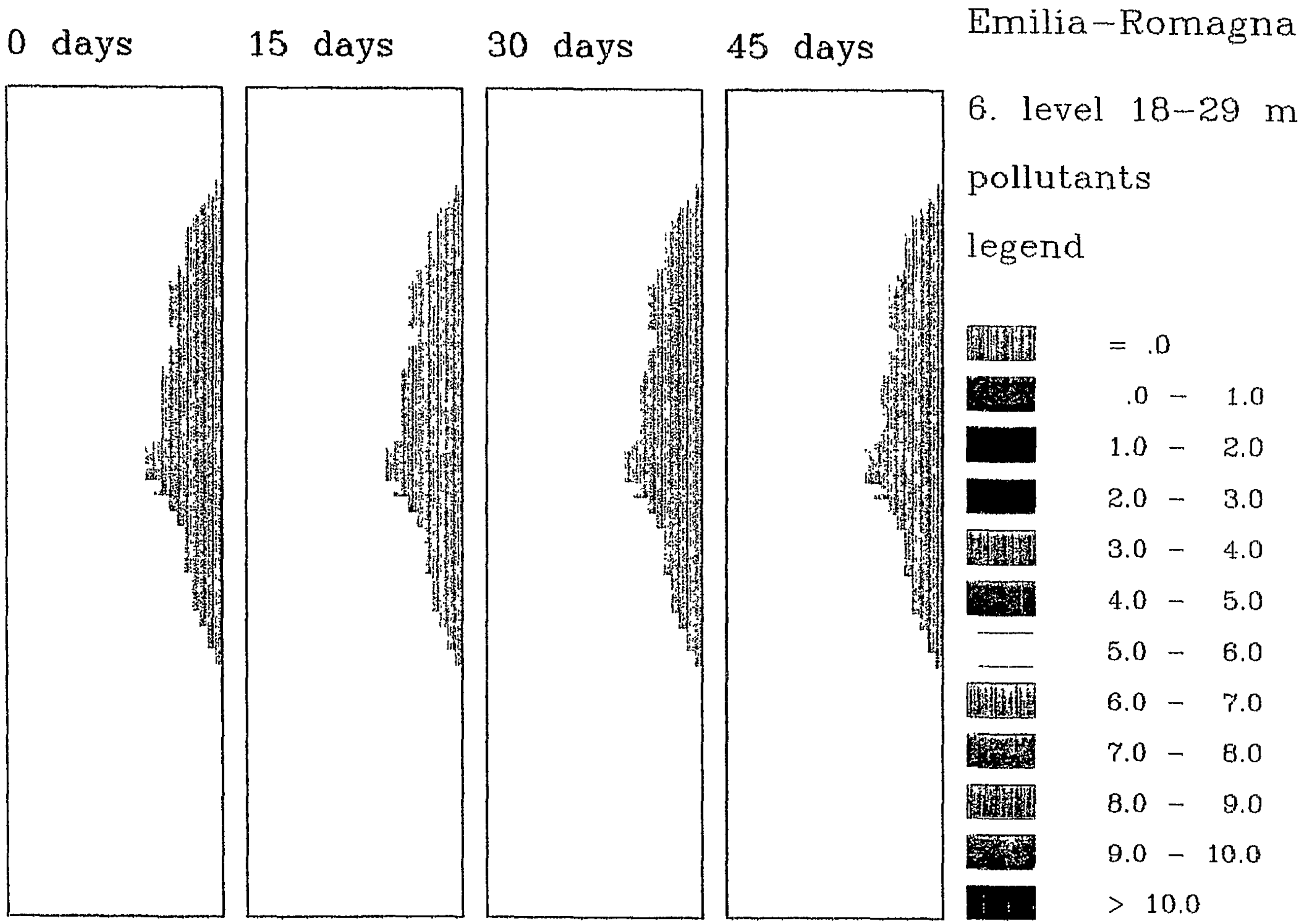



Figure 15(f). Simulated concentration of a conservative pollutant in the sixth layer (18-29m)

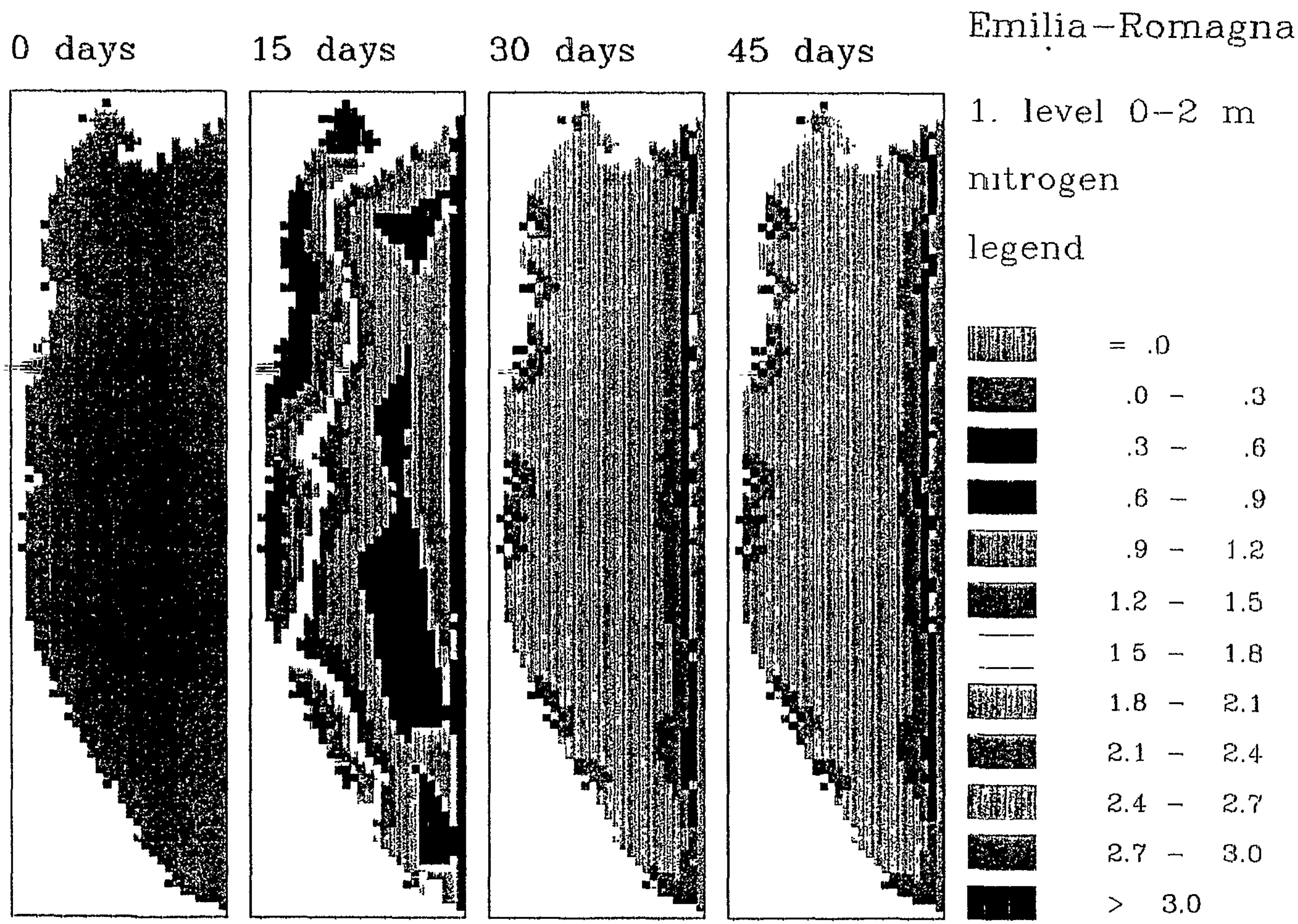



Figure 16(a). Simulated nitrogen concentration in the first layer (0-2m)

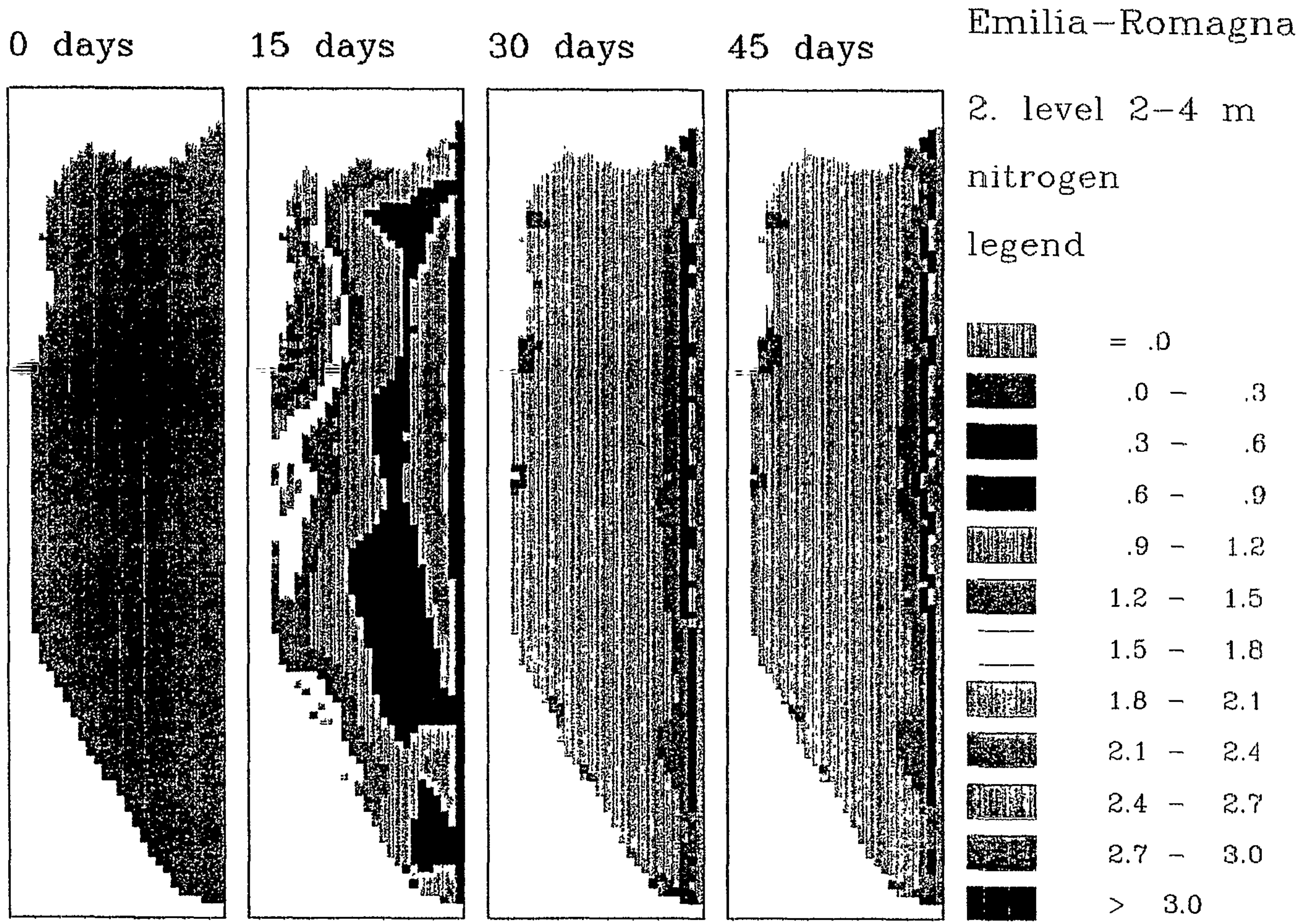



Figure 16(b). Simulated nitrogen concentration in the second layer (2-4m)

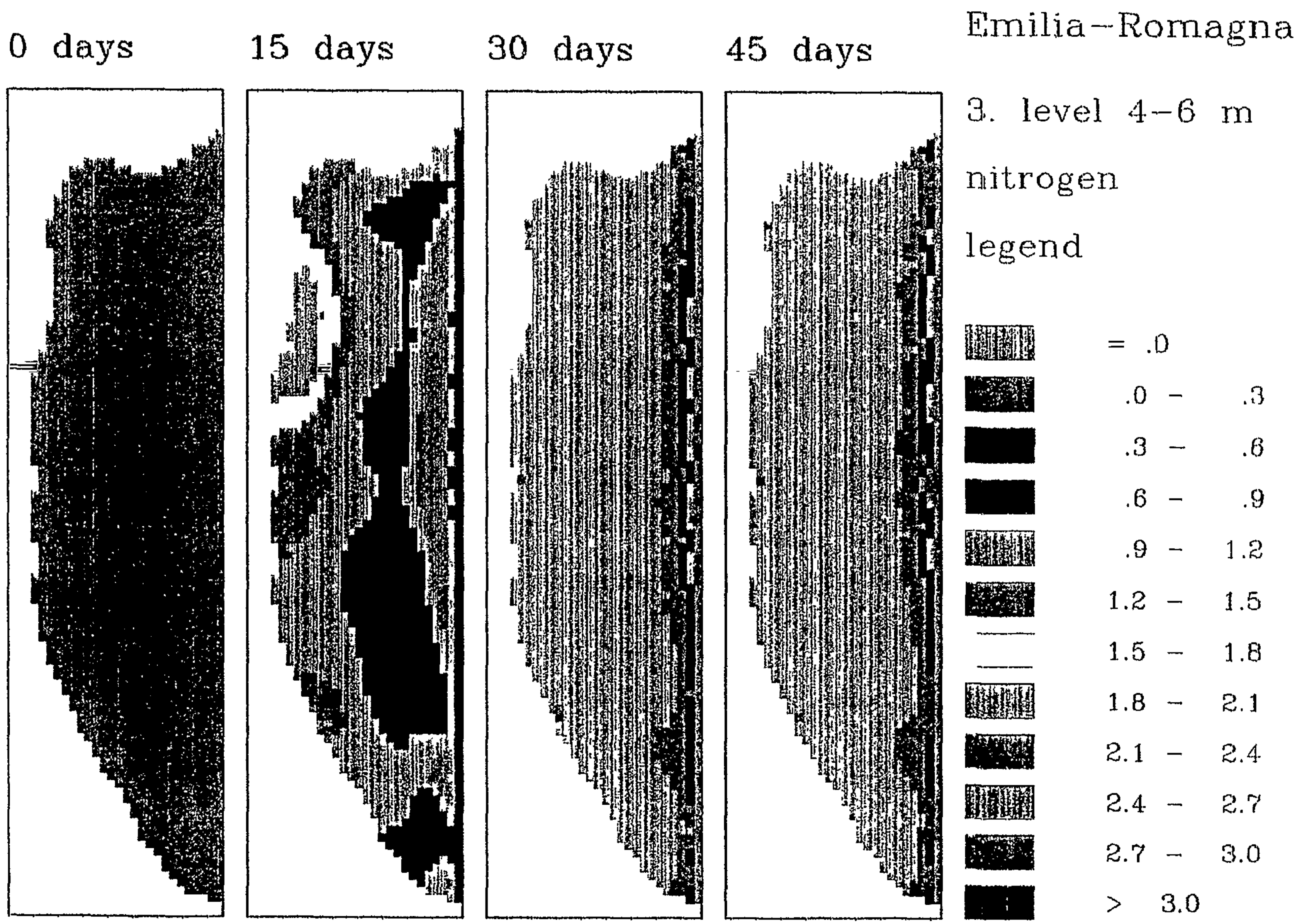



Figure 16(c). Simulated nitrogen concentration in the third layer (4-6m)

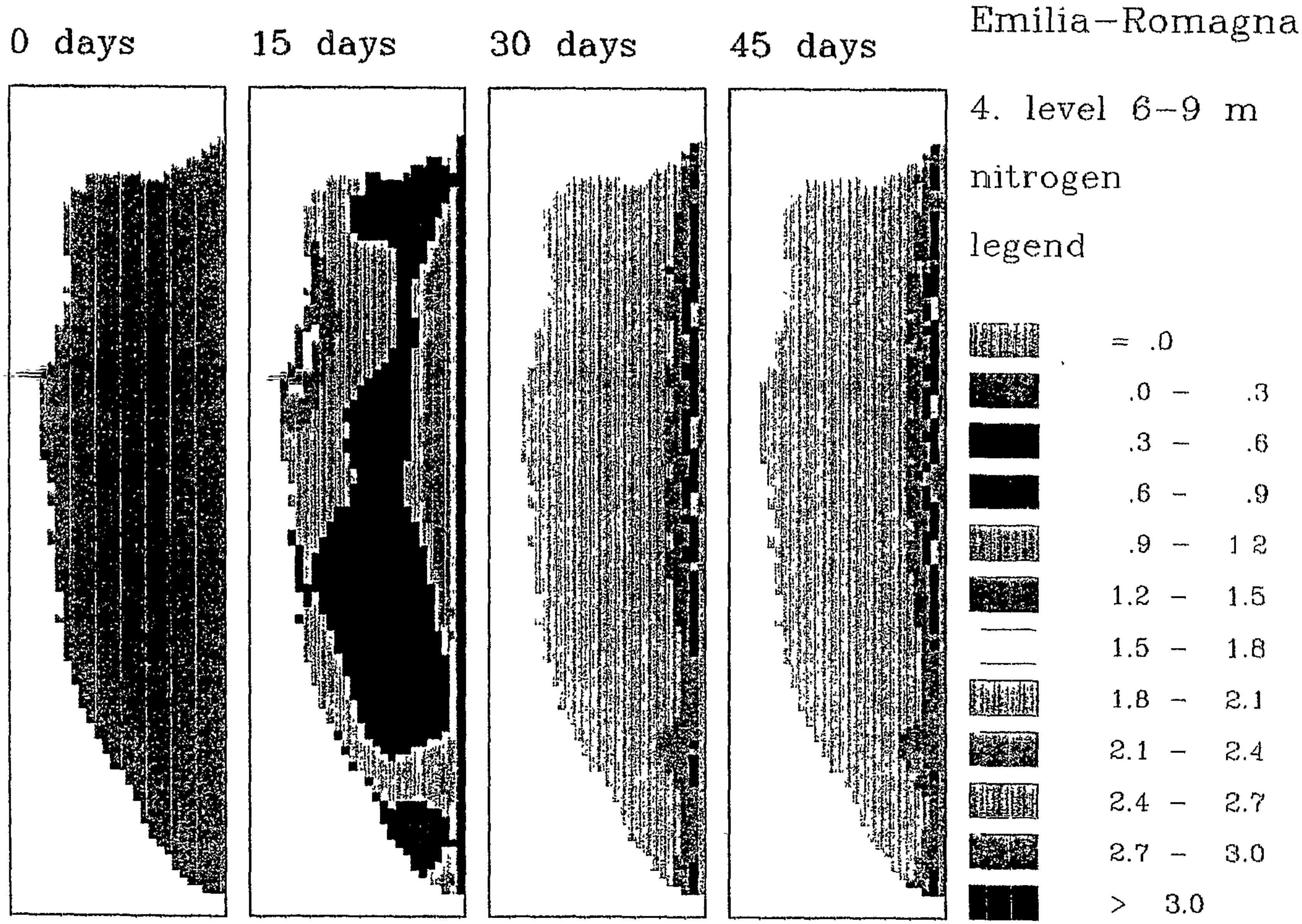



Figure 16(d). Simulated nitrogen concentration in the fourth layer (6-9m)

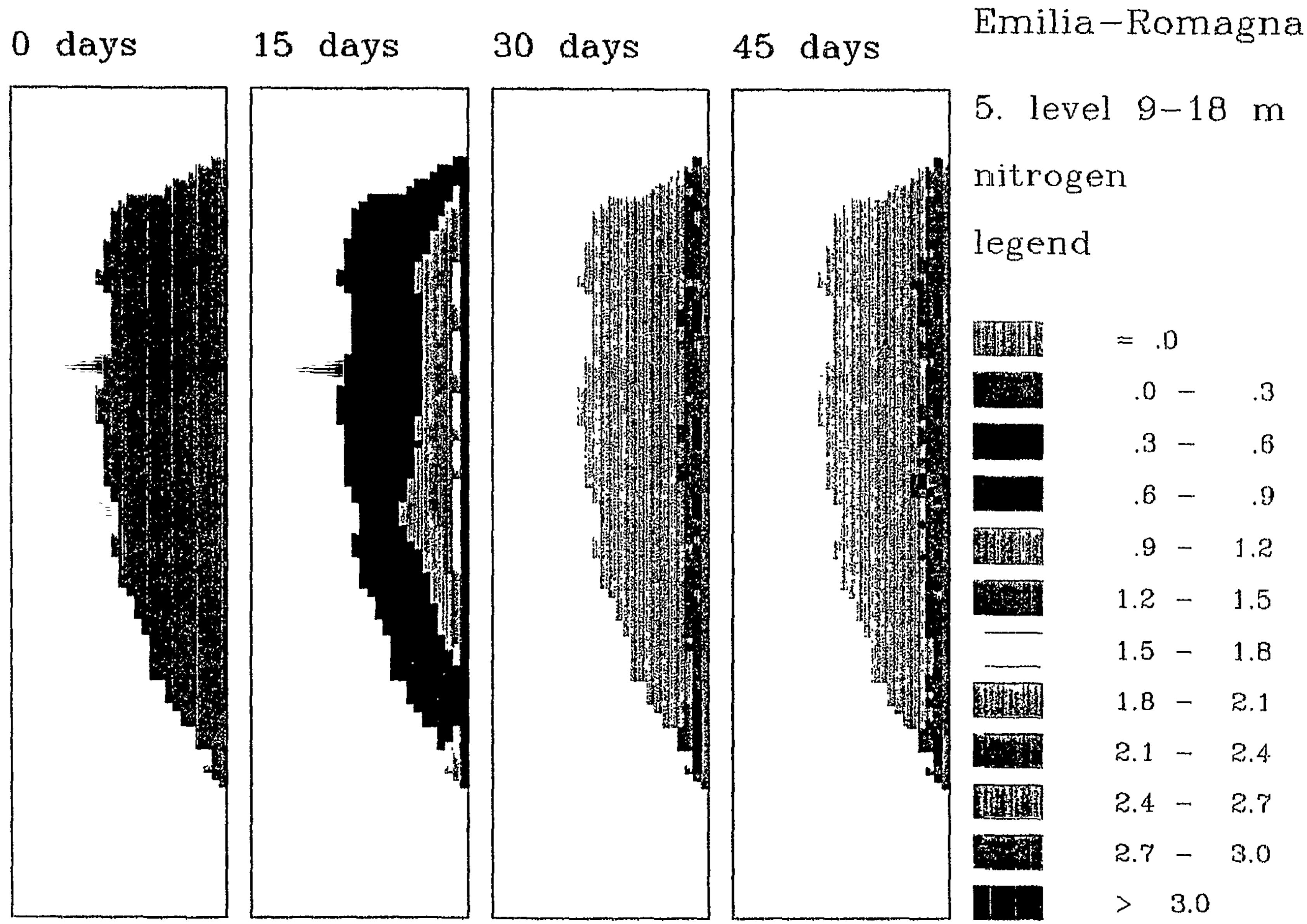



Figure 16(e). Simulated nitrogen concentration in the fifth layer (9-18m)

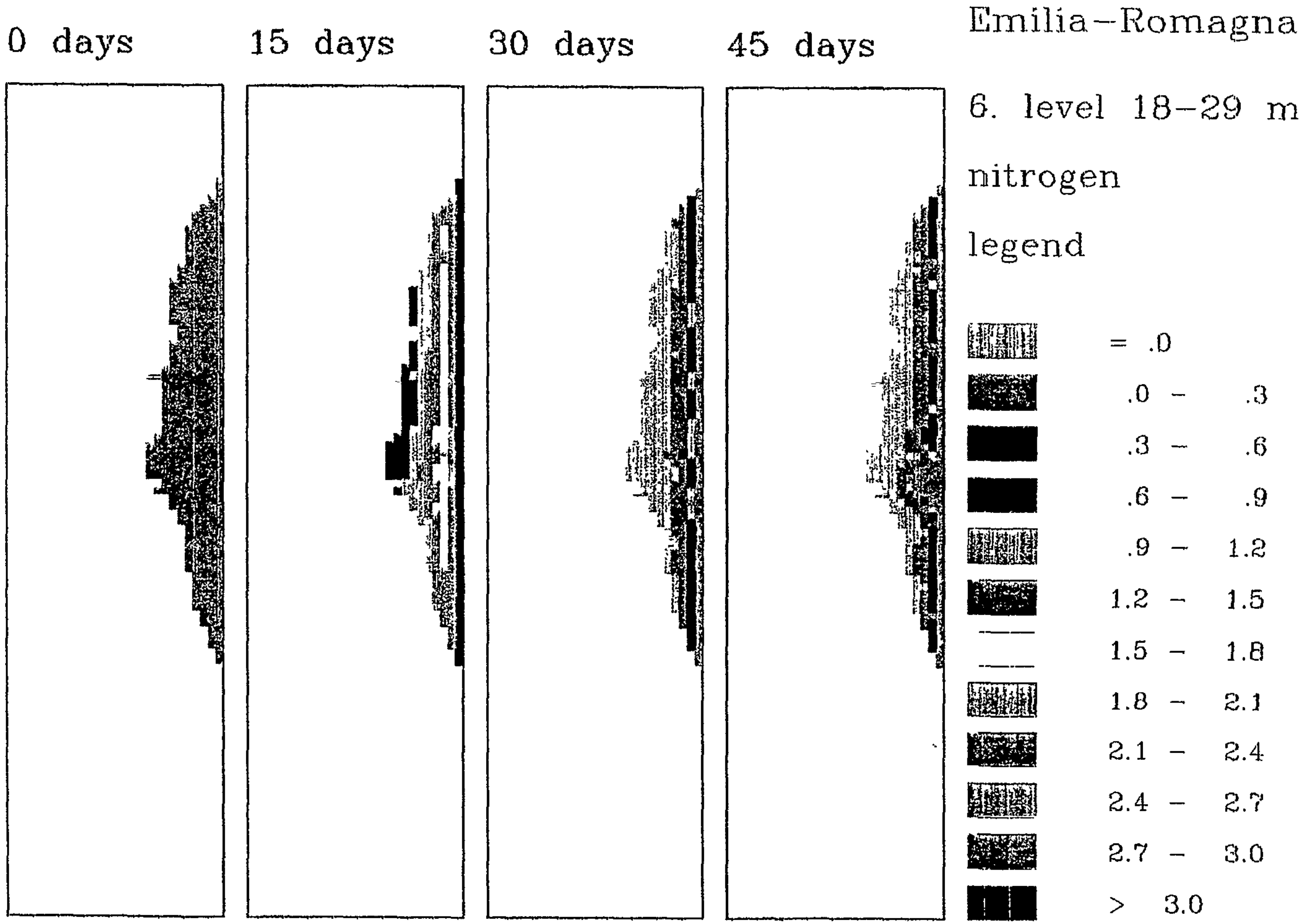



Figure 16(f). Simulated nitrogen concentration in the sixth layer (18-29m)

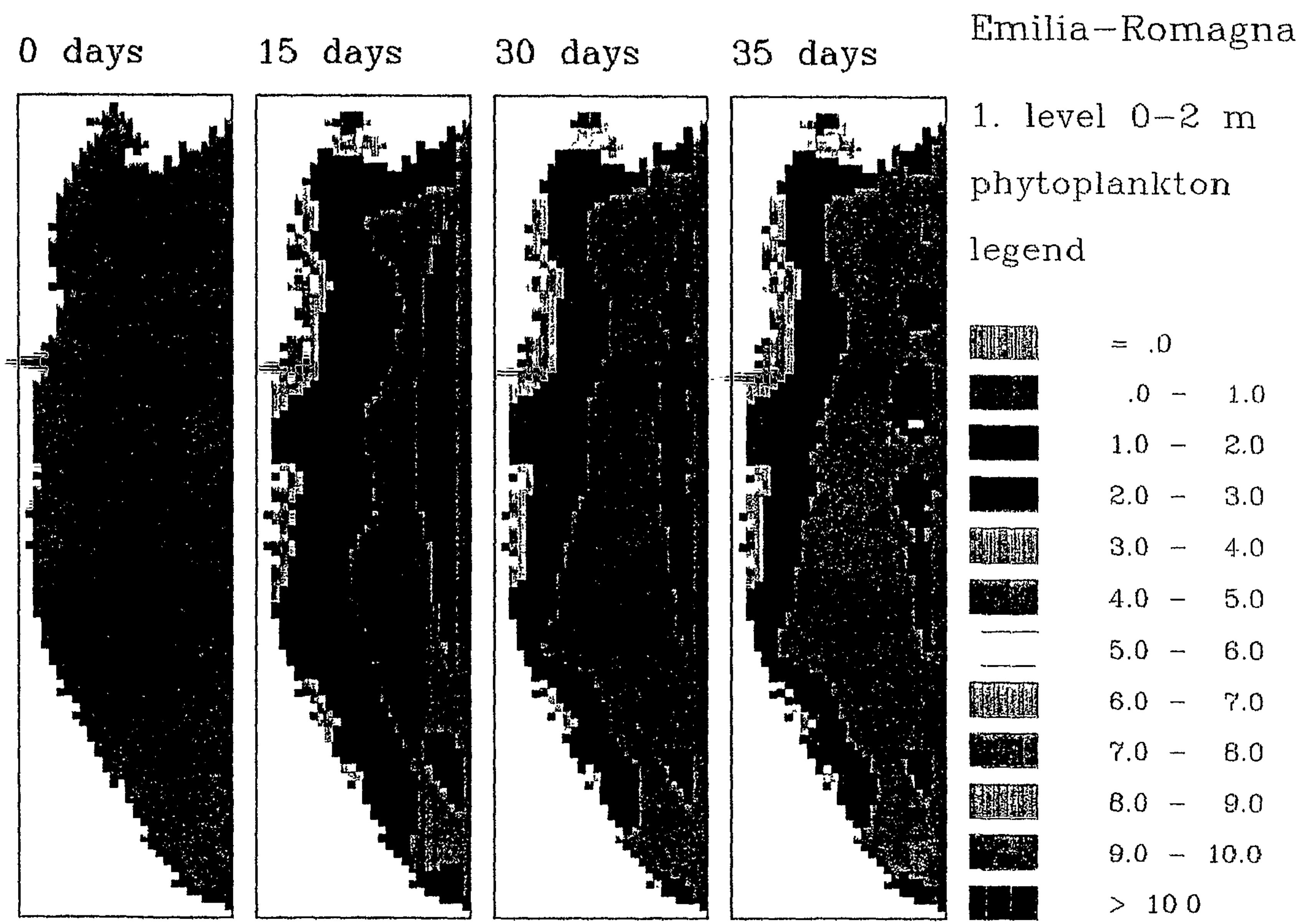



Figure 17(a). Simulated phytoplankton growth in the first layer (0-2m)

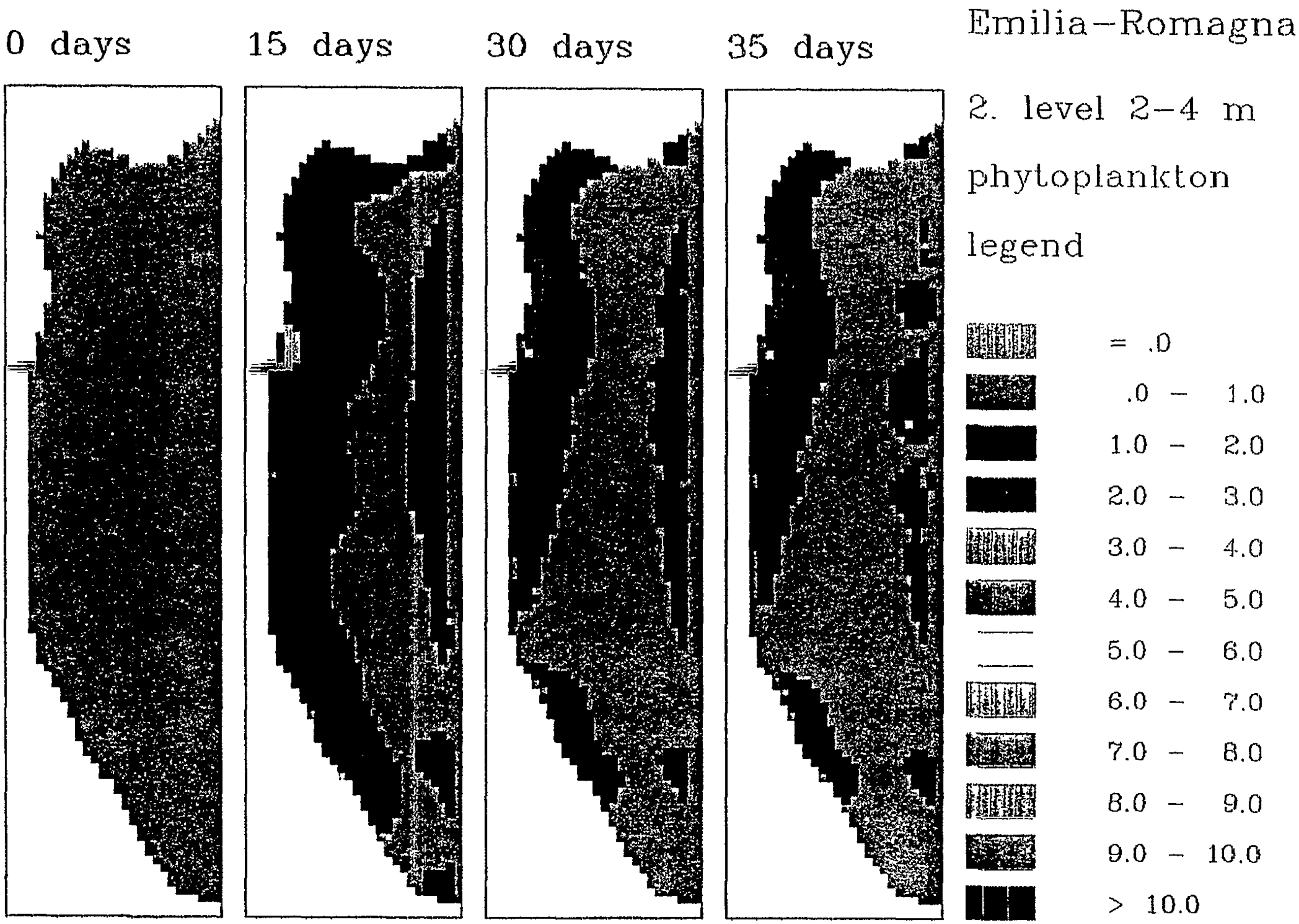



Figure 17(b). Simulated phytoplankton growth in the second layer (2-4m)

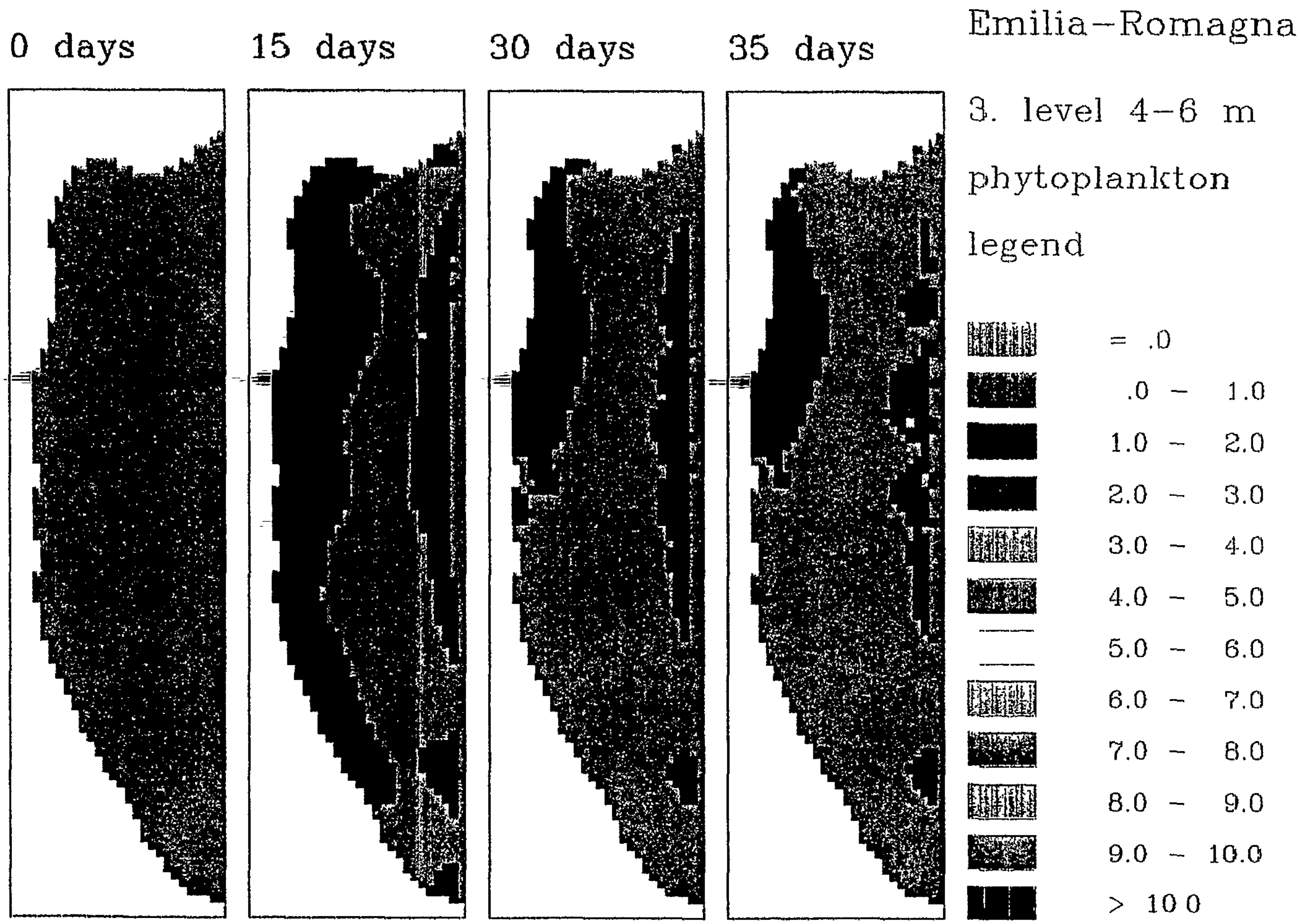



Figure 17(c). Simulated phytoplankton growth in the third layer (4-6m)

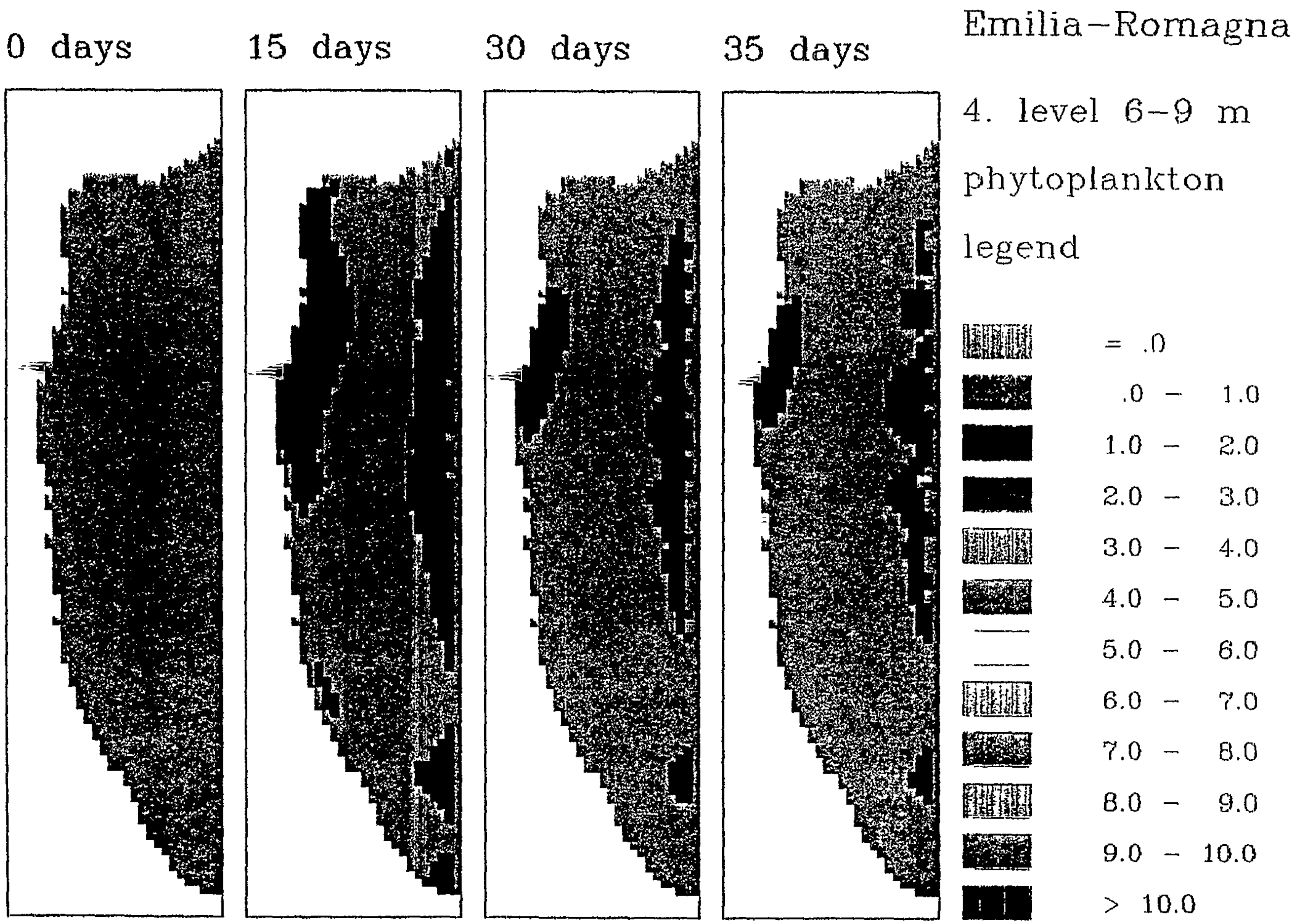



Figure 17(d). Simulated phytoplankton growth in the fourth layer (6-9m)

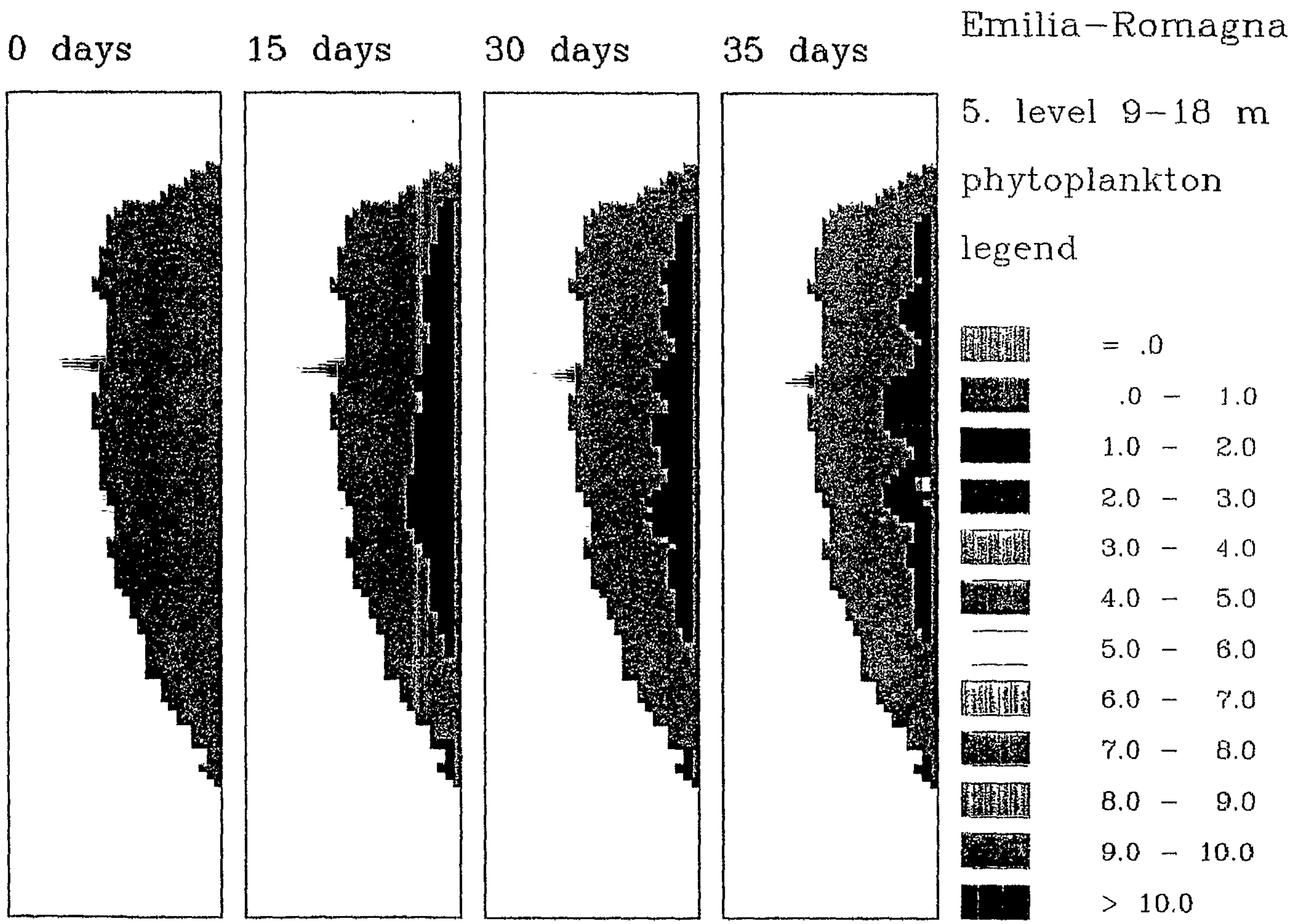



Figure 17(e). Simulated phytoplankton growth in the fifth layer (9-18m)

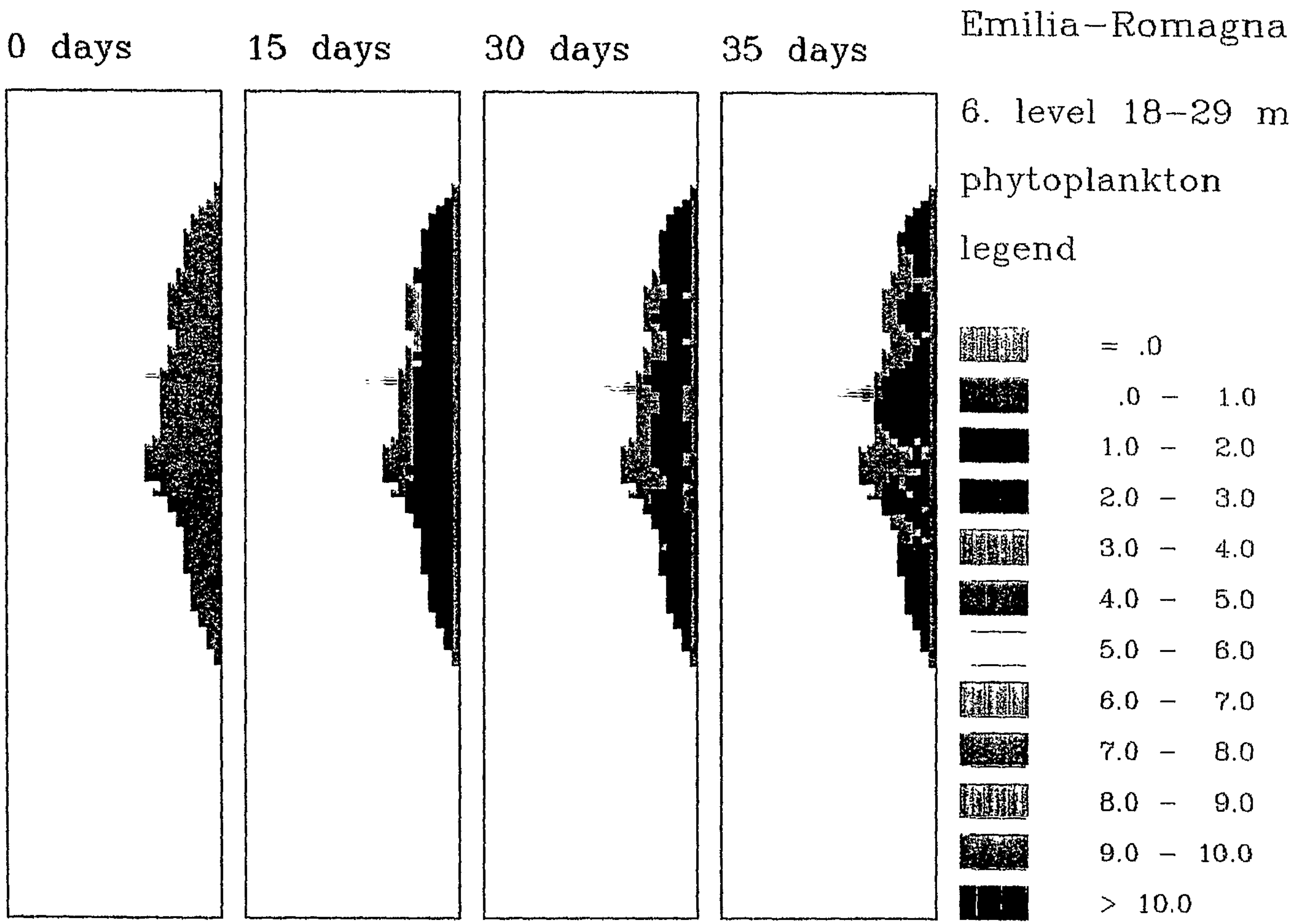



Figure 17(f). Simulated phytoplankton growth in the sixth layer (18-29m)

## 9. CONCLUSIONS

Circulation in the stratified basin is complex, being determined by many interacting factors associated with the above-described density structure. In the surface layer, the circulation seems to be primarily controlled by the horizontal thermohaline gradient and secondarily by the component mechanically induced by sea level oscillations and wind stress. The current field is weak and labile when the density distribution in the layer is homogeneous, the latter condition may be due either to low rate dilution or to intense mechanically-induced vertical mixing. On the contrary, strong horizontal thermohaline gradients coincide with an active circulation. In general, the wind action generates surface drift currents, which are rather unstable owing to the irregular wind intensity and direction, and inertial currents, which have a poor advective component.

The Po river seems to be the major allochtonous source, both for the quantity of nutrients transported (Fossato, 1971, 1973; Provini et al., 1992) and for the role its water runoff plays in determining the dynamics of dispersion processes in the basin. Nutrients injected into the Po plume are dispersed semi-conservatively near the mouth, by turbulent dilution of fluvial waters in the thin (1-2 m thick) surface layer. The fast growing phytoplankton populations are transported and dispersed in the diluting water masses and are exploited by planktonic and nektonic grazers. Thus, in the dispersion system of the plume, nutrients are rapidly transferred to the particulate phase and then recycled by different mechanisms and at different speeds depending on the general, both structural and dynamic conditions of the basin.

The concentrations of nutrients injected by the Po river system into the surface layer of the basin progressively decrease from the input point towards the peripheral area of the dispersion system, which is formed by the plume and by the turbulent diffusion area fed by the plume itself. The nutrient distribution tends to become variable both in time and space, vertically and horizontally, owing to the different degrees of coupling occurring between the processes of uptake and release and those of transport.

In the surface layer, when the Po system shows a medium or high rate of discharge, nutrients distribution seems to be driven by the horizontal transport, with the gradient of concentrations ranging from one to three orders of magnitude from the input point to the periphery of the diluted area. As the river flow decreases, concentrations in the area outside the plume frontal system shift to lower levels, which are maintained by biological regeneration processes.

The general physico-chemical conditions of the area in question are determined by several factors that have to be visualized in the context of the oceanographic characteristics of the Adriatic Sea as a whole, and particular of its northern basin. In this regard, the current regime of the Adriatic Sea plays a major role. Its prevailing geostrophic currents are counter-clockwise with ascending currents north along the Croatian coast and descending currents south along the Italian side. These conditions also determine the prevailing flow of freshwater from rivers discharging to the Adriatic Sea, particularly its major tributary, the River Po, and its mixing with the saline water.

## REFERENCES

Andersen V. (1986)
Modélisation d'écosystèmes pélagiques; étude de processus. Thèse de Doctorat, Océanographie Biologique, Université P. & M. Curie. Paris IV.

Barnes R.S.K. and Hughes R.N. (1988)
An Introduction to Marine Ecology. Second Edition. Blackwell Scientific Publications.

Buckley, A.M., (1995),
Modeling Primary Production in River Plumes, Ph.D. Thesis, Dept. of Civil Engineering, University College, Cork.

Fenchel T., (1987), Patterns in microbial aquatic communities. Organisation of Communities Past and Present, in Gee J.H.R. and Giller P.S. (eds). Blackwell Scientific Publications, pp. 281-295.

Fossato V. U., (1971),
Ricerche idrologiche e chimico-fisiche sul fiume Po a Polesella. Luglio 1968-Giugno 1970. Archo. Oceanog. Limnol., vol. 17:125-139.

Fossato V. U., (1973),
Ricerche idrologiche e chimico-fisiche sul fiume Po a Polesella. Luglio 1970-Giugno 1972. Archo. Oceanog. Limnol., vol. 18: 47-58.

Leendertse, J.J., Alexander, R.C. and Shiao-Kung Liu, (1973),
A three-dimensional model for estuaries and coastal seas: Volume I, Principles of Computation, The Rand Corporation, R-1417-OWRR.

Leendertse, J.J., and Shiao-Kung Liu, (1977),
A three-dimensional model for estuaries and coastal seas: Volume IV, Turbulent Energy Computation, The Rand Corporation, R-2187-OWRT.

Mann, K.H. and Lazier, J.R.N., (1991),
Dynamics of marine ecosystems, Blackwell Scientific Publications.

Marchetti R., Provini A. and Crosa G. (1989)
Nutrient load by the River Po into the Adriatic Sea, 1968/87. Mar. Pollut. Bull., 20,4:168-172.

Marchetti, R. and Verna, N., (1990)
Quantification of the phosphorus and nitrogen loads in the minor rivers of the Emilia-Romagna coast (Italy). A methodological study on the use of theoretical coefficients in calculating the loads, in Vollenweider R.A., Marchetti R. and Viviani R. (eds.) "Marine Coastal Eutrophication", Elsevier, pp. 315-336.

O'Kane, J.P., Suppo, M., Todini, E. and Turner, J., (1990),
Physical intervention in the lagoon of Sacca di Goro. An examination using a 3-D numerical model, in Vollenweider R.A., Marchetti R. and Viviani R. (eds.) "Marine Coastal Eutrophication", Elsevier, pp. 489-510.

Provini, A., Crosa, G. and Marchetti R., (1992),
Nutrient export from the Po and Adige river basins over the last 20 years.Sci. Total Environ., Suppl. 1992:291-313.

Reic, P. (1992),
A three dimensional hydrodynamical-diffusion model of the Adriatic sea, Ph.D. Thesis, Milan Politechnic, Italy.

Rinaldi, A.(1989),
Eutrofia e distrofia dell'Adriatico Nord-Occidentale, Proc. Conf. "Emergenza Adriatico", Urbino, pp. 39-50.

Todini, E. and Bizzarri, A., (1988),
Eutrophication in the coastal area of the Regione Emilia-Romagna, In "Eutrophication in the Mediterranean Sea: receiving capacity and monitoring of long-term effects", UNESCO Reports in Marine Science No. 49, pp. 143-152.

UNESCO, (1988),
Eutrophication in the Mediterranean Sea - receiving capacity and monitoring of long-term effects", Report and Proceedings of a Scientific Workshop Bologna, Italy, March 1987, UNESCO Reports in Marine Science No. 49.

Vollenweider, R.A., Rinaldi, A. and Montanari, G. (1990),
Eutrophication, structure and dynamics of a marine coastal system: results of ten-year monitoring along the Emilia-Romagna coast (Northwest Adriatic Sea), in Vollenweider R.A., Marchetti R. and Viviani R. (eds.) "Marine Coastal Eutrophication", Elsevier, pp. 63-106.

## PUBLICATIONS OF THE MAP TECHNICAL REPORTS SERIES

1. UNEP/IOC/WMO: Baseline studies and monitoring of oil and petroleum hydrocarbons in marine waters (MED POL I). MAP Technical Reports Series No. 1. UNEP, Athens, 1986 (96 pages) (parts in English, French or Spanish only).

2. UNEP/FAO: Baseline studies and monitoring of metals, particularly mercury and cadmium, in marine organisms (MED POL II). MAP Technical Reports Series No. 2. UNEP, Athens, 1986 (220 pages) (parts in English, French or Spanish only).

3. UNEP/FAO: Baseline studies and monitoring of DDT, PCBs and other chlorinated hydrocarbons in marine organisms (MED POL III). MAP Technical Reports Series No. 3. UNEP, Athens, 1986 (128 pages) (parts in English, French or Spanish only).

4. UNEP/FAO: Research on the effects of pollutants on marine organisms and their populations (MED POL IV). MAP Technical Reports Series No. 4. UNEP, Athens, 1986 (118 pages) (parts in English, French or Spanish only).

5. UNEP/FAO. Research on the effects of pollutants on marine communities and ecosystems (MED POL V). MAP Technical Reports Series No. 5. UNEP, Athens, 1986 (146 pages) (parts in English or French only).

6. UNEP/IOC: Problems of coastal transport of pollutants (MED POL VI). MAP Technical Reports Series No. 6. UNEP, Athens, 1986 (100 pages) (English only).

7. UNEP/WHO: Coastal water quality control (MED POL VII). MAP Technical Reports Series No. 7. UNEP, Athens, 1986 (426 pages) (parts in English or French only).

8. UNEP/IAEA/IOC: Biogeochemical studies of selected pollutants in the open waters of the Mediterranean (MED POL VIII). MAP Technical Reports Series No. 8. UNEP, Athens, 1986 (42 pages) (parts in English or French only).

8\. Add. UNEP: Biogeochemical studies of selected pollutants in the open waters of the Mediterranean MED POL VIII). Addendum, Greek Oceanographic Cruise 1980. MAP Technical Reports Series No. 8, Addendum. UNEP, Athens, 1986 (66 pages) (English only).

9. UNEP: Co-ordinated Mediterranean pollution monitoring and research programme (MED POL - PHASE I). Final report, 1975-1980. MAP Technical Reports Series No. 9. UNEP, Athens, 1986 (276 pages) (English only).

10. UNEP: Research on the toxicity, persistence, bioaccumulation, carcinogenicity and mutagenicity of selected substances (Activity G). Final reports on projects dealing with toxicity (1983-85). MAP Technical Reports Series No. 10. UNEP, Athens, 1987 (118 pages) (English only).

11. UNEP: Rehabilitation and reconstruction of Mediterranean historic settlements. Documents produced in the first stage of the Priority Action (1984-1985). MAP Technical Reports Series No. 11. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1986 (158 pages) (parts in English or French only).

12. UNEP: Water resources development of small Mediterranean islands and isolated coastal areas. Documents produced in the first stage of the Priority Action (1984-1985). MAP Technical Reports Series No. 12. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (162 pages) (parts in English or French only).

13. UNEP: Specific topics related to water resources development of large Mediterranean islands. Documents produced in the second phase of the Priority Action (1985-1986). MAP Technical Reports Series No. 13. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (162 pages) (parts in English or French only).

14. UNEP: Experience of Mediterranean historic towns in the integrated process of rehabilitation of urban and architectural heritage. Documents produced in the second phase of the Priority Action (1986). MAP Technical Reports Series No. 14. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (500 pages) (parts in English or French only).

15. UNEP: Environmental aspects of aquaculture development in the Mediterranean region. Documents produced in the period 1985-1987. MAP Technical Reports Series No. 15. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (101 pages) (English only).

16. UNEP: Promotion of soil protection as an essential component of environmental protection in Mediterranean coastal zones. Selected documents (1985-1987). MAP Technical Reports Series No. 16. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (424 pages) (parts in English or French only).

17. UNEP: Seismic risk reduction in the Mediterranean region. Selected studies and documents (1985-1987). MAP Technical Reports Series No. 17. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (247 pages) (parts in English or French only).

18. UNEP/FAO/WHO: Assessment of the state of pollution of the Mediterranean Sea by mercury and mercury compounds. MAP Technical Reports Series No. 18. UNEP, Athens, 1987 (354 pages) (English and French).

19. UNEP/IOC: Assessment of the state of pollution of the Mediterranean Sea by petroleum hydrocarbons. MAP Technical Reports Series No. 19. UNEP, Athens, 1988 (130 pages) (English and French).

20. UNEP/WHO: Epidemiological studies related to environmental quality criteria for bathing waters, shellfish-growing waters and edible marine organisms (Activity D). Final report on project on relationship between microbial quality of coastal seawater and health effects (1983-86). MAP Technical Reports Series No. 20. UNEP, Athens, 1988 (156 pages) (English only).

21. UNEP/UNESCO/FAO: Eutrophication in the Mediterranean Sea: Receiving capacity and monitoring of long-term effects. MAP Technical Reports Series No. 21. UNEP, Athens, 1988 (200 pages) (parts in English or French only).

22. UNEP/FAO: Study of ecosystem modifications in areas influenced by pollutants (Activity I). MAP Technical Reports Series No. 22. UNEP, Athens, 1988 (146 pages) (parts in English or French only).

23. UNEP: National monitoring programme of Yugoslavia, Report for 1983-1986. MAP Technical Reports Series No. 23. UNEP, Athens, 1988 (223 pages) (English only).

24. UNEP/FAO: Toxicity, persistence and bioaccumulation of selected substances to marine organisms (Activity G). MAP Technical Reports Series No. 24. UNEP, Athens, 1988 (122 pages) (parts in English or French only).

25. UNEP: The Mediterranean Action Plan in a functional perspective: A quest for law and policy. MAP Technical Reports Series No 25. UNEP, Athens, 1988 (105 pages) (English only).

26. UNEP/IUCN: Directory of marine and coastal protected areas in the Mediterranean Region. Part I - Sites of biological and ecological value. MAP Technical Reports Series No. 26. UNEP, Athens, 1989 (196 pages) (English only).

27. UNEP: Implications of expected climate changes in the Mediterranean Region: An overview. MAP Technical Reports Series No. 27. UNEP, Athens, 1989 (52 pages) (English only).

28. UNEP: State of the Mediterranean marine environment. MAP Technical Reports Series No. 28. UNEP, Athens, 1989 (225 pages) (English only).

29. UNEP: Bibliography on effects of climatic change and related topics. MAP Technical Reports Series No. 29. UNEP, Athens, 1989 (143 pages) (English only).

30. UNEP: Meteorological and climatological data from surface and upper measurements for the assessment of atmospheric transport and deposition of pollutants in the Mediterranean Basin: A review. MAP Technical Reports Series No. 30 UNEP, Athens, 1989 (137 pages) (English only).

31. UNEP/WMO: Airborne pollution of the Mediterranean Sea. Report and proceedings of a WMO/UNEP Workshop. MAP Technical Reports Series No. 31. UNEP, Athens, 1989 (247 pages) (parts in English or French only).

32. UNEP/FAO: Biogeochemical cycles of specific pollutants (Activity K). MAP Technical Reports Series No. 32. UNEP, Athens, 1989 (139 pages) (parts in English or French only).

33. UNEP/FAO/WHO/IAEA: Assessment of organotin compounds as marine pollutants in the Mediterranean. MAP Technical Reports Series No. 33. UNEP, Athens, 1989 (185 pages) (English and French).

34. UNEP/FAO/WHO: Assessment of the state of pollution of the Mediterranean Sea by cadmium and cadmium compounds. MAP Technical Reports Series No. 34. UNEP, Athens, 1989 (175 pages) (English and French).

35. UNEP: Bibliography on marine pollution by organotin compounds. MAP Technical Reports Series No. 35. UNEP, Athens, 1989 (92 pages) (English only).

36. UNEP/IUCN: Directory of marine and coastal protected areas in the Mediterranean region. Part I - Sites of biological and ecological value. MAP Technical Reports Series No. 36. UNEP, Athens, 1990 (198 pages) (French only).

37. UNEP/FAO: Final reports on research projects dealing with eutrophication and plankton blooms (Activity H). MAP Technical Reports Series No. 37. UNEP, Athens, 1990 (74 pages) (parts in English or French only).

38. UNEP: Common measures adopted by the Contracting Parties to the Convention for the Protection of the Mediterranean Sea against pollution. MAP Technical Reports Series No. 38. UNEP, Athens, 1990 (100 pages) (English, French, Spanish and Arabic).

39. UNEP/FAO/WHO/IAEA: Assessment of the state of pollution of the Mediterranean Sea by organohalogen compounds. MAP Technical Reports Series No. 39. UNEP, Athens, 1990 (224 pages) (English and French).

40. UNEP/FAO: Final reports on research projects (Activities H,I and J). MAP Technical Reports Series No. 40. UNEP, Athens, 1990 (125 pages) (English and French).

41. UNEP: Wastewater reuse for irrigation in the Mediterranean region. MAP Technical Reports Series No. 41. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1990 (330 pages) (English and French).

42. UNEP/IUCN: Report on the status of Mediterranean marine turtles. MAP Technical Reports Series No. 42. UNEP, Athens, 1990 (204 pages) (English and French).

43. UNEP/IUCN/GIS Posidonia: Red Book "Gérard Vuignier", marine plants, populations and landscapes threatened in the Mediterranean. MAP Technical Reports Series No. 43. UNEP, Athens, 1990 (250 pages) (French only).

44. UNEP: Bibliography on aquatic pollution by organophosphorus compounds. MAP Technical Reports Series No. 44. UNEP, Athens, 1990 (98 pages) (English only).

45. UNEP/IAEA: Transport of pollutants by sedimentation: Collected papers from the first Mediterranean Workshop (Villefranche-sur-Mer, France, 10-12 December 1987). MAP Technical Reports Series No. 45. UNEP, Athens, 1990 (302 pages) (English only).

46. UNEP/WHO: Epidemiological studies related to environmental quality criteria for bathing waters, shellfish-growing waters and edible marine organisms (Activity D). Final report on project on relationship between microbial quality of coastal seawater and rotarus-induced gastroenterities among bathers (1986-88). MAP Technical Reports Series No.46, UNEP, Athens, 1991 (64 pages) (English only).

47. UNEP: Jellyfish blooms in the Mediterranean. Proceedings of the II workshop on jellyfish in the Mediterranean Sea. MAP Technical Reports Series No.47. UNEP, Athens, 1991 (320 pages) (parts in English or French only).

48. UNEP/FAO: Final reports on research projects (Activity G). MAP Technical Reports Series No. 48. UNEP, Athens, 1991 (126 pages) (parts in English or French only).

49. UNEP/WHO: Biogeochemical cycles of specific pollutants. Survival of pathogens. Final reports on research projects (Activity K). MAP Technical Reports Series No. 49. UNEP, Athens, 1991 (71 pages) (parts in English or French only).

50. UNEP: Bibliography on marine litter. MAP Technical Reports Series No. 50. UNEP, Athens, 1991 (62 pages) .(English only).

51. UNEP/FAO: Final reports on research projects dealing with mercury, toxicity and analytical techniques. MAP Technical Reports Series No. 51. UNEP, Athens, 1991 (166 pages) (parts in English or French only).

52. UNEP/FAO: Final reports on research projects dealing with bioaccumulation and toxicity of chemical pollutants. MAP Technical Reports Series No. 52. UNEP, Athens, 1991 (86 pages) (parts in English or French only).

53. UNEP/WHO: Epidemiological studies related to environmental quality criteria for bathing waters, shellfish-growing waters and edible marine organisms (Activity D). Final report on epidemiological study on bathers from selected beaches in Malaga, Spain (1988-1989). MAP Technical Reports Series No. 53. UNEP, Athens, 1991 (127 pages) (English only).

54. UNEP/WHO: Development and testing of sampling and analytical techniques for monitoring of marine pollutants (Activity A): Final reports on selected microbiological projects. MAP Technical Reports Series No. 54. UNEP, Athens, 1991 (83 pages) (English only).

55. UNEP/WHO: Biogeochemical cycles of specific pollutants (Activity K): Final report on project on survival of pathogenic organisms in seawater. MAP Technical Reports Series No. 55. UNEP, Athens, 1991 (95 pages) (English only).

56. UNEP/IOC/FAO: Assessment of the state of pollution of the Mediterranean Sea by persistent synthetic materials which may float, sink or remain in suspension. MAP Technical Reports Series No. 56. UNEP, Athens, 1991 (113 pages) (English and French).

57. UNEP/WHO: Research on the toxicity, persistence, bioaccumulation, carcinogenicity and mutagenicity of selected substances (Activity G): Final reports on projects dealing with carcinogenicity and mutagenicity. MAP Technical Reports Series No. 57. UNEP, Athens, 1991 (59 pages) (English only).

58. UNEP/FAO/WHO/IAEA: Assessment of the state of pollution of the Mediterranean Sea by organophosphorus compounds. MAP Technical Reports Series No. 58. UNEP, Athens, 1991 (122 pages) (English and French).

59. UNEP/FAO/IAEA: Proceedings of the FAO/UNEP/IAEA Consultation Meeting on the Accumulation and Transformation of Chemical contaminants by Biotic and Abiotic Processes in the Marine Environment (La Spezia, Italy, 24-28 September 1990), edited by G.P. Gabrielides. MAP Technical Reports Series No. 59. UNEP, Athens, 1991 (392 pages) (English only).

60. UNEP/WHO: Development and testing of sampling and analytical techniques for monitoring of marine pollutants (Activity A): Final reports on selected microbiological projects (1987-1990). MAP Technical Reports Series No. 60. UNEP, Athens, 1991 (76 pages) (parts in English or French only).

61. UNEP: Integrated Planning and Management of the Mediterranean Coastal Zones. Documents produced in the first and second stage of the Priority Action (1985-1986). MAP Technical Reports Series No. 61 UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1991 (437 pages) (parts in English or French only).

62. UNEP/IAEA: Assessment of the State of Pollution of the Mediterranean Sea by Radioactive Substances. MAP Technical Reports Series No. 62, UNEP, Athens, 1992 (133 pages) (English and French).

63. UNEP/WHO: Biogeochemical cycles of specific pollutants (Activity K) - Survival of Pathogens - Final reports on Research Projects (1989-1991). MAP Technical Reports Series No. 63, UNEP, Athens, 1992 (86 pages) (French only).

64. UNEP/WMO: Airborne Pollution of the Mediterranean Sea. Report and Proceedings of the Second WMO/UNEP Workshop. MAP Technical Reports Series No. 64, UNEP, Athens, 1992 (246 pages) (English only).

65. UNEP: Directory of Mediterranean Marine Environmental Centres. MAP Technical Reports Series No. 65, UNEP, Athens, 1992 (351 pages) (English and French).

66. UNEP/CRU: Regional Changes in Climate in the Mediterranean Basin Due to Global Greenhouse Gas Warming. MAP Technical Reports Series No. 66, UNEP, Athens, 1992 (172 pages) (English only).

67. UNEP/IOC: Applicability of Remote Sensing for Survey of Water Quality Parameters in the Mediterranean. Final Report of the Research Project. MAP Technical Reports Series No. 67, UNEP, Athens, 1992 (142 pages) (English only).

68. UNEP/FAO/IOC: Evaluation of the Training Workshops on the Statistical Treatment and Interpretation of Marine Community Data. MAP Technical Reports Series No. 68. UNEP, Athens, 1992 (221 pages) (English only).

69. UNEP/FAO/IOC: Proceedings of the FAO/UNEP/IOC Workshop on the Biological Effects of Pollutants on Marine Organisms (Malta, 10-14 September 1991), edited by G.P. Gabrielides. MAP Technical Reports Series No. 69. UNEP, Athens, 1992 (287 pages) (English only).

70. UNEP/IAEA/IOC/FAO: Organohalogen Compounds in the Marine Environment: A Review. MAP Technical Reports Series No. 70. UNEP, Athens, 1992 (49 pages) (English only).

71. UNEP/FAO/IOC: Selected techniques for monitoring biological effects of pollutants in marine organisms. MAP Technical Reports Series No. 71. UNEP, Athens, 1993 (189 pages) (English only).

72. UNEP: Costs and Benefits of Measures for the Reduction of Degradation of the Environment from Land-based Sources of Pollution in Coastal Areas. A - Case Study of the Bay of Izmir. B - Case Study of the Island of Rhodes. MAP Technical Reports Series No. 72. UNEP, Athens, 1993 (64 pages) (English only).

73. UNEP/FAO: Final Reports on Research Projects Dealing with the Effects of Pollutants on Marine Communities and Organisms. MAP Technical Reports Series No. 73. UNEP, Athens, 1993 (186 pages) (English and French).

74. UNEP/FIS: Report of the Training Workshop on Aspects of Marine Documentation in the Mediterranean. MAP Technical Reports Series No. 74. UNEP, Athens, 1993 (38 pages) (English only).

75. UNEP/WHO: Development and Testing of Sampling and Analytical Techniques for Monitoring of Marine Pollutants (Activity A). MAP Technical Reports Series No. 75. UNEP, Athens, 1993 (90 pages) (English only).

76. UNEP/WHO: Biogeochemical Cycles of Specific Pollutants (Activity K): Survival of Pathogens. MAP Technical Reports Series No. 76. UNEP, Athens, 1993 (68 pages) (English and French).

77. UNEP/FAO/IAEA. Designing of monitoring programmes and management of data concerning chemical contaminants in marine organisms. MAP Technical Reports Series No. 77. UNEP, Athens, 1993 (236 pages) (English only).

78. UNEP/FAO: Final reports on research projects dealing with eutrophication problems. MAP Technical Reports Series No. 78. UNEP, Athens, 1994 (139 pages) (English only).

79. UNEP/FAO: Final reports on research projects dealing with toxicity of pollutants on marine organisms. MAP Technical Reports Series No. 79. UNEP, Athens, 1994 (135 pages) (parts in English or French only).

80. UNEP/FAO: Final reports on research projects dealing with the effects of pollutants on marine organisms and communities. MAP Technical Reports Series No. 80. UNEP, Athens, 1994 (123 pages) (English only).

81. UNEP/IAEA. Data quality review for MED POL: Nineteen years of progress. MAP Technical Reports Series No. 81. UNEP, Athens, 1994 (79 pages) (English only).

82. UNEP/IUCN: Technical report on the State of Cetaceans in the Mediterranean. MAP Technical Reports Series No. 82. UNEP, Regional Activity Centre for Specially Protected Areas, Tunis, 1994 (37 pages) (English only).

83. UNEP/IUCN: Specially protected Areas in Mediterranean. Sketch of an Analytical Study of Relevant Legislation. MAP Technical Reports Series No. 83. UNEP, Regional Activity Centre for Specially Protected Areas, Tunis, 1994 (55 pages) (French only).

84. UNEP: Integrated Management Study for the Area of Izmir. MAP Technical Reports Series No. 84, UNEP, Regional Activity Centre for Priority Actions Programme, Split, 1994 (130 pages) (English only).

85. UNEP/WMO: Assessment of Airborne Pollution of the Mediterranean Sea by Sulphur and Nitrogen Compounds and Heavy Metals in 1991. MAP Technical Report Series No. 85, Athens, 1994 (304 pages) (English only).

86. UNEP: Monitoring Programme of the Eastern Adriatic Coastal Area - Report for 1983-1991. MAP Technical Report Series No. 86, Athens, 1994 (311 pages) (English only).

87. UNEP/WHO: Identification of microbiological components and measurement development and testing of methodologies of specified contaminants (Area I) - Final reports on selected microbiological projects. MAP Technical Reports Series No. 87, UNEP, Athens, 1994 (136 pages) (English only).

88. UNEP: Proceedings of the Seminar on Mediterranean Prospective. MAP Technical Reports Series No. 88, UNEP, Blue Plan Regional Activity Centre, Sophia Antipolis, 1994 (176 pages) (parts in English or French only).

89. UNEP: Iskenderun Bay Project. Volume I. Environmental Management within the Context of Environment-Development. MAP Technical Reports Series No. 89, UNEP, Blue Plan Regional Activity Centre, Sophia Antipolis, 1994 (144 pages) (English only).

90. UNEP: Iskenderun Bay Project. Volume II. Systemic and Prospective Analysis. MAP Technical Report Series No. 90, Sophia Antipolis, 1994 (142 pages) (parts in English or French only).

91. UNEP: A Contribution from Ecology to Prospective Studies. Assets and Issues. MAP Technical Reports Series No. 91, Sophia Antipolis, 1994 (162 pages) (French only).

92. UNEP/WHO. Assessment of the State of Pollution in the Mediterranean Sea by Carcinogenic, Mutagenic and Teratogenic Substances. MAP Technical Reports Series No. 92, UNEP, Athens, 1995 (238 pages) (English only).

93. UNEP/WHO: Epidemiological studies related to the environmental quality criteria for bathing waters, shellfish-growing waters and edible marine organisms. MAP Technical Reports Series No. 93, UNEP, Athens, 1995 (118 pages) (English only).

94. UNEP: Proceedings of the Workshop on Application of Integrated Approach to Development, Management and Use of Water Resources. MAP Technical Reports Series No. 94, UNEP, Athens, 1995 (214 pages) (parts in English or French only).

95. UNEP: Common measures for the control of pollution adopted by the Contracting Parties to the Convention for the Protection of the Mediterranean Sea against Pollution. MAP Technical Reports Series No 95, UNEP, Athens, 1995 (69 pages) (English and French).

96. UNEP/FAO: Final reports of research projects on effects (Research Area III) - Pollution effects on plankton composition and spatial distribution, near the sewage outfall of Athens (Saronikos Gulf, Greece). MAP Technical Reports Series No. 96, UNEP, Athens, 1996 (121 pages) (English only).

97. UNEP/FAO: Final reports of research projects on effects (Research Area III) - Pollution effects on marine communities. MAP Technical Reports Series No. 97, UNEP, Athens, 1996 (141 pages) (English and French).

98. UNEP: Implications of Climate Change for the Albanian Coast. MAP Technical Reports Series No. 98, UNEP, Athens, 1996 (179 pages) (English only).

99. UNEP: Implications of Climate Change for the Sfax Coastal Area (Tunisia). MAP Technical Reports Series No. 99, UNEP, Athens, 1996 (326 pages) (English and French).

100. UNEP: *State of the Marine and Coastal Environment in the Mediterranean Region.* MAP Technical Reports Series No. 100, UNEP, Athens, 1996 (142 pages) (English only).

101. UNEP. State of the Marine and Coastal Environment in the Mediterranean Region. MAP Technical Reports Series No. 101, UNEP, Athens, 1996 (148 pages) (French only).

102 UNEP: Implications of Climate Change for the Coastal Area of Fuka-Matrouh (Egypt). MAP Technical Reports Series No 102, UNEP, Athens, 1996 (238 pages) (English only)

103. UNEP/FAO: Final reports on research projects dealing with biological effects (Research Area III). MAP Technical Reports Series No 103, UNEP, Athens, 1996 (128 pages) (English and French).

104. UNEP/FAO: *Final reports on research projects dealing with eutrophication and heavy metal* accumulation. MAP Technical Reports Series No. 104, UNEP, Athens, 1996 (156 pages) (English and French).

105. UNEP/FAO/WHO: Assessment of the state of pollution of the Mediterranean sea by zinc, copper and their compounds MAP Technical Reports Series No 105, UNEP, Athens, 1996 (288 pages) (English and French).

106. UNEP/FAO/WHO: Assessment of the state of eutrophication in the Mediterranean sea MAP Technical Reports Series No 106, UNEP, Athens, 1996 (456 pages) (English and French).

107. UNEP/WHO· Guidelines for authorization for the discharge of liquid wastes into the Mediterranean Sea. MAP Technical Reports Series No. 107, UNEP, Athens, 1996 (200 pages) (English and French)

108. UNEP/WHO: *Assessment of the state of microbiological pollution of the Mediterranean Sea.* MAP Technical Reports Series No 108, UNEP, Athens, 1996 (270 pages) (English and French).

109. UNEP/WHO: Survey of pollutants from land-based sources in the Mediterranean. MAP Technical Reports Series No 108, UNEP, Athens, 1996 (188 pages) (English and French).

110. UNEP/WHO: Assessment of the state of pollution of the Mediterranean Sea by anionic detergents. MAP Technical Reports Series No. 110, UNEP, Athens, 1996 (260 pages) (English and French)

111. UNEP/WHO: Guidelines for treatment of effluents prior to discharge into the Mediterranean Sea. MAP Technical Reports Series No. 111, UNEP, Athens, 1996 (247 pages) (English only).

112. UNEP/WHO: Guidelines for submarine outfall structures for Mediterranean small and medium-sized coastal communities. MAP Technical Reports Series No. 112, UNEP, Athens, 1996 (98 pages) (English and French).

**PUBLICATIONS "MAP TECHNICAL REPORTS SERIES"**

1. PNUE/COI/OMM: Etudes de base et surveillance continue du pétrole et des hydrocarbures contenus dans les eaux de la mer (MED POL I). MAP Technical Reports Series No. 1. UNEP, Athens, 1986 (96 pages) (parties en anglais, français ou espagnol seulement).

2. PNUE/FAO: Etudes de base et surveillance continue des métaux, notamment du mercure et du cadmium, dans les organismes marins (MED POL II). MAP Technical Reports Series No. 2. UNEP, Athens, 1986 (220 pages) (parties en anglais, français ou espagnol seulement).

3. PNUE/FAO: Etudes de base et surveillance continue du DDT, des PCB et des autres hydrocarbures chlorés contenus dans les organismes marins (MED POL III). MAP Technical Reports Series No. 3. UNEP, Athens, 1986 (128 pages) (parties en anglais, français ou espagnol seulement).

4. PNUE/FAO: Recherche sur les effets des polluants sur les organismes marins et leurs peuplements (MED POL IV). MAP Technical Reports Series No. 4. UNEP, Athens, 1986 (118 pages) (parties en anglais, français ou espagnol seulement).

5. PNUE/FAO: Recherche sur les effets des polluants sur les communautés et écosystèmes marins (MED POL V). MAP Technical Reports Series No. 5. UNEP, Athens, 1986 (146 pages) (parties en anglais ou français seulement).

6. PNUE/COI: Problèmes du transfert des polluants le long des côtes (MED POL VI). MAP Technical Reports Series No. 6. UNEP, Athens, 1986 (100 pages) (anglais seulement).

7. PNUE/OMS: Contrôle de la qualité des eaux côtières (MED POL VII). MAP Technical Reports Series No. 7. UNEP, Athens, 1986 (426 pages) (parties en anglais ou français seulement).

8. PNUE/AIEA/COI: Etudes biogéochimiques de certains polluants au large de la Méditerranée (MED POL VIII). MAP Technical Reports Series No. 8. UNEP, Athens, 1986 (42 pages) (parties en anglais ou français seulement).

8. PNUE: Etudes biogéochimiques de certains polluants au large de la Méditerranée (MED POL VIII).
Add. Addendum, Croisière Océanographique de la Grèce 1980. MAP Technical Reports Series No. 8, Addendum. UNEP, Athens, 1986 (66 pages) (anglais seulement).

9. PNUE: Programme coordonné de surveillance continue et de recherche en matière de pollution dans la Méditerranée (MED POL -PHASE I). Rapport final, 1975-1980. MAP Technical Reports Series No. 9. UNEP, Athens, 1986 (276 pages) (anglais seulement).

10. PNUE: Recherches sur la toxicité, la persistance, la bioaccumulation, la cancérogénicité et la mutagénicité de certaines substances (Activité G). Rapports finaux sur les projets ayant trait à la toxicité (1983-85). MAP Technical Reports Series No. 10. UNEP, Athens, 1987 (118 pages) (anglais seulement).

11. PNUE: Réhabilitation et reconstruction des établissements historiques méditerranéens. Textes rédigés au cours de la première phase de l'action prioritaire (1984-1985). MAP Technical Reports Series No. 11. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1986 (158 pages) (parties en anglais ou français seulement).

12. PNUE: Développement des ressources en eau des petites îles et des zones côtières isolées méditerranéennes. Textes rédigés au cours de la première phase de l'action prioritaire (1984-1985). MAP *Technical Reports Series* No. 12. UNEP, *Priority Actions Programme, Regional* Activity Centre, Split, 1987 (162 pages) (parties en anglais ou français seulement).

13. PNUE: Thèmes spécifiques concernant le développement des ressources en eau des grandes îles méditerranéennes. Textes rédigés au cours de la deuxième phase de l'action prioritaire (1985-1986). MAP Technical Reports Series No. 13. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (162 pages) (parties en anglais ou français seulement).

14. PNUE: L'expérience des villes historiques de la Méditerranée dans le processus intégré de réhabilitation du patrimoine urbain et architectural. Documents établis lors de la seconde phase de l'Action prioritaire (1986). MAP Technical Reports Series No. 14. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (500 pages) (parties en anglais ou français seulement).

15. PNUE: Aspects environnementaux du développement de l'aquaculture dans la région méditerranéenne. Documents établis pendant la période 1985-1987. MAP Technical Reports Series No. 15. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (101 pages) (anglais seulement).

16. PNUE: Promotion de la protection des sols comme élément essentiel de la protection de l'environnement dans les zones côtières méditerranéennes. Documents sélectionnés (1985-1987). MAP Technical Reports Series No. 16. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (424 pages) (parties en anglais ou français seulement).

17. PNUE: Réduction des risques sismiques dans la région méditerranéenne. Documents et études sélectionnés (1985-1987). MAP Technical Reports Series No. 17. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1987 (247 pages) (parties en anglais ou français seulement).

18. PNUE/FAO/OMS: Evaluation de l'état de la pollution de la mer Méditerranée par le mercure et les composés mercuriels. MAP Technical Reports Series No. 18. UNEP, Athens, 1987 (354 pages) (anglais et français).

19. PNUE/COI: Evaluation de l'état de la pollution de la mer Méditerranée par les hydrocarbures de pétrole. MAP Technical Reports Series No. 19. UNEP, Athens, 1988 (130 pages) (anglais et français).

20. PNUE/OMS: Etudes épidémiologiques relatives aux critères de la qualité de l'environnement pour les eaux servant à la baignade, à la culture de coquillages et à l'élevage d'autres organismes marins comestibles (Activité D). Rapport final sur le projet sur la relation entre la qualité microbienne des eaux marines côtières et les effets sur la santé (1983-86). MAP Technical Reports Series No. 20. UNEP, Athens, 1988 (156 pages) (anglais seulement).

21. PNUE/UNESCO/FAO· Eutrophisation dans la mer Méditerranée: capacité réceptrice et surveillance continue des effets à long terme. MAP Technical Reports Series No. 21. UNEP, Athens, 1988 (200 pages) (parties en anglais ou français seulement).

22. PNUE/FAO: Etude des modifications de l'écosystème dans les zones soumises à l'influence des polluants (Activité I). MAP Technical Reports Series No. 22. UNEP, Athens, 1988 (146 pages) (parties en anglais ou français seulement).

23. PNUE: Programme national de surveillance continue pour la Yougoslavie, Rapport pour 1983-1986. MAP Technical Reports Series No. 23. UNEP, Athens, 1988 (223 pages) (anglais seulement).

24. PNUE/FAO: Toxicité, persistance et bioaccumulation de certaines substances vis-à-vis des organismes marins (Activité G). MAP Technical Reports Series No. 24. UNEP, Athens, 1988 (122 pages) (parties en anglais ou français seulement).

25. PNUE: Le Plan d'action pour la Méditerranée, perspective fonctionnelle; une recherche juridique et politique. MAP Technical Reports Series No. 25. UNEP, Athens, 1988 (105 pages) (anglais seulement).

26. PNUE/UICN: Répertoire des aires marines et côtières protégées de la Méditerranée. Première partie - Sites d'importance biologique et écologique. MAP Technical Reports Series No. 26. UNEP, Athens, 1989 (196 pages) (anglais seulement).

27. PNUE: Implications des modifications climatiques prévues dans la région méditerranéenne: une vue d'ensemble. MAP Technical Reports Series No. 27. UNEP, Athens, 1989 (52 pages) (anglais seulement).

28. PNUE: Etat du milieu marin en Méditerranée. MAP Technical Reports Series No. 28. UNEP, Athens, 1989 (225 pages) (anglais seulement).

29. PNUE: Bibliographie sur les effets des modifications climatiques et sujets connexes. MAP Technical Reports Series No. 29. UNEP, Athens, 1989 (143 pages) (anglais seulement).

30. PNUE: Données météorologiques et climatologiques provenant de mesures effectuées dans l'air en surface et en altitude en vue de l'évaluation du transfert et du dépôt atmosphériques des polluants dans le bassin méditerranéen: un compte rendu. MAP Technical Reports Series No. 30. UNEP, Athens, 1989 (137 pages) (anglais seulement).

31. PNUE/OMM: Pollution par voie atmosphérique de la mer Méditerranée. Rapport et actes des Journées d'étude OMM/PNUE. MAP Technical Reports Series No. 31. UNEP, Athens, 1989 (247 pages) (parties en anglais ou français seulement).

32. PNUE/FAO· Cycles biogéochimiques de polluants spécifiques (Activité K). MAP Technical Reports Series No. 32. UNEP, Athens, 1989 (139 pages) (parties en anglais ou français seulement).

33. PNUE/FAO/OMS/AIEA: Evaluation des composés organostanniques en tant que polluants du milieu marin en Méditerranée. MAP Technical Reports Series No. 33. UNEP, Athens, 1989 (185 pages) (anglais et français).

34. PNUE/FAO/OMS: Evaluation de l'état de la pollution de la mer Méditerranée par le cadmium et les composés de cadmium. MAP Technical Reports Seri es No. 34. UNEP, Athens, 1989 (175 pages) (anglais et français).

35. PNUE: Bibliographie sur la pollution marine par les composés organostanniques. MAP Technical Reports Series No. 35. UNEP, Athens, 1989 (92 pages) (anglais seulement).

36. PNUE/UICN: Répertoire des aires marines et côtières protégées de la Méditerranée. Première partie - Sites d'importance biologique et écologique. MAP Technical Reports Series No. 36. UNEP, Athens, 1990 (198 pages) (français seulement).

37. PNUE/FAO: Rapports finaux sur les projets de recherche consacrés à l'eutrophisation et aux efflorescences de plancton (Activité H). MAP Technical Reports Series No. 37. UNEP, Athens, 1990 (74 pages) (parties en anglais ou français seulement).

38. PNUE: Mesures communes adoptées par les Parties Contractantes à la Convention pour la protection de la mer Méditerranée contre la pollution. MAP Technical Reports Series No. 38. UNEP, Athens, 1990 (100 pages) (anglains, français, espagnol et arabe).

39. PNUE/FAO/OMS/AIEA: Evaluation de l'état de la pollution par les composés organohalogénés. MAP Technical Reports Series No. 39. UNEP, Athens, 1990 (224 pages) (anglais et français).

40. PNUE/FAO: Rapports finaux sur les projets de recherche (Activités H, I et J). MAP Technical Reports Series No. 40. UNEP, Athens, 1990 (125 pages) (anglais et français).

41. PNUE: Réutilisation agricole des eaux usées dans la région méditerranéenne. MAP Technical Reports Series No. 41. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1990 (330 pages) (anglais et français).

42. PNUE/UICN: Rapport sur le statut des tortues marines de Méditerranée. MAP Technical Reports Series No. 42. UNEP, Athens, 1990 (204 pages) (anglais et français).

43. PNUE/UICN/GIS Posidonie: Livre rouge "Gérard Vuignier" des végétaux, peuplements et paysages marins menacés de Méditerranée. MAP Technical Reports Series No. 43. UNEP, Athens, 1990 (250 pages) (français seulement).

44. PNUE: Bibliographie sur la pollution aquatique par les composés organophosphorés. MAP Technical Reports Series No. 44. UNEP, Athens, 1990 (98 pages) (anglais seulement).

45. PNUE/AIEA: Transfert des polluants par sédimentation: Recueil des communications présentées aux premières journées d'études méditerranéennes (Villefranche-sur- Mer, France, 10-12 décembre 1987). MAP Technical Reports Series No. 45. UNEP, Athens, 1990 (302 pages) (anglais seulement)

46. PNUE/OMS: Etudes épidémiologiques relatives aux critères de la qualité de l'environnement pour les eaux servant à la baignade, à la culture de coquillages et à l'élevage d'autres organismes marins comestibles (Activité D). Rapport final sur le projet sur la relation entre la qualité microbienne des eaux marines côtières et la gastroentérite provoquée par le rotavirus entre les baigneurs (1986-88). MAP Technical Reports Series No.46. UNEP, Athens, 1991 (64 pages) (anglais seulement).

47. PNUE: Les proliférations de méduses en Méditerannée. Actes des IIèmes journées d'étude sur les méduses en mer Méditerranée. MAP Technical Reports Series No.47. UNEP, Athens, 1991 (320 pages) (parties en anglais ou français seulement).

48. PNUE/FAO· Rapports finaux sur les projets de recherche (Activité G). MAP Technical Reports Series No. 48. UNEP, Athens, 1991 (126 pages) (parties en anglais ou français seulement).

49. PNUE/OMS. Cycles biogéochimiques de polluants spécifiques. Survie des Pathogènes. Rapports finaux sur les projets de recherche (activité K). MAP Technical Reports Series No. 49. UNEP, Athens, 1991 (71 pages) (parties en anglais ou français seulement).

50. PNUE: Bibliographie sur les déchets marins. MAP Technical Reports Series No. 50. UNEP, Athens, 1991 (62 pages) (anglais seulement).

51. PNUE/FAO: Rapports finaux sur les projets de recherche traitant du mercure, de la toxicité et des techniques analytiques. MAP Technical Reports Series No. 51. UNEP, Athens, 1991 (166 pages) (parties en anglais ou français seulement).

52. PNUE/FAO: Rapports finaux sur les projets de recherche traitant de la bioaccumulation et de la toxicité des polluants chimiques. MAP Technical Reports Series No. 52. UNEP, Athens, 1991 (86 pages) (parties en anglais ou français seulement).

53. PNUE/OMS: Etudes épidémiologiques relatives aux critères de la qualité de l'environnement pour les eaux servant à la baignade, à la culture de coquillages et à l'élevage d'autres organismes marins comestibles (Activité D). Rapport final sur l'étude épidémiologique menée parmi les baigneurs de certaines plages à Malaga, Espagne (1988-1989). MAP Technical Reports Series No. 53. UNEP, Athens, 1991 (127 pages) (anglais seulement).

54. PNUE/OMS: Mise au point et essai des techniques d'échantillonnage et d'analyse pour la *surveillance continue des polluants marins* (Activité A): *Rapports finaux sur certains projets de* nature microbiologique. MAP Technical Reports Series No. 54. UNEP, Athens, 1991 (83 pages) (anglais seulement)

55. PNUE/OMS: Cycles biogéochimiques de polluants spécifiques (Activité K): Rapport final sur le *projet sur la survie des microorganismes pathogènes dans l'eau de mer.* MAP Technical Reports Series No. 55. UNEP, Athens, 1991 (95 pages) (anglais seulement).

56. PNUE/COI/FAO: Evaluation de l'état de la pollution de la mer Méditerranée par les matières synthétiques persistantes qui peuvent flotter, couler ou rester en suspension. MAP Technical Reports Series No. 56. UNEP, Athens, 1991 (113 pages) (anglais et français).

57. PNUE/OMS: Recherches sur la toxicité, la persistance, la bioaccumulation, la cancérogénicité et la mutagénicité de certaines substances (Activité G). Rapports finaux sur les projets ayant trait à la cancérogénicité et la mutagénicité. MAP Technical Reports Series No. 57. UNEP, Athens, 1991 (59 pages) (anglais seulement).

58. PNUE/FAO/OMS/AIEA: Evaluation de l'état de la pollution de la mer Méditerranée par les composés organophosphorés. MAP Technical Reports Series No. 58. UNEP, Athens, 1991 (122 pages) (anglais et français).

59. PNUE/FAO/AIEA: Actes de la réunion consultative FAO/PNUE/AIEA sur l'accumulation et la *transformation des contaminants chimiques par les processus biotiques et abiotiques dans le* milieu marin (La Spezia, Italie, 24-28 septembre 1990), publié sous la direction de G.P. Gabrielides. MAP Technical Reports Series No. 59. UNEP, Athens, 1991 (392 pages) (anglais seulement).

60. PNUE/OMS: Mise au point et essai des techniques d'échantillonnage et d'analyse pour la surveillance continue des polluants marins (Activité A): Rapports finaux sur certains projets de nature microbiologique (1987-1990). MAP Technical Reports Series No. 60. UNEP, Athens, 1991 (76 pages) (parties en anglais ou français seulement).

61. PNUE: Planification intégrée et gestion des zones côtières méditerranéennes. Textes rédigés au cours de la première et de la deuxième phase de l'action prioritaire (1985-1986). MAP Technical Reports Series No. 61. UNEP, Priority Actions Programme, Regional Activity Centre, Split, 1991 (437 pages) (parties en anglais ou français seulement).

62. PNUE/AIEA: Evaluation de l'état de la pollution de la mer Méditerranée par les substances radioactives. MAP Technical Reports Series No. 62, UNEP, Athens, 1992 (133 pages) (anglais et français).

63. PNUE/OMS: Cycles biogéochimiques de polluants spécifiques (Activité K) - Survie des pathogènes - Rapports finaux sur les projets de recherche (1989-1991). MAP Technical Reports Series No. 63, UNEP, Athens, 1992 (86 pages) (français seulement).

64. PNUE/OMM: Pollution par voie atmosphérique de la mer Méditerranée. Rapport et actes des deuxièmes journées d'études OMM/PNUE. MAP Technical Reports Series No. 64, UNEP, Athens, 1992 (246 pages) (anglais seulement).

65. PNUE: Répertoire des centres relatifs au milieu marin en Méditerranée. MAP Technical Reports Series No. 65, UNEP, Athens, 1992 (351 pages) (anglais et français).

66. PNUE/CRU: Modifications régionales du climat dans le bassin méditerranéen résultant du réchauffement global dû aux gaz à effet de serre. MAP Technical Reports Series No. 66, UNEP, Athens, 1992 (172 pages) (anglais seulement).

67. PNUE/COI: Applicabilité de la télédétection à l'étude des paramètres de la qualité de l'eau en Méditerranée. Rapport final du projet de recherche. MAP Technical Reports Series No. 67, UNEP, Athens, 1992 (142 pages) (anglais seulement).

68. PNUE/FAO/COI: Evaluation des ateliers de formation sur le traitement statistique et l'interprétation des données relatives aux communautés marines. MAP Technical Reports Series No. 68. UNEP, Athens, 1992 (221 pages) (anglais seulement).

69. PNUE/FAO/COI. Actes de l'Atelier FAO/PNUE/COI sur les effets biologiques des polluants sur les organismes marins (Malte, 10-14 septembre 1991), publié sous la direction de G.P. Gabrielides. MAP Technical Reports Series No. 69. UNEP, Athens, 1992 (287 pages) (anglais seulement).

70. PNUE/AIEA/COI/FAO: Composés organohalogénés dans le milieu marin: Une synthèse. MAP Technical Reports Series No. 70. UNEP, Athens, 1992 (49 pages) (anglais seulement).

71. PNUE/FAO/COI: Techniques sélectionnées de surveillance continue des effets biologiques des polluants sur les organismes marins. MAP Technical Reports Series No. 71. UNEP, Athens, 1993 (189 pages) (anglais seulement).

72. PNUE: Coûts et bénefices des mesures pour la réduction de la dégradation de l'environnement des sources de pollution d'origine tellurique dans les zones côtières. A -Etude de cas de la baie d'Izmir. B - Etude de cas de l'île de Rhodes. MAP Technical Reports Series No. 72. UNEP, Athens, 1993 (64 pages) (anglais seulement).

73. PNUE/FAO: Rapports finaux sur les projets de recherche traitant des effets de polluants sur les communautés et les organismes marins. MAP Technical Reports Series No. 73. UNEP, Athens, 1993 (186 pages) (anglais et français).

74. PNUE/FIS: Rapport de l'Atelier de formation sur les aspects de la documentation marine en Méditerranée. MAP Technical Reports Series No. 74. UNEP, Athens, 1993 (38 pages) (anglais seulement)

75. PNUE/OMS: Mise au point et essai des techniques d'echantillonnage et d'analyse pour la surveillance continué des polluants marins (Activité A). MAP Technical Reports Series No. 75. UNEP, Athens, 1993 (90 pages) (anglais seulement).

76. PNUE/OMS: Cycles biogeochimiques de polluants spécifiques (Activité K): Survie des pathogènes MAP Technical Reports Series No. 76. UNEP, Athens, 1993 (68 pages) (anglais et français).

77. PNUE/FAO/AIEA: Conception des programmes de surveillance continue et de gestion des données concernant les contaminants chimiques dans les organismes marins. MAP Technical Reports Series No. 77. UNEP, Athens, 1993 (236 pages) (anglais seulement).

78. PNUE/FAO: Rapports finaux sur les projets de recherche traitant des problèmes de l'eutrophisation. MAP Technical Reports Series No. 78. UNEP, Athens, 1994 (139 pages) (anglais seulement).

79. PNUE/FAO: Rapports finaux sur les projets de recherche traitant de la toxicité des polluants sur les organismes marins. MAP Technical Reports Series No. 79. UNEP, Athens, 1994 (135 pages) (parties en anglais ou français seulement).

80. PNUE/FAO: Rapports finaux sur les projets de recherche traitant des effets des polluants sur les organismes et communautés marins. MAP Technical Reports Series No. 80. UNEP, Athens, 1994 (123 pages) (anglais seulement).

81. PNUE/AIEA: Examen de la qualité des données pour le MED POL: Dix-neuf années de progrès. MAP Technical Reports Series No. 81. UNEP, Athens, 1994 (79 pages) (anglais seulement).

82. PNUE/UICN: Rapport technique sur l'état des cétacés en Méditerranée. MAP Technical Reports Series No. 82. PNUE, Centre d'activités régionales pour les aires spécialement protégées, Tunis, 1994 (37 pages) (anglais seulement).

83. PNUE/UICN: Les aires protégées en Méditerranée. Essai d'étude analytique de la législation pertinente. MAP Technical Reports Series No. 83. PNUE, Centre d'activités régionales pour les aires spécialement protégées, Tunis, 1994 (55 pages) (français seulement).

84. PNUE: Etude de gestion intégrée pour la zone d'Izmir. MAP Technical Reports Series No. 84, PNUE, Centre d'activités régionales pour le programme d'actions prioritaires, Split, 1994 (130 pages) (anglais seulement).

85. PNUE/OMM: Evaluation de la pollution transférée par voie atmosphérique en mer Méditerranée pour les composés soufrés, azotés et pour les métaux lourds en 1991. MAP Technical Reports Series No. 85, UNEP, Athens, 1994 (304 pages) (anglais seulement).

86. PNUE: Programme de surveillance continue de la zone côtière de l'Adriatique Est - Rapport pour 1983-1991. MAP Technical Reports Series No. 86, UNEP, Athens, 1994 (311 pages) (anglais seulement).

87. PNUE/OMS: Identification de constituants microbiologiques et de dosage (mise au point et essai de méthodes) de contaminants donnés (Domaine de recherche I) - Rapports finaux sur certains projets de nature microbiologique. MAP Technical Reports Series No. 87, UNEP, Athens, 1994 (136 pages) (anglais seulement).

88. PNUE: Actes du Séminaire débat sur la prospective méditerranéenne. MAP Technical Reports Series No. 88, UNEP, Blue Plan Regional Activity Centre, Sophia Antipolis, 1994 (176 pages) (parties en anglais ou français seulement).

89. PNUE. Projet de la Baie d'Iskenderun. Volume I. Gestion de l'environnement dans le cadre de l'environnement-développement. MAP Technical Reports Series No. 89, PNUE, Centre d'activités régionales pour le Plan Bleu, Sophia Antipolis, 1994 (144 pages) (anglais seulement).

90. PNUE: Projet de la Baie d'Iskenderun. Volume II. Analyse systémique et prospective. MAP Technical Reports Series No. 90, UNEP, Sophia Antipolis, 1994 (142 pages) (parties en anglais ou français seulement).

91. PNUE: Une contribution de l'écologie à la prospective. Problèmes et acquis. MAP Technical Reports Series No. 91, Sophia Antipolis, 1994 (162 pages) (français seulement).

92. PNUE/OMS: Evaluation de l'état de la pollution de la mer Méditerranée par les substances cancérigènes, tératogènes et mutagènes. MAP Technical Reports Series No. 92, UNEP, Athens, 1995 (238 pages) (anglais seulement).

93. PNUE/OMS: Etudes épidémiologiques relatives à la qualité de l'environnement pour les eaux servant à la baignade, à la culture des coquillages et à l'élevage d'autres organismes marins comestibles. MAP Technical Reports Series No. 93, UNEP, Athens, 1995 (118 pages) (anglais seulement).

94. PNUE: Actes de l'Atelier sur l'application d'une approche intégrée au développement, à la gestion et à l'utilisation des ressources en eau. MAP Technical Reports Series No. 94, UNEP, Athens, 1995 (214 pages) (parties en anglais ou français seulement).

95. PNUE: Mesures communes de lutte contre la pollution adoptées par les Parties contractantes à la Convention pour la protection de la mer Méditerranée contre la pollution. MAP Technical Reports Series No. 95, UNEP, Athens, 1995 (69 pages) (anglais et français).

96. PNUE/FAO: Rapports finaux des projets de recherche sur les effets (Domaine de recherche III) - Effets de la pollution sur la composition et la répartition spatiale à proximité de l'émissaire d'eaux usées d'Athènes (Golfe Saronique, Grèce). MAP Technical Reports Series No. 96, UNEP, Athens, 1996 (121 pages) (anglais seulement).

97. PNUE/FAO: Rapports finaux des projets de recherche sur les effets (Domaine de recherche III) - Effets de la pollution sur les communautés marines. MAP Technical Reports Series No. 97, UNEP, Athens, 1996 (141 pages) (anglais et français).

98. PNUE: Implications du changement climatique pour la zone côtière d'Albanie. MAP Technical Reports Series No. 98, UNEP, Athens, 1996 (179 pages) (anglais seulement).

99. PNUE: Implications des changements climatiques sur la zone côtière de Sfax. MAP Technical Reports Series No. 99, UNEP, Athens, 1996 (326 pages) (anglais et français).

100. PNUE: Etat du milieu marin et du littoral de la région méditerranéenne. MAP Technical Reports Series No. 100, UNEP, Athens, 1996 (142 pages) (anglais seulement).

101. PNUE: Etat du milieu marin et du littoral de la région méditerranéenne. MAP Technical Reports Series No. 101, UNEP, Athens, 1996 (148) (français seulement).

102. PNUE: Implications des changements climatiques sur la zone côtière de Fuka-Matrouh (Egypte). MAP Technical Reports Series No. 102, UNEP, Athens, 1996 (238 pages) (anglais seulement).

103. PNUE/FAO: Rapports finaux sur les projets de recherche relatifs aux effets biologiques (Domaine de Recherche III). MAP Technical Reports Series No. 103, UNEP, Athens, 1996 (128 pages) (anglais et français).

104. PNUE/FAO: Rapports finaux sur les projets de recherche relatifs à l'eutrophisation et à l'accumulation des métaux lourds. MAP Technical Reports Series No. 104, UNEP, Athens, 1996 (156 pages) (anglais et français).

105. PNUE/FAO/OMS: Evaluation de l'état de la pollution de la mer Méditerranée par le zinc, le cuivre et leurs composés. MAP Technical Reports Series No. 105, UNEP, Athens, 1996 (288 pages) (anglais et français).

106. PNUE/FAO/OMS: Evaluation de l'état de l'eutrophisation en mer Méditerranée. MAP Technical Reports Series No. 106, UNEP, Athens, 1996 (456 pages) (anglais et français).

107. PNUE/OMS: Lignes directrices concernant les autorisations de rejet de déchets liquides en mer Méditerranée. MAP Technical Reports Series No. 107, UNEP, Athens, 1996 (200 pages) (anglais et français).

108. PNUE/OMS: Evaluation de l'état de la pollution microbiologique de la mer Méditerranée. MAP Technical Reports Series No. 108, UNEP, Athens, 1996 (270 pages) (anglais et français).

109. PNUE/OMS: Evaluation de l'enquête sur les polluants d'origine tellurique en Méditerranée. MAP Technical Reports Series No. 109, UNEP, Athens, 1996 (188 pages) (anglais et français).

110. PNUE/OMS: Evaluation de l'état de la pollution de la mer Méditerranée par les détergents anioniques. MAP Technical Reports Series No. 110, UNEP, Athens, 1996 (260 pages) (anglais et français).

111. PNUE/OMS: Lignes directrices pour le traitement des effluents avant leur rejet en mer Méditerranée. MAP Technical Reports Series No. 111, UNEP, Athens, 1996 (247 pages) (anglais seulement).

112. PNUE/OMS: Lignes directrices pour les émissaires des collectivités côtières de petite et moyenne taille en Méditerranée. MAP Technical Reports Series No 112, UNEP, Athens, 1996 (98 pages) (anglais et français).

Issued and printed by:

Mediterranean Action Plan
United Nations Environment Programme

Additional copies of this and other publications issued by the Mediterranean Action Plan of UNEP can be obtained from:

Coordinating Unit for the Mediterranean Action Plan
United Nations Environment Programme
Leoforos Vassileos Konstantinou, 48
P.O.Box 18019
11610 Athens
GREECE

Publié et imprimé par:

Plan d'action pour la Méditerranée
Programme des Nations Unies pour l'Environnement

Des exemplaires de ce document ainsi que d'autres publications du Plan d'action pour la Méditerranée du PNUE peuvent être obtenus de:

Unité de coordination du Plan d'action pour la Méditerranée
Programme des Nations Unies pour l'Environnement
Leoforos Vassileos Konstantinou, 48
B.P. 18019
11610 Athènes
GRECE