MEDITERRANEAN ACTION PLAN
MED POL

UNITED NATIONS ENVIRONMENT PROGRAMME

JELLYFISH BLOOMS IN THE MEDITERRANEAN

LES PROLIFERATIONS DE MEDUSES EN MEDITERRANEE

Proceedings of the II Workshop on Jellyfish
in the Mediterranean Sea
(Trieste, 2-5 September 1987)

Actes des IIèmes journées d'étude sur les méduses
en mer Méditerranée
(Trieste, 2-5 septembre 1987)

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

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

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

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

TABLE OF CONTENTS

LIST OF THE PAPERS PRESENTED

BIOLOGY AND INFLUENCE OF JELLYFISH ON THE PELAGIC ECOSYSTEM

BIOCHEMICAL, TOXICOLOGICAL AND SANITARY ASPECTS

GENERAL INTRODUCTION

The United Nations Environment Programme (UNEP) convened an Intergovernmental Meeting on the Protection of the Mediterranean (Barcelona), 28 January - 4 February 1975), which was attended by representatives of 16 States bordering on 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 and exchange of information and assessment of the state of pollution and of 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 interdependent 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.

MED POL - Phase I (1976-1980)

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

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

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

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

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

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

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

MED POL - Phase I was implemented in the period from 1975 to 1980. The large number of national research centres designated by their Governments to participate in MED POL (83 research centres) from 15 Mediterranean States and the EEC), the diversity of the programme and its geographic coverage, the impressive number of Mediterranean scientists and technicians (about 200) and the number of co-operating agencies and supporting organizations involved in it, qualifies MED POL as certainly one of

the largest and most complex co-operative scientific programmes with a specific and well-defined aim ever undertaken in the Mediterranean Basin.

MED POL - Phase II (1981-1990)

The Intergovernmental Review Meeting of Mediterranean Coastal States and First Meeting of the Contracting Parties to the Convention for the Protection of the Mediterranean Sea against Pollution, and its related protocols (Geneva, 5-10 February 1989), having examined the status of MED POL - Phase I, recommended that during the 1979/80 biennium a Long-term pollution monitoring and research programme should be formulated.

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

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

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

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

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

-information which could be used in formulating environmentally sound rational, 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.

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, 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 first eight volumes of the MAP Technical Reports Series present the collection of final reports of the principal Investigators who participated in the relevant pilot projects (MED POL I - MED POL VIII). The ninth volume of the MAP Technical Reports Series is the final report on the implementation of MED POL-Phase I, prepared, primarily, on the basis of individual final reports of the principal investigators with the co-operation of relevant United Nations Agencies (FAO, UNESCO, WHO, WMO, IAEA, IOC).

From the tenth volume onwards, the MAP Technical Report Series contains final reports on research projects, assessment documents, and other reports on activities performed within the framework of MED

POL-Phase II, as well as documentation originating from other components of the Mediterranean Action Plan.

The forty-seventh volume of the MAP Technical Reports Series contains the proceedings of the II Workshop on jellyfish in the Mediterranean Sea (Trieste, Italy, 2-5 September 1987) which was organized by the University of Trieste in co-operation with the MAP Co-ordinating Unit.

INTRODUCTION GENERALE

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

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

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

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

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

MED POL - Phase I (1976-1980)

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

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

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

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

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

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

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

La Phase I du MED POL a été mise en oeuvre au cours de la période 1975-1980. Le grand nombre de centres de recherche nationaux désignés par leurs gouvernements pour participer au MED POL (83 centres de recherche de 15 Etats méditerranéens et de la CEE), la diversité du programme et sa couverture géographique, l'effectif impressionnant de scientifiques et techniciens méditerranéens (environ 200) ainsi que la quantité d'organismes coopérants et d'organisations d'appui qui y étaient engagés permettent

sans conteste de caractériser le MED POL comme l'un des programmes de coopération scientifique les plus vastes et les plus complexes, comportant un objectif spécifique et bien défini, qui ait jamais été entrepris dans le bassin méditerranéen.

MED POL-Phase II (1981-1990)

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

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

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

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

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

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

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

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

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

Les huit premiers volumes de la Série des rapports techniques du PAM rassemblent les rapports finaux de chercheurs responsables qui ont participé aux projets pilotes correspondants (MED POL I - MED POL VIII). Le neuvième volume de cette même Série se compose du rapport final sur la mise en oeuvre

de la Phase I du programme MED POL, établi essentiellement sur la base des rapports finaux individuels des chercheurs responsables avec la coopération des organismes compétents des Nations Unies (FAO, UNESCO, OMS, OMM, AIEA, COI).

A partir du dixième volume, la Série des rapports techniques du PAM, comprends des rapports finaux sur les projets de "recherche", des documents d'évaluation et d'autres rapports d'activités effectués dans le cadre de MED POL-Phase II, ainsi que de la documentation prise dans d'autres domaines du Plan d'action pour la Méditerranée.

Le quarante-septième volume de la Série des rapports techniques comprend les actes des IIèmes Journées d'étude sur les méduses en mer Méditerranée (Trieste, Italie, 2-5 septembre 1987) qui ont été organisées par l'Université de Trieste en coopération avec l'Unité de coordination du PAM.

EXECUTIVE SUMMARY

At the Third Meeting of the Contracting Parties to the Barcelona Convention held in Dubrovnik (28 February - 4 March 1983), the problem of the occurrence of Jellyfish blooms in some areas of the Mediterranean was raised, and a request was formulated to UNEP for action in the framework of the MED POL - PHASE II Programme as part of the Mediterranean Action Plan (MAP).

In response to this request, a Workshop on Jellyfish blooms in the Mediterranean was organized by the MAP Co-ordinating Unit in Athens from 31 October to 4 November 1983, as part of the MED POL - PHASE II activities. Biological and environmental conditions related to the occurrence of jellyfish swarms were analyzed and their impact on human activities were reviewed and discussed.

As a follow-up to the Workshop, and after the matter was reviewed by the Second Meeting of the Working Group on Scientific and Technical Co-operation (UNEP/WG. 91/12), National Co-ordinators for MED POL were asked to initiate immediate action in the framework of national monitoring programmes, extending the monitoring activities to cover qualitative and quantitative observations of jellyfish. At the same time, the submission of research proposals in the framework of MED POL research activities was encouraged.

At the same time, an operational document for the implementation of a project on jellyfish at Mediterranean scale was prepared by a small expert Group convened in Athens from 6 to 7 February 1984 and the proposed programme was subsequently adopted by the Extraordinary Meeting of the Contracting Parties to the Barcelona Convention (UNEP/IG.49/Inf.5).

As a result, a number of activities were implemented from 1985 to 1987 either in the framework of the monitoring component or the research component of MED POL. In particular, thirty-two projects were carried out during the three-year period in France, Greece, Italy, Malta, Spain, Turkey and Yugoslavia. Two review meetings were also organized in cooperation with the University of Trieste to discuss the difficulties and the achievements of the programme. The meetings took place in Trieste, 27-29 January 1986 and 2-5 September 1987. In addition, a reference method for Sampling and Identification of common Mediterranean Scyphomedusae was prepared (UNEP Regional Seas Reference Methods No.51).

The present volume contains the Proceedings of the II Workshop on Jellyfish in the Mediterranean held in Trieste from 2 to 5 September 1987 which was organized by the University of Trieste in cooperation with the MAP Co-ordinating Unit. In addition to a review paper, which synthesizes the major findings of the programme, the volume presents all the papers which were presented at the Workshop, which in most cases represent the final reports of the work carried out by the Institutes participating in the Programme, and a number of papers by other scientists outside the Mediterranean who had been working on the same subject.

The species whose coastal aggregations caused most concern was *Pelagia noctiluca.* The MED POL Programme generated a significant volume of new information on the physiology, reproduction, development, behavioural responses, histology, biochemistry as well as the temporal and spatial distribution of this species in the field. Details of this new information are described in the individual papers of this volume.

Work was also carried out on the likely role of the capsule wall in the nematocyst discharge mechanism, as well as the subsequent dermatoxicological response both of humans as well as of experimental animals. Epidemiological studies have been conducted to identify the medical significance of jellyfish stinging.The monitoring activities gave results on the occurrence of different jellyfish species (*Aurelia aurita, Rhyzostoma pulmo, Cothyloriza tubercolata, Chrysaora quinquecirrha*, and on the following characteristics of *Pelagia* aggregations:

a)the big amplitude of the fluctuations in the number of individuals,

b)such fluctuations in populations of jellyfish have been shown to occur since at least 200 years ago,

c) the pattern is essentially that of abundance for several successive years, with little inter-year variations, followed by a period of absence or very low population densities,

d) the occurrence of aggregations usually extend over a wide geographical extent in the Mediterranean.

As a result of the present knowledge of the overall problematics related to the *Pelagia* blooms in the Mediterranean, the following hypotheses have been suggested regarding the causes leading to this phenomenon:

a) an increase in productivity, either due to natural fluctuations or to organic pollution, resulting in an increased food availability to the jellyfish,

b) changes in the number of predators/competitors of *Pelagia* leading to a decrease in the normal factors controlling its population density,

c) major displacement of water masses to explain the appearance of *Pelagia* in areas previously unrecorded,

d) major hydroclimatic changes affecting the factors normally controlling *Pelagia*'s population.

Though human activities such as overfishing and land-based pollution may help to sustain *Pelagia* blooms over longer periods of time, their occurrence is a natural phenomenon and, to date, no direct relationship between coastal aggregations of this species and pollution has been proved.

Regarding the recent occurrences of coastal aggregations on *Pelagia noctiluca,* while they were first recorded in 1977, they reached maximum intensity and the largest geographical extent in the 1980-1983 period. Since then, a significant decrease in numbers was recorded in the Greek and Central Mediterranean coastal waters, while large numbers for 1985 were only being reported in the Adriatic region. *Pelagia noctiluca* is essentially an offshore species and coastal swarms have been in some cases interpreted as passive aggregations of moribund individuals at the end of their biological cycle, driven into coastal waters under the action of water movements, while active aggregations may be more frequently found in offshore areas. The vertical distribution/migration of such species is at present not fully understood and the possibility that the occurrence of such species is being determined by movements of intermediate waters has been suggested. The present data and information is as yet unsufficient to explain the apparent disappearance of *Pelagia* during the non-swarming periods. It has been proved that in the Mediterranean *Pelagia noctiluca* reproduces all the year round. Temperature has been identified as a major environmental factor affecting the population densities of the species. The time series population densities of both adults and ephyrae varies with geographical locality. Above 2.5 cm in rhopallial diameter, the size is not related either to age or to reproductive maturity.

It has been proved that temperature greatly affects several physiological processes. During the summer months it is expected that the increased metabolic rates and production of wastes would be high so that due to the large population densities, the impact of such swarms on the pelagic ecosystem could be significant. Considering the relatively high energy content of the species, it must represent a significant energy source for likely predators.

From the data resulting from this project, there are indications that the phenomenon does not really represent a serious health hazard since only few cases of stinging led to severe medical complications, although the problem of sensitization (due to repeated stinging) has not been significantly investigated. However, the mass occurrence of jellyfish may disrupt recreational activities as holidaymakers may be averse to bath in the sea for fear of being stung. The most significant impact is now thought to be on the general pelagic ecosystem. Physiological data on *Pelagia noctiluca* indicate that the presence of enormous numbers of this species might exert a significant impact on the nutrient regeneration mechanisms of the ecosystem and on the other members of the pelagic community. These may well lead to important implications on the marine food resources and the natural stability of such pelagic ecosystem.

RESUME

Lors de la Troisième réunion des Parties contractantes à la Convention de Barcelone qui s'est tenue à Dubrovnik (28 février-4 mars 1983), le problème de l'apparition des proliférations anormales de méduses dans certaines zones de la Méditerranée a été soulevé, et il a été demandé au PNUE d'entreprendre une action dans le cadre du programme MED POL - Phase II s'inscrivant dans le Plan d'action pour la Méditerranée (PAM).

En conséquence, l'Unité de coordination du PAM a organisé à Athènes, du 31 octobre au 4 novembre 1983, des Journées d'étude sur les proliférations anormales de méduses en Méditerranée, dans le cadre des activités de MED POL - Phase II. Les conditions biologiques et environnementales liées à l'apparition des essaims de méduses ont été analysées et leurs incidences sur les activités humaines ont été examinées et discutées.

Suite aux Journées d'études et après examen de la question par la deuxième réunion du Groupe de travail sur la coopération scientifique et technique (UNEP/WG.91/12), les Coordonnateurs nationaux du MED POL ont été invités à amorcer sans délai une action dans le cadre des programmes nationaux de surveillance continue en étendant les activités de surveillance de manière à y englober les observations qualitatives et quantitatives de méduses. Dans le même temps, la soumission de propositions de recherche dans le cadre des activités de recherche du MED POL était encouragée.

Parallèlement, un document opérationnel pour la mise en oeuvre d'un projet relatif aux méduses à l'échelle de la Méditerranée a été établi par un Groupe restreint d'experts qui s'est réuni à Athènes les 6 et 7 février 1984 et le programme proposé a été ensuite adopté par la réunion extraordinaire des Parties contractantes à la Convention de Barcelone (UNEP/IG.49/Inf. 5).

En conséquence, un certain nombre d'activités ont été menées de 1985 à 1987 dans le cadre soit de la composante "surveillance continue" soit de la composante "recherche" du MED POL. Plus concrètement, au cours de ces trois années, trente-deux projets ont été exécutés dans les pays suivants: Espagne, France, Grèce, Italie, Malte, Turquie et Yougoslavie. Deux réunions ont également été organisées en coopération avec l'Université de Trieste afin d'examiner les difficultés et les résultats du programme. Ces réunions ont eu lieu à Trieste les 27-29 janvier 1986 et 2-5 septembre 1987. En outre, une méthode de référence pour l'échantillonnage et l'identification des scyphoméduses méditerranéennes communes a été mise au point (N 51 de méthodes de référence des mers régionales du PNUE).

Le présent volume contient les actes des IIèmes Journées d'étude sur les méduses en Méditerranée qui se sont tenues à Trieste du 2 au 5 septembre 1987 et étaient organisées par l'Université de Trieste en coopération avec l'Unité de coordination du PAM. En plus d'une communication de synthèse qui récapitule les principaux résultats du programme, ce volume offre toutes les communications présentées lors des Journées d'étude et qui, dans la plupart des cas, constituent les rapports finaux des travaux menés par les instituts participant au programme, ainsi que plusieurs communications faites par d'autres scientifiques ayant travaillé en dehors de la Méditerranée sur le même sujet.

L'espèce dont les pullulations côtières ont le plus préoccupé était *Pelagia noctiluca*. Le programme MED POL a permis d'obtenir une masse importante de nouvelles données sur la physiologie, la reproduction, le développement, les réactions comportementales, l'histologie, la biochimie ainsi que sur la distribution dans le temps et l'espace de cette espèce *in situ*. Ces nouvelles données sont exposées en détail dans diverses communications du présent volume.

Des travaux ont également été menés sur le rôle probable de la paroi capsulaire dans le mécanisme d'émission par les nématocystes de même que sur la réaction toxique cutanée que celle-ci provoque tant chez l'homme qu'en expérimentation animale. Des études épidémiologiques ont été réalisées pour préciser l'importance médicale des piqûres de méduse.

Les activités de surveillance continue ont fourni des résultats sur l'apparition des diverses espèces de méduse (*Aurelia aurita, Rhyzostoma pulmo, Cothyloriza tuberculata, Chrysaora quinquecirrha*) et sur les caractères suivants des pullulations de Pelagia:

a)la grande amplitude de fluctuation dans le nombre d'individus;

b)la démonstration que de telles fluctuations se produisent depuis 200 ans au moins;

c)le profil évolutif qui présente essentiellement une prolifération abondante sur plusieurs années successives, avec de légères variations entre les années, suivie d'une période de disparition ou de densités de population très faibles;

d)l'apparition de pullulations s'étendant généralement sur une vaste zone géographique en Méditerranée.

En se fondant sur les connaissances actuelles concernant l'ensemble des problèmes liés aux blooms de méduses en Méditerranée, les hypothèses suivantes ont été avancées quant aux causes du phénomène:

a)une augmentation de productivité due soit à des fluctuations naturelles soit à une pollution organique provoquant une augmentation de la nourriture disponible pour les méduses;

b)des changements dans le rapport prédateurs/concurrents de *Pelagia* entraînant une diminution des facteurs limitant la densité des populations;

c)un déplacement important de masses d'eau expliquant l'apparition de *Pelagia* dans des zones où cette espèce n'était pas relevée auparavant;

d)d'importants changements hydroclimatiques retentissant sur les facteurs qui régissent normalement les populations de *Pelagia*.

Bien que des activités humaines telles que la surpêche et la pollution d'origine tellurique puissent contribuer à entretenir les blooms de *Pelagia* sur des périodes prolongées, la survenue de ces blooms est un phénomène naturel et, jusqu'à ce jour, il n'a pas été possible d'établir une relation entre les proliférations côtières de cette espèce et la pollution.

En ce qui concerne les apparitions récentes de pullulations de *Pelagia noctiluca*, bien qu'elles aient été pour la première fois relevées en 1977, elles ont atteint une intensité maximale sur la plus vaste étendue géographique au cours de la période 1980-1983. Depuis lors, une réduction importante du nombre d'individus a été enregistrée dans les eaux littorales de la Grèce et de la Méditerranée centrale, alors que pour 1985 il n'était fait état d'effectifs importants que dans la seule région de l'Adriatique. *Pelagia noctiluca* est essentiellement une espèce du large et les essaims côtiers ont été, dans certains cas, interprétés comme des proliférations passives d'individus moribonds à la fin de leur cycle biologique, amenés dans les eaux littorales sous l'effet des mouvements d'eau, alors que les proliférations actives se rencontreraient plus fréquemment dans les zones du large. La distribution/migration verticale de telles espèces n'est pas encore totalement comprise et il a été suggéré qu'il se pouvait que l'apparition de ces espèces soit déterminée par les mouvements des eaux intermédiaires. Les données et renseignements actuels sont encore insuffisants pour expliquer la disparition apparente de *Pelagia noctiluca* au cours des périodes sans essaims. Il a été prouvé que, en Méditerranée, *Pelagia noctiluca* se reproduit tout au long de l'année. La température s'est avérée être un facteur environnemental important influant sur les densités de population de l'espèce. Les séries chronologiques des densités de population tant pour les adultes que pour les éphyres varient selon la situation géographique. Au-dessus d'un diamètre rhopallial de 2,5 cm, la taille n'a aucun rapport avec l'âge ni avec la maturité reproductive.

Il a été démontré que la température influe grandement sur plusieurs processus physiologiques. On estime que, au cours des mois d'été, l'augmentation de la vitesse du métabolisme et de la production de déchets est si élevée que, en raison des importantes densités de population, l'impact de tels essaims sur

l'écosystème pélagique pourrait être marqué. Vu la teneur énergétique relativement élevée de l'espèce, celle-ci doit représenter une source d'énergie importante pour les prédateurs éventuels.

Il ressort des données fournies par ce projet que le phénomène ne constitue par vraiment un risque grave pour la santé puisque seuls quelques cas de piqûre ont entraîné des complications médicales sérieuses, encore que le problème de la sensibilisation (par piqûres répétées) n'ait pas fait l'objet d'investigations poussées. Cependant, l'apparition massive de méduses peut perturber les activités récréatives puisque les vacanciers peuvent renoncer à se baigner par crainte d'être piqués. On pense actuellement que l'impact le plus important s'exerce sur l'ensemble de l'écosystème pélagique. Les données physiologiques concernant *Pelagia noctiluca* indiquent que la présence d'effectifs énormes de cette espèce peuvent avoir un impact notable sur les mécanismes de renouvellement des éléments nutritifs de l'écosystème et sur les autres membres de la communauté pélagique. Ces incidences pourraient fort bien entraîner des répercussions graves sur les ressources en produits de la mer et sur la stabilité naturelle d'un tel écosystème pélagique.

JELLYFISH BLOOMS IN THE MEDITERRANEAN: CAUSES, MECHANISMS, IMPACT ON MAN AND THE ENVIRONMENT. A PROGRAMME REVIEW

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1. INTRODUCTION

1.1. Man and the epipelagic zone

The epipelagic zone is a 'tenuous membrane covering the world ocean' which is of paramount importance both to marine life as well as to man himself. Unfortunately, our knowledge of this zone especially with regard to the gelatinous zooplankton remains rudimentary. We are unable to understand and predict with any certainty the occurrence of apparently perfectly normal massive blooms of certain noxious species which may constitute a health hazard and which may exert an impact on fishing, tourism and recreation. This is because in no other major type of habitat may we find the degree of complexity in the way that a biological community interacts with its physico-chemical environment, as we find in this zone.

A case in point is the recent occurrence of a massive 'bloom period' of the schyphomedusa *Pelagia noctiluca* in various areas of the Mediterranean. This phenomenon was first reported in the Adriatic in 1977; during its peak (1981-1983) it involved extensive areas of coastal waters throughout the Northwestern, Central and Northeastern Mediterranean. It caused widespread public concern which rapidly led to the mobilisation of several scientific institutes which participated in a regional programme of research and monitoring of jellyfish blooks (the MED POL jellyfish Programme) under the coordination and with the financial support of the UNEP/MAP Programme. It generated a massive volume of new information on the biology of jellyfish in general and on *Pelagia* in particular as well as on the related clinical and epidemiological aspects. It declined in intensity after 1984 and practically disappeared by 1986, leaving behind in its wake a number of hypothesis which attempt to explain it and which still need to be tested by further field data and observations.

The aim of this paper is to summarize this new body of knowledge, review the various hypothesis which were put forward to explain the occurrence of this *Pelagia* bloom period and assess the likely impact which it exerted on man and on the regional pelagic ecosystem in general.

The various methodologies of monitoring of coastal and off-shore aggregations of jellyfish used throughout this programme were reviewed in a previous paper (Axiak and Civili, 1986), which also presented a preliminary review of the whole programme, and were later revised and presented in a document (UNEP/IAEA, 1988). The programme participants included researchers embracing the broadest possible diversity of groups and approaches: ecologists, systematists, workers on zooplankton and fish, physiologists, physical oceanographers and epidemiologists.

1.2. The phenomena of aggregations and blooms in gelatinous zooplankton

Two dominant features of the recent *Pelagia* phenomenon is that of: (a) apparently irregular massive fluctuations in population densities over time so as to include periods of blooms alternating with periods of apparently total absence over a wide geographical area; (b) a highly heterogenous distribution in space so as to often form discrete patches of high density aggregations. Several epigelagic investigations indi-

cate that both these characteristics are relatively common attributes to several planktonic forms (Omori and Hamner, 1982; Boero, 1987).

Spectacular monospecific blooms are evident in phytoplankton and gelatinous zooplankton such as siphonophores, salpes and appendicularia and represent a normal aspect of behaviour of pelagic ecosystems (Goy, 1987). Besides the well documented seasonal changes in the species composition of planktonic communities, long-term fluctuations are also evident such as those described for the Ligurian Sea by Balestra *et al.*, (1976). Such changes include restricted periods of 'population explosions' alternating with periods of absence or rarity. This long-term phenomenon is rather difficult to interpret from data and observations obtained by various authors over different periods of time and often utilizing different sampling methodologies. Gelatinous zooplankton in particular, because of their delicate constitution and patchy distribution, may not be adequately sampled solely by the classical plankton net hauls (Hamner *et al.*, 1975) and an accurate estimate of their abundance is very difficult to obtain. Moreover, these animals are often difficult to maintain in a laboratory over any significant period of time in order to investigate their basic biology under controlled conditions. Therefore very little information is actually available on the role which their physiological and reproductive responses play in the mechanisms of their blooms.

The temporal and spatial attributes of zooplankton aggregations as well as their adaptive significance have been discussed by Omori and Hamner (1982). Aggregations may arise from responses to temperature and salinity gradients or discontinuities, wave motion, light intensity or food availability as well as from complex social behaviour. When an aggregation is maintained by active swimming resulting from interspecific behavioural responses it is referred to as a "swarm". Very often a species may be found in a highly aggregated phase at one time and then in a dispersed phase at another time. Moreover, some species form intense aggregations only during specific times of day or season. The role of the species in the epipelagic community will be different between the aggregated and dispersed phases. Different degrees of size segregation may be present in these aggregations and this may be relevant to identify their likely biological role. In some scyphomedusae (e.g. *Mastigias* sp.) size segregation results from different mobilities of medusae of different sizes coupled with swimming interference.

Aggregations are bound to have some adaptive value. Animals may aggregate for reproductive purposes, to facilitate feeding or as protection against predators. The biological significance of the overall strategy of blooming is more difficult to interpret though several theoretical considerations have been put forward. In a 'stable' environment such as the open ocean epipelagic zone, speciation cannot take place if their is no isolating mechanism to prevent gene flow between different populations. It has been suggested that the alternation of periods of rarity and abundance in a species is of evolutionary significance (Boero, 1987). In between the bloom periods when the individuals are presumably found in small and isolated populations, mutations will occur more frequently. During the bloom periods, when previously isolated populations will merge over a wide geographical extent, latent favourable mutations may then become available to a wider gene pool thus leading to a gradual evolution of the species.

The biotic and abiotic components of an ecosystem interact in a complex manner so as to set up a state of equilibrium during which maximum use is made by the living forms of the energy and material made available by the physical environment. Within the biotic component itself, there exist an internal equilibrium as expressed by complex interactions between the various trophic levels. Changes in the physical environment are therefore bound to be reflected by changes in the trophic interactions and on the community species structure. For example, the blooms of *Pelagia* may indicate a shift in the trophic interactions within the epipelagic community so as to favour the carnivorous gelatinous zooplankton. In this way, blooms may be viewed as a highly visible response of the biological component of the epipelagic ecosystem to long-term fluctuations in the physico-chemical environment.

2. BLOOMS OF PELAGIA NOCTILUCA IN THE MEDITERRANEAN

P. noctiluca (Semaeostomeae, Pelagiidae) was first described by Forskal in 1775 as *Medusa noctiluca*. Unlike meroplanktonic medusae (anthomedusae and leptomedusae) which are usually restricted to shallow waters because of their dependence on a hard substrate on which their benthic life stages may settle, holoplanktonic medusae like *P. noctiluca*, may complete their life cycle in open waters because of the absence of a benthic stage. *P. noctiluca* is in fact normally described as an oceanic species and it is widely distributed in all warm and temperate waters (Russell, 1970). Its umbrella and four oral arms are covered with brightly coloured warts each of which consists of thousands of nematocysts and may inflict powerful stings to man.

As a direct result of the MEDPOL Jellyfish programme of research and monitoring, the major attributes of the occurrence of this species in the Mediterranean have now been identified and will be discussed below.

2.1. Time-dependent attributes

2.1.1 Phases of occurrence

There are two major phases of occurrence of *P. noctiluca* in the Mediterranean and possibly elsewhere: periods of enormous abundance in offshore and coastal waters alternating with periods of rarity or absence. This fact has been established by Goy (1984a) who after an extensive bibliographic study showed that this phenomenon dates back at least since the end of the eighteenth century. This in itself presented and still presents a problem for the scientific studies of this species due to the fortuitous availability of specimens. It also rules out the possibility of a direct anthropogenic cause for such blooms though environmental changes due to man's activities may, at least theoretically, affect this 'normal' cycle of occurrences.

2.1.2 Frequency

The periodicity of occurrence of the bloom period appears to differ greatly with region within the Mediterranean. In the Western Mediterranean, or at least in the Ligurian Sea, there appears to be a rough periodicity of 12 years (Morand and Dallot, 1985). Bloom periods appear to be much less frequent in the Adriatic during the present century where they were reported during 1907-1914 and then not until 1977 (Vucetic, 1983). On the other hand, no aggregations of *Pelagia* were reported along the Lebanese and Turkish shores.

2.1.3 Duration of bloom periods

The phenomenon has not been studied over a sufficiently long period of time to enable us to reach definite conclusions in this regard. Nonetheless, the present data indicates that: (a) the bloom period as recorded in the Ligurian coastal waters may vary from two to six years with a mean duration of approximately four years during the present century; (b) the bloom period appears to be more extended in the Adriatic, with the more recent period being approximately 9 years.

2.1.4 Amplitude

Most of the quantitative data which is available on the population densities of *P. noctiluca* comes from coastal waters. During the bloom period, enormous numbers of *Pelagia* individuals were concentrated in coastal waters and left stranded on the shores along the Ligurian Sea, Central Mediterranean, the Adriatic and parts of the Aegean Sea. In between the bloom periods, *Pelagia* appears to be absent from the Adriatic and rare in the Western Mediterranean off-shore waters. In the latter case, there is insufficient data to decide whether in between the bloom periods there is no *Pelagia* in off-shore waters or whether it may persist in a dispersed phase in some particular autochthonous zone as has been suggested by Vucetic (1983).

2.1.5 Time-dependent features of recent bloom period

For the sake of convenience the bloom period is here divided into three phases: the initial phase, the peak phase and the phase of decline. For the recent blook period of *Pelagia* in the Mediterranean, the initial phase was first recorded at different times in the different regions. Thus the first reports of *Pelagia* aggregations in coastal waters come from the North Adriatic in 1977 (Rottini-Sandrini *et al.*, 1980) though ephyrae were already recorded off-shore in 1976 (Benovic and Blender, 1987), these being absent from plankton samples taken in 1974 and 1975. On the other hand, coastal aggregations were first observed in

1980 in Maltese waters (Central Mediterranean; Axiak, 1983a) and as late as 1982 in the Ligurian Sea (Goy, 1984b).

The occurrence of the peak phase appears to be more synchronized over the whole geographical region affected. Thus, maximum densities of coastal and off-shore aggregations of *P. noctiluca* from the Ligurian, Central Mediterranean, Adriatic and Aegean Seas were recorded in 1982/1983 (Axiak and Civili, 1986). A steady decline in numbers has been registered since then. Bernard (1987) reported a decrease in *Pelagia* individuals stranded along the French Mediterranean coastline from 1984 to 1986, so that by the summer of 1986 there were practically no jellyfish reports. The same observations apply to the Central Mediterranean (Axiak *et al.*, 1987). In the Adriatic the onset of the decline phase was well evident from off-shore samples from March to July of 1983 (Piccinetti Manfrin and Piccinetti, 1986). Coastal aggregations were still reported by February 1986 for the North Adriatic (Zavodnik, 1987a), by September 1986 for the South Adriatic (Scalera Liaci, 1987) and by autumn 1985 in Greek waters (Papathanassiou, *et al.* 1987).

One interesting feature which emerges from the data collected so far is that pronounced seasonal fluctuations in the populations of *Pelagia* were evident both during the initial and declining phases of the bloom period so that coastal aggregations were more evident during the March-June period. On the other hand, during the peak phase, though coastal aggregations were more frequently recorded during the summer and autumn months, *Pelagia* adults could be detected throughout the whole year. For example, during 1981/1983 (peak phase) the presence of *Pelagia* in the coastal waters off Villefranche did not change significantly though the seasonal fluctuations in seawater temperatures ranging from 13° to 26°C (Goy, 1984a).

2.2 Space-dependent attributes

2.2.1 Geographical extent

Figure 1 indicates the wide geographical extent over which coastal aggregations of *P. noctiluca* were reported in the Mediterranean during its most recent bloom period. This figure shows the location of stations at which *Pelagia* aggregations were reported from 1980 till 1986. There appears to be remarkably defined boundaries both on the North Western Mediterranean and on the Eastern Mediterranean beyond which little or no coastal aggregations of this jellyfish were reported even during the peak phase. On the western side, Bernard (1987) reported that while this species was very common in the coastal waters along Provence, the Alpes and the Côte d'Azure, during 1984 and 1985, this occurrence diminished progressively from Monaco towards Marseille, and suggests that such medusae were being transported into the area with the Ligurian current coming from the East. On the Eastern side of the Mediterranean *Pelagia* was reported to be absent from coastal waters, at least between the Bay of Mersin, Turkey (Bingel *et al.*, 1987) and the Lebanese coastline (Lakkis, 1987).

2.2.2 Dimensions and distributions

Aggregations of *P. noctiluca* were reported to occur both offshore and in coastal waters. In offshore aggregations the reported densities varied, with individuals being usually 5 to 10m appart, and sometimes 1m or less appart at the centre of an aggregation (Zavodnik, 1987a). Individuals were mostly abundant in the upper 20- to 30-m layer at least during the daytime (Zavodnik, 1987b).

Reports from the North Adriatic indicate that some aggregations were formed by actively swimming individuals generally at subsurface levels (Malej, 1986). Such aggregations had a variable shape, most frequently ellipsoidal and were up to 15m deep and several km long. No definite size segregations were ever observed in such aggregations. Reports from the same region (Malej, 1986) as well as from the Central Mediterranean (Axiak, 1984b) indicate that other surface aggregations could also be passively maintained by surface currents and generally took the shape of long patches and wind rows. Larson (unpublished report) reports belt-like patches of this species in the Northwestern Atlantic, which were parallel to the direction of the wind and 'apparently in Langmuir cells'. After extensive field observations by scuba divers, Zavodnik (1987b) concludes that most of the aggregations he studied in the Adriatic were passively maintained by water movements. However, he reported several cases of active moving of individuals to form couples and in one case a mid-layer cluster was formed of several hundred medusae interlaced by their manubria and tentacles and pulsating normally.

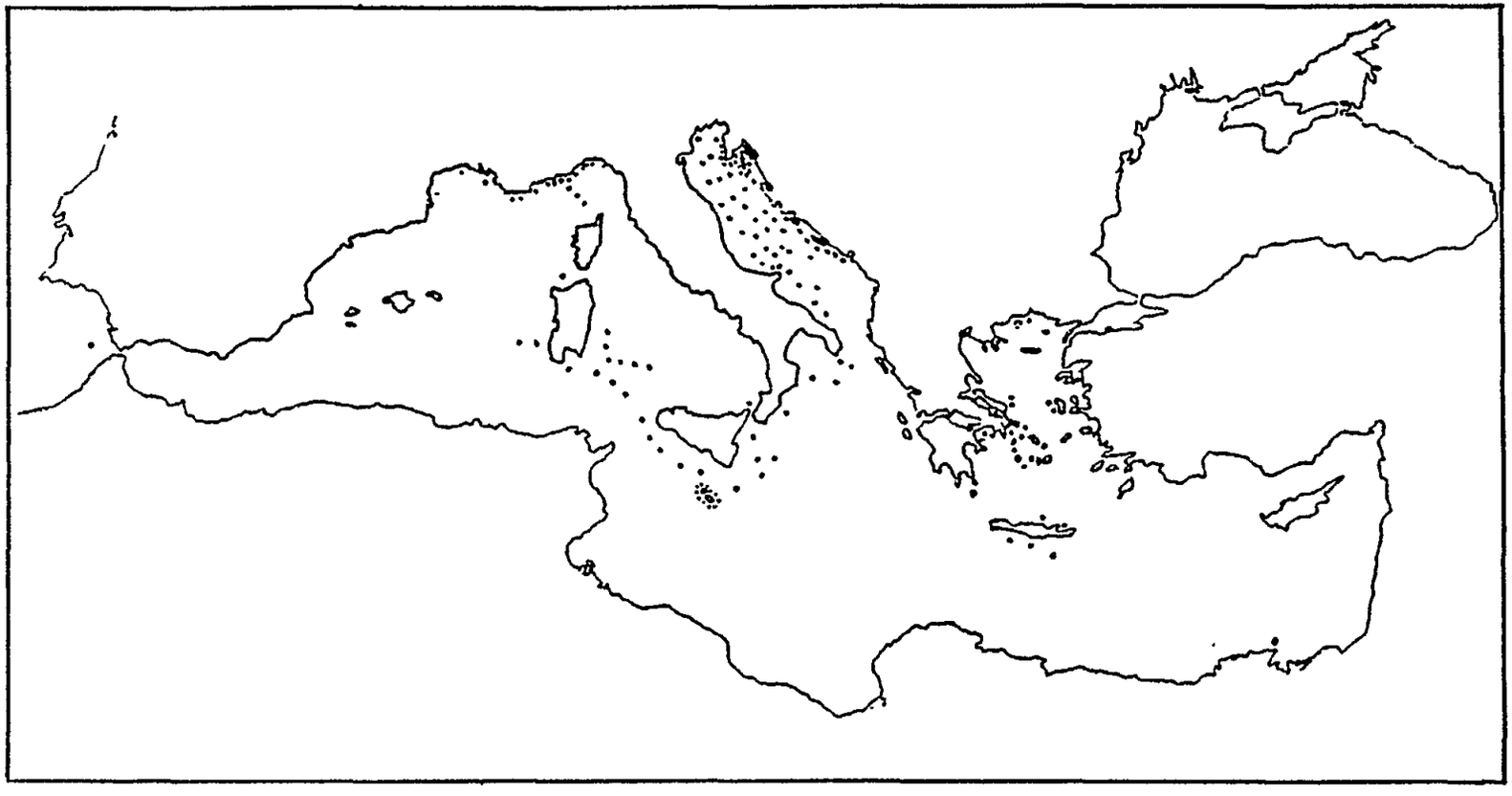

Fig. 1. Geographical distribution of reports od sightings of major aggregations of *Pelagia noctiluca* in the Mediterranean from 1980 to 1986

2.2.3 Factors affecting distribution of aggregations

The distribution of *Pelagia* in the Mediterranean during the recent 'bloom period' appears to have been determined by the hydrological and, possibly, the natural trophic characteristics of the particular area. For example, in the Ligurian Sea, this was found to be correlated with natural eutrophic conditions so that relatively large numbers were found to be concentrated on both sides of the Liguro-Provincial Front (Goy, 1986). The same author reported that in a previous 'bloom period' of *Pelagia* in 1910, aggregations appeared more frequently in zones of divergence as indicated by the THOR expedition. The recent occurrence of *Pelagia* in the Adriatic has been tentiatively correlated with a general increase in the primary and secondary productivity of offshore waters in the area from the early 1970's to the present. This increase as measured by chlorophyll content, phytoplankton and zooplankton biomass as well as water transparency has been reported by several authors including Pucher-Petkovic and Marasovic (1979,1981), Vucetic (1980) and Malej (1987b).

Trends of increasing eutrophication in the Central Adriatic may be at least partly attributed to land-based sources of enrichment. On the other hand, no direct correlation was observed between localized eutrophic conditions resulting directly from land-based pollution and the occurrence of coastal aggregations of *Pelagia*. No *Pelagia* were found in Elefsis Bay which has a major sewage outfall (Papathanassiou *et al.*, 1985; Papathanassiou and Anagnostaki, 1984), while *Aurelia aurita* did accumulate in this area presumably because of the eutrophic conditions present. As to the Adriatic, though *Pelagia* was present almost everywhere, it was never reported in front of the Po delta and very few specimens were found in the coastal waters of Emilia-Romagna (Rottini-Sandrini, 1987), both zones being particularly affected by land-based pollution. Likewise, Piccinetti-Manfrin and Piccinetti (1984) could find no correlation between the presence of *Pelagia* aggregations and coastal pollution during three sampling cruises in the summer of 1983, which covered the Adriatic, Central Mediterranean and parts of the Western and Eastern Mediterranean.

Therefore, the occurrence of *Pelagia* aggregations was never found to be directly correlated with localized land-based pollution. However any enrichment in nutrients whether by natural means or as a result of man's activities may lead to localized increased productivity and this in turn may be expected to support the increased numbers of *Pelagia*.

Physico-chemical parameters may be expected to influence the occurrence and stability of surface aggregations of *Pelagia*. Reports from the Aegean Sea suggest that surface aggregations were more frequently reported during the daytime (Papathanassiou, *et al.* 1987) while those from around the Maltese Islands suggest otherwise (Axiak, 1984b). Larson (unpublished report) also states that *Pelagia* were reported to be more abundant at the surface layers during the night in the Northwestern Atlantic.

It has been suggested that temperature may play a dominant influence on the stability and persistence of an aggregation which is maintained by the active movements of an aggregation which is maintained by the active movements of its individuals (Legovic and Rottini-Sandrini, 1986). Rottini-Sandrini (1987) in fact states that aggregations in the Gulf of Trieste were normally formed when the seawater temperature ranged from 16° to 20°C. Papathanassiou *et al.* (1987) indicated that coastal aggregations in Greek waters were more often associated with seawater temperatures ranging from 20° to 25°C, and were rarely seen at temperatures above 25°C. On the other hand, Zavodnik (1987b) concludes from his observations carried out in the North Adriatic that the local occurrence of aggregations and their depth distributions were correlated neither with temperature nor with salinity or zooplankton standing crop.

It is obviously difficult to try and correlate environmental parameters directly with blooms of *Pelagia*. Fluctuations in such parameters are expected to bring about changes in the whole of the planktonic community and not just the gelatinous macrozooplankton. Blooms of specific species would represent just one facet of the overall planktonic community response. Ultimately our aim is to know enough about the mechanics of interactions between the whole planktonic community and the physico-chemical environment and as a result to be able to understand the mechanics of such blooms and possibly predict their occurrence.

2.3 Adaptive value of Pelagia aggregations

As indicated in section 1.2, it is expected that biological aggregations must have some kind of adaptive value. In the case of *Pelagia*, Malej (1986) has suggested that aggregations serve to increase the concentration of gametes after their release in the surrounding medium and thus to maximize reproductive success.

Zavodnik's observations of *Pelagia* clustered in pairs or larger numbers may be significant in this respect. Rottini-Sandrini (1987) has suggested that reproduction occurs inside aggregations which are actively maintained by the swimming of the individual medusae. Such active aggregations or swarms can withstand to some extent the dispersive force of water movements. It was suggested (Malej, 1986) that under the influence of several factors including high temperatures (which have been proved to limit the mobility of this species in the laboratory), lack of food and completion of the reproductive cycle, such active swarms will disintegrate into passive aggregations which are maintained only by surface currents. Unfortunately, this idea has not yet been fully confirmed by field observations from other regions within the Mediterranean.

Swarming may be of protective adaptation in some planktonic species (e.g. *Labidocer pavo*) and in such cases swarms tighten up when distributed (Omori and Hamner, 1982). For the case of *Pelagia*, Malej (1987a, b) reports that when distributed, passive aggregations react only to a slight extent with some individuals increasing their rates of pulsation briefly, while in active aggregations individuals swim away from the source of disturbance but in an uncoordinated manner. Such observations suggest that the adaptive value of aggregations in *Pelagia* is more likely to be reproductive than anything else.

The possible long-term evolutionary significance of the occurrence of blooms in the gelatinous zooplankton has already been referred to in section 1.2. It has been suggested that beneficial mutations which have been acquired by isolated small populations may diffuse over a wide region when such small populations merge into one another during a bloom period. Such theoretical considerations have yet to be proved by experimental data, which is at present lacking both for *Pelagia* and for other species which behave in the same manner.

3. GENERAL BIOLOGY OF PELAGIA NOCTILUCA

Much of what has been known about the biology of *P. noctiluca* prior to 1983 has been reviewed by Vucetic (UNEP, 1985). Since then, the MEDPOL Jellyfish programme has generated an enormous amount of new information on this species and this section will review the more salient points.

3.1 Reproduction and life cycle

Much of the new available information comes from studies carried out in the Adriatic where a number of investigations have shown that in the Central and Northern parts all the developing stages of this species may be present throughout the whole year, at least during the peak phase of the bloom period (Rottini-Sandrini *et al.*, 1981; Piccinetti, *et al.*, 1986; Piccinetti-Manfrin and Piccinetti, 1984).

Histological studies indicated that oocytes in all the various stages of maturity may be present within the gonads of *Pelagia* throughout the year. However, reproductive effort was found to reach a maximum during autumn and a minimum during the summer months (Avian *et al.*, 1987a). The authors have suggested that temperature as well as food availability and calorific value of food greatly influence the reproductive effort of this species.

From studies of size frequency distributions of specimens collected from the region during 1983, Piccinetti *et al.*, 1986, suggested that reproduction reached maximum intensity during winter with subsequent growth rates being highly dependent on temperature and generally in agreement with growth rates of ephyrae as measured in the laboratory. In the latter case, the growth rate of ephyrae at 19°C was found to be twice that occurring at 13.5°C (Avian, 1986a). Piccinetti *et al.*, (1986) also suggested heavy mortalities of *Pelagia* so that as much as 99% of those individuals born before March died by December of 1983. The extent to which the transport of *Pelagia* in and out of the Adriatic region may influence such conclusions is as yet to be determined.

The various features of the life cycle and population dynamics of *Pelagia* may be modified according to the environmental conditions prevalent in the different Mediterranean regions. Present data suggest that this species may have two generations per year both in the Adriatic and the Western Mediterranean though growth rates, maximum adult size as well as minimum size for maturation may differ so as to be higher in the Western Mediterranean. Estimates carried out by Morand *et al.* (1987), based on the daily nitrogen requirements of *Pelagia* as measured in the laboratory and the availability of natural prey in the Ligurian Sea, showed that in such regions populations of this species should be well fed and may show rapid growth rates.

Ultimately, the possible existence of a benthic stage as yet undetected for this scyphomedusa has been raised during discussions at several international meetings. The existence of a resting stage in 'holoplanktonic' forms is only a guess for many species, but it has been demonstrated for others, e.g. *Margelopsis baeckeli* in the North Sea. It has been pointed out by Boero (1987) that it is very hard to explain the 'sudden' blooms of *Pelagia* across a wide zone only in terms of sexual reproduction of a few and scattered specimens. It is obvious that much more is still to be discovered as regards the ways in which the lifecycle and reproduction of Pelagia are modified by the complex interactions with the physico-chemical environment.

3.2 Feeding and predation

Studies of the stomach contents of *Pelagia* have revealed its opportunistic mode of feeding, with diet being mostly determined by the planktonic composition prevalent in the area. This diet includes hydromedusae, siphonophora, young stages of gastropods, bivalvia and crustacea, chaetognaths, appendicularia, thaliacia and fish eggs and larvae. This non-selective mode of feeding renders this species less dependent on the seasonal fluctuations in the plankton community structure. Zavodnik (1987c) and Giorgi *et al.*, (1987) could detect no difference in the diet of different size classes of *Pelagia*. The latter authors also studied the roles played by the oral arms and manubrium in the feeding behaviour of *Pelagia*. Morand *et al.*, (1987) performed feeding experiments on small laboratory-reared individuals and showed specific daily rations of 13 and 35% at 5 and 20 Artemia prey per 1 respectively. They concluded that this species can have a strong predatory impact in the Ligurian Sea especially during the summer and early autumn.

Chemical analysis carried out by Malej (1985) indicate that the mean dry weight of *Pelagia* amounted to approximately 7% of the total weight. The protein content ranged from 10.9 to 19.8% of dry weight, while the mean lipid and carbohydrate contents were 2% and less than 1% respectively (Malej, 1987a). The calorific value was calculated to be 3.1 to 4.1 J/mg dry weight indicating that the high abundance and considerable dry weight render *Pelagia* a considerable energy source for possible predators.

It has been suggested during discussions at UNEP Workshops that fish may be important predators of *Pelagia* (UNEP, 1985). Several species of fish have been actually observed to feed on this species (e.g. mackerel, horse mackerel and bogue). There are also reports that sea turtles and even dolphins may be occasional predators of *Pelagia*. However, according to Zavodnik (1987c) only about 0.3% of individuals collected from coastal aggregations showed signs of predatory damage to the manubrium. Moreover lipid analysis of *Pelagia* and *Boops boops* do not substantiate the suggestion of a predatory relationship (Mastronicolis *et al.*, 1987).

3.3 Metabolic activities

The rates of several physiological activities as related to size of medusae and temperature have been worked out by Malej and Vukovic (1986); Malej (1987) and Morand *et al.* (1987). These investigations showed the overriding influence of ambient temperature on rates of oxygen consumption and excretion, with estimated Q_{10} values ranging from 2.6 to 3.8. Investigations on the carbon and oxygen isotopic compositions of the body water of *Pelagia*, carried out by D'Angela *et al.* (1985) as quoted by Rottini-Sandrini (1987) also provided that the metabolic activities of this species are more dependent on temperature than on size.

Estimates based on the rates of several physiological processes as measured in the laboratory (Malej and Vukovic, 1986; Malej, 1987) and on the natural availability of zooplankton in the Northern Adriatic, show that on an annual basis *Pelagia* respired approximately 22% of the zooplankton production of the area. During summer, such production is insufficient to satisfy the respiratory demands of the enormous aggregations present, while in other seasons, the respiratory food demand varied from less than 10% to about 50% of the zooplankton production. The same authors estimated that on an annual basis, *Pelagia* regenerates 7% and 9% of the nitrogen and phosphorus respectively, indicating that the impact of this species on the turnover of nutrients and on the rest of the epipelagic community in the area is expected to be highly significant.

3.4 Behavioural activities

Pelagia was found to exhibit maximum mobility within a temperature range of 18° to 20°C. (Rottini-Sandrini, 1982) and a salinity range of 35 to 38 ppt (Catalano *et al.*, 1985). Outside these optimum ranges, umbrella pulsations become irregular and eventually cease. Progressively decreasing light intensities were shown to increase umbrella pulsations in the laboratory (Axiak, 1984a). Rates of umbrella pulsations are expected to influence to some extent both the stability of aggregations (when these are being maintained by active mobility of the individuals) as well as their vertical distribution in the water column. Both aspects of the distribution of *Pelagia* have been discussed in section 2.2.

Field observations reported by Zavodnik (1987b) indicate that under normal conditions *Pelagia* tend to actively avoid swimming at the water surface or touching the bottom. Clustering of *Pelagia* individuals into pairs or larger numbers have already been referred to in section 2.2.2.

3.5 Nematocysts and toxicology

P. noctiluca was the first scyphomedusa whose nematocysts were observed (Wagner, 1841 as quoted by Russell, 1970). Three types of nematocysts were identified by Weill (1934) while in recent studies as much as six different types were characterized by Avian *et al.* (1987b). This indicates the complex nature of stinging and the possibility of the existence of different types of toxins in different nematocysts (Rottini-Sandrini, 1987).

Studies on the discharge mechanisms of such nematocysts have been undertaken by Salleo *et al.*, (1983, 1984a,b, 1986). Prior to their discharge, the nematocysts have been observed to increase in volume and there is an accompanying increase in the level of free calcium. The inverted tubule undergoes morphological changes and after its eversion the capsule shrinks. The available results support the hypothesis that the wall of the capsule and tubule play a primary role in the discharging mechanisms. The triggering stimulus may cause a conformational change in protein molecules which are found in such walls,thereby producing a change in their mechanical properties, such as a release of stored elastic tension. Alternatively, proteins found in the capsule fluid may change shape causing an increase in volume of the capsule's matrix followed by tubule eversion and discharge.

Jellyfish toxins are polypeptides and enzymes which may be both toxic and antigenic to humans (Burnett, 1987). Efforts to isolate and characterize the toxins of *P. noctiluca* are in progress. According to Maretic *et al.*, (1987), the toxin of *Pelagia* is antigenic and acts dermonecrotically and haemolytically. These authors identified eight fractions by electrophoreses with molecular weights ranging from 14.5 to 33 Kdal. Other authors (Quadrifoglio, *et al.*, 1987) suggest that the active components of the toxin may have a molecular weight ranging from 44 to 66 Kdal. Dermatoxicological studies both on 'hairless' mice and humans are still in progress though preliminary results have already been reported (Della Loggia, 1984; Del Negro *et al.*, 1987). A neurotoxicological activity has been so far demonstrated; but lack of availability of specimens is at present holding progress in this direction.

4. IMPACT OF PELAGIA BLOOMS ON MAN AND THE ENVIRONMENT

4.1 Human health

Pelagia may inflict powerful stings to bathers and fishermen and the severity of cases varies depending on the extent and duration of skin contact, sensitivity of the victim as well as the promptness and correctness of the first aid applied. The sting itself is felt like a sharp pain which is often described as similar to that from an electric shock. Some statistics are available as regards the number of reported stinging incidents from the Adriatic and Greek waters. However such statistics may only be vaguely indicative of the actual number of bathers affected during the bathing season since most cases do not need medical attention and are not reported. Maretic *et al.* (1987) reports that during 1978 from a random sample of 214 bathers from Pula (Yugoslavia) 52% were stung by *Pelagia* during the summer months. The authors suggest that the actual number of bathers stung per year within the Adriatic may be in the order of hundreds

of thousands and even millions! Papathanassiou *et al.* (1987) stated that in 1982 some Greek localities reported over 1500 incidents with a daily frequency of 2 to 3 incidents in some cases.

Vlachos and Kontoes (1987) carried out more detailed epidemiological studies on cases which were reported to the Poison Control Centre (Children's Hospital 'P. A. Kyriakou', Athens) from 1981 to 1983 (averaging about 240 cases per year). Over 75% of such victims were adults and the majority of cases were reported during July and August. Over 90% of the cases involved local symptoms including redness, pain, burning and itching. Only about 8% of the cases involved general systemic symptoms: mostly dizziness and vomiting but also to a less extent a decrease in blook pressure, diarrhea and shock. Maretic *et al.*, (1987) reports that only 24 out of 138 cases investigated from Istria (Yugoslavia) involved general symptoms. The above reports indicate that symptoms generally last from 1 to 10 days, with an approximate average of 2 to 3 days. In some cases, persistent skin hyperpigmentation was reported. According to Burnett (personal communication) human death due to *Pelagia* stings would result either from anaphylaxis or renal failure. No such fatal cases have been as yet reported. Moreover, the dose of *Pelagia* venom per body weight is probably not sufficient to affect cardiorespiratory functions. Therefore, the present data indicate that though *Pelagia* stings are a nuisance to swimmers, they represent a real danger to human health only a minority of cases. Nonetheless their psychological impact on bathers may be significant and they may potentially exert a negative impact on tourism and on water sports activities.

The importance of proper health education in minimizing such negative effects is self-evident. Bathers who are aware of this potential nuisance and who are able to apply the correct first aid treatment would be pyschologically more prepared and would be able to minimize health problems. After gently removing the parts of tentacles adhering to the skin, the affected site may be flushed with seawater but not with fresh water. The rubbing of affected skin should be avoided as this will encourage further discharge of the adhering nematocysts. There is not as yet a generally accepted therapeutic method for local symptoms. The local application of corticosteroids and antihistamines gave a significantly faster relief than no treatment (Vlachos and Kontoes, 1987). Other medications such as ammonia solution, aluminium subacetate, Burow's solution and alcohol are also used (Maretic *et al.*, 1987).

4.2 Fishing activities

Coastal aggregations of jellyfish may negatively affect fishing activities in different ways. Maretic *et al.*, (1987) have described stinging by *Pelagia* as a professional disease for fishermen who are particularly exposed to this hazard during nethauling and washing. Very limited quantitative data is available in this respect. Kokelj and Scarpa (1987) reported that an average of one out of approximately 700 fishermen was stung by this species over 192 days of fishing in 1985 in the Gulf of Trieste. This value is bound to be much higher for the peak bloom period of 1982-1983. The same authors indicate that from the same area during 1983, as much as 0.5kg/h of *Pelagia* were caught in fishing nets during trawling activities in the Gulf. Rottini-Sandrini *et al.*, (1984) also reported that the accumulation of jellyfish (especially *Rhizostoma pulmo*) in fishing nets reduced the efficiency of fish catch and occasionally led to the rupture of nets. Furthermore, this author (Rottini-Sandrini *et al.*, 1986) stated that fish which has either ingested or come in excessive contact with Pelagia during net trawling may assume 'an organoelectic quality' and lead to reduced market prices.

4.3 Impact on fish stocks

Scyphozoans may be considered as important planktonic predators. Predation on ichthyoplankton is reported to be especially severe in some cases, resulting in a damaging reduction to the recruitment of commercially valuable fish stocks (Larson, 1987). Moller (1984) suggested that predation by *Aurelia aurita* is a major limiting factor for the survival of larval herring in Kiel Fjord (Baltic Sea). Based on predator-prey standing stocks collected in the Ligurian Sea as well as on predatory rates of *Pelagia* as measured in the laboratory, Morand *et al.* (1987) concluded that this species should be expected to exert a strong predatory impact in the region. However, Zavodnik (1987c) could find no clear evidence of any significant predatory impact of *Pelagia* on fish stocks in the Northern Adriatic. Of the specimens of *Pelagia* examined, only about 20% contained fish eggs in their coelenteron (usually not more than 1 to 2 eggs per animal) while fish larvae and postlarvae were extremely rare. Maso and Castellon (1985) similarly concluded that *Pelagia* is not an important fish predator. This may be partly explained by the fact that most of the eggs

of some pelagic fish (e.g. anchovy and sardines) are located in the surface layers of offshore waters and as has been shown by Zavodnik (1987b) *Pelagia* tend to avoid swimming directly on the surface.

4.4 Impact on the pelagic environment

As indicated in section 3.2, the huge numbers of *Pelagia* during the blook period are expected to exert significant impact on the regeneration of nutrients and the structure of planktonic communities in localized areads. For example, there are strong indications (Morand and Dallot, 1985) that during periods of population explosion, *Pelagia* appears to displace other macroplanktonic carnivores such as ctenophores (*Leucothea multicornia* and *Cestum veneris*) and siphonophores (*Hippopodius hippurus*) in the Ligurian Sea. Malej (1987b) suggested that recent modifications of the zooplankton community in the Gulf of Trieste may be correlated with *Pelagia* blooms. These changes include an approximate 68% increase in the total zooplankton stock and a relative increase in the plankton fraction size which is bigger than 500 μm. Malej (1986) suggested that the grazing of *Pelagia* of herbivorous zooplankton in summer and autumn may have contributed to an intensive irregular bloom of *Gyrodinium* sp. in October 1984.

5. CAUSES AND MECHANISMS OF PELAGIA BLOOMS

As indicated in the introduction, there is at present no consensus as regards the factor or factors which trigger and control the occurrence of bloom periods of *Pelagia*. The insufficient long-term quantitative data; the problems associated with accurate sampling of gelatinous zooplankton, the gaps in our knowledge of the biology of this particular species as well as of the manner in which this single phenomenon fits into the complete picture of the way in which the epipelagic community responds to the physical environment, require that most insights will have to be made indirectly and that as yet only suggestive hypothesis may be proposed.

Nonetheless this review of the data and observations collected so far undoubtedly proves that the occurrence of *Pelagia* blooms in the Mediterranean is not of recent origin but is a 'normal' and recurrent biological expression of a pelagic ecosystem as it responds to long-term fluctuations in the physical environment.

5.1 Primary centre(s) for spread of blooms

An important aspect of the problem is whether this biological response is initially triggered in some restricted area of the Mediterranean or whether it is evident over the whole geographical extent which was ultimately affected by such blooms. In fact, the recent onset of blooms in the various localities exhibited a certain chronological order as indicated in section 2.1.5. They were first reported in the Adriatic, then in the Central Mediterranean and Greek coastal waters and finally in the Ligurian Sea. Moreover, Benovic (1987) suggested that *Pelagia* blooms occurring in the Adriatic sea were most probably transported from the Ionian Sea. Such data may suggest that the recent *Pelagia* phenomenon radiated out of one or a limited number of 'primary' centres which is/are outside the Adriatic, and probably somewhere in the Ionian Sea or whereabouts. Subsequent transport by water currents from such centre(s), may have introduced *Pelagia* individuals into other localities (e.g. the Adriatic and Ligurian Seas) where because of the relatively high levels of productivity and favourable conditions for reproduction, further increases in the populations of this opportunistic species were sustained. This idea assumes that blooms were first triggered by some local environmental factor(s) in a restricted locality or 'primary centre'.

5.2 Autochthonous zones and anomalous water dynamics

Another hypothesis proposed by Vucetic (1983) is that large populations of *Pelagia* are permanently present in such localized centres and that anomalies in water circulation patterns sometimes transport such aggregations into other Mediterranean regions such as the Adriatic. Vucetic (1983) also suggests that the circulation of the intermediate levantine waters play a dominant role in the distribution of this species in the Mediterranean and that the recent appearance of *Pelagia* blooms in the Adriatic were due to the anomalous ingression of such waters into this area. Vucetic (1983) suggests that *Pelagia* is probab-

ly autochthonous in deep waters in various centres within the Tyrrhenian, Central and Ionian Seas. However, due to the lack of long-term systematic surveys of zooplankton in such areas, it is not certain whether *Pelagia* is permanently present here, even if in a dispersed phase, or alternatively, whether massive aggregations of *Pelagia* first triggered here in the period just prior to 1977 as suggested by the previous hypothesis.

It is difficult to understand how a holoplanktonic species like *Pelagia* may reside in any one restricted locality. Furthermore, coastal aggregations of *Pelagia* in the Central Mediterranean (e.g. around Malta and Sicily) have only been known to occur during the *Pelagia* bloom period and are definitely not more frequent in occurrence than in other localities. Such observations do not support the idea that permanent massive aggregations of *Pelagia* are present at least in the Central Mediterranean. On the other hand, as stated in section 2.1.2, over the past hundred years, *Pelagia* bloom period occurred with markedly different frequencies in the various Mediterranean localities. It may be that the frequency of occurrence of blooms in a particular area will depend on the probability that the triggering of massive aggregations of *Pelagia* in certain primary centres coincide with the occurrence of favourable anomalous water movements which are required to transport these aggregations from such primary centres to the area in question. For example, the fact that only two periods of *Pelagia* blooms were recorded during the present century for the Adriatic, may be explained by assuming that on only two occasions did the triggeting of massive blooms in the primary centres outside the Adriatic coincide with the 'unusually' intensive ingression of Mediterranean waters into the Adriatic. The fact that several earlier ingressions in the Adriatic were recorded, not coinciding with the concurrent massive occurrence of jellyfish (Legovic, 1987) in Adriatic waters, supports the idea of the existence of 'primary centres' in which blooms of *Pelagia* are first triggered, but not the idea that blooms of *Pelagia* are permanently present in such centres.

5.3 Factors triggering blooms

Three factors have been proposed to trigger the *Pelagia* blooms. These include (i) physical environmental factors related to climate, (ii) anthropogenic factors such as pollution and overfishing and (iii) internal physiological factors such as circannual biological clocks. These factors are assumed to exert their influence either on the reproductive potential of the adults of this species or on the survival rates of its immature stages or on both.

5.3.1 Climatic factors

Goy (1984b) suggested that the occurrence of *Pelagia* bloom periods in the Northwest Mediterranean over the last hundred years may be correlated with pluri-annual climatic and hydrological cycles. This author suggested that thc ycars prior to the bloom periods are characterized by a deficit in rain fall and by anomalous high temperatures and atmospheric pressures particularly during May and June. Such climatic factors may possibly enhance the reproductive potential of this species and lead to the marked seasonal occurrence of *Pelagia* during the onset and declining phases of the blooms period (as identified in section 2.1.5). It is not clear whether these, or other climatic conditions, may (i) trigger the appearance of blooms in all of the Mediterranean areas affected, or (ii) trigger the occurrence of blooms only in the primary centres (as identified above) and then encourage their subsequent transport by creating the favourable anomalous water movements, or (iii) create the anomalous water movements which would transport *Pelagia* away from centres in which they are permanently present.

5.3.2 Effect of environmental stressors - hormesis

Vucetic (1983) suggested that the transport of *Pelagia* by anomalous water currents into new areas (including coastal waters) may itself constitute a stress on the species which in turn responds by increasing its reproductive effort which eventually leads into blooms. Various investigations by Stebbing (1980, 1981, 1982, 1987) show that coelenterates in particular may respond to natural (e.g. reduced salinity) or toxic stress (e.g. pollution) by increasing investment in growth (hormesis) or reproductive processes. As indicated by Stebbing (1987), in order to identify the nature of such stressors and possibly the geographical region in which they act on *Pelagia* adults, it would be necessary to back-calculate from data on the size distribution and growth rates of medusae together with data on the direction and velocities of water currents.

Boero (1987) argued that hormesis can be effective as a triggering mechanism of blooms, only if the source of disturbance or stress is restricted in space so as to act only on the reproducing adults but not on the resulting larval stages which need to survive if blooms are to follow. Moreover, nothing is known to have happened in the Mediterranean which could have caused a wide scale hormesis for *Pelagia* in the whole basin. Naturally, such objections will not remain valid, if we assume that hormesis will in fact act only as a triggering mechanism in the geographically restricted 'primary centres' as indicated above. Moreover, if this 'hormesis' is right, we would expect that the stressor(s) involved would be natural and not anthropogenic, since such blooms are known to have been occurring at least, for the past two centuries.

Unfortunately, no laboratory investigations have been carried out as yet, to identify any growth or reproductive responses by *Pelagia*, (or any other schyphomedusa) on exposure to low levels of natural stressors.

5.3.3 Pollution

Two types of anthropogenic activities have been proposed as causing the recent blooms of *Pelagia* in the Mediterranean, namely pollution from land-based sources (Aubert, 1986) and overfishing (Legovic, 1987). In the former case, it was proposed that land-based pollution may have led to eutrophication of coastal areas and thus to increased productivity and increased populations of jellyfish. However, as indicated in section 2.2.3, the present available data on the distribution of *Pelagia* aggregations do not support the idea that such blooms were initially triggered by pollution. On the other hand, blooms of *A. aurita* appear to be correlated with coastal waters exposed to organic pollution (Papathanassiou *et al.*, 1986).

5.3.4 Overfishing

Fish catch in the Adriatic has increased at least four fold between 1965 and 1980 (Legovic, *et al*, as reported by Legovic, 1987). This has been interpreted as causing a decrease in predators and competitors of *Pelagia* and other jellyfish, therefore leading to their blooms. Both anthropogenic activities can however neither explain the occurrence of past blooms of *Pelagia*, nor the decline and disappearance of the recent bloom period. While Rottini-Sandrini (1987) reports a diminished fishing effort in the Adriatic, this certainly does not apply for other Mediterranean regions. While present data do not support the hypothesis of anthropogenic triggering factors for *Pelagia* blooms, it does not rule out the possibility that such man-induced changes in the pelagic environment may intensify and sustain the natural occurrence of such blooms for longer periods.

5.3.5 The role of internal biological clocks

A more recent hypothesis regarding the possible mechanism of blooms in the marine environment was proposed by Boero (1987). The author points out that many marine forms, particularly coelenterates, possess internal cirannual clocks anticipating the generally regular and seasonal fluctuations in the physical environment. *Laomedea flexuosa* exhibits active growth and reproduction just prior to the onset of the favourable season (Brock, 1975). If a species at the onset of its bloom period is better 'tuned' with the seasonal changes it may be able to exploit the favourable conditions before its natural competitors and thereby increasing its reproductive success and larval recruitment at their expense. This will lead to a population explosion of this species and such blooms may well be sustained over a couple of years until biological negative feedback mechanisms come into effect and the bloom period disappears. This hypothesis may again be more easily sustained if we assume that initially this 'tuning' phenomenon occurs in a limited population which is restricted to one or more localized 'primary centres'. However, like all the other hypothesis put forward, this one is still to be tested by further field and other investigations.

6. STUDIES ON OTHER JELLYFISH SPECIES

Approximately eleven other species of scyphomedusae have been recorded in the Mediterranean (Tragouboff and Rose, 1957). Their occurrence appears to vary substantially from year to year as well as on a seasonal basis, and may reach high densities in certain months and in certain localized regions. Vaissiere (1984) has carried out a comprehensive literature review on these species in the Mediterranean and

on their general biology. The following is a brief review of some of the work carried out on such jellyfish within the framework of the MED POL Jellyfish Programme.

6.1 Aurelia aurita

The common jellyfish *A. aurita* is known to form coastal aggregations in several Mediterranean areas, especially from May to July. Its reproduction and growth has been studied by Papathanassiou *et al* (1986) in Elefsis Bay (Gulf of Saronikos, Greece) where its biomass may reach 50g/m^2 wet-weight during the summer months. This locality is one of the most eutrophic regions in Greece and is exposed to massive organic pollution. Most ephyrae were found to be liberated during January or February when the local zooplankton biomass is at a maximum. Mass mortalities of medusae occur after the summer months probably due to insufficient food availability as well as low levels of dissolved oxygen (Panayotidis *et al.*, 1986).

Castritsi-Catharios *et al.* (1987) carried out histological and biochemical studies on this species, while Mastronicolis *et al.*(1987) also carried out detailed analysis on its lipid composition. Due to its massive occurrence, the ecological impact in the Black Sea is considered to be highly significant (Bingel, 1987) especially with regard to its effects on fish stocks. This author recorded a mean biomass of 10.7g m^3 wt-weight of this species in the Bosphorous area. Its ecological impact in other Mediterranean areas is still to be assessed, though it may be expected to be significant in localized regions such as Elefsis Bay.

6.2 Rhizostoma pulmo

This is essentially a near-shore species and its coastal aggregations are frequently reported especially along the Eastern Mediterranean shores during the summer months. According to Lakkis (1987), this is the most frequent and regular scyphomedusa in Lebanese coastal waters. However, the occurrence of its coastal aggregations is not a regular phenomenon and since 1968, the author reported three bloom periods for this species in this area: 1972, 1979 and 1986. During 1986, such aggregations lasted from late May till June and disappeared after mid-August. This phenomenon created a significant public concern since many people claimed that it could inflict quite powerful stings. It may have also affected the local fishing industry. The author correlated the occurrence of such aggregations with a sudden increase in surface sea temperature during May, changes in salinity, and an increase in zooplankton biomass. The correlation with the latter factor is to be expected since this species is a microphagous feeder.

Nahhas (personal communication) observed the same phenomenon along the Syrian coast during 1986 and reported a maximum density of 4 medusae/10m^2 in July. Bingel *et al.* (1987) reported no similar massive blooms of this species in Mersin Bay (Turkish coast) during this period. Therefore it appears that the geographical extent of this *Rhizostoma* bloom period was restricted to the Syrian and Lebanese coastal waters.

6 . 3 Cotylorhiza tuberculata

The reproductive cycle of this species has been recently studied in two different localities: in the Gulf of Trieste (Avian, 1986b) and in the Bay of Vlyho, Greece (Kikinger, 1986). Both reports indicated that sexual reproduction occurred more frequently during summer and autumn. In the latter region, the planulae were mostly abundant during September and October. The resulting scyphostomae were found to be perennial and their rate of strobilation was greatly dependent on availability of food as well as on seasonal temperature fluctuations. No evidence of overwintering was found for the adult medusae and the whole local population probable die by autumn.

Aggregations of this species were found to be formed under the action of water currents but were probably maintained at least to some extend, by the swimming behaviour. This species as well as *R. pulmo* were in fact found to be sensitive to and reacted by swimming against water currents.

7. SUMMARY AND CONCLUSIONS

The three-year MED POL Jellyfish Programme is one of the few exceptional cases where a non-edible marine species has generated so much scientific effort which produced a significant volume of new information within a relatively short period of time. The present work attempts to integrate the results produced by the various participants in this monitoring and research programme and to review their significance in relation to our overall understanding of jellyfish blooms.

The major spatial and temporal features of the blooms of *P. noctiluca* in particular have been now identified. The distribution of aggregations of this species during its most recent bloom period in the Mediterranean which initiated in 1977 was determined by the hydrological and possibly by the natural trophic conditions of the various regions. The main features of its reproduction and life cycle in the region were identified. Several laboratory and field investigations clarified other aspects of its biology, including: its feeding rates, diet, metabolic activities, behaviour, as well as the mechanisms and toxicology of its sting.

Though it may constitute a particular health nuisance to selected population groups such as fishermen, its overall impact on human health was not considered to be highly significant and may be minimized by properly and intelligently planned programmes of health education. The impact of blooms of *Pelagia* and other jellyfish species on the fishing activities in the region may be more significant. It has been shown that jellyfish may interfere with such activities by the clogging of fish nets, thereby reducing their catch efficiency, and possibly by reducing the market value of fish which have been exposed to or ingested *Pelagia* while in the net. The occurrence of massive numbers of jellyfish is also expected to cause a significant impact on the epipelagic ecosystem, by inducing changes in the rates of nutrients turnover, as well as by overcoming natural competitors for food and other requirements (such as dissolved oxygen) and thereby causing a change in the species composition of the local communities. There were indications of such ecosystem changes in certain localities of the Mediterranean during the recent *Pelagia* bloom period.

The phenomenon of blooms of *P. noctiluca* in the Mediterranean may be considered as a highly visible biological expression of the epipelagic community's response to long-term hydroclimatic changes in the physical environment. Though human activities such as over fishing and land-based pollution may help to sustain its blooms for longer periods of time, their occurrence is a natural phenomenon which has been recorded in the region long before man's impact on the marine environment could have reached any significant proportions. In the case of other species such as *A. aurita*, blooms are usually triggered by seasonal fluctuations in the environment including temperature and food availability. The occurrence of coastal aggregations of this species have been proved to be encouraged by man-induced eutrophic conditions.

The various hypothesis to explain the triggering and controlling mechanisms of the *Pelagia* blooms have been reviewed. Pluri-annual climatic and hydrological cycles have been suggested to be correlated with enhanced reproductive potential of this species in particular months of the year. Such enhanced reproductive potential and increased investment in growth (hormesis) may constitute the biological response of this species to natural stressors as its populations are introduced into new areas by anomalous water currents. Another hypothesis suggests that blooms in *Pelagia* or other planktonic species may result when their internal cirannual clocks anticipate the regular and seasonal fluctuations in the environment so that they would be able to exploit the favourable season with greater success than their natural competitors. It has still to be established whether any of such factors trigger the blooming phenomenon simultaneously in the various Mediterranean regions affected, or alternatively in some restricted primary centres from which it later radiates out as determined by water movements.

A deeper understanding of this phenomenon will depend on a sustained research effort on the whole epipelagic ecosystem, including studies on the life cycles of other planktonic species and on the role they play in the epipelagic community. In the process, several methodological problems such as proper field sampling and observations, and the maintenance of gelatinuous zooplankton for long-term laboratory investigations have to be overcome. In a region which is so much economically dependent on tourism and fisheries and where swimming and other water sports are a way of life, it is of paramount importance to understand enough of the dynamics of the planktonic communities in order to be able to predict and possibly control or at least minimize the impact of jellyfish blooms.

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SEASONAL INFLUENCE ON THE VITELLOGENESIS OF Pelagia noctiluca IN THE NORTHERN ADRIATIC SEA

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ABSTRACT

The analysis made of the seasonal influence on the oocyte development in *Pelagia noctiluca* (Forskal) shows that:

(1) In *Pelagia noctiluca* there are always ovocytes in all development stages. Accordingly, in the Adriatic Sea, the reproduction of *P. noctiluca* takes place throughout the year.

(2) Converserly, the seasonal abundance of the ovocytes in a gonad is variable with a minimum in summer and two peaks in spring and autumn. This quantitative distribution is related to seawater temperature, to the metabolic rate of *Pelagia* and to food availability in the area examined.

1. INTRODUCTION

The reproductive period of *Pelagia noctiluca* (Forskal) was investigated on off-shore and in-shore samples of the various developmental stages.

The fact that the scyphistoma stage is lacking and the fact that this species occurs irregularly cause great difficulties in this type of research; this can explain the fragmentation of available data (Krohn, 1855; Metschnikoff, 1886; Goette, 1893; Lo Bianco, 1888, 1909; Delap, 1906; Mayer, 1910; Kramp, 1924; Russell, 1970; Franqueville, 1971; Bratina *et al.*, 1981; Rottini Sandrini and Avian, 1983; Piccinetti Manfrin and Piccinetti, 1983/84, 1986; Rottini Sandrini *et al.*, 1983-84; Avian, 1986; Legovic and Rottini Sandrini, 1986; Piccinetti *et al.*, 1986).The analysis of the male and female gonadic maturative processes is a useful technique to test the reproductive potential of a species. In order to evaluate the time of development of the gametes and the meteoclimatic influence on it, we had to establish whether the species reproduces continuously or in some seasons only.

The aim of this research is to evaluate the seasonal influence on the vitellogenetic processes in *P. noctiluca* in the Northern Adriatic Sea by means of a videoanalyzer in order to obtain a large number of morphometric observations of a better quality, and to relate these data with histological observations. Thus, the ovaries were analyzed in specimens with a diameter between opposite rhopalia >3-3.5cm; the testes always show mature spermatozoans; the cytological observations were briefly summarized by Hertwig and Hertwig, 1879; Claus, 1883; Widersten, 1965; Kessel, 1968; Chapman, 1974; Bratina *et al.*, 1981, 1982; Rottini Sandrini *et al.*, 1983, 1983-84, 1985; Avian *et al.*, 1985-86; Avian and Rottini Sandrini, 1986).

2. MATERIALS AND METHODS

Coastal and off-shore samples were collected monthly in the Northern and Central Adriatic Sea. Three specimens of *P. noctiluca* (Forskal) were examined per month. The diameter between opposite rhopalia ranged between 3.5 and 4.5cm. One ovary was excised from each living specimen and cut into two pieces. One of them was fixed in neutralized formaldehyde 4% in filtered seawater, for *in toto* analysis. The second used in histological studies was fixed in glutaraldehyde 2.5% in cacodylate buffer 0.1M, pH 7.2, adjusted to seawater tonicity (1150 mOsm) adding NaCl 0.35 M and $CaCl_2$ mM. Washes were made in the vehicle buffer (NaCl 0.35 M). The samples were postfixed in OsO_4 1% in the same buffer, washed as above and dehydrated in a graded series of ethanol. They were washed three times in propylene oxide and embedded in a mixture of Epon 812 and Araldite (Avian, 1983). Semi-thin sections were stained with toluidine blue, PAS-malachite green, methylene blue-azure II-basic fuchsin; ultrathin sections were stained with lead citrate and uranyl acetate.

Each sample was examined under a videoanalyzer. The sample fixed in formaldehyde was analyzed in order to count and measure the oocytes present in a piece 740 long. The second piece of each gonad was also sectioned in order to observe the cytology and development of the oocytes.

The methods usually employed to study the vitellogenesis are based primarily on nuclear development and RNA synthesis (Biggers and Schuetz, 1972; Campbell, 1974; Chapman, 1974); in marine organisms whose water content is high like jellyfish, common techniques such as paraffin or similar wax embedding media considerably disrupt the intracellular structures and cause great difficulties in observing nuclear development. For this reason, we considered the beginning of the vitellogenetic processes the first appearance of small cytoplasmic vesicles lipidic in content, which result from an active endo-cytoplasmic synthesis. These first vesicles appear in the cytoplasmic area between the nucleus and a structure of endodermic origin called Paraovular body which develops side by side with the oocytes.

3. RESULTS

Diameter measurements were grouped in classes of 10 μ each, from a minimum of 10 μ to a maximum of 300 μ (Table 1).

These data indicate that all diameter classes are present in each season, even if in different quantities.

The beginning of the vitellogenetic processes starts in oocytes the diameter of which ranges between 20 and 50 μ, depending on the season considered (Table 2, Fig. 3).

The vitellogenetic processes which occur within the ovaries of *P. noctiluca* can be summarized as follows:

(1) Diameter 20μ:

Small oogonia separate in the endodermic layer at the base of the gonadic folding and protrude internally.

(2) Diameter between 20 and 50μ:

The small oocytes remain in contact with the endoderm by means of a structure of endodermic origin, called "Paraovular body" (P.O.B.), which develops side by side with the oocytes; at this stage the oocytes start the vitellogenetic processes. Little vesicles of lipidic content are evident, mainly between the nucleus and the P.O.B.

(3) Diameter between 50 and 200μ :

The oocytes increase rapidly in size; so does P.O.B. There is a large increment of PAS positive cytoplasmic vesicles, equally distributed in the cytoplasm. There is also a slight increase of an extracellular membrane which covers the whole oocyte, as well as the space between the P.O.B. and the oocyte

(4) Diameter between 200 and 300μ :

Table 1. Size distribution of the oocytes (mean N specimen^{-1}) of *Pelagia noctiluca*.

SEASON	WINTER		SPRING		SUMMER		AUTUMN	
Class (μ)	FREQUENCY ABS.	REL.	FREQUENCY ABS.	REL.	FREQUENCY ABS.	REL.	FREQUENCY ABS.	REL.
10-20	10.00	5.21	5.11	2.53	5.44	4.29	28.67	11.99
20-30	39.89	20.79	49.56	24.57	27.56	21.74	60.56	25.34
30-40	36.56	19.05	44.00	21.82	23.33	18.41	47.11	19.71
40-50	25.56	13.32	25.89	12.84	18.22	14.37	27.89	11.67
50-60	17.78	9.26	16.56	8.21	11.44	9.03	18.78	7.86
60-70	16.44	8.57	14.33	7.11	9.00	7.09	13.22	5.53
70-80	12.33	6.43	11.78	5.84	6.78	5.35	10.22	4.28
80-90	9.56	4.98	8.89	4.41	5.44	4.29	7.11	2.98
90-100	6.89	3.59	5.89	2.92	4.11	3.24	4.11	1.72
100-110	3.44	1.80	5.11	2.53	2.11	1.67	3.67	1.53
110-120	3.00	1.56	2.67	1.32	1.11	0.88	3.67	1.53
120-130	2.89	1.51	2.44	1.21	2.11	1.67	3.33	1.39
130-140	1.56	0.81	1.22	0.61	2.00	1.58	2.56	1.07
140-150	1.00	0.52	1.33	0.66	0.67	0.53	1.78	0.75
150-160	1.44	0.75	1.44	0.72	1.44	1.14	1.78	0.75
160-170	1.00	0.52	1.44	0.72	0.56	0.44	1.11	0.46
170-180	1.22	0.64	1.00	0.49	0.67	0.53	0.67	0.28
180-190	0.22	0.12	0.56	0.28	0.78	0.60	0.11	0.05
190-200	0.00	0.00	0.33	0.17	0.89	0.70	0.33	0.14
200-210	0.22	0.11	0.67	0.33	0.11	0.08	0.33	0.14
210-220	0.11	0.06	0.22	0.11	0.78	0.60	0.44	0.19
220-230	0.22	0.11	0.33	0.17	0.22	0.18	0.22	0.09
230-240	0.33	0.17	0.11	0.05	0.22	0.18	0.22	0.09
240-250	0.00	0.00	0.22	0.11	0.33	0.26	0.22	0.09
250-260	0.00	0.00	0.33	0.17	0.67	0.53	0.22	0.09
260-270	0.11	0.06	0.11	0.05	0.22	0.18	0.33	0.14
270-280	0.11	0.06	0.11	0.05	0.22	0.18	0.00	0.00
280-290	0.00	0.00	0.00	0.00	0.22	0.18	0.00	0.00
290-300	0.00	0.00	0.00	0.00	0.11	0.08	0.33	0.14
TOTAL	191.89	100.00	201.67	100.00	126.78	100.00	239.00	100.00

Table 2. Seasonal distribution of oocyte diameter (mean value) related to the beginning of vitellogenetic processes.

SEASON	WINTER	SPRING	SUMMER	AUTUMN
DIAMETER (μ)	38.76	37.42	28.80	36.80

The oocytes continue to increase in size and the cytoplasm is filled with large vesicles whose content is now lipoproteinic. There is little PAS positive reacion. The cytoplasm has the classic aspect of yolk. The outer membrane thickens and the P.O.B. contains very large PAS positive vesicles. At the end of this stage, the P.O.B. degenerates, and the ripe oocyte goes out in the genital sinus. An oocyte is ripe when it reaches a diameter of 270-300 μ.

In order to show clearly the seasonal development of ovocytes, in accordance with the histological observations, we have reduced the number of diameter classes to four: 10-20μ, 21-50μ, 51-200μ, 201-300μ (Table 3 and Figs. 1 and 2).

Table 3. Size distribution of ovocytes (mean N specimen$^{-1)}$ of *Pelagia noctiluca*; four diameter classes.

SEASON	FREQ.	CLASS (μ) 10-20	21-50	51-200	201-300	TOTAL
WINTER	ABS.	10.00	102.00	78.78	1.11	191.89
	REL.	5.21	53.16	41.06	0.57	100.00
SPRING	ABS.	5.11	119.44	75.00	2.11	201.67
	REL.	2.53	59.23	37.20	1.04	100.00
SUMMER	ABS.	5.44	69.11	49.11	3.11	126.78
	REL.	4.29	54.52	38.74	2.45	100.00
AUTUMN	ABS.	28.67	135.56	72.44	2.33	239.00
	REL.	11.99	56.72	30.32	0.97	100.00

From the data presented above, it is possible to draw the following conclusions:

(1) In each season all the developmental stages of the oocytes of *Pelagia noctiluca* are present (Figs. 1, 2 and 4).

(2) The previtellogenetic oocytes (10-20μ) exhibit abundance in autumn and winter, with a minimum in spring (Figs. 1 and 2). The starting of the vitellogenetic processes (21-50μ) is earlier in summer, followed by spring, autumn and winter (Fig. 3). This class is well represented in all seasons (Figs. 1 and 2), with a maximum in spring and a minimum in winter. The third class (51-200μ), which summarizes the greatest part of vitellogenesis, is also well represented in all seasons, but faster in winter. The last class (201-300μ), which contains the final maturative processes and the ripe oocytes, is the least represented, with a maximum in summar and a minimum in winter. The total amount of oocytes shows a minimum in summer and a maximum in autumn followed by spring and winter.

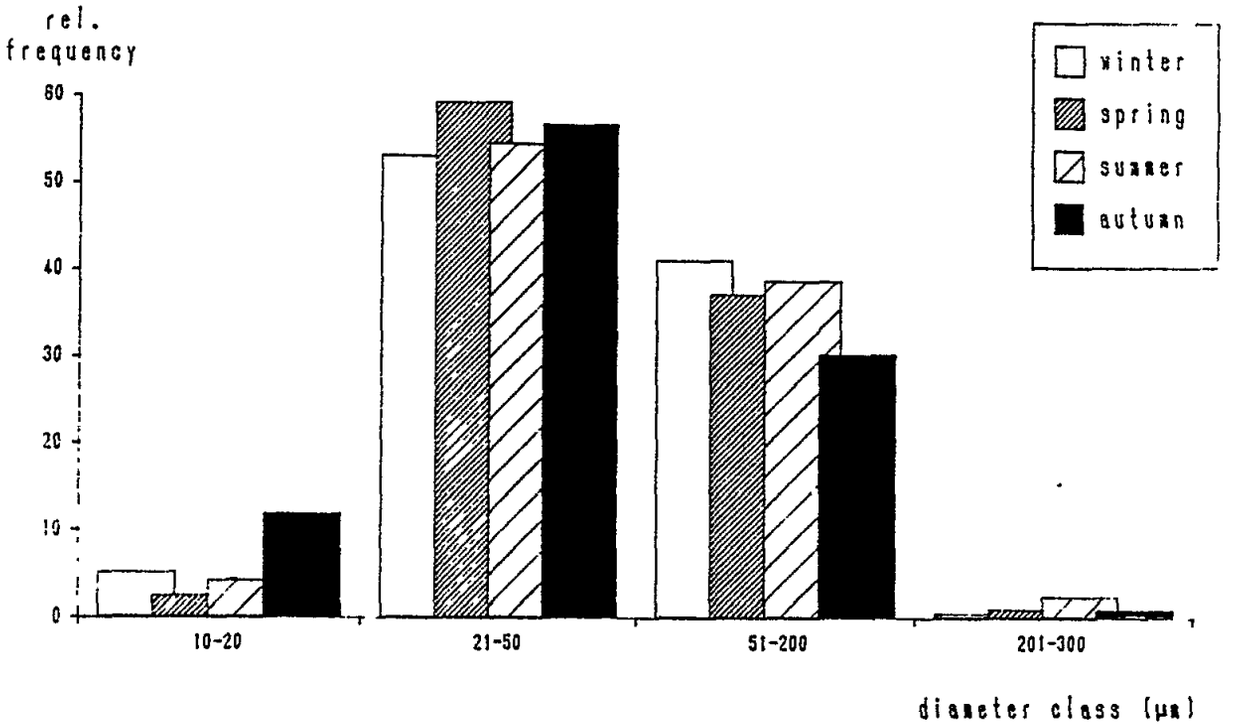

Fig. 1. Seasonal size distribution of the oocytes of *Pelagia noctiluca*

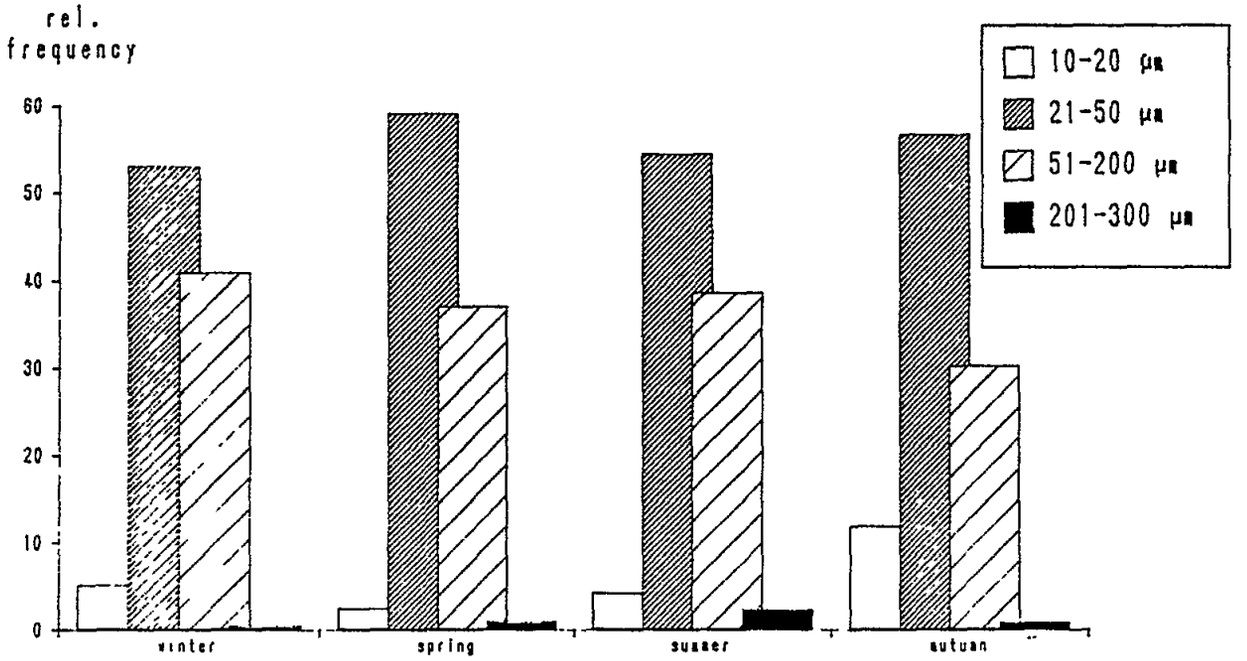

Fig. 2. Diameter distribution of the oocytes of *Pelagia noctiluca*.

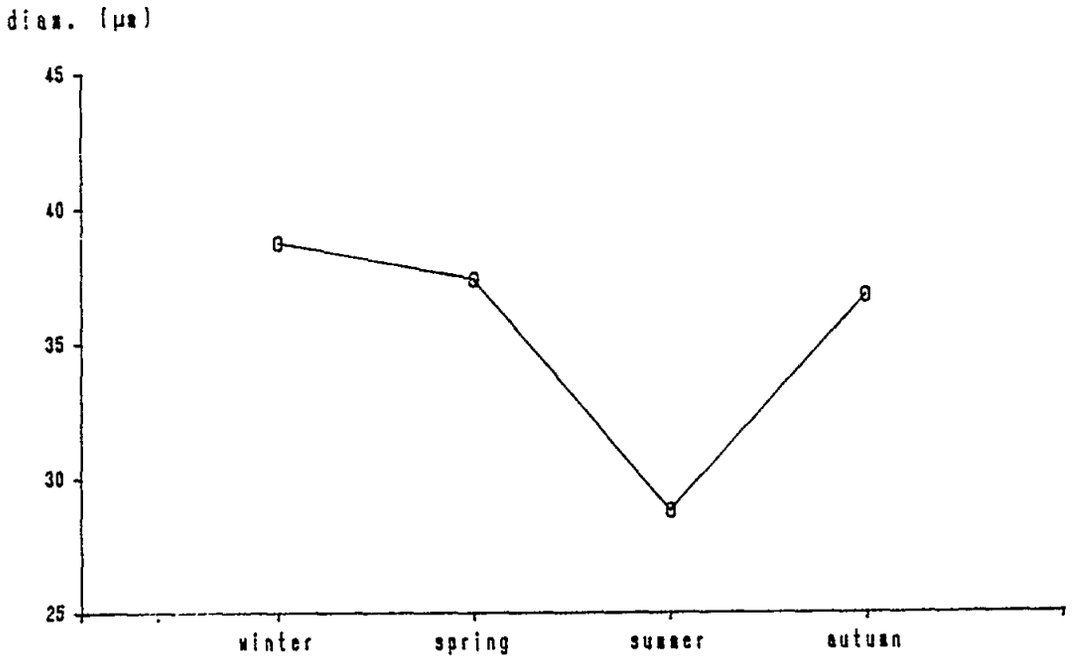

Fig. 3. Mean diameter of the oocytes related to the beginning of the vitellogenesis, seasonal variation.

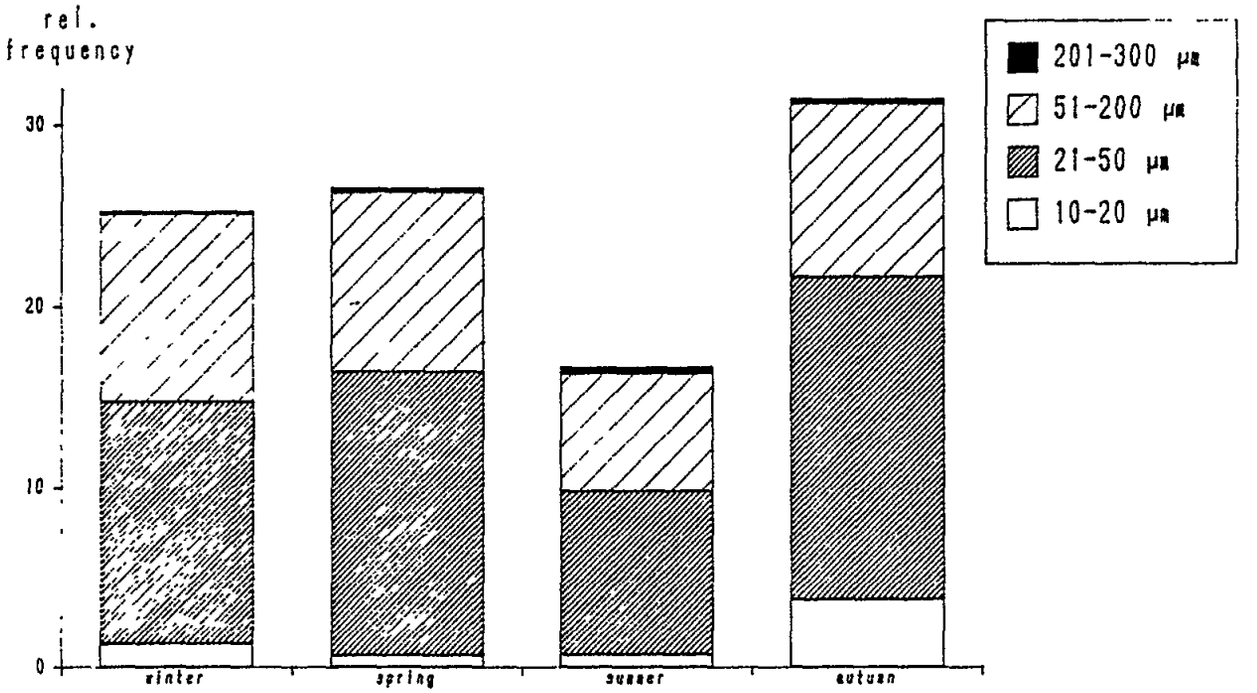

Fig. 4. Seasonal size distribution of the oocytes related tp the seasonal frequency

4. DISCUSSION AND CONCLUSIONS

Lo Bianco (1909) and Kramp (1924) assumed on inconclusive evidence that in the Mediterranean Sea *P. noctiluca* can reproduce throughout the year. Previous studies (Rottini Sandrini *et al.*, 1983-84), based on the observation and distribution of the various developmental stages, gave the same pattern for the Central and Northern Adriatic Sea, with the

exception of areas with strong climatic conditions (Bratina *et al.*, 1981; Stravisi, 1984). From the above results it is possible to confirm that Pelagia can spawn throughout the year.

Seawater temperature affects directly the time of development of oocytes. The production and spawning of ripe eggs increase with temperature. The relation of temperature and reproduction is a general feature in marine organisms and was investigated on another scyphozoan, *Aurelia aurita* (Hernroth and Gröndahl, 1983).

Temperature influences food availability in the Adriatic Sea, and consequently the metabolism of *P. noctiluca* (D'Angela *et al.*, 1985; Faganeli *et al.*, 1986; Malej and Vukovic, 1986 a, b); when temperature reaches 19°C or more, the metabolism of *Pelagia* increases so much that the food availability is not sufficient to satisfy its necessities.

Moreover in the warmer months, as for instance in July, zooplankton is mostly represented by *Penilia avirostris* Dana, the C content of which is low, if compared with other zooplanktonic species (Benovic *et al.*, 1984; Fonda Umani, 1985).

A connection between zooplankton biomass variations and the biological cycle of the scyphozoan *A. aurita* was also observed in Northern Europe (Hernroth and Gröndahl, 1983; Möller, 1984 a; 1984b; Hernroth, 1986).

The decrease of the total quantity of oocytes observed in summer can be explained as follows: even if the beginning of the vitellogenetic processes occurs earlier than in other seasons (Fig. 3), and the speed of maturation of oocytes is increased, the high metabolism of this jellyfish and the zooplankton composition, typical of the warmer season, cause a strong decrease in the total amount of the oocytes per specimen (Figs. 1, 2 and 4).

When the temperature slowly decreases and the zooplankton composition changes (in autumn) it is possible to observe a new increase of oocyte production and spawning, followed by a decrease in winter, due to the harder climatic conditions and to the decrease in the quantity of the zooplankton available.

It is possible to conclude that in the Northern and Central Adriatic Sea *P. noctiluca* exhibits two reproductive peaks, the first in late spring and the second in early autumn, and two drops in summer and winter. We should also note the connection with the seasonal quantitative distribution trend of the phytoplankton biomass (Franco, 1973; Ghirardelli, 1981). However, there are no data for the possible relation between the feeding of *P. noctiluca* and phytoplankton; it would be of great interest to investigate this trophic relation in future studies.

Finally, we had the opportunity to use the videoanalyzer in order to evaluate with increased precision the size development of the oocytes in relation to the histological observation of the vitellogenetic processes (Bratina *et al.*, 1981, 1982; Rottini Sandrini *et al.*, 1983, 1983-84, 1985; Avian *et al.*, 1985-86, 1986; Avian and Rottini Sandrini, 1986). It is a useful technique for the analysis of seasonal influences on the reproductive period.

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COASTAL AGGREGATIONS OF THE JELLYFISH Pelagia noctiluca (SCYPHOZOA) IN MALTESE COASTAL WATERS DURING 1980-1986.

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ABSTRACT

The temporal and spatial distributions of coastal aggregations of the scyphomedusa *Pelagia noctiluca* around the Maltese Islands during the period 1980 to 1986 were investigated by means of sighting reports from volunteers as well as by periodic monitoring at fixed stations both offshore and onshore. The available data indicate that the outbreaks of coastal aggregations of this species started in 1980 and reached maximum densities during 1981-1983. During the period 1984 to 1985, these occurrences decreased both in duration and population density, with coastal aggregations being more frequent during March and April. Such aggregates were characterized by large numbers of small medusae, probably of recent spawning. Sexually mature medusae as well as ephyrae were however present in coastal waters almost throughout the year for the period 1981-1982. The geographic distribution of such aggregates of jellyfish in the coastal areas indicate that they are passive accumulations, the pattern of which is largely determined by the prevalent wind direction.

1. INTRODUCTION

Several species of scyphozoa have been recorded in Maltese coastal waters, including *Charybdea marsupialis, Pelagia noctiluca* and *Cotylorhiza tuberculata*. Coastal aggregations of the last two species have been known to occur. However, during the early 1980's the numbers of *P. noctiluca* in coastal waters assumed uncommon proportions both as regards density as well as geographical and temporal extent. Preliminary studies of this phenomenon were initiated in January 1982 and these eventually developed into a programme of monitoring within the framework of the MEDPOL Jellyfish Programme. The aim of this project was to identify the characteristic features of such coastal aggregations of this species and the major environmental factors associated with such aggregations.

2. MATERIALS AND METHODS

Initially, systematic population counts at six fixed coastal stations were undertaken. However, due to the high variability in the occurrence of inshore aggregations of *Pelagia*, it was virtually impossible to collect reliable data in this manner, unless the number of stations as well as the frequency of counts were substantially increased. This proved to be beyond the resources available. Therefore, volunteers were asked to report sightings of jellyfish stranded on the shore and/or in the immediate vicinity of the coastline (i.e. within 1 to 3m off the shore) as well as jellyfish sightings at sea following the methodology outlined in UNEP (1983). Shore sightings were reported by coastal touristic establishments and the Beach Cleaning Section of the Department of Tourism as well as by other volunteers using a standard report sheet. Sightings at sea were reported by the Maritime Section of the Task Force (local coast guards during their normal coastal patrolling duties). Such reports included data on the prevalent wind direction and speed. Jellyfish aggregates reported were classified as large, with more than 10 individuals per m^3, medium and

small, with less than one individual per m3. Species identification charts enabled volunteers to indicate the type of jellyfish seen.

Systematic shore sightings and counts were carried out at two fixed coastal stations: Bighi, Kalkara Bay and Haywharf, Marsamxett. The number of jellyfish stranded on the shore or within 2m off the shoreline, along a measured distance was recorded daily during 1984 and 1985 together with surface sea temperature (SST) and wind speed and direction as indicated in UNEP (1983).

Medusae and ephyrae in the plankton were sampled using plankton nets with mouth diameters 1m and 1.5mm nylon mesh for the former, and 0.5m and 200 μ nylon mesh for the latter. Nets were towed for 10 mins. at the surface at a speed of 2 knots. Samples were fixed in 5% formalin (neutral). The sampling station is indicated in Fig. 1. Seawater temperature and salinity at the surface and at 1m depth were recorded by a Salinity Temperature Bridge Type M.C.5. Water samples for nutrient and chlorophyll analyses were collected from a depth of 1m by a plastic Van-Dorn bottle. Analyses were carried out as described by Strickland and Parsons (1972) within 24h of collection.

Histological studies of the gonads of several individuals caught during 1982 were carried out as indicated by Rottini-Sandrini *et al.* (1983).

3. RESULTS

The first recent coastal aggregations of *P. noctiluca* were observed in April-July 1980 (Axiak, 1983). It is most likely that in the period 1958 to 1960, similar large aggregations of the same species were observed in local coastal waters. Although accurate population counts for the period 1980 to 1983 are not available, our reports indicate that during this time, huge quantities of jellyfish were stranded on several stretches of the coastline. Maximum densities of 30 individuals m^{-3} in the sea and 50 individuals m^{-2} on shore have been recorded. The animals varied in size from 3 to 12 cm umbrella diameter.

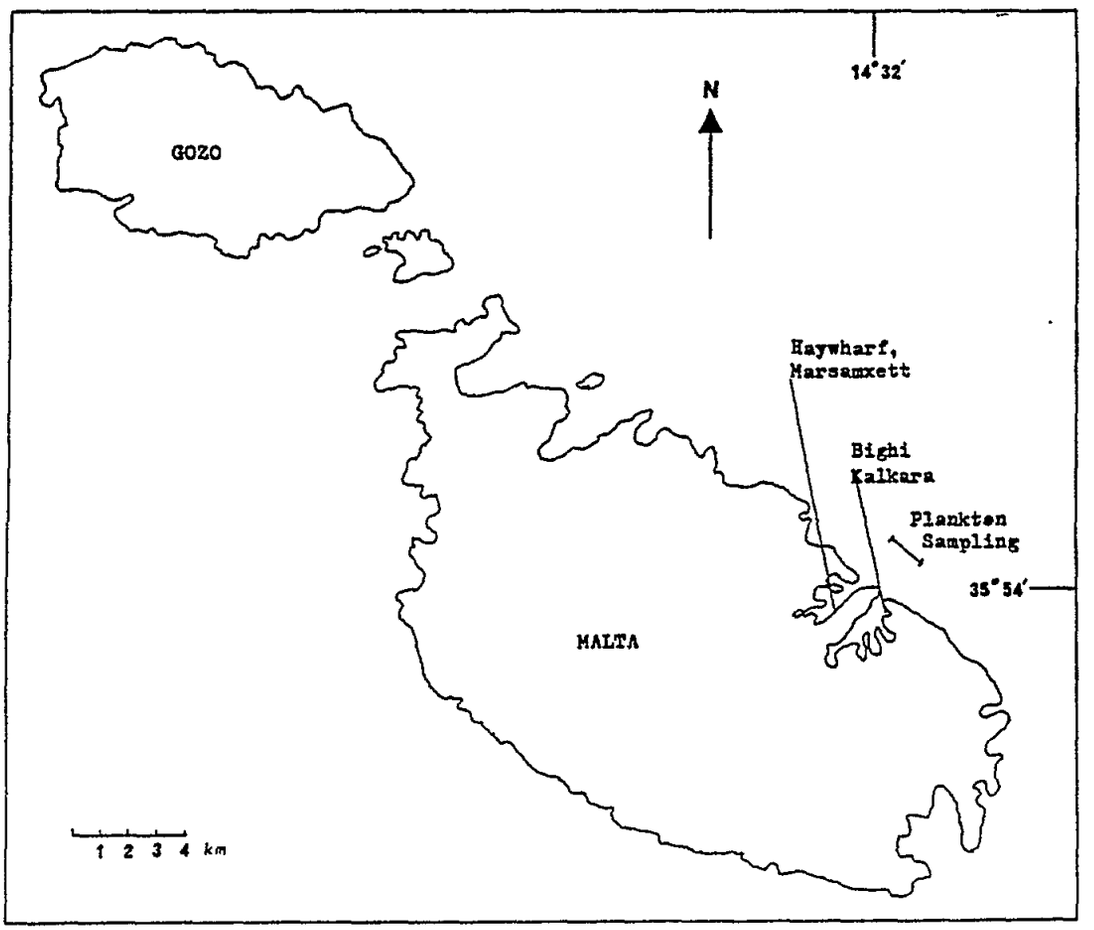

Fig.1. Locations of stations for shore counts and plankton sampling

Table 1. Montly occurrence of coastal aggregations of *Pelagia noctiluca* in the various sectors as indicated in Fig.2.. Densities reported as high (H), medium (M) and low (L) or none (-). For further explanations see text.

	SECTOR																
1984	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jan	-	-	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	H	-	-	-	-	-	-	-	-
Mar	-	M	-	H	-	H	-	H	H	-	M	L	-	H	-	-	L
Apr	H	F	-	-	M	L	-	H	H	H	H	H	-	-	-	-	H
May	L	M	-	-	-	-	-	-	L	-	-	-	-	-	-	-	H
Jun	-	-	-	-	-	-	-	-	L	-	-	-	-	-	-	-	L
Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oct	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985																	
Jan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mar	-	-	-	-	-	-	-	-	-	M	H	M	L	L	H	-	M
Apr	-	-	-	-	-	-	-	-	-	M	H	M	L	L	H	-	M
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Reports of coastal aggregations were more frequent during the summer months for the period 1980-1983. During the winter months, isolated individuals of *P. noctiluca* and less frequently coastal swarms of medium size were reported. Reports from volunteers also indicate that for this period, coastal aggregations were more frequenly sighted during March, April and May up to 10km off Malta (Axiak, 1983). Such early spring aggregations were characterized by very small individuals of 10 to 20mm diameter. Ephyrae and planulae were collected from coastal waters during 1981-1982 during February, April, May, July and December (Rottini-Sandrini et al., 1983). Individuals with fully mature gonads were collected in February, June, July and December 1982.

More quantitative data are available for the period 1984-1986. Table 1 shows a summary of the data collected from monthly reports of sightings of jellyfish aggregations in various sectors of our coastal waters as indicated in Fig. 2. High density aggregations (i.e. more than 10 individuals m^{-3}) were reported from January till May for 1984 and in March for 1985 in areas ranging from 1 to 13 km offshore. No coastal aggregations were reported after May 1985. Aggregations during January to April were again characterized by the presence of large numbers of small medusae ranging from 10 to 20m umbrella diameter.

The highest densities and more frequent reports were recorded in March and April 1984, although these were still less than those during 1980-1983. Tables 2 and 3 show the daily reports of sightings at sea in the various coastal sectors for these peak months. Data on the prevalent wind direction are also included. To present such data graphically, each report of high, medium or low density aggregations was assigned a score of 3, 2 and 1 respectively; the mean daily scores for each sector over this period (i.e. March, April 1984) were calculated and are presented graphically in Fig. 2. The percentage frequencies of wind speed and direction for the period January-March 1984 are also shown in Fig. 2 and these indicate that for this period the prevalent wind direction was from the NW.

Data from shore sightings and counts at the two fixed coastal stations for 1984 and 1985 are summarized in Tables 4 and 5. These indicated that maximum densities of approximately 0.8 individuals m^{-2} were recorded in May for both years, while no jellyfish were observed during the summer months. No significant inshore aggregations of *Pelagia* were observed in 1986 and 1987.

Table 2. Daily sighting reports for March 1984 of coastal aggregations of Pelagia noctiluca, showing sector (see Fig. 2); reported density : low (l), medium (m), high (h), as well as prevalent wind direction on site

	Sector No.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Day																	
1	a/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	h/E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	h/V	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	a/W	-	-	-	-	-	-	a/NE	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	h/NW	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	h/NW
12	-	-	-	-	a/NW	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	1/0	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	a/W	-	-	-	-	-	-	h/NNE		-	-	-	-	-	-	l/N
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	a/NW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	l/NW	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	h/SW	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	l/NW	-	-	-	-	-	-	m/SW	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	l/SW	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	m/NW		-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Regular plankton sampling could not be carried out on a monthly basis as originally planned. Moreover, it was initiated during the second half of the time period under consideration (i.e. 1980-1986) when the occurrences of jellyfish aggregations were much less frequent and less intense. The various environmental parameters recorded at the plankton sampling station are presented in Table 6. Except for nitrates, all the other parameters are comparable to similar data obtained for coastal waters in the Central Mediterranean. The unusually high levels of nitrates are due to the presence of a major sewage outfall in the vicinity. In fact, on several occasions during sampling the effluent plume was sighted in the vicinity. Single ephyrae which ranged from 0.5 to 1mm diameter were collected in March and June 1984 and then in April 1985. No medusae or ephyrae were ever recorded as from May 1985.

Other observations were reported by divers and local fishermen. Several species of fish, including *Boops boops, Spondyliosoma cantharus* and *Oblada melanura*, have been observed to feed on *Pelagia* in our coastal waters. In many cases, specimens of *P. noctiluca* observed inshore had incomplete manubria or significant areas of their oral tentacles missing. This damage may be due both to abrasion against the bottom of the shore as well as to predation.

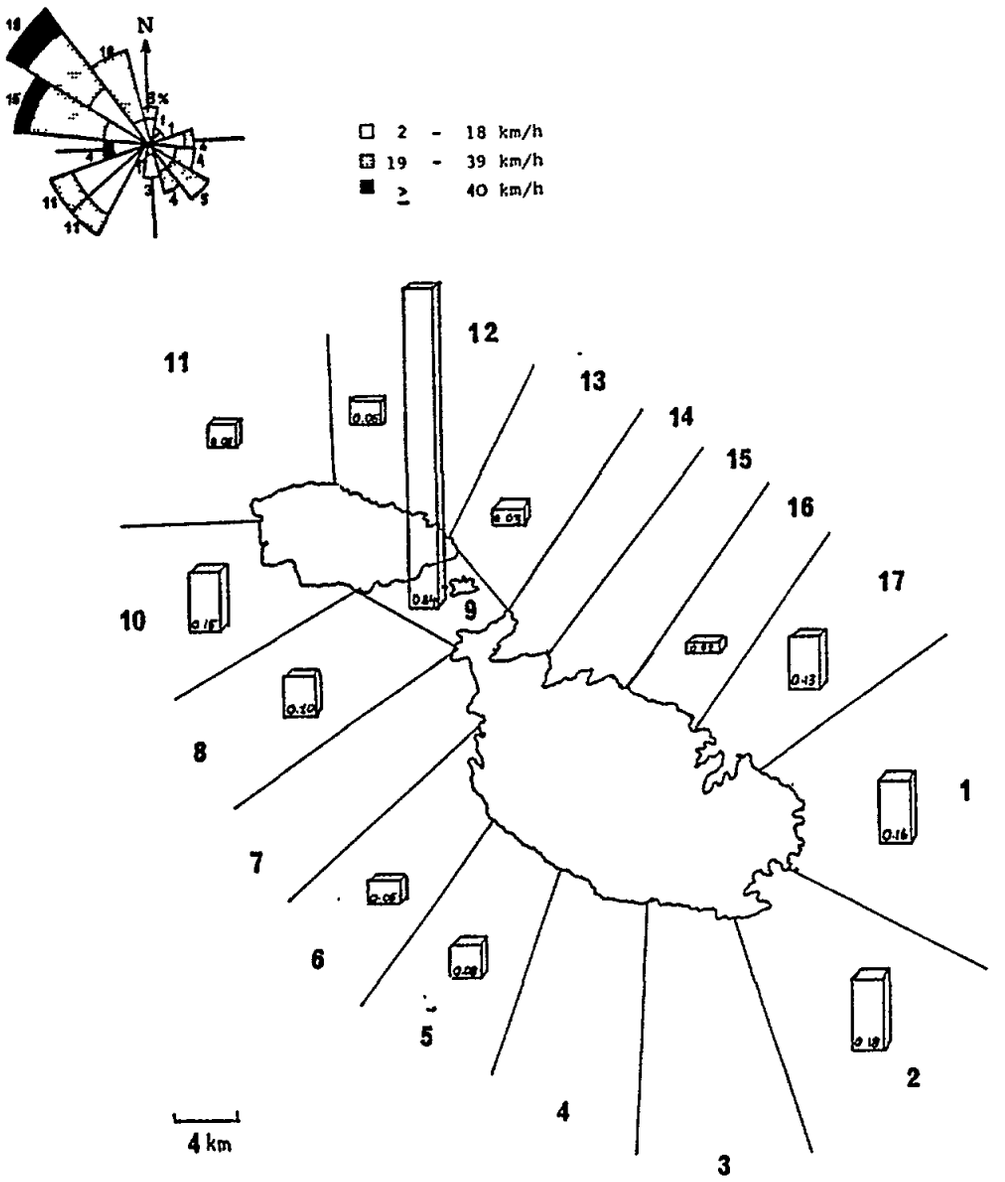

Fig. 2. The distribution of coastal aggregations of *Pelagia noctiluca* in various coastal sectors during March, April 1984, as indicated by reports of sightings at sea by volunteers. The bars indicated the relative frequency and density of aggregates in each sector (1 to 13 km offshore) as explained in the text. The percentage frequencies of wind speed and direction for January-March 1984 are also indicated

Table 3. Daily sighting reports for April 1984 of coastal aggregations of *Pelagia noctiluca*, showing sector (see Fig 2); reported density: low (l), medium (m), high (h); as well as prevalent wind direction on site

	Sector No.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Day																	
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	h/W	-	-	-	-	-	-	-	-
3	m/E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	l/NW
4	-	-	-	-	-	-	-	-	-	m/N	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	l/W	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	m/NW	-	-	-	-	-	-	-	-
8	f/NW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	l/NW	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	h/NW	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	h/NW	-	-	-	-	-	-	-	-
14	-	l/NW	-	-	-	-	-	-	m/NW	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	m/NE	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	l/NW	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	f/NW	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	h/N	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	h/NE	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	h/V	-	-	-	-	-	-	-	-
22	h/W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	h/W
23	-	-	-	-	a/V	-	-	-	l/V	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	h/V	a/NW	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	l/E	a/NE	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	h/SE	h/NE	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	a/W	-	h/W	-	-	-	-	-	-
28	-	-	-	-	l/V	-	-	-	l/SW	-	-	-	a/SE	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-		-	-	-	-	-	-	l/E	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	h/W	-	h/SSE	-	-	-	-	-

4. DISCUSSION AND CONCLUSIONS

Outbreaks of offshore and coastal aggregations of *P. noctiluca* have been reported in several Mediterranean areas since 1977 (Vucetic, 1985, Axiak and Civili, 1986). This phenomenon is not of recent origin and has been reported to occur in other regions since the 18th century and at least during 1898-1903 and 1908-1912 along the French Mediterranean coastline (Goy, 1984). Vaissiere (1984) reported dense aggregations again in the latter area during 1959. Locally, there are indications that coastal swarms of *Pelagia* occurred during 1958-1960 (Axiak, 1983).

In more recent times, the first dense coastal aggregations of this scyphomedusa were observed in 1980. During 1981-1983, this phenomenon was recorded on an unually large scale, with large numbers of *Pelagia* being reported on several occasions in all coastal areas and in most bays with apparently equal frequency throughout the year. During 1984, most coastal aggregations occurred in March-April while a year later they again recurred during March although at an ever decreasing density. During 1986, no significant aggregations were reported in our coastal waters. Therefore, a seasonal pattern in occurrence was evident when this phenomenon was on the decline, with peak densities being recorded in the early spring months.

Such early spring coastal aggregations were always characterized by the presence of a significant proportion of small medusae, which were presumably of recent spawning. Therefore it has been suggested (Axiak, 1984) that in the Central Mediterranean the reproductive rate of this species may be more pronounced during early winter. However, during the years of maximum occurrence (1981-1982) sexually mature individuals as well as ephyrae were recorded throughout the year.

Table 4. Sightings and counts for 1984 and 1985. Station : Haywharf, Marsamxett.

Month	Day of Sighting	SST in °C at sighting or range	Estimated Density (ind m^{-2})
Mar 84	28	15.5	0.02
Mar	29	16	0.04
Apr	27	17	0.04
Apr	28	17	0.004
May	17	19	0.09
May	18	17.5	0.32
May	23	17.5	0.8
Jun	-	17-21	0
Jul	-	23-27	0
Aug	-	26-27.5	0
Sep	-	24-26	0
Oct	-	N.A.	0
Nov	-	N.A.	0
Dec	-	N.A.	0
Jan 85	-	N.A.	0
Feb	-	N.A.	0
Mar	31	15	0.85
Apr	-	15-17	0
May	-	18-22	0
Jun	-	22-23.5	0
Jul	-	N.A.	0
Aug	-	N.A.	0
Sep	-	N.A.	0
Oct	-	N.A.	0

Table 5. Sightings and counts for 1984 and 1985. Station : Bighi, Kalkara

Month	Day of Sighting	SST in °C at sighting or range	Estimated Density (ind. m^{-2})
Mar 84	27	16.50.02	
Mar	28	170.23	
Apr	24	17	0.004
Apr	25	18	0.004
May	17	19	0.09
May	18	18.5	0.8
May	25	18.5	0.02
Jun	5	18.5	0.008
Jul	-	23-27	0
Aug	-	26-27.5	0
Sep	-	24-26	0
Oct	-	22.5-25	0
Nov	-	20-22.5	0
Dec	-	16-19	0
Jan 85	-	15-16	0
Feb	-	14-15.5	0
Mar	26	16	0.004
Mar	28	16	0.33
Apr	3	17	0.004
Apr	12	18.5	0.8
May	-	18-22	0
Jun	-	22-23.5	0
Jul	-	24-28	0
Aug	-	27-29	0
Sep	-	25-26	0
Oct	-	21-23	0

Table 6. Various parameters of surface sea water at plankton sampling station (see Fig. 1)

Data	Temp °C	Salinity ppt	Nitrates μ- at N/l	Phosphates μ- at /l	Chlorophyll-3 mg m^{-3}
22/3/84	15	NA	7.8	0.07	0.18
12/6/84	20.5	37.5	2.6	0.15	2.05
3/4/85	15.8	37.9	5.5	0.21	0.46
20/5/85	19.8	37.7	15.4	0.12	0.35
19/6/85	22.2	37.6	17.3	0.08	0.26
22/7/85	27	37.8	18.3	0.04	0.36
20/9/85	24	37.6	48.0	0.34	0.12
27/11/85	19.6	37.6	27.1	0.14	0.29
2/2/86	15	36.5	NA	NA	NA
6/3/86	NA	NA	26.2	0.17	0.47
10/4/86	15.8	37.0	22.9	0.09	0.09
22/5/86	20.0	36.8	21.5	0.17	0.18
27/6/86	23.8	36.8	17.03	0.16	0.21
30/7/86	25.8	36.8	20.5	0.18	0.17
29/8/86	27.6	37.0	16.9	0.13	NA
14/10/86	24.8	37.1	NA	0.104	NA

The spatial pattern of aggregations of *P. noctiluca* in our coastal waters was mostly determined by the prevalent wind direction and speed. During periods of light surface winds (less than 18 km h^{-1}) the surface current sets along the coast to the southeast for the greater part of the day (Havard, 1980). During periods of strong northwesterly winds (more than 40 km h^{-1}) the current sets always to the southeast with a maximum velocity of 0.5 m s^{-1} with a diurnal variation in speed but not in direction. From the present study it is evident that the higher reports of aggregations in the south east coastal sectors of both Gozo and Malta may be at least partly explained as passive accumulations of these medusae in the eddy sea water currents resulting from the prevalent northwesterly winds. A similar island effect has been reported by Zavodnik (1987) for coastal aggregations of this species in the Northern Adriatic.

5. ACKNOWLEDGMENTS

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THE ASPECT OF JELLYFISH DISTRIBUTION IN THE ADRIATIC SEA

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ABSTRACT

The distribution of jellyfish in the offshore waters of the Adriatic Sea is discussed on the basis of theoretical views on swarm transportation, through a study on the occurrence of jellyfish along the Eastern Adriatic coast, and plankton material collected during seasonal cruises in 1972, 1974, 1975, 1976, 1984 and 1985.

A comparison of our results with data published previously shows a decrease in the Northern Adriatic hydromedusan fauna. This coincides with an increase in eutrophication and a decrease in oxygen concentration in the near-bottom layers, with changes on bottom substrata and an increase in predator numbers.

The main factors regulating distribution of jellyfish in the Adriatic Sea are water-mass movement and the bathymetry of different regions. *Pelagia noctiluca* blooms along the Adriatic coast and especially in the Northern Adriatic corroborate this observation.

1. INTRODUCTION

From 1977 onwards (Vucetic and Rottini-Sandrini, 1982) large swarms of *Pelagia noctiluca* have been noted in the Adriatic Sea, causing considerable concern in tourist areas, especially in the Northern Adriatic. Other countries like Italy, Greece and Malta have also expressed serious concern about the ecological, medical and economic consequences resulting from cases of stingings by jellyfish. Therefore, the UNEP Mediterranean Unit in Athens launched a joint programme in order to investigate various aspects of medusan biology in the Mediterranean Sea (origin of blooms, distribution, pathology, ecology etc.). A considerable number of scientists from various institutions in the Mediterranean region investigated different aspects of these blooms and in three years contributed appreciably to the knowledge of this natural phenomenon (Axiak and Civili, 1986).

Investigations on jellyfish in the Adriatic Sea began in 1844 when Will first described the Adriatic species from the Bay of Trieste (Will, 1844). All papers preceding the UNEP/MAP programme (see Benovic 1973, Benovic and Bender 1987) had been written from a biological point of view, describing mainly the distribution and morphology of species. The UNEP/MAP jellyfish programme has resulted in papers dealing with other subjects as well. This paper is a summary of the research on the Adriatic Sea jellyfish carried out at the Biological Institute of Dubrovnik as part of a joint UNEP/MAP programme. Theoretical views, historical data, results of sample analysis and recent data have all been taken into account. Papers already published in connection with this research are: Legovic and Benovic (1984), Benovic (1984), Bender and Benovic (1986), Benovic *et al.* (1987) and Benovic and Bender (1987).

2. MATERIALS AND METHODS

In order to obtain data on the *P. noctiluca* occurrence in the Adriatic, a number of specially designed forms were distributed by the Yugoslav National Coordinator for MED/POL to coastal municipal governments, so that fishing and coastguard authorities could participate in jellyfish monitoring during their usual supervision work. Slightly different forms were distributed by the Croatian Tourist Association to major hotel companies along the Eastern Adriatic Coast.

Plankton samples were collected with standard plankton nets of 0.250 and 0.180mm mesh netting, by vertical hauls from sea-bed to surface. Sometimes oblique tows were made (the tows were equipped with a flowmeter). Samples were fixed and preserved in 2.5% neutral formaldehyde/sea water. The samples were examined microscopically for all specimens of jellyfish.

The 1972 plankton samples from the Northern Adriatic were collected by A. Malej, Marine Biological Station, Piran, Yugoslavia. The "Andrija Mohorovicic" cruises covered open waters of the entire Adriatic Sea (in all 40 stations) on the following dates: September 22-October 16, 1974, April 20-May 17, 1975, February 2-March 1, 1976, and July 6-30, 1976. The "Vila Velebita" and the "Bios" cruises in the Northern Adriatic, encompassing all 9 stations, took place in December 1984 and August 1985 respectively.

The scientific names of species and genera mostly follow Kramp (1961).

3. RESULTS

During the 1983 observation period *P. noctiluca* was reported to occur at 31 locations along the eastern Adriatic coast. Higher numbers of specimens were observed at 8 sites situated nearer and towards the open Adriatic Sea except for the two locations of Cavtat and Palagruza. All the summer/autumn "blooms" were recorded in the Northern Adriatic (Fig. 1), whereas in the Southern Adriatic large swarms were observed from November to May.

During the 1984-1985 observation period, large swarms of *P. noctiluca* were again reported in the Southern Adriatic during the colder season and in the Northern Adriatic during the warmer season (Table 1).

Table 1. Monitoring data on the appearance of "blooms of Pelagia noctiluca in the Adriatic Sea during 1984-1985 (Benovic and Bender, 1986)

Budva	Dubrovnik	Mljet	Korcula	Hvar	Zirje	Losinj	Pula	Rovinj	Porec	Piran
1984										
5.10	6.10	7.10	8.10							
4.11	6-10.11	13.11	20.11							
19.11	4-29.11	25.11	29-30.11							
			1-3.12							
1985										
23.3	8-11.4		5-6.5	8.5						
1-8.5	29-30.4		7-12.6	16-20.5	7-10.6					
8-10.6	1-7.5									
	21-23.5									
	26-29.5					20.7-27.8		13-31.7	25.7	
	13-22.6								15-20.8	
							Sept.		1-2.9	25.9
							Oct.		0.10	10.10

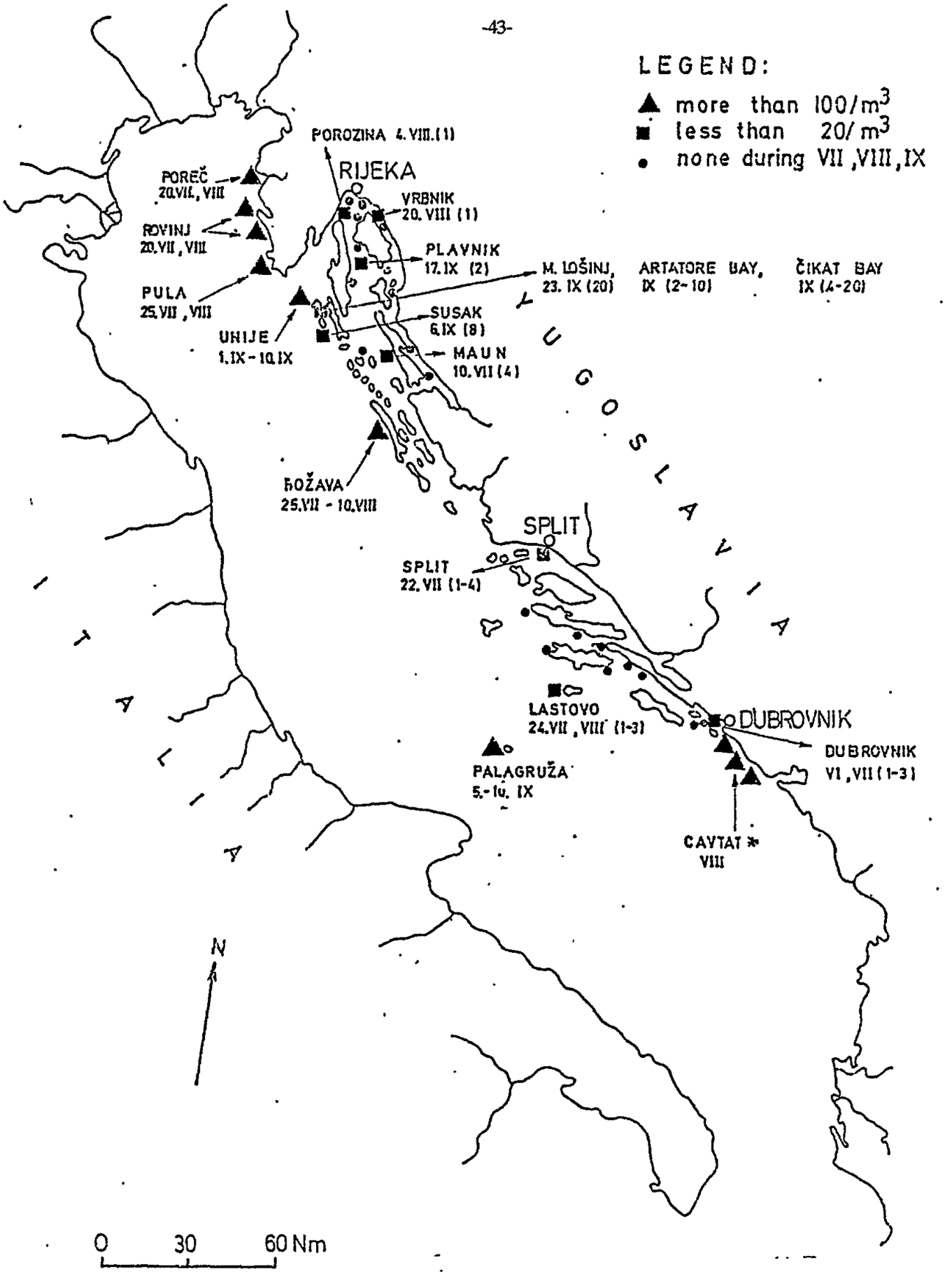

Fig. 1. Appearance of the jellyfish *Pelagia noctiluca* in the Adriatic Sea during July, August and September 1983. (From: Benovic, 1984

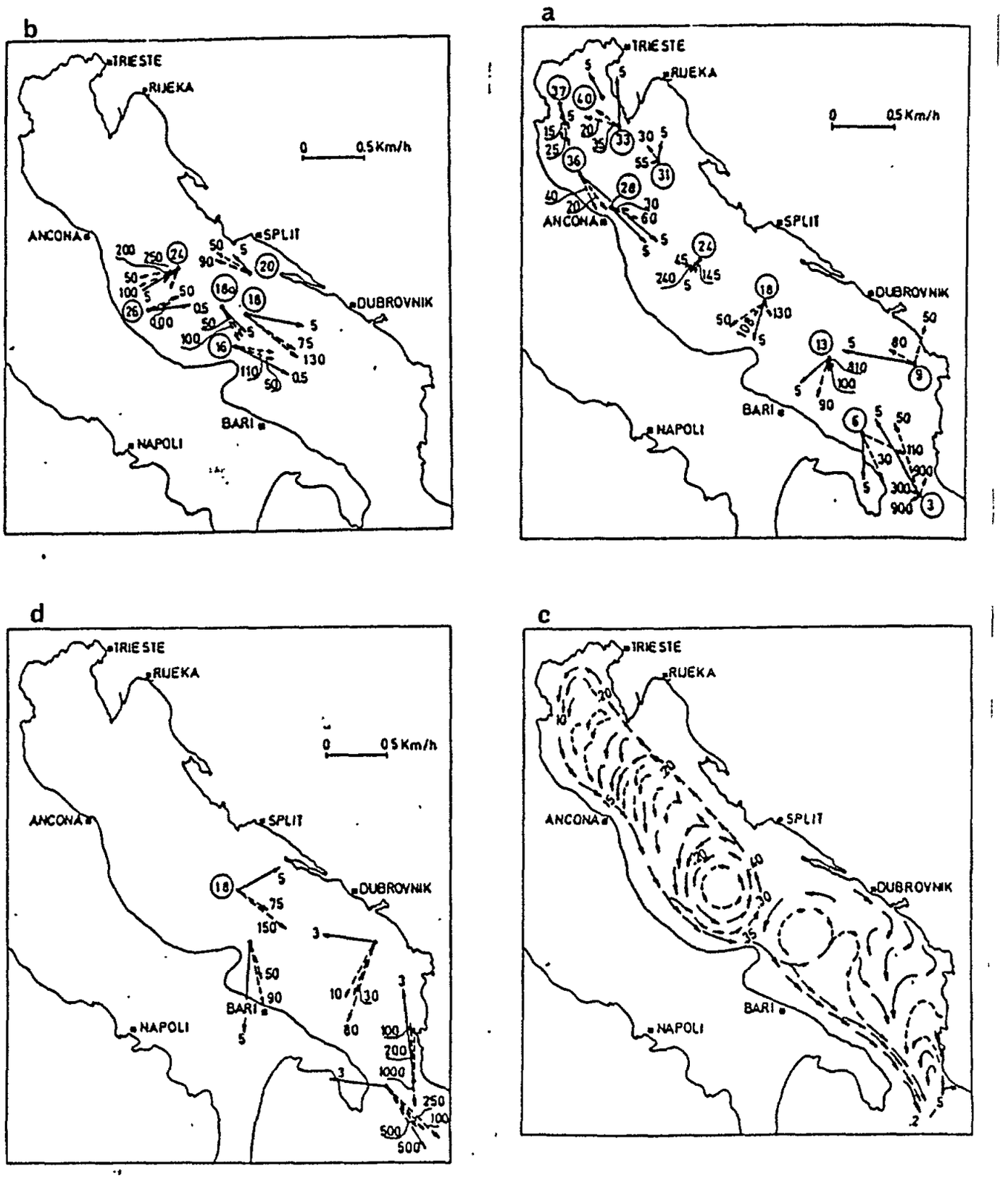

Fig. 2. Average currents in the Adriatic Sea during (a) September-October 1974, (b) March 1975, (c) February 1976 and (d) June 1976. (From: Benovic and Bender, 1987)

Table 2. List of the medusa species found in the Adriatic Sea. Scale of abundance according to the total quantitative figures (+ = present, c = low abundance, cc = high abundance, ccc = dominant). Asterisk (*) refers to the species previously reported in the Northern Adriatic (From Benovic and Bender, 1987)

	CRUISES					
	1974 IX/X	1975 IV	1976 II	1976 VII	1984 XII	1985 VIII
HYDROMEDUSAE						
Anthomedusae						
1* Sarsia gemmifera		+		+		
2* Ectopleura dumortieri		+				
3* Euphysa aurata	+	+		+		
4* Rhabdoon singulare	+	+	+	+		
5* Corymorpha nutans		+		+		
6* Zanclea costata		+	+	+		
7 Oceania armata		+	+			
8 Podocoryne areolata			+			
9* Podocoryne minima	+	CCC	+	+	+	+
10* Podocoryne minuta		CCC	+	+	+	CC
11* Bougainvillia ramosa				+		
12* Amphinema dinema				+		
13* Leuckartiara octona		+		+	+	
14* Neoturris pileata			+			
15 Bythotiara murrayi	+	+				
Leptomedusae						
16 Krampella dubia			+			
17 Laodicea ocellata		+				
18* Laodicea undulata		+	+	+		
19* Obelia spp.	+	CC	CC	+	CCC	CC
20* Clytia hemisphaerica	+	CC	C	C	+	CCC
21 Octophialucium funerarium		+	+	+		
22 Eirene viridula		+				
23* Helgicirrha schulzei	+	+		+		
24* Eutima gegenbauri		+	+	+		
25* Eutima gracilis						+
Trachymedusae						
26* Liriope tetraphylla	CCC	CC	C	CC	CC	
27* Aglaura hemistoma	+	CCC	CCC	CC	C	C
28 Arctapodema australis	+		+	+		
29* Persa incolorata	C	+	C	CCC	+	
30* Rhopalonema velatum	CCC	CC	C	CC	+	
31 Sminthea eurygaster	+	+		+		
Narcomedusae						
32* Solmundella bitentaculata	+	C	+	CC	+	
33* Solmaris leucostyla	+	+		+		+
34 Solmissus albescens	+	+	+	+		
SCYPHOMEDUSAE						
35* ephyrae	+	+	+	+	+	+
36* Pelagia noctiluca juv.			+	+	+	
37 Nausithoe spp. juv.				+		
Totals	17	28	22	28	12	8

In the 1972 plankton samples collected in the Northern Adriatic, a total of 18 species of hydromedusae was recorded, dominated by *Clytia hemisphaerica, Obelia* spp. and *Podocoryne* sp., whereas scyphomedusae were not recorded at all (Benovic *et al.*, 1987).

In the 1974-1985 plankton samples, scyphomedusae were found sporadically; they were only ephyrae, young and adult individuals of *P. noctiluca* and *Nausithoe punctata* (Table 2). Hydromedusae dominated and a total of 34 species was found, all of which had been previously recorded in the Adriatic Sea. In general, holoplankton species were dominant in the central and southern regions, while meroplankton species predominated in northern areas. *Aglaura hemistoma* and *Solmissus albescens*, and *C. hemisphaerica* and *Podocoryne minuta* predominated in the holoplankton and meroplankton, respectively. More species were found in spring (28), and fewer in autumn (17) and winter (22). Some holoplanktonic species were also found in the northern Adriatic, but only during the colder seasons. Nine species (Table 2) were common. Among them trachymedusae dominated in the central and southern regions. In the Northern Adriatic, a very low number of species was recorded, with an obvious decline in numbers from 18 (1972) to 11 (1985). Only three species were found in higher numbers.

4. DISCUSSION

P. noctiluca, trachymedusae and narcomedusae belong to the holoplankton, while anthomedusae and leptomedusae to the meroplankton. To understand plankton distribution in the seas it is important to appreciate that meroplanktonic species have a benthic stage in their life cycle while holoplanktonic species complete their life cycle in the water column. Holoplanktonic species reproduce in the open waters and can be carried long distances by sea currents, whereas meroplankton does not extend into deeper waters because it must reach the sea-bed to reproduce. Therefore, meroplanktonic medusae prevail in shallow sea areas whereas holoplanktonic species inhabit offshore pelagic waters.

The Adriatic Sea is usually divided into Northern (shallow), Central (transitional) and Southern (deep). Along the eastern coast there are numerous islands, while towards the western coast there is almost none. It has been observed that incoming water masses from the Ionian Sea enter the Strait of Otranto, follow the eastern side, turn counterclockwise in the northern area and flow out along the western Adriatic shore (Zore-Armanda, 1967). Incoming currents enter between some islands and, due to the bottom and coastal configuration, turn partly counterclockwise in the southern and central regions (Fig. 2).

The study of the transport of medusan swarms in the Southern Adriatic demonstrated that they enter the Adriatic only during the colder seasons, due to the incoming surface currents from the Ionian Sea. Following a crude estimate of the time needed, swarms can reach Dubrovnik in approximately 15 to 20 days after passing through the Strait of Otranto (Legovic and Benovic, 1984). It can be supposed that *P. noctiluca* may reach the Northern Adriatic three months after passing through the Strait of Otranto. During the period of favourable weather conditions only large swarms have a chance to enter the Northern Adriatic above the connecting line Pula-Ravenna (Benovic and Bender, 1986). This is apparent from the 1983, 1984 and 1985 monitoring data.

The quantitative distribution of hydromedusae (Fig. 3) demonstrates similar transportation patterns, but owing to their size they are less capable than *P. noctiluca* (Zavodnik, 1987) of escaping unfavourable conditions and weak currents. Hydromedusae follow general circulation patterns and concentrate along the fronts of surface currents. It seems that intensive blooms of *P. noctiluca* in the Northern Adriatic, as well as in other regions along the eastern Adriatic coast, may only occur if very large swarms cross the Strait of Otranto during colder seasons.

The specific current regime in the Northern Adriatic (Melanotte-Rizzoli and Bergamasco, 1983; Vucak, 1985; Kuzmic and Orlic , 1985; Orlic *et al.*, 1986; Kuzmic and Orlic, 1987) keeps the majority of jellyfish in the region until the beginning of a stronger outflow of the surface currents (Vucetic, 1982)

Due to its specific hydrographical conditions and a considerable fresh water influx, mainly from the Po river, the northern Adriatic has become increasingly eutrophic (Smodlaka, 1985). Local and brief mass mortalities (Stachowitsch, 1984; Faganeli *et al.*, 1985; Tornati, 1985) warn us about ecosystem "sickness". It seems that irreversible perturbations in the Northern Adriatic ecosystem began in 1955-1965 (Benovic *et al.*, 1987) when separation of oxygen saturation in surface and the near sea-bed layers along with an obvious decrease in hydromedusan species numbers were first noticed (Fig. 4). This coincides in the post-war period with intensive investments, construction and use of modern technologies without adequate pollution control.

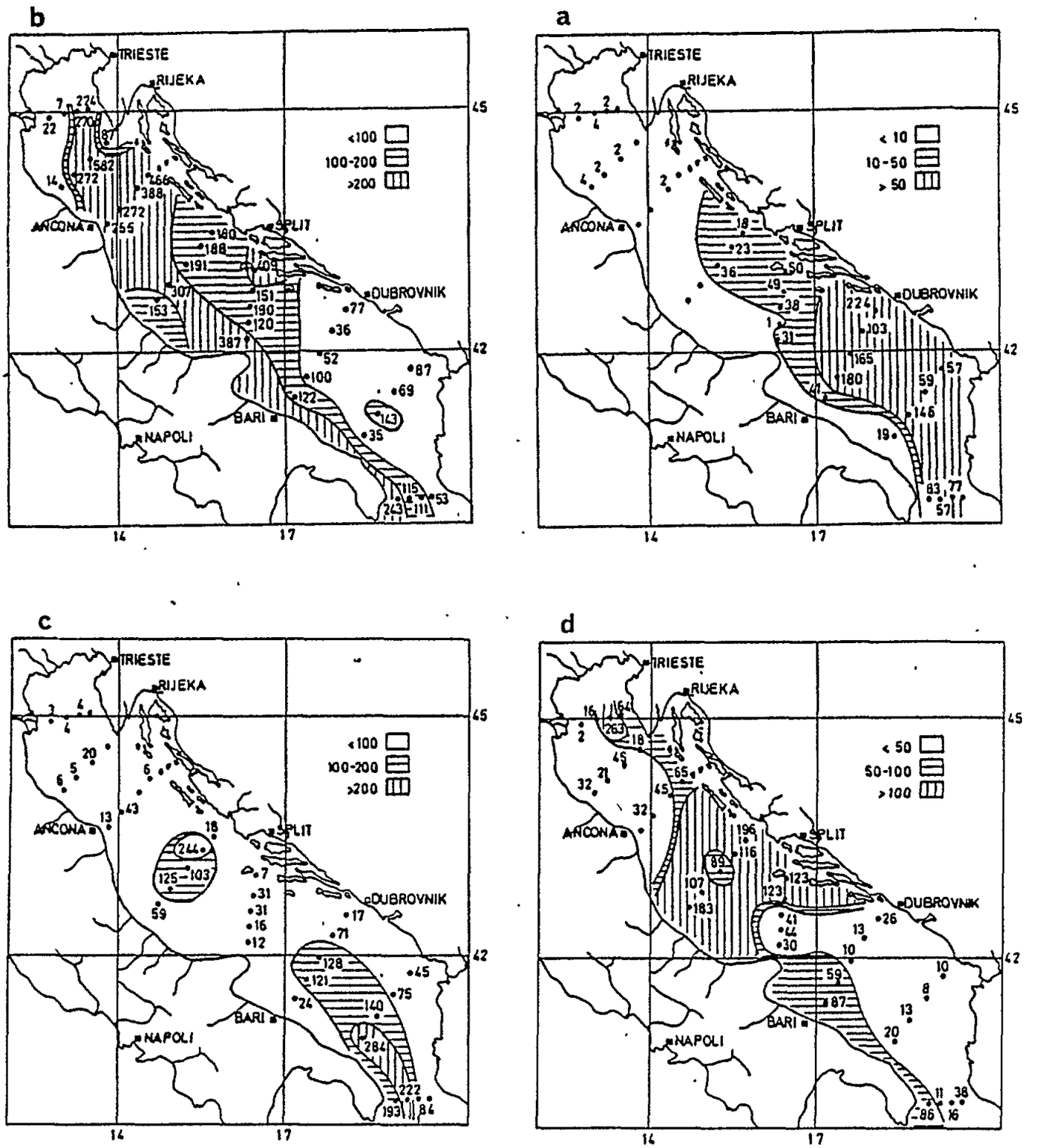

Fig. 3Seasonal distribution of the jellyfish in the Adriatic Sea (a = September/October 1974; b = April/May 1975; c = February 1976; d = July 1976). (From: Benovic and Bender, 1987)

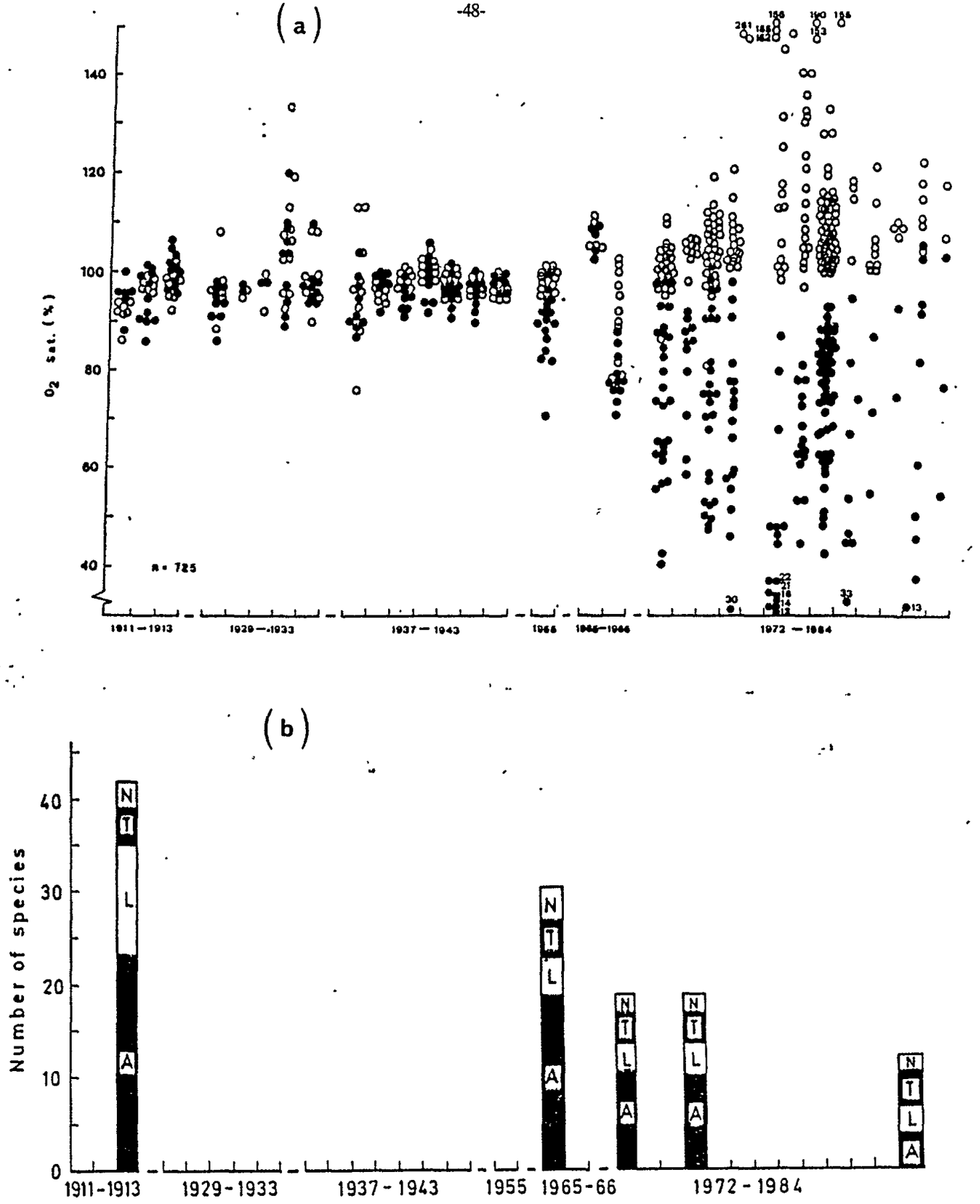

Fig. 4. a = Surface (O) and bottom (o) oxygen saturation during summer, and b = total number of hydromedusan species in the Northern Adriatic Sea from 1911 to 1984. (From: Benovic *et al.*, 1987)

5. CONCLUSIONS

1. This study was carried out as part of the UNEP/MAP jellyfish investigation programme carried out at the Biological Institute, Dubrovnik, and is a contribution to the knowledge of the Adriatic ecosystem.

2. It seems that *Pelagia noctiluca* blooms in the Adriatic Sea occur only if very large swarms are imported into the Southern Adriatic from the Ionian Sea during the colder seasons.

3. A significant change in the hydromedusan fauna of the Northern Adriatic Sea has been shown to exist.

4. It is possible that hydromedusan species may have been reduced by an interplay of several factors but the dominant cause is likely to be irreversible eutrophication processes.

6. ACKNOWLEDGMENTS

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RECAPITULATION DES RESULTATS DE LA SURVEILLANCE DES PROLIFERATIONS DE MESUDES SUR LES COTES MEDITERRANEENNES FRANCAISES DURANT L'ETE 1987

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Les rapports précédents ont décrit la mise en place (1984) et le suivi de 1984 à 1986 du réseau français de surveillance des proliférations de méduses, ainsi que les résultats obtenus.

Durant l'été 1985, la synthèse des rapports des 43 postes de secours des CRS-MNS de la Police Nationale a montré une baisse du nombre de méduses urticantes observées (*Pelagia noctiluca*). Durant l'été 1986 (82 postes de surveillance), la chute des apparitions a été brutale : aucun banc de *P. noctiluca* n'a été observé (cette espèce est la principale méduse qui soit dangereuse sur les côtes méditerranéennes du fait de son nombre et de son venin).

Concernant l'été 1987, la liste des 76 postes de secours ayant participé aux observations est présentée dans le tableau n° 1. La figure no 1 indique l'emplacement de ces postes. Les tableaux no 2 à 4 présentent les résultats ventilés par départements et régions. Ces résultats sont présentés en nombres et en pourcentages de jours où l'on a observé la méduse *Pelagia noctiluca*. Ainsi, dans le tableau no II, les résultats concernant le département du Var sont les suivants : 17 postes de secours ont envoyé deux rapports, un pour juillet et un pour août. Ceci correspond à 1020 journées d'observation (en comptant 30 jours/mois pour simplifier). Durant ce laps de temps, il a été observé entre 1 et 10 *Pelagia* pendant 4 journées et entre 11 et 100 *Pelagia* pendant 1 seule journée. Durant ces 1020 jours d'observation, on n'a pas observé de journées avec 100 *Pelagia*. Dans les tableaux 2 à 4, en dessous du nombre de journées, est indiqué le pourcentage (nombre de journées de présence de la méduse divisé par le nombre total de journées d'observation). Le pourcentage est le paramètre le plus important car il permet une comparaison dans le temps (un même département sur plusieurs années) ou dans l'espace (des départements différents pour une même saison).

La très faible valeur des pourcentages de présence de *P. noctiluca* durant l'été 1987 confirme la chute brutale de la présence de cette méduse observée durant l'été 1986. Durant ces deux derniers étés, aucun banc n'a été signalé.

Ces observations sont confirmées par l'étude du nombre de soins légers dûs aux piqûres de méduses (tableau no 5).

Enfin, il convient de signaler une augmentation du nombre de méduses *Aurelia aurita* et *Cotylorhiza tuberculata*. Ces deux espèces présentent peu de danger pour l'homme. Toutefois, s'échouant en grand nombre, elles peuvent provoquer un trouble chez les plaisanciers.

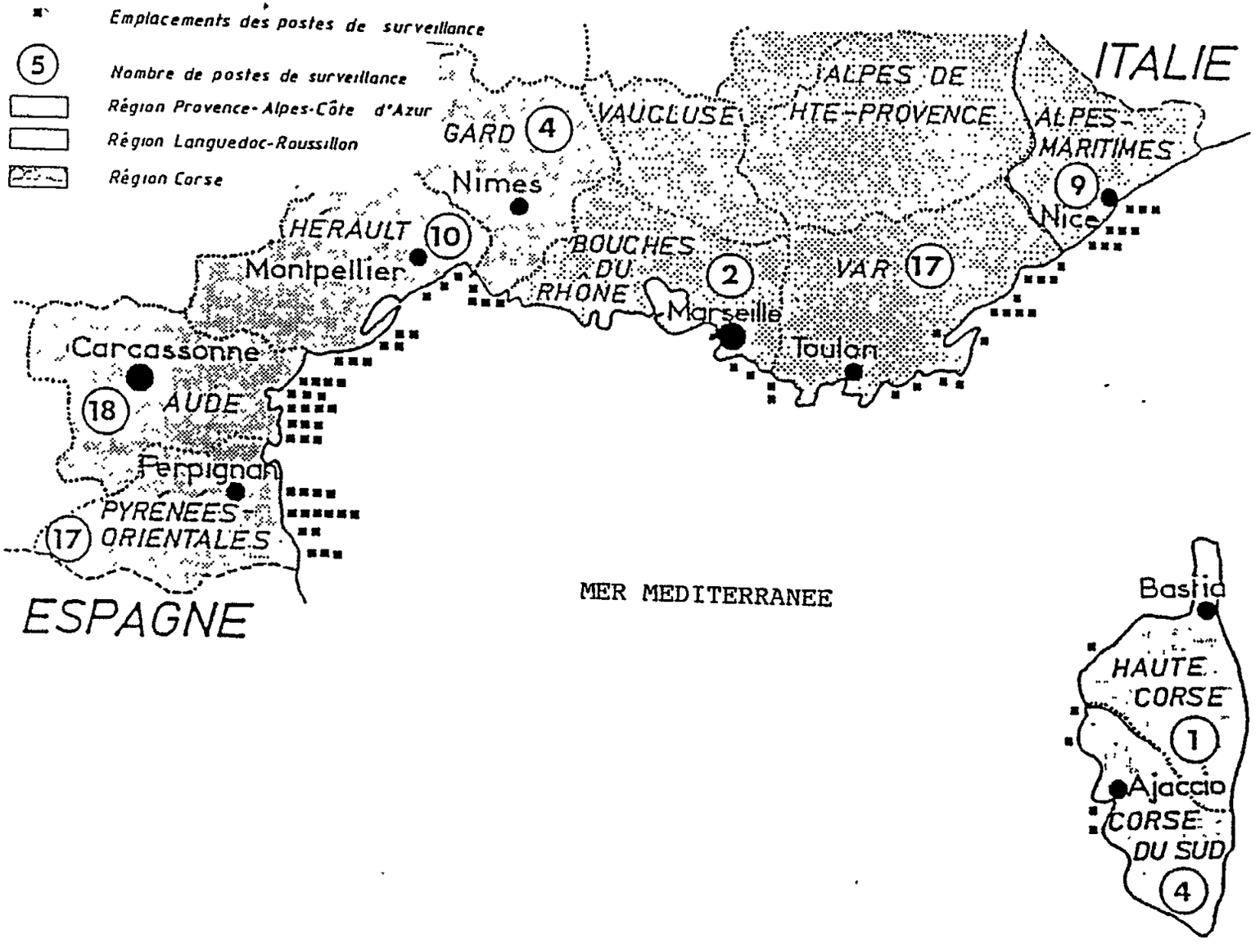

Fig. 1. Emplacements des postes d' observation du Réseau Francais de surveillance des Méduses durant l' été 1986

Tableau 1. Liste des postes de surveillance des proliférations de méduses durant l été 1987.

1. Région Provence-Alpes-Côte d'Azur (30 postes)

1.1 Département des Alpes-Maritimes (10 postes)

- Cap d'Ail	1 poste
- Eze sur Mer	1 poste
- Villeneuve-Loubet	2 postes
- Cagnes sur Mer	1 poste
- Saint Laurent du Var	1 poste
- Cannes	3 postes
- Golfe-Juan	1 poste

1.2 Département du Var (17 postes)

- Saint-Raphaël	1 poste
- Agay	1 poste
- Fréjus	6 postes
- Saint-Tropez	1 poste
- La Croix-Valmer	1 poste
- Le Lavandou	1 poste
- Six-Fours	1 poste
- Sanary	1 poste
- Bandol	2 postes

1.3 Département des Bouches-du-Rhône (3 postes)

- Carry-le-Rouet	1 poste
- La Ciotat	2 postes

2. Région Languedoc-Roussillon (41 postes) (*)

2.1 Département du Gard (4 postes)

- Grau du Roy	4 postes

2.2 Département de l'Hérault (14 postes)

- Agde	4 postes
- Viar	2 postes
- Marseillan	2 postes
- Valras	3 postes
- La Grande Motte	3 postes

2.3 Département de l'Aude (16 postes)

- Port La Nouvelle	2 postes
- Leucate	3 postes
- Gruissan	3 postes
- Narbonne	4 postes
- Fleury d'Aude	4 postes

2.4 Département des Pyrénées-Orientales (7 postes)

- Barcarès	2 postes
- Banyuls-sur-Mer	1 poste
- Argelès-sur-Mer	1 poste
- Collioure	1 poste
- Sainte Marie de la Mer	2 postes

3. Région Corse (5 postes)

3.1 Département de la Corse du Sud (5 postes)

- Vico-Sagone	1 poste
- Ajaccio	1 poste
- Porticcio	1 poste
- Ota	1 poste
- Vico	1 poste

(*) Certains postes de secours n'ont envoyé qu'un seul rapport.

Tableau 2. Nombres et pourcentages de journées d' observation de la méduse *Pelagia* (surveillance de 8 heures/jour/1000m de plage), pour la région Provence-Alpes-Côte d' Azur durant l été 1987.

	Nombre de postes de surveillance (N)	Total des journées de surveillance (N x t*)	Jours où l'on a observé des Pelagia (1) en nombre (N x t) en pourcentage			
			0 Pelagia observée	1-10 Pelagia observées	11-100 Pelagia observées	100 Pelagia observées
Alpes-Maritimes	10 en juillet 10 en août	600	600 100%	0	0	
Var	17 en juillet 17 en août	1020	1015 99,5%	4 0,4%	1 0,1	0
Bouches-du-Rhône	3 en juillet 3 en août	180	180 100%	0	0	0
TOTAL	30 en juillet 30 en août	1800	1795	4	1	0
Pourcentage			99,7%	0,2%		

* t = nombre de jours de surveillance (t = 0 jours)

(1) : effectifs non cumulés

Tableau 3. Nombres et pourcentages de jounées d' observation de la méduse *Pelagia* (surveillance de 8 heures/jour/1000m de plage), pour la région Languedoc-Roussillon durant l été 1987.

	Nombre de postes de surveillance (N)	Total des journées de surveillance (N x t*)	Jours où l'on a observé des Pelagia (1) en nombre (N x t) en pourcentage			
			0 Pelagia observée	1-10 Pelagia observées	11-100 Pelagia observées	100 Pelagia observées
Gard	4 en juillet 4 en août	240	235 98%	5 2%	0	0
Hérault	14 en juillet 8 en août	660	659 99,9%	1 0,1	0	
Aude	16 en juillet 12 en août	840	832 99%	8 1%	0	0
Pyrénées Orientales	7 en juillet 7 en août	420	417 99,3%	3 0,7%	0	0
TOTAL	41 en juillet 31 en août	2160	2143	17	0	0
Pourcentage			99,2%	0,8%		

* = nombre de jours de surveillance (t = 60 jours)

(1): effectifs non cumulés

Remarque: les 43 soins légers donnés pour causes de piqûres entre les 13 et 17 juillet 1987 au poste de secours du Grau d' Agde (Hérault) n' ont pas été inventoriés du fait de leur origine incertaine (méduses, anémones, plancton utricant?)

Tableau 4. Nombres et pourcentages de journées d' observation de la méduse *Pelagia* (surveillance de 8 heures/jour/1000m de plage), pour le littoral méditerranéen francais durant l été 1987.

	Nombre de postes de surveillance (N	Total des journées de surveillance (N x t*)	Jours où l'on a observé des Pelagia (1) en nombre (N x t) en pourcentage			
			0 Pelagia observée	1-10 Pelagia observées	11-100 Pelagia observées	100 Pelagia observées
Provence Alpes Côte d'Azur	30 en juillet 30 en août	1800	1795 99,7%	4 0,2%	1	0
Languedoc Roussilon	41 en juillet 31 en août	2160	2143 99,2%	17 0,8	0	0
Corse	5 en juillet 5 en août	300	300	0 100%	0	0
TOTAL	76 en juillet 66 en août	4260	4238	21	1	0
Pourcentage			99,4%	0,6%		

* = nombre de jours de surveillance (t = 60 jours)

(1): effectifs non cumulés

Tableau 5. Nombre de soins légers dûs aux piqûres de méduses et donnés par les CRS-MNS de la Police Nationale dans chaque département durant les étés 1984, 1985, 1986 et 1987.

	1984	1985	1986	1987
Alpes-Maritimes	508 (1)	564	63	0
Var	-	611 (2)	15	12
Bouches-du-Rhône	-	100	0	1
Gard	-	0	16	8
Hérault	-	28	0	0
Aude	-	4	2	10
Pyrénées-Orientales	-	13	27	23
Haute Corse	-	22	0	
Corse du Sud	-	35	0	0

(1) : pour la seule ville de Cnnes durant juillet et août.

(2) : résultatsdu mois d' août uniquement

OCCURRENCE OF JELLYFISH AT THE BLACK SEA - MARMARA JUNCTIONS OF THE BOSPHORUS

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ABSTRACT

Jellyfish (*Aurelia*) populations have increased in significant proportions in the entire Black Sea in all seasons. This increase is considered "an ecological event of great importance" (Gomoyu, 1981) and leads to significant fluctuations in jellyfish biomass at the Bosphorus region. The results emerging from the present study on this aspect of the biology of the region can be summarized as follows:

-Most jellyfish species consist of *Aurelia aurita.*

-The jellyfish biomass over the water column varies both in space and in time.

-The mean biomass decreased between December and March and then increased between March and-July.

-The mean jellyfish concentration in the study period is 10.65g wet weight per cubic metre. This value is in excellent agreement with the mean jellyfish concentration for the entire Black Sea.

-Comparison of visual observations made in 1985 and 1986 indicate that jellyfish surface concentrations appear to be declining on an interannual basis.

1. INTRODUCTION

A noticeable increase in the concentration of jellyfish has been observed in recent years in the Mediterranean generally and in the Black Sea particularly. The most striking population explosion of jellyfish was reported by Shushkina and Musayeva (1983) for the Black Sea region. These authors indicate that the main mass of jellyfish is concentrated at depths of 0-50m over the entire Black Sea and that the most abundant individuals are of the genus *Aurelia.*

In the Black Sea, the population of *Aurelia* consumes daily about 15% of the biomass of zooplankton in the fall, and up to 25% of the production of non-predatory zooplankton. In a year, *Aurelia* consumes on the average 10% of the production of the whole non-predatory zooplankton per square metre in every 24 hours, about 30% of the production of the non-predatory crustaceans. *Aurelia* is slightly susceptible to the pollution of its environment (Shushkina and Musayeva, 1983). Similar characteristics and impact on the marine life of *Aurelia* are reported for various other oceans of the world, e.g. the Baltic Sea (Möller, 1980, 1984).

There are several biomass estimates of the jellyfish in the Black Sea, the most reliable being 350-450 million tons by Gomoyu and Kupriyanov (1980). This is much greater than the biomass of anchovy in the Black Sea. The mean biomass of the jellyfish *Aurelia* in the Black Sea, between 1950 and 1962, is 1.4g wet weight per cubic metre (Mironov, 1971). The observations carried out from 1978 to 1981 showed that in the period May-June the mean biomass wet weight) amounts to 25g of jellyfish in a cubic metre, the corresponding figure in summer-fall being 1g (Gomoyu & Kupriyanov, 1980; Shushkina *et al.*, 1980 (cited in

Shushkina and Musayeva, 1983)). Taking these two jellyfish concentrations as first order averages for the periods during which they were measured, an annual mean value of 13g wet weight in a cubic metre can be inferred.

The considerable jellyfish biomass of the Black Sea, the predatory capacity of the jellyfish on the eggs and larvae of economically important plankton-eating pelagic fish, their ability to occupy the ecological niches and their inability to swim against sufficiently strong currents, call for a time series investigation in places of sufficiently strong currents, for example the Marmara and Black Sea junctions of the Bosphorus. Jellyfish carried out with currents to places where water masses are more or less stagnant will influence the organic matter input significantly and contribute to the deficiency of the dissolved oxygen content in deeper layers especially the sea bed. In fact, the two generations of *A. aurita* (winter generation from December to May and spring generation from April to August) introduced in succession to the basin may easily constitute a natural source of a smaller organic input to the Marmara Sea.

Within the ISKI (Department of Water and Sewage Administration, Municipality of Istanbul) project, IMS-METU (Institute of Marine Sciences; Middle East Technical University) has been carrying out a jellyfish monitoring study since December 1985. The preliminary results obtained in conjunction with this aspect of the monitoring programmes at large are presented in the following chapters.

2. MATERIALS AND METHODS

Jellyfish were collected during the cruises of the R/V BILIM along the Bosphorus as well as in the regions surrounding the junctions of the straits with the Black Sea and the Sea of Marmara. The monitoring stations are shown in Fig. 1. The dates of the cruises and the stations visited are summarized in Table I.

Fig. 1. Location of jellyfish sampling stations

Table 1. Jellyfish biomass from various stations (December 1985-July 1986).

Date of Cruise	Station code	Water filtered in m^3	Amount of jellyfish g/m^3	Species Identifed	
20.12.85	M 2	49.3			
20.12.85	M 7	11.8			
20.12.85	M 6	912.3	1.21	Aurelia	
20.12.85	M 14	456.1	0.02	Aurelia	
20.12.85	M 16	532.2	0.28	Aurelia	
20.12.85	C 45	532.2	1.88	Aurelia	
21.12.85	M 5	532.2	1.32	Aurelia	Rhizostoma
21.12.85	A 20	380.1	6.18	Aurelia	
21.12.85	M 12	608.2	1.50	Aurelia	
21.12.85	M 20	608.2	4.04	Aurelia	
21.12.85	M 10	608.2	0.58	Aurelia	
21.12.85	B 4	304.1	149.13	Aurelia	
21.12.85	B 14	608.2	1.64	Aurelia	
21.01.86	M 2	1064.3	0.33	Aurelia	
21.01.86	M 6	881.9	5.33	Aurelia	
22.01.86	M 14	790.7	0.25	Aurelia	
22.01.86	M 8	532.2	0.38	Aurelia	
22.01.86	M 20	881.9	0.28	Aurelia	
23.01.86	M 10	425.7	0.23	Aurelia	
23.01.86	M 5	760.2			
27.01.86	K 13	49.3	23.33	Aurelia	
27.01.86	K 16	49.3	13.18	Aurelia	
27.01.86	K 14	49.3	17.24	Aurelia	
27.01.86	K 17	49.3	7.10	Aurelia	
27.01.86	K 19	49.3	9.74	Aurelia	
28.01.86	K 20	49.3	1.01	Aurelia	
28.01.86	K 21	49.3	11.16	Aurelia	
28.01.86	K 21*	49.3	128.80	Aurelia	
13.03.86	B 4	29.6			
13.03.86	K 0	49.3			
13.03.86	K 2	49.3			
13.03.86	M 2	49.3			
13.03.86	M 3	49.3			
14.03.86	M 14	49.3			
14.03.86	M 16	49.3	0.20	Aurelia	
14.03.86	M 18	49.3			
14.03.86	M 20	49.3			
06.05.86	M 3	19.7	20.30	Aurelia	
06.05.86	M 2	33.5			
06.05.86	M 14	49.3	4.06	Aurelia	
06.05.86	M 16	49.3	0.41	Aurelia	
06.05.86	M 5	14.8			
07.05.86	M 18	49.3			
07.05.86	M 20	49.3			
20.05.86	B 4	19.7	5.08	Aurelia	
20.05.86	B 10	19.7	17.77	Aurelia	
20.05.86	K 0	49.3			
24.05.86	M 2	21.4	46.30	Aurelia	
24.05.86	M 14	26.3			
24.05.86	M 16	19.7			
24.05.86	M 17	19.7	35.50	Aurelia	
25.05.86	M 19	19.7			
25 05.86	M 20	19.7	0.25	Aurelia	
14.07.86	B 4	9.9	20.20	Aurelia	
14.07.86	B 14	9.9	2.02	Aurelia	
17.07.86	M 3	11.5	115.65	Aurelia	
18.07.86	M 14	9.9			
18.07.86	M 15	9.9			
18.07.86	M 5	12.8			
18 07.86	M 18	19.7			
18.07 86	M 20	26.3			

* Two tows within 10 minutes

The jellyfish net constructed at IMS-METU (Bingel *et al.*, 1987), was operated from the crane of the vessel. To increase the area covered, extra tows (mostly vertical and horizontal) were carried out. Jellyfish was weighted on board. When it was possible, species were identified and their wet weights recorded.

3. RESULTS AND DISCUSSION

During the December 1985-July 1986 period, an average jellyfish biomass of 10.6g wet weight m^{-3} was measured. This value is in excellent agreement with the jellyfish biomass reported for the Black Sea and is indicative of strong biological interactions betweeen the Sea of Marmara and the Black Sea, anticipated earlier. Seasonal averages of the jellyfish biomass were found to be as follows:

TIME PERIOD	BIOMASS - WET WEIGHT g per cubic metre
Winter 1985-1986	6.94
Spring 1985-1986	4.08
Summer 1985-1986	17.20

Mean jellyfish biomass for different regions and time periods are summarized in Table 2.

Shushkina and Musayeva (1983) suggest that two generations of *Aurelia* occupy the Black Sea. The first generation is observed during a 6-month period between December and May and the second from April to August. The largest individuals of these generations are found in May and September respectively. These decreases and increases in jellyfish biomass correlate well with the changes in plankton biomass (Figs. 2 and 3).

The time series plot of the mean wet weight of the jellyfish biomasses for the Istanbul region indicates that probably both generations were caught during the investigation period (Fig. 3). The decrease in the mean biomasses from December to March corroborated Shushkina and Musayeva's (1983) observations,

Table 2. Mean jellyfish biomass at different times in the junction of the Bosphorus.

Months	Region	Wet weight (g/m^3)
December 1985	Bosphorus	75.385
December 1985	Marmara junction	1.546
January 1986	Black Sea	26.450
January 1986	Marmara junction	0.971
March 1986	Black Sea junction	0.000
March 1986	Bosphorus	0.000
March 1986	Marmara junction	0.033
May 1986 *	Marmara junction	3.539
May 1986 +	Black Sea junction	0.000
May 1986	Bosphorus junction	11.425
May 1986	Marmara junction	19.275
(*) In the first half and (+) in the second half		

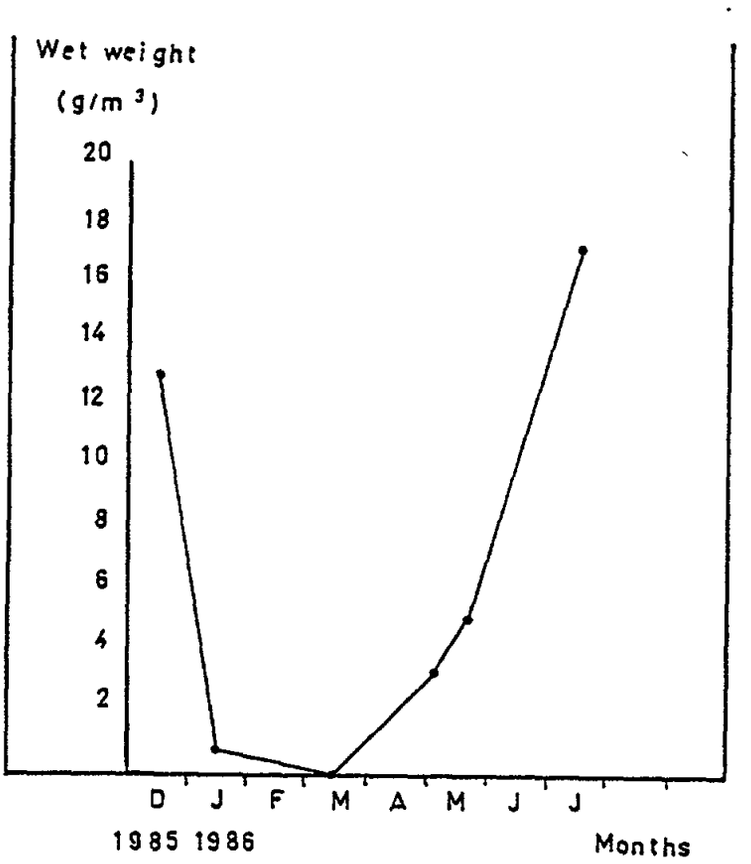

Fig. 2. Monthly variations in the mean wet weights of jellyfish at the Black Sea-Marmara junctions of the Bosphorus.

i.e. that the so-called first generation biomasses are much lower than those of the second (or spring) generation. Miranov's (1971) observations on the other hand are contrary to the findings of Shuskina and Musayeva (1983). The time series obtained in the present study is too short to allow us at this stage to draw any firm conclusion on the seasonal variations of jellyfish in the region monitored. It is however quite clear that significant variability in time and space of jellyfish exists and that this aspect of the monitoring programmes should be followed (and is) in order to obtain a better understanding of the biological cycles that are relevant to the programmes at large.

It is also worth pointing out that prior to the present quantitative sampling, visual observations indicated the presence of large amounts of jellyfish in the entire Turkish straits. In comparison, the visual observations made in the region during the recent cruises are indicative of a remarkable decrease in the occurrence of the surface concentrations of jellyfish. The reasons for this apparent decrease are not yet clear.

4. ACKNOWLEDGMENTS

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The commitment of the captain and crew of the R/V Bilim is much appreciated. I would also like to express my thanks to the participating IMS-METU students for their assistance during sampling.

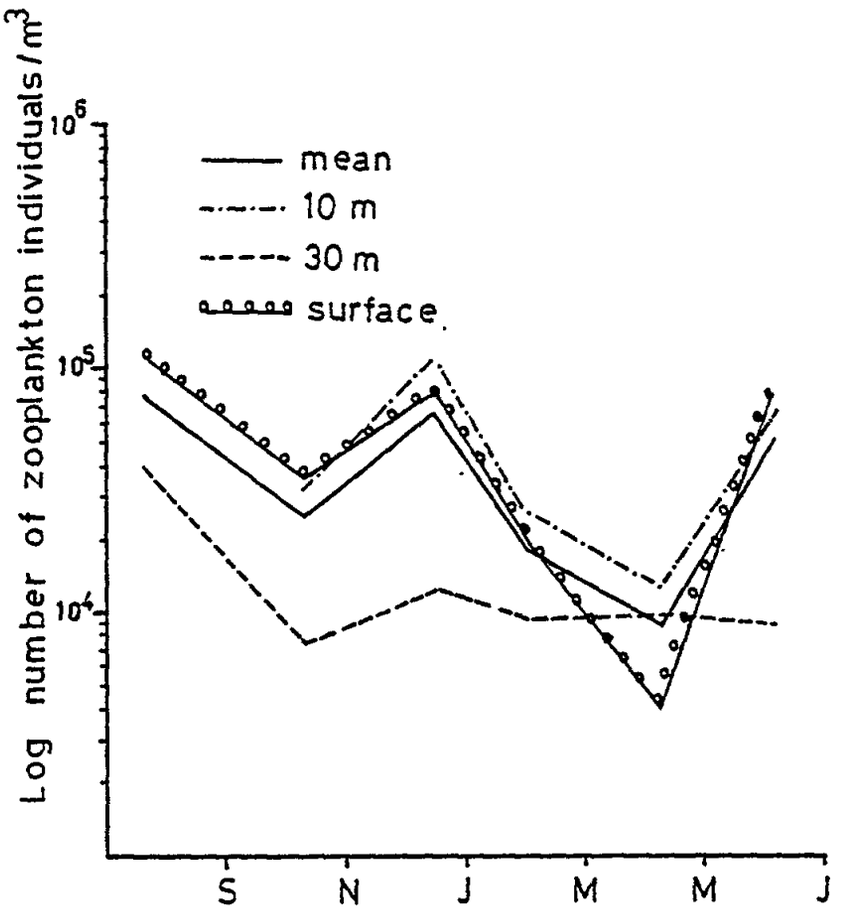

Fig. 3. Bimonthly distribution of zooplankton from September 1985 to July 1986 at the Marmara junction of the Bosphorus

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OCCURRENCE OF JELLYFISH IN MERSIN BAY

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ABSTRACT

Data from concurrent research activities have been combined with data collected during the UNEP Jellyfish Monitoring Programmes (1986-87) to explain the occurrence of jellyfish in the bay of Mersin. Measurements of different years indicate that a quantitative (significant) link can not be found by the Spearman's rank correlation test for the monthly data pairs during which the jellyfish were present.

1. INTRODUCTION

In recent years, a noticeable increase in the concentration of jellyfish has occurred in different parts of the Mediterranean waters. The increased abundance of the unusual swarming of various jellyfish species has induced considerable international interest.

In the last 20 years reports on the occurrence of jellyfish are rapidly increasing, but the real reasons for the fluctuations in the abundance of these organisms are still not very well understood.

It has been suggested that the jellyfish blooms are related to increasing levels of pollution. An increased level of pollution is also suggested in Mersin Bay on the eastern Mediterranean coast of Turkey. This area is located close to the delta region of the Tarsus and Seyhan rivers. These rivers carry run-off from regions where considerable agricultural and industrial activity is known to take place. Most of the industries in the provinces of Adana and Mersin discharge their wastes without any treatment into this Bay (Bingel, 1984), (Fig. 1).

During fishery studies carried out in the region between the years May 1980 and November 1982, quantitative data were also collected on jellyfish occurrence along the Turkish coast east of the Goksu river in monthly intervals; a short report was also prepared (Bingel, 1984).

The overall objective of the present study was the monitoring of the jellyfish swarms in order to obtain a detailed distribution of their occurrences within Mersin Bay. The abundance of the jellyfish was correlated with parameters such as Chlorophyll-a, phyto- and zooplankton counts in order to find an explanation of the swarms in time and space

2. MATERIALS AND METHODS

Material for the study was collected in Mersin down to a depth of approximately 100 metres by two small research vessels (R/V LAMAS, 16m and R/V ERDEMLI, of 18m length Figs. 1 and 2). In the periods of expected jellyfish bloom, namely March-September (Bingel, 1984) biweekly cruises were carried out. Extra tows were made to increase the area coverage. Sampling tows were carried out with a newly constructed home-made net, which is similar to that proposed by UNEP (1983) and shown in Fig. 3.

Besides jellyfish sampling, sea water was sampled at standard depths (0m; 10m; 20m; 30m and 50m) for chlorophyll-a determinations. Samples taken with the aid of a 1.5 litre metal Nansen bottle on board were transferred to plastic jars and magnesium carbonate added. Samples were stored in an icebox until analyzed. In the laboratory, samples were filtered through GF/B filters and then treated with 10ml of 90% acetone (analytical quality) and centrifuged. Centrifuged material was left in the dark for at least 18 hours in a refrigerator to achieve maximum extraction of all pigments. Spectrofluorometric measurements were taken at room temperature, where an emission wavelength of 660nm and an extinction wavelength of 425nm was used. The calibration of the instrument was performed using acetone blanks. The chlorophyll-a content was calculated using the following relation:

Chl-a = Calibration factor * Fluorescence intensity of the sample * Acetone volume for extraction/Volume of water filtered

The original data collected at different stations (Fig. 2) are summarized and averaged for the whole Bay because of the unexpected scarcity of jellyfish in the region in contrast to the situation in the period 1980-1982, approximately 4 years before the start of the present study. The resulting data are summarized in Table 1 and a Spearman's rank correlation test (cited in Snedecor and Cochran, 1976) is performed. Additional data from concurrent research activities were also used, in order to explain the occurrence of jellyfish in the bay of Mersin (Fig. 4). In addition to the field studies, 14 different local newspapers [1] were reviewed for the years 1981-1986 for possible records of jellyfish swarms in the region in general and more particularly in the bay of Mersin.

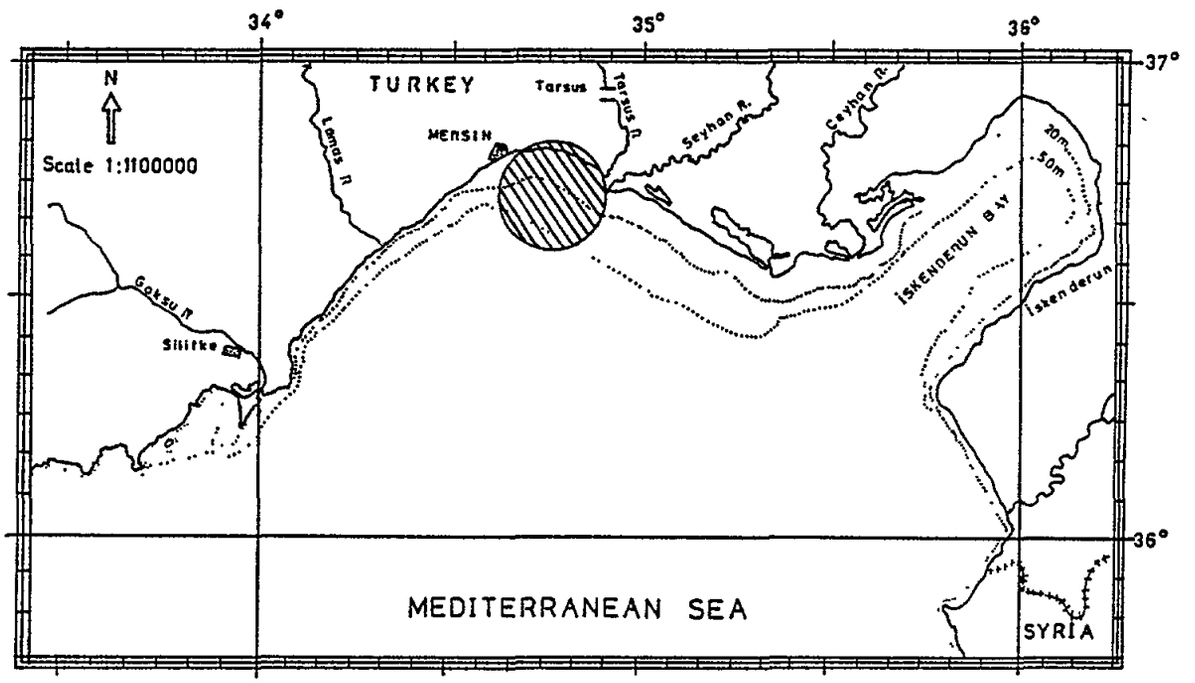

Fig. 1. Location of Mersin Bay in the northeastern Mediterranean

[1] Cukurova, Derya, Gunes, Guney, Hakikat, Hakimiyet
Icel Ekpres, Kurtulus, Mersin Ticaret, Son Haber
Son Havadis, Ticaret, Yeni Akdeniz, Zafer

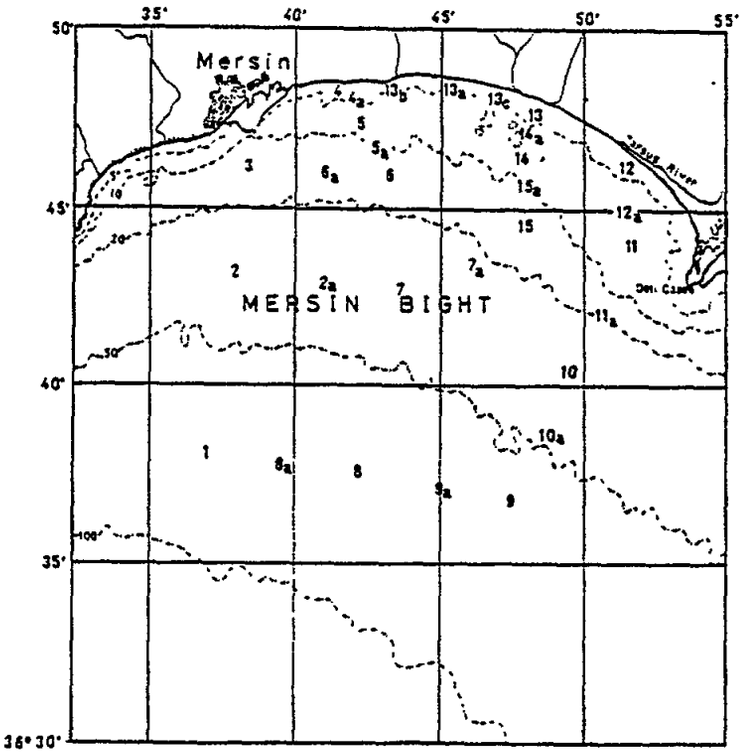

Fig. 2. Sampling stations in Mersin Bay

Table 1. Jellyfish data summarized and averaged for the whole Bay of Mersin.

Time Months	Chl-a ln ((mg l^{-1} *100))	Phytoplankton counts (*) 3 Cells m^{-1}	Zooplankton counts (*) 3 Ind. m^{-1}	Jellyfish ln (kg h^{-1})*1000)
SEP	5.495+	10.12	6.380	6.440**
OCT	5.795+	10.92	6.590	6.550**
NOV	6.860	9.53	5.935	-
DEC	5.170+	11.53	5.520	-
JAN	5.990	12.22	5.555	-
FEB	7.080	15.71	7.270	7.170
MAR	6.015+	12.81	6.550	-
APR	5.960+	12.74	6.530	8.033
MAY	5.765+	11.49	5.705	8.602
JUN	4.700+	8.31	5.635	9.243
JUL	4.270+	6.38	6.105	6.153
AUG	4.150+	8.95	5.330	9.024

(+)Data combined with Yilmaz (1982)
(*)Data from Kideys (1987) and
(x)Data from Gucu (1987)
(**)Present study; Units converted to ((ln(kg h^{-1})*1000)); the remaining are taken from Bingel (1984).

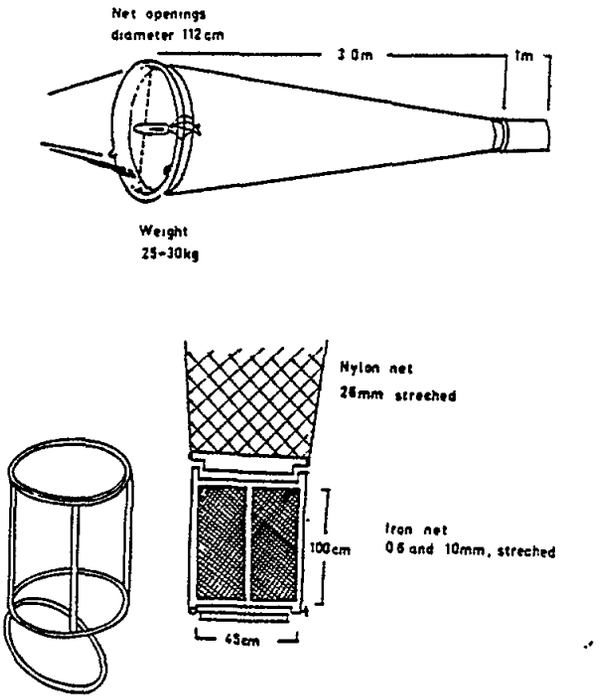

Fig. 3. Dimensions and mesh sizes of the jellyfish sampling net

3. RESULTS AND DISCUSSION

Unfortunately a collection of older local daily newspapers was not available. There are relatively high fluctuations in the numbers given by the newspapers locally published.

In the 14 different local newspapers that were reviewed, no record of jellyfish occurrence was found although for some years (April-August 1980-1982) the period of high catches of jellyfish in the trawling studies was well documented by Bingel (1984).

As mentioned above (Fig. 4) data from different sources have been combined. There are three curves corresponding to Chlorophyll-a measurements at the sea surface and in the water column. The data obtained by IMS-METU (1987) studies (indicated in Fig. 4 with bars) show seasonal course of surface chlorophyll, which is relatively high between January and March with a peak in February. The minimum is reached in April, while in the other months a smooth increase is observed. Data from September to May (indicated as + + +) are taken from Yilmaz (1982) while the data from March to October (+ - +) is actually observed in 1986-87 during the present study in the same region. The magnitudes of these two measurements appear to be different. This is probably caused by the different methods used in the analysis. While Yilmaz (1982) filtered the samples through a membrane filter of 0.45 micron pore size, the present samples were filtered through a GF/B filter of 1.2 micron pore size. Many of the small sized phytoplanktonic cells would explain the difference in values of the chlorophyll measurements, but nevertheless the combined data clearly show the tendencies in surface chlorophyll. The above data indicate a steady production of phytoplankton all year around with respective peaks in November, February and May, which correlate well with the seasonal course of the surface plankton (dotted line in Fig. 4).

In addition to the chlorophyll data, the phytoplankton cell counts in the entire water column (0-75cm depth range) taken from Kideys (1987) are also plotted.

The time series of the phytoplankton cell counts give a maximum in February while the minimum is reached with a slight decrease in July (Fig. 4).

In agreement with Kideys (1987), Gucu (1987) finds that the amount of zooplankton in a 0-25m depth range reaches its maximum in February with secondary peaks in March-April, while the minimum is found from mid-May to mid-June (Fig. 4).

In addition to the above, the jellyfish data from bottom trawl catches (Bingel, 1984) and catches with jellyfish nets (Fig. 3) are also plotted. As seen in Fig. 4 where jellyfish are also plotted, the main bulk of the jellyfish is found from April to August. This seems to coincide with the period of decreasing

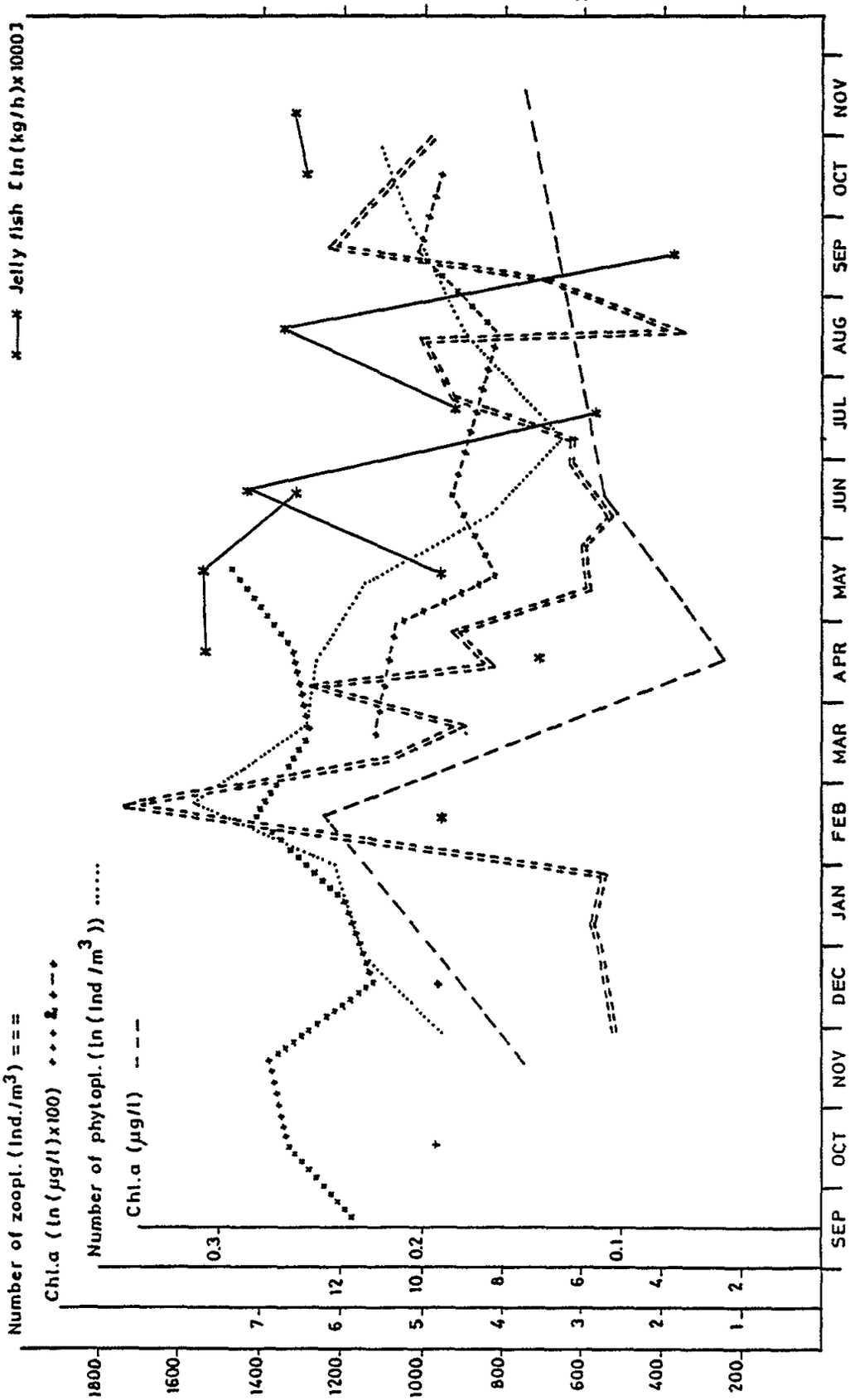

Fig. 4. Plotted diagramme of the data from the present study and concurrent research activities

zooplankton counts which on the other hand agree with the seasonal course of the surface Chlorophyll as was to be expected. Wilkerson & Dugdale (1984) argue that the possible concentration of nutrients (eutrophication) would cause the blooms of jellyfish since the latter are indirect consumers of ammonium and nitrate and on the other hand, direct consumers of planktonic organisms as shown by Shuskina and Musayeva (1983). However, in the present study, direct and quantitative (significant) relations between different parameters were not found by the Spearman's rank correlation test for the monthly data pairs during which the jellyfish were present.

At this stage, and because we have no comprehensive time series data set covering several years of investigations, there is only a speculative explanation of the jellyfish blooms in Mersin Bay (cf. also Bingel, 1984). Vucetic (1984) advanced the hypothesis that there may be changes in water quality or interannual (long-term) cycles which may influence, favourably or unfavourably, the jellyfish reproductive capacity and hence their blooms. The winter of 1986-1987 was the most severe in the last 30 years with long periods of cold weather lasting until the end of April. Therefore it is assumed that the local long-term climatological conditions may be important in the occurrence of jellyfish blooms. In any event, the occurrence of jellyfish in Mersin Bay was not a serious problem for at least the study period. A review of the local newspapers also confirms this suggestion.

4. SUMMARY

Monitoring programmes of jellyfish in Mersin Bay show that:

(a) contrary to expectations (Bingel, 1984) there is a significant drop (almost to non-existence) in jellyfish abundance in this Bay in the period studied;
(b) an increase of the area covered by additional vertical and horizontal tows did not increase the catches of jellyfish individuals; and
(c) during the study period only two species were detected. These were *Rhizostoma pulmo* and *Chrysaora hysoscella.*

Data from different sources (Phyto- and Zooplankton counts) and additional measurements of surface Chlorophyll and jellyfish catches are indicative of the following:

(i) measurements of different years indicate no significant link between the occurrence of jellyfish and secondary production;
(ii) since in half a decade the abundance of jellyfish has changed significantly, their abundance may be linked to changes in the local climate;
(iii) the data recently collected and evaluated as well as a review of the local newspapers also indicate that the occurrence of jellyfish is not yet a serious problem in the Bay of Mersin.

5. ACKNOWLEDGMENTS

The jellyfish monitoring study in the Bay of Mersin was supported by UNEP and by the Institute of Marine Sciences of the Middle East Technical University.

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CONTRIBUTION TO THE UNDERSTANDING OF BLOOMS IN THE MARINE ENVIRONMENT

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ABSTRACT

The overall characteristics of dynamic equilibria in the marine environment are described, stressing the importance of seasonal and pluriannual fluctuations in the abundance of organisms. A mechanism of blooms is proposed, postulating that blooming species may be, in some years, in a particularly favourable position as regards seasonal changes of the main environmental factors, thus overcoming their competitors. The role of circannual rhythms in this process is discussed. On the basis of a series of observations, the hypothesis is advanced that alternate blooms of different species may be quite a normal characteristic of the seasonal dynamics of gelatinous zooplankton. A possible adaptive value of the alternation of periods of rarity and abundance is discussed, suggesting that rarity periods may facilitate the appearance of mutations in isolated populations, and that bloom periods may contribute to the establishment of favourable mutations over a vast geographic scale.

1. INTRODUCTION

The quality of the physical environment, with its continuous changes, has a determining influence on organic evolution. On the other hand, the evolution of new forms or simply the alternation of the dominance of forms with differing adaptations, modifies the environment. The reciprocal influences between the physical and the biological components of the environment result however in some balances which guarantee the survival of the biocoenoses. In other words there is a homeostasis between the biological and non-biological features of a given environment, so that the overall processes determining its functional aspects are not affected by structural changes. The biological component has to find an external equilibrium with the physical one as well as an internal equilibrium within all the living forms which constitute it.

A well known example of adaptation of the biological fraction of the environment to the changes occurring in the physical fraction is the response of organisms to the alternation of seasons. Shallow water marine environments, for instance, are typically characterized by two different seasons, determined by fluctuations in some important physical factors. Temperature determines a cold and a warm season in temperate areas; turbidity and, to a lesser extent, salinity are the main factors affected by the alternation of a dry and a wet season at tropical latitudes. The organisms have adapted to a certain range of conditions and, usually, they show circannual rhythms of activity. For perennial organisms, living more than one year, it is mainly reproduction which is influenced. On the other hand seasonal organisms disappear under unfavourable conditions, usually surviving as resting stages, and play an important structural and functional role only in restricted periods, when the conditions are favourable for their reproduction and growth. Perennial organisms can have resting periodsalso, when individuals are present but with reduced or nearly non-existent activity. This is true of seagrasses such as *Posidonia*, and of hydroids such as *Eudendrium*.

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In some cases perennial species are important structural elements, as is the case with *Posidonia* meadows on coral reefs, so that the main characteristics of the environment are not strikingly altered in the different seasons. In other cases there can be a substitution of the characteristic species, as happens in the Mediterranean for the *Eudendrium* and the algal communities, characterizing respectively cold and warm seasons on rocky sea beds (Boero and Fresi, 1986; Boero *et al.*, 1986). These structural changes are particularly evident in planktonic communities with completely different species assemblages characterizing the two seasons and the intermediate periods.

Benthic communities are characterized by a high number of perennial species, whereas seasonal species are typical of planktonic communities. Nectonic communities have an intermediate position. The three different domains of the marine environment are anyway strictly linked from a functional point of view, each one depending on the others.

Fluctuations

If recurring differences in physical conditions cause structural changes in the biocoenoses, it is probable that the structure of the populations undergoes a certain degree of variation in the same seasons of different years. This is more evident when varying species are important for human activities. Balestra *et al.*, (1976) study the structure of a pelagic community sampled by a tunny fishing net operating at Camogli (Ligurian Sea) over a period of 25 years (1950-1974). It was observed that some species can show a continuous increase or diminution in presence, whereas other species undergo more or less regular cycles in their abundance, and yet others may explode for short periods and then be completely absent for several years. The overall biomass, however, does not show dramatic changes. It is possible that different species can play similar roles, so that the structural changes do not necessarily cause functional modifications of the biological processes: this situation constitutes a clear example of dynamic equilibrium, in which the yearly changes in structure of a given population do not affect its functionality. This means that in addition to the seasonal changes already cited the biological component of the environment can also undergo long-term fluctuations, not directly caused by the alternation of seasons. A vast number of examples of this phenomenon exists in studies on fisheries.

Long term surveys are necessary to detect this kind of phenomena, which may be too rapid to be recognized from the fossil record, but too slow to be detected in a few years of observation. These processes are far better known for the terrestrial environment in regions, such as Great Britain (Hawksworth, 1974) that have been studied in depth, but it is probable that, with proper observation, they can be gradually recognized as rules than as exceptions in nearly every type of well structured community.

In any event, it is difficult to recognize pluriannual fluctuations by simply comparing the results of ecological studies on the same area by different researchers in different periods. Ecologists do not always have a similar knowledge of all groups, often stressing the importance of the organisms they know best. Sometimes they use different sampling techniques so that, for instance, it is hazardous to compare a faunal list obtained by dredge samplings with a list obtained by samples collected by scuba divers. In any case, some examples are available of important fluctuations of certain marine invertebrates. For instance, Boero and Cattaneo-Vietti (in prep.) have seen that species of hydroids and opisthobranch molluscs which were unknown to science a few decades ago, are now important components of shallow water benthic communities. Other species reported as fairly common in the first decades of the century are now rare.

Long-term fluctuations, then, are possibly a normal event and only in certain cases they can be considered as dystrophic.

Blooms

The dynamic balances described which characterize the annual and pluriannual changes in the structure of marine communities can be temporarily altered by the apparently abnormal abundance of one or a few species. These phenomena are called blooms. In some cases they can even become a regular feature of restricted and simple environments, such as the alpine lake of Tovel. They usually, however, have a negative impact on marine communities and can be considered as dystrophic events, sometimes caused by

natural phenomena (El Niño), and other times possibly by human activities (red tides in the Adriatic). Furthermore, the abnormal increase in the numbers of the crown of thorns starfish (*Acanthaster planci*) in the Great Barrier Reef can be considered as a bloom; the same goes for the seasonal mass appearances of the planktonic hydroid *Velella* in the Pacific. However there is a big difference between these two phenomena. The starfish, in fact, is usually represented by low population density which only occasionally increase in number; *Velella* is regularly represented by large population during certain periods; thus, the former can be considered an abnormal phenomenon, while the latter is quite normal, because it is regular.

The blooms of *Pelagia noctiluca* observed in the Mediterranean in the last few years could be considered abnormal, even if similar events had appeared in the past. It could also be that they are the result of long-term fluctuations, like other apparently abnormal blooms.

Bloom formation mechanism

The causes of blooms and the mechanisms involved are a subject of debate among specialists. Some claim that blooms are caused by physical events occurring on a planetary or even cosmic scale such as solar spots, changes in oceanic circulation e.t.c. Other specialists blame mainly human activities. Both positions may be right in some cases, even if they do not fully explain what is the mechanism which leads to the "victory" of one species over all others.

Some researchers (Vucetic, 1983) have proposed hormesis (the increase in sexual reproduction to escape the effect of sublethal agents) as a possible cause of *Pelagia* blooms, but this seems only partially practicable to explain large scale phenomena. Hormesis can be effective only if the source of disturbance is restricted in space. Otherwise the conditions should also be unfavourable for larvae, so that they can not develop into adults. The effects of hormesis would then affect a small population, without significant impact on the environment. It could be argued that the disturbance is restricted in time and widespread in space, but such a phenomenon would be evident and, as a matter of fact, nothing is known to have happened in the Mediterranean which could have caused a wide scale hormesis for *Pelagia* in the whole basin.

A possible answer to the general problem of blooms can be derived from all the observations mentioned above concerning annual and pluriannual cycles and from the discovery that many animals and especially cnidarians possess internal circannual clocks, anticipating more or less regular changes of physical factors. Brock (1975) has demonstrated that the hydroid *Laomedea flexuosa*, shows active growth and reproduction before the beginning of the favourable season. The species seems to be "ready" to take advantage of a certain situation in the most efficient way.

Thus, it is possible that in a given year a certain species is better "tuned" to seasonal changes than its competitors. This would result in a very efficient larval recruitment and a consequent increase in population size. This species would therefore "fill" the environment almost competely from a structural and a functional point of view, exploiting the available resources and overcoming its competitors. A bloom would then occur.

Such an increase in population size of the population causes an increase in the reproductive effort so that, in the next favourable seasons, the species is again in an advantageous position, even without a favourable "tuning" of the circannual clock. The decrease of the competitors in the preceeding year reduces their reproductive potential while that of the blooming species increases. The bloom may therefore continue for some years but the exploitation of the available resources decreases the stocks of the prey species, whereas the populations of possible predators and parasites presumable increase. This leads to a return of the "normal" situation and other species may take advantage of the situation.

Gelatinous zooplankton blooms

It is possible that such phenomena are almost the rule for gelatinous zooplankton but that they are recognized only when noxious species are involved. Periodical blooms of siphonophores, hydromedusae, ctenophores and tunicates are continuously observed by fishermen and field researchers all over the world, but their impact on human activities is less important than that of *Pelagia*, so they often pass unnoticed. Bouillon *et al.*, (1986), on the basis of more than ten years of daily samplings of hydromedusae in the Bismarck Sea (Papua, New Guinea) observed that different species characterize certain periods and that blooms are quite a normal event for medusae. In August 1986 a bloom of *Pelagia* was observed in Papua New Guinea (Boero and Bouillon, unpublished observation), where environmental conditions are much

different than in the Mediterranean. *P. noctiluca* is a circumtropical species and it is possible that local populations undergo what appear to be abnormal increases in different periods and in different years. However, such phenomena are noticed and reported only when they constitute a disturbance for human activities. Very few humans cared about the above mentioned bloom of *Pelagia* in Papua New Guinea.

Hammer and Schneider (1986) have shown that jellyfish and presumably all gelatinous zooplankton can be gathered by Langmuir circulation to form long patches on the sea surface. This phenomenon has been described for *Aurelia* in the North Sea, but similar patterns of distribution have been observed by Boero, Bouillon and Seghers (unpublished observation) in the Bismarck Sea; it is possible that we are dealing with a rather common mechanism of concentration of scattered populations for the purpose of making more evident the presence of a conspicuous species when prolonged periods of calm weather occur.

2. CONCLUSIONS

Future research on blooms

The situation outlined in the present paper is based on the interpretation of a series of observations and is at this point hypothetical. The only way to test it, is to promote long-term and large-scale studies on the structure and function of the communities of gelatinous zooplankton, to see whether what is called a bloom for *Pelagia* is happening normally for other less conspicuous (or dangerous) species in a cyclical or erratic way. With this kind of approach it will be possible to know whether the blooms of *Pelagia* are really a dystrophic event or whether they are normal, even if noxious, phenomena.

It is important, at this point, that sampling methods be standardized throughout the research area in order to have comparable data. Plankton nets are usually not a very good instrument for the collection of gelatinous zooplankton and can rarely give an idea about the abundance of species. Furthermore, the study the gut content of gelatinous organisms collected by plankton nets does not give reliable results because gelatinous organisms are inevitably exposed for a rather long period to abnormally high concentrations of organisms that they actively kill and ingest. This of course does not mean that they would have similar diets under normal conditions, when they can be more selective.

The best method of sampling and observation of gelatinous zooplankton seems to be diving (see Zavodnik, 1987), because the situation can be directly inspected *in situ*, without having to use sampling instruments which inevitably give a distorted picture of population structure and distribution.

Light must be shed on the life cycles of gelatinous forms; the fertility periods of the various species must be clarified, in order to have advance knowledge of species which would be in bloom in a given season. The majority of the life cycles of hydromedusae, for instance, is unknown and further research in this field would be helpful to understand better the bloom phenomenon.

Evolutionary meaning of blooms

The ultimate target for any biological research should be to understand the phenomena involved and include them in the framework of the most synthetic of all biological sciences: evolutionary biology. Phenomena, such as blooms, which seem to be dystrophic, can reveal a certain adaptive value, with a possible influence on evolutionary processes. Isolation or fragmentation of local populations is one of the prerequisites for the establishment of favourable mutations and thus evolution. Small populations, on the other hand, have a limited impact on the structure of a certain environment, so that mutations must be of dramatic importance if they manage to bring about the explosion and sudden success of a small population of a given organism. Such events are presumably very rare. They are taken into consideration by the theory of punctuated evolution and are possibly valid under certain circumstances (see Boero and Sarà, in press, for a discussion of punctuated evolution in hydrozoan life cycles). But, as remarked by Boero and Sarà (in press), it is also possible that gradual modification may result in speciation. If mutations are more frequent in fragmented populations, temporary rarity may have a potential evolutionary value. The significance of blooms is that the fragmented populations of a species in a given area (for example the Mediterranean) have the possibility of merging, so that latent favourable mutations may rapidly spread over a vast geographic area.

The alternation of periods of rarity and abundance of a species, according to the mechanism described above, could lead to a gradual evolution in the marine environment, where geographic barriers are not as defined as on land.

3. ACKNOWLEDGEMENTS

Thanks are due to Prof. Michele Sarà (Genova), Prof. Jean Bouillon (Bruxelles) and Dr. Carlo Nike Bianchi (La Spezia, Santa Teresa) for their valuable comments.

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MACROPLANKTONIC JELLYFISH IN THE LIGURIAN SEA (1984-1986). MONITORING AND BIOLOGICAL CHARACTERISTICS.

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1. INTRODUCTION

The research project on jellyfish, part of the MED POL Programme of UNEP/MAP), was launched on June 21, 1984, at a meeting held in S. Margherita Ligure of the Contracting Parties to the Convention for the Protection of the Mediterranean Sea.

The study of jellyfish blooms in the Ligurian waters was set up with special regard to species harmful to man and his activities at sea, according to some axes which can be summed up as follows:

- jellyfish monitoring in a large area of the Ligurian Sea;

- observation of the plankton samples taken at different points in the Ligurian Sea during periods previous to that of the bloom in order to find jellyfish ephyrae;

- biochemical aspects of some jellyfish species in terms of substances such as proteins, lipids and fatty acids.

The first stage of the research was to send specially, prepared sighting cards to the Mayors of the Riviera Municipalites from Ventimiglia to La Spezia. This card gave some details and a brief morphological description of the Scyphomedusae species generally occurring in the Ligurian Sea. In the card information was requested regarding the number of individuals sighted and any other information concerning hydrological and atmospherical parameters. The following were the species mentioned: *Aurelia aurita, Pelagia noctiluca, Crysaora hisoscella, Cotylorhiza tuberculata, Rhizostoma pulmo.*

Most mayors attached little importance to the matter and only the Municipalities of Rapallo, Recco, Spotorno, Ceriale and Imperia returned cards, completed either directly or through Sporting Clubs or by owners of bathing establishments. The "G. S. Olimpia Sub Spotorno", in particular, returned completed cards with almost daily observations (Sept. 1, 1984-Jan. 31, 1985).

The co-operation of the "Centro Carabinieri Subacquei" of Genova-Voltri has been invaluable in jellyfish monitoring since August 1984 and it continues to provide information on the occurrence of jellyfish in the area between Imperia and La Spezia.

2. CARD EXAMINATION

The explored sea area of Spotorno - about 15 Km^2 - lies between Capo Noli and Bergeggi Island. The cards report the data obtained between September 1984-January 1985; exploration was conducted for a total of 141 days. Observations were carried out both in- and off-shore, at depths of about 400 metres. The results of this activity were the subject of a paper presented at the "XVII Convegno di Biologia Marina" held at Ferrara in 1985.

In this area, during the period of study there was a prevailing occurrence of *Pelagia noctiluca*, which constituted about 57.2% of the organisms found in the open sea and 52.6% inshore. *Aurelia aurita* follows with percentages of 31.0% and 32.7% in the open sea and inshore waters, respectively. Other species represented a considerably lower percentage: *Rhizostoma pulmo* about 7%, *Cotylorhiza tuberculata* about 5%, *Crysaora hysoscella* 3.5%, both in the open sea and inshore waters. The negative effect of turbid, wavy

or rough seas on the presence and/or the individualization of jellyfish in the open sea was also pointed out.

Regarding data obtained from the inshore area, there is considerable parallelism with those from the open sea which is remarkable, even if the total number of jellyfish is lower.

As regards the other areas of the Ligurian Sea, the cards gave us data from 124 observations in the open sea between August and December 1984, from 285 sailings and 70 divings in different localities for 1985 and from 295 observations in the sea of which 179 by divers for 1986. All observations and divings were carried out by the divers of the "Centro Carabinieri Subacquei" of Genova-Voltri.

Table 1 lists the localities explored both by means of sightings and divings during the three years period.

In the year 1984, the area between S. Margherita Ligure and Diano Marina was explored. In 1985, observations relating to the stretch of sea between Alassio and La Spezia were carried out and extended to the Elba and Montecristo Islands. For the year 1986, the localities covered were those considered in previous years as well as new areas such as Porto Maurizio, Portoferraio, Rosignano Marittimo and the Gallinara Island.

Table 2 contains details on localities, species found, abundance, number of days and months with reference to the three years considered.

Table 1. Explored localities in the considered three years, distinguished by activity.

ACTIVITY	EXPLORED LOCALITIES	YEAR
DIVINGS	not specified	1984
SAILINGS	Portofino-Varazze; Genova-Camogli-Punta Chiappa; Genova-Diano Marina; Genova-S.Margherita Ligure.	
DIVINGS	Montecristo island, Pareti (Elba island), La Spezia, Sestri Levante, Lavagna, Zoagli, Portofino, S.Fruttuoso, Punta Chiappa, Genova (harbour), Genova Sestri, Genova Pegli, Genova Voltri, Vesima, Crevari (facing zone), Arenzano, Cogoleto, Bergeggi island, Albenga, Alassio, Diano Marina, Oneglia.	1985
SAILINGS	Porto S.Stefano-Montecristo island; Portofino-Portofino Faro; Portofino-Varazze; Camogli-Punta Chiappa; Genova-Rapallo; Genova-San Fruttuoso; Genova Voltri-Arenzano; Genova Voltri-Cogoleto; Spotorno-Bergeggi island.	
DIVINGS	Portoferraio, Rosignano Marittimo, La Spezia, Riomaggiore, S.Margherita L., Paraggi, Portofino, S.Fruttuoso, Punta Chiappa, Sori, Genova Nervi, Genova Punta Vagno, Genova (harbour), Genova Sestri, Genova Pegli, Genova Voltri, Arenzano, Cogoleto, Varazze, Vado Ligure, Bergeggi island, Albenga, Gallinara island,Diano Marina, Imperia, Porto Maurizio.	1986
SAILINGS	Genova-S.Margherita Ligure; Genova-Sori; Genova-Genova Voltri; Genova-Arenzano; Genova-Cogoleto.	

In 1984 (even if the observations were limited to the last four months), considerable aggregations of individuals occurred in August, September and October (no sighting in November). The presence of jellyfish was ascertained by means of sightings, during the four months considered, over a period of 53 days. The species found in a sufficiently extended area (from Diano Marina to Portofino) were *P. noctiluca* and *R. pulmo.*

However, a progressive decrease of the sightings occurred in the following years, despite the greater number of sailings. In fact, only on twelve days out of six months of observations carried out in 1985, was the presence of jellyfish was noted. Their abundance also underwent a clear decrease with poor findings. The species sighted were: *A. aurita, P. noctiluca* and *R. pulmo*.

In 1986, observations were positive during the months of January, May, July and August, for only seven days. In this period a slight increase was noted in the first months with some abundant sightings.

Figure 1 shows the localities where the presence of jellyfish was noted during the three years mentioned.

3. PLANKTON EXAMINATION

The study of the presence and distribution of jellyfish in the Ligurian Sea was considered from the reproductive potential aspect through the analysis of plankton collected in different localities in the years previous to the bloom in order to search for planulae and ephyrae. Samples from the periods 1978-79 and

Table 2. Abundance and species of jellyfish in the various localities and number of sighting days, distinguished by months, in the considered three years.
(Abundance: * scarce, ** abundant, *** very abundant)

YEAR	MONTH	SIGHTING (n. days)	JELLYFISH ABUNDANCE	JELLYFISH SPECIES	LOCALITIES
1984	August	10	***	Pelagia noctiluca Rhizostoma pulmo	S.Margherita Ligure
	September	25	***	Pelagia noctiluca Rhizostoma pulmo	Diano Marina
	October	17	***	Pelagia noctiluca	Portofino-Varazze
	December	1	*	Rhizostoma pulmo	Punta Chiappa
total	4	53			
1985	January	4	*	Aurelia aurita	Punta Chiappa
	June	2	*	Pelagia noctiluca	Oneglia
	July	2	*	Pelagia noctiluca	Arenzano Genova Voltri
	August	1	*	Pelagia noctiluca	Diano Marina
	September	1	*	Rhizostoma pulmo	Vesima
	November	2	*	Aurelia aurita	Portofino
total	6	12			
1986	January	2	**	Pelagia noctiluca	Arenzano S.Fruttuoso
	May	1	**	Rhizostoma pulmo	Cogoleto
	July	3	*	Rhizostoma pulmo	Punta Chiappa S.Margherita Ligure
	August	1	*	Cotylorhiza tuberculata	Albenga(Gallinara is.)
total	4	7			

1984-85 were analyzed *in toto*. In 1978-79 plankton samples taken during the months of May, June, July, September and November 1978, and February, April and August 1979 were examined. In 1978 observations were made in Savona, Varazze, Genova and Camogli, and in 1979 in Varazze and S. Margherita Ligure. No planulae or ephyrae were observed on the samples examined.

A larger presence, chiefly of ephyrae at low depths, was noted quite clearly in the investigations carried out in 1984 and 1985, compared to 1978-79. Although 42 plankton samples were examined in toto, the data obtained did not give useful information for interpreting the phenomenon occurring at the time because the occurrence of planulae and ephyrae was evident only in a limited number of samples.

4. LABORATORY EXPERIMENTS

Laboratory research was carried out into the biochemical composition of the jellyfish *R. pulmo* and *C. tuberculata* sampled in the area of Spotorno in April and October 1986 respectively. The aspects studied

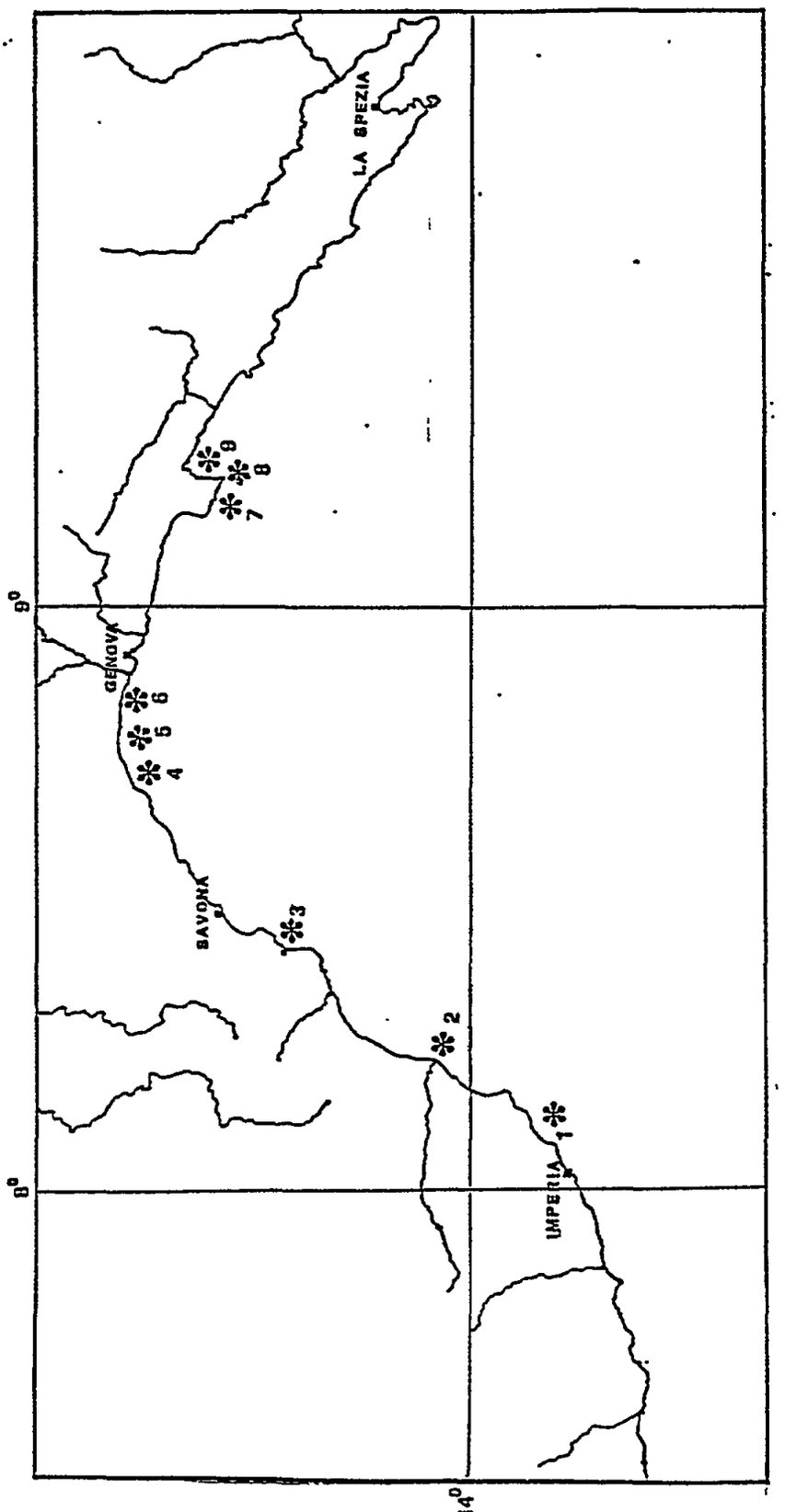

Fig. 1. Sighting localities of jellyfish in the years 1984/85/86. {1: Diano Marina, Oneglia 2: Albenga (Gallinara island). 3: Spotorno 4: Varazze. 5: Arenzano, Cogoleto. 6: Vesima, Genova-Voltri. 7: Punta Chiappa, S. Fruttuoso. 8: Portofino. 9: S. Margherita Ligure}.

regarded the content in proteins, lipids, fatty acids and water of some jellyfish structures. Bibliographical information about these research subjects is very poor. The topics appear important from the point of view of the connection with the reproductive cycle, food availability and environmental factors. Consequently in our study we aimed at gathering quantitative data which may also serve as a basis for comparative work with other zooplankton groups.

Dosages taken on the different structures of the jellyfish observed resulted in a dry weight value varying from 3.80% to 5.19% for *R. pulmo* while for *C. tuberculata* the values were generally higher, varying from 5.67% to 8.10%. Protein content percentages varied between 8.7% and 28.0% for *R. pulmo*, while in the case of *C. tuberculata* they varied between 7.56% and 36.84%. The percentage of chloroform extract in the structure of the two species varied from a minimum of 0.4% to a maximum of 6.40%. All percentages refer to dry weight.

The gas chromatographic analysis of the fatty acids contained in the lipids of the various jellyfish structures showed the presence, in percentage, of saturated acids with 14, 16 and 18 carbon atoms, monounsaturated with 16 and 18 carbon atoms and of some polyunsaturated with 18, 20 and 22 carbon atoms. No substantial differences in the percentages of the single fatty acids were observed regarding total fatty acids among the single structures of each jellyfish, while of the two species *R. pulmo* showed higher incidence of polyunsatured acids with respect to *C. tuberculata*.

5. CONCLUSIONS

The phenomenon of massive proliferation of jellyfish in the Mediterranean Sea has been complex, remarkable in amplitude and unexpected, considering its suddenness and the fact that it disappeared soon after it occurred.

The monitoring data of jellyfish in the Ligurian Sea compiled since the beginning of 1984 (the collection of data is still ongoing) show that the phenomenon attained remarkable proportions during 1984, decreasing progressively in subsequent years. In particular, the presence of *Pelagia noctiluca* since 1985 occurred occasionally and in limited numbers, with the exception of January and May 1986, when numerous specimens in the Arenzano and S. Fruttuoso areas, both in the Province of Genova, were sighted.

Generally, the Ligurian Riviera localites where the jellyfish were found with greatest frequency in the three years mentioned lie between S. Margherita Ligure and Punta Chiappa, Genova-Voltri and Varazze, Albenga and Diano Marina, as well as Spotorno.

The analysis of biochemical features, particularly fatty acids, which aimed at clarifying the diet of the two species considered, have to be verified further with data from various classes, ages, individuals and reproduction states.

6. ACKNOWLEDGMENTS

The Chair of Planktology was included in the research project "Sample monitoring of *Pelagia noctiluca* in the Ligurian Sea" with a first financing of $1,500, received in 1986. A further contribution ($2,000) was authorized recently for research conducted between 1986 and 1987. As stated in the applications for financing, these contributions must be considered symbolic, i.e. insufficient to carry out the whole research programme. Local financing of Italian Lire 2,500,000 was obtained at 60%; at the national level requests for 40% financing of the programme submitted in conjunction with other Universities were not accepted.

GENERAL FEATURES OF THE PLANKTONIC SYSTEM IN THE GULF OF TRIESTE AND THEIR VARIATIONS IN THE LAST DECADE

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1. INTRODUCTION

The Gulf of Trieste, the farthest north eastern part of the Northern Adriatic Sea, stretches from the mouth of river Isonzo to the Valley of Muggia.

The morphology of the coasts varies from the sandy mouth to the rocky coastline with cliffs falling sheer to the sea.

The fresh water inputs are the rivers Isonzo, Timavo, Rosandra and Ospo, as well as a number of submarine water springs along the whole coast.

The coasts are more or less densely inhabited, e.g. the town of Trieste (200,000 inhabitants), Monfalcone (40,000 inhabitants) and Muggia (15,000 inhabitants).

The most important winds are the Bora - NNE - dry and chill in summer, icy cold in winter and the Scirocco - SE - damp and warm, generally associated with atmospheric disturbance (Mosetti, 1968).

The hydrodynamism of the whole Gulf is primarily linked to the ascending eastern current, from the Istrian coasts, which transports high salinity waters from the Middle Adriatic into basin. This current produces and anti-clockwise circulatory movement which affects bottom and intermediate layers. Conversely, the fresh water from western areas tends to flow on the surface towards SW.

These morphological and climate conditions highly influence the characteristics of the Gulf waters; though typical of the Northern Adriatic, they are somewhat increased by the shallowness of the bottom, the conspicuous fresh water inputs, the high urbanization of the coast and the rather severe winter climate.

Specific planktonological research in the Gulf of Trieste date back to the end of 1800. Steuer, Cori, Claus, Graeffe, Kajdiz, Leder, Neppi and Stiasny left important records of the structure of the planktonic populations, but without any quantitative information and environmental data.

The research works in this field were resumed in 1961 and since 1970 they have been carried out with periodic collections at sampling stations.

This paper is meant to be a synthesis of all the studies in the planktonological field since 1970. The research was carried out by planktonologists of the Department of Biology, with the collaboration of Chemical Division of the USL n. 1, the Thalassographic Experimental Institute of CNR, the Institute of Geology and Paleontology and the Institute of Microbiology of the University of Trieste.

Most of the data have already been presented elsewhere in specific papers. Here will be examined only the data concerning the collections at sea at the same time of the day (from 9 to 11 a.m.), in the same sampling station, about 200m off the coast, at a depth of about 18m.

2. MATERIALS AND METHODS

From 1970 to 1976 temperature was recorded by inverted thermometers; in the following years (until 1987) by a Beckman sonde (model RSS - 3 salinometer); salinity was determined with a Beckman salinometer until 1976, later it was directly drawn from the conductivity through the Beckman sonde. Density was worked out by means of the UNESCO algorithms (1981).

The determinations of the chemical parameters, the total particles, the chlorophyll a, the phytoplankton and the microzooplankton were carried out with 5 l capacity Niskin PVC bottle on the surface, at the depth of 5 and 10m and close to the bottom.

The dissolved oxygen was determined with the Winkler method, at 5m intervals expressed as saturation percentage, calculated after the Weiss formula (Weiss,1970).

The analysis of N, P and Si were made only at the surface layer in the period 1976 -1980. The Solorzano method was used for ammonia, the Shin, Bendscheneider and Robison for nitrites, the Murphy and Riley method for phosphates and the Mullin and Riley method for silicates.

The chlorophyll a has been determined on the surface since 1980, in 1986-1987 even at 5, 10 and 15m depths, following the indications of Strikland and Parson (1972).

The primary production was monthly measured from April 1984 to October 1985 at 0m, 2m and 10m depths using the ^{14}C method (Magazzu, 1978).

The weight of total particulate matter was determined twice a month in the years 1983-1984, according to the method suggested by Banse *et al.*, (1963), modified by Brambati *et al.*, (1983), on the surface, at an intermediate layer and near the bottom.

The phytoplankton was studied in the years 1980, 1982, 1984, 1985 and 1986, the microzooplankton in 1986-1987. The water samples were fixed at 3% with neutralized formaldehyde and later analyzed on the Leitz Labovert or Diavert inverted microscope with the Uthermöhl method (Uthermöhl, 1958).

The zooplankton 200m was collected from 1970 to 1986 with WP 2 model nets of 200m mesh size, with vertical hauls from bottom to surface, fixed with 4% neutralized formaldehyde and then analyzed and counted on significant sub samples on the stereo - microscope.

The biomass of netzooplankton was expressed both as individuals per m^3 and as dry weight and ash weight, obtained by drying at 100 °C for 24 h and muffle combusting at 550 °C for 4 h (Lovegrove, 1966).

The mean and standard deviation for all the examined parameters were obtained for the same depths on the total number of data and expressed as monthly average means.

3. ANALYSIS OF RESULTS

Temperature

The surface thermic trend (Fig. 1) is very homogeneous, since it always records a minimum in February (average value 7.2 $\pm$ 0.69 °C) and a maximum in August (24.4 $\pm$ 1.36 °C) with highest variations of nearly 19 °C; at the other depths the difference between minimum and maximum values tends to decrease, though generally showing the same trend (Fig. 2).

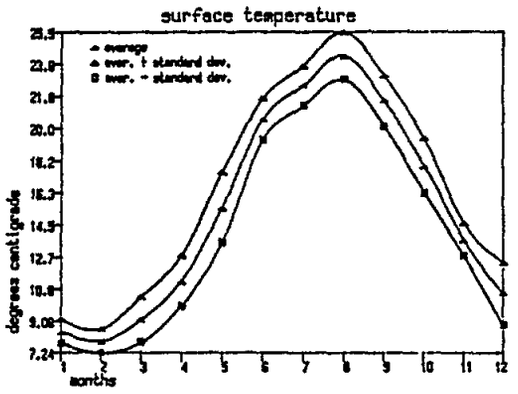


Fig. 1

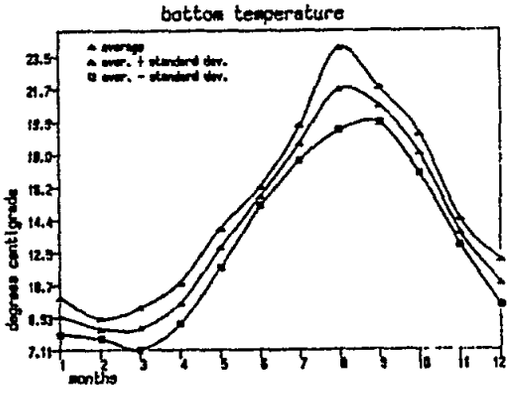


Fig. 2

The trend is typical of the Gulf waters, as related by Mosetti (1967), by Specchi and Famiani (1976) and by Stravisi (1983).

The water column shows conditions of mixing, which remains unaltered even in the coldest periods, from October to April, when a net thermocline begins to form at surface layers at first, it then tends to deepen with the passing of the season until September when it separates a layer, a couple of meters high, next to the bottom.

Salinity

The data on salinity, always recorded at the same time as temperature, show rather high standard deviations. These may be ascribed both to the different methods of analysis employed and to the intrinsic variability of the parameter in inshore environments.

On the surface (Fig. 3) a minimum is usually observed in June (average value 32.7 $\pm$ 0.48) and a maximum in February (37.6 $\pm$ 0.34), this maximum being mainly linked to the inlet of deep waters from the South into the Gulf.

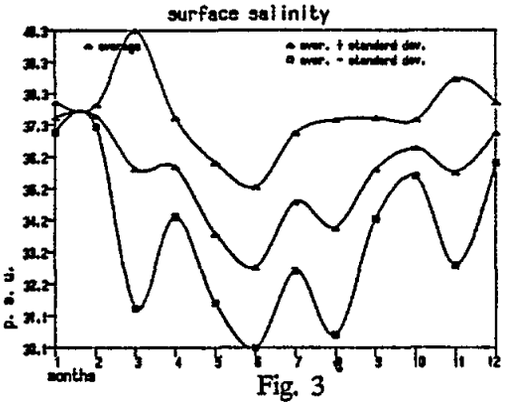


Fig. 3

Even the salinity trend at deep depths reflects the surface one, yet it is less variable, the layer closest to the bottom being more constant and varying from 36.2 to 38.5.

The surface haline stratification coincides with the rainfalls of the area, which are heavier from March to June and in October-November.

Density

During winter the water column is rather mixed (Fig. 4) characterized by dense, cold and salty water. In spring, the progressive surface heating and, to a lesser extent, the fresh water supplies bring forth subsequent stratification (Fig. 5). Only the denser, deep, residual water nucleus can be identified and, on the

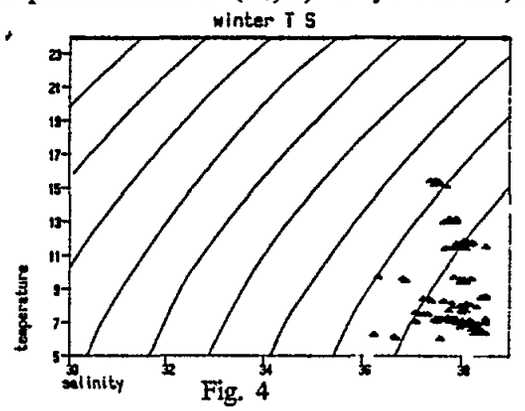


Fig. 4

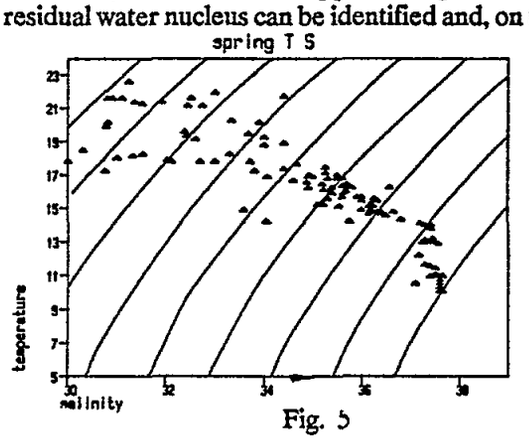


Fig. 5

surface, the water becomes progressively lighter, fresher and warmer. During the summer (Fig. 6) two neatly divided water bodies with a high stability are observed. A denser one, from the winter deep body and a less dense, warmer surface body which is persisting salty because of the intense evaporation. In autumn (Fig. 7), the column tends towards the winter scheme, i.e. an isothermic and isohaline structure.

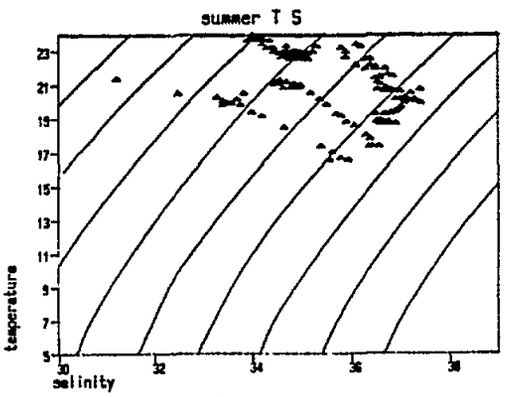


Fig. 6

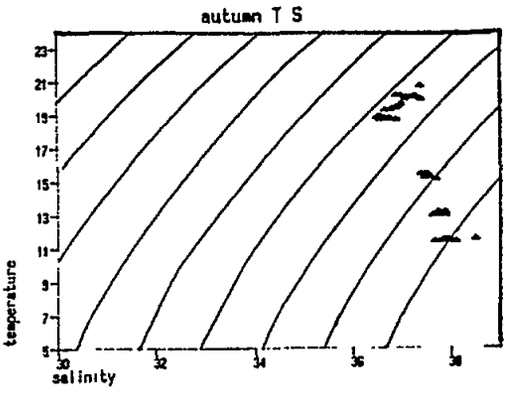


Fig. 7

Dissolved oxygen

On the surface (Fig. 8) the maximum saturation is recorded in July (average value 134.6 ± 11.5%) and the minimum in November (92.0 ± 19.6%).

On the bottom (Fig. 9) subsaturation is more frequent (February, June, September, October, November and December), but only in September it reaches important amounts (average value 86.3 ± 18.3%)

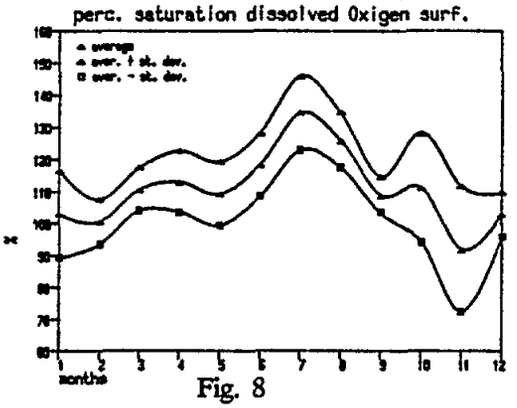


Fig. 8

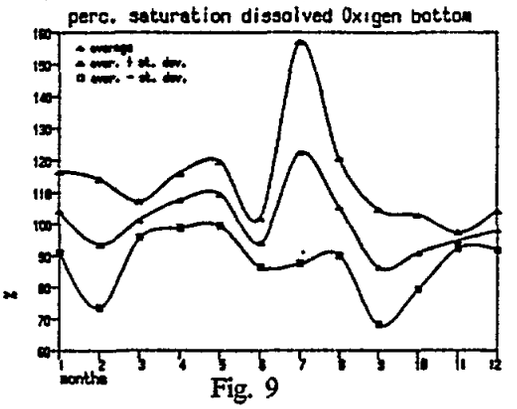


Fig. 9

and is linked to the thermohaline structure of the water column which, as mentioned above, is characterized by a net thermohaline change, two meters from the bottom. The remineralization of the whole organic substance produced in the surface layers during the summer occurs here with further oxygen consumption.

Nutrient salts

Ammonia (Fig. 10) reports the highest value on the surface in March and the lowest in May. During the summer, values are relatively high, due to the excretion phenomena of the pelagic populations and to the almost continuous terrigenus inputs.

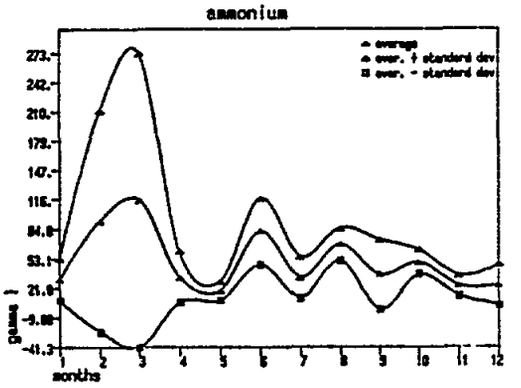


Fig. 10

The values of the nitrites (Fig. 11) are highest during the winter and lowest from April to September, while the phosphates (Fig. 12) trend is quite similar to that of ammonia even if during the summer their levels are extremely low.

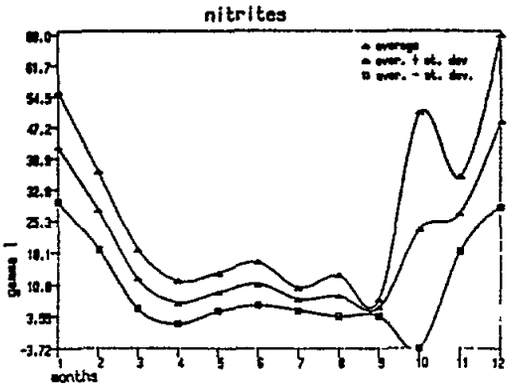


Fig. 11

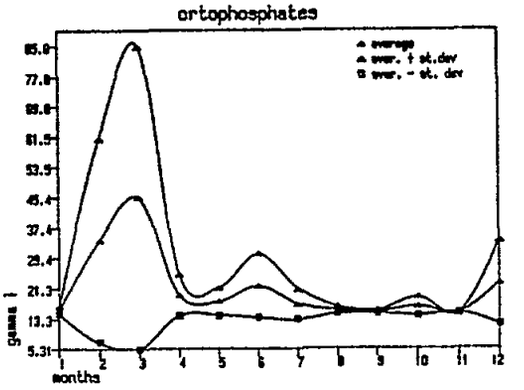


Fig. 12

Total particulate matter

The highest weight increase in the total particulate matter, expressed as mg/dm^3 of dry weight, is recorded between April and September (Fig. 13). Fonda Umani *et al.*, (1985) suggest it might be related both to terrigenus inputs and to the maximum values of phytoplanktonic blooms. Most of the suspended particulate matter is formed by inorganic detritus, and this is due to the vicinity of the coast and the shallowness of the sea bottom.

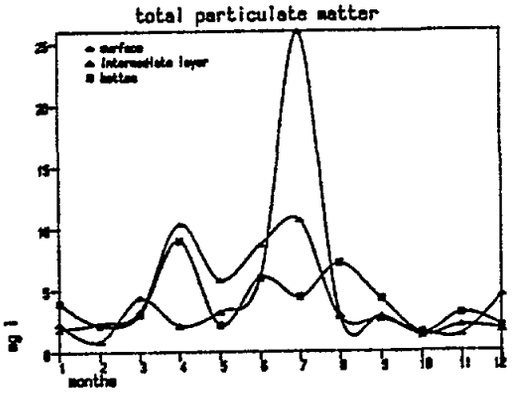


Fig. 13

Chlorophyll -a

The monthly average values at the surface (Fig. 14) show a particular trend with a maximum in November and a minimum in May, varying, however, within a little interval (from 0.4 to 4.3 mg/m^3). Chlorophyll values are rather high even in other periods when also abundance of phytoplankton populations is high.

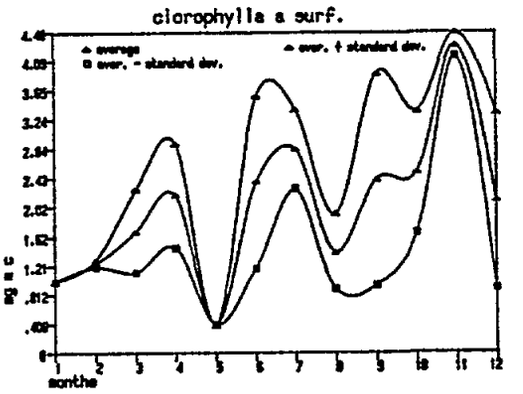


Fig. 14

Primary production

The highest values occur in June and September (Fig. 15). Significant peaks are not observed in spring; this may be ascribed to the lack of data in March, when a high primary production should occur. Faganeli *et al.*, (1981) have found the same trend in the Gulf of Trieste. Monthly average values vary from a minimum in December of 0.8 to a maximum of 14 g C/ m^2 / month in June for an annual value of 53 g C / m^2 / year (42 g C / m^2 / year for Faganeli *et al.*, 1981).

The primary production maxima generally occur in the subsurface layers, except in September when a remarkably higher values was observed in correspondence to the deepest layer. The phytoplankton populations as well as particulate matter are particularly scarce in this period in the whole column, thus further encouraging the penetration of radiant energy as deep as the bottom layer, richer in nutrient salts for the remineralization.

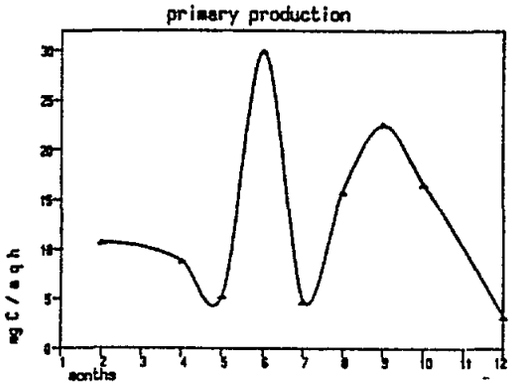


Fig. 15

Phytoplankton

The surface monthly values of phytoplankton abundance, expressed as cells / dm^3 (Fig. 16), show an absolute maximum in summer and a relative one in April. The spring maximum are mainly due to diatoms,

whereas the summer values are due to the smaller size phytoplankton fraction (nanoplankton); therefore, if we translate the cellular abundance values into C content we find a completely different trend, with a sole absolute maximum in spring (Cabrini *et al.*, in press).

The maxima on the column are recorded on the surface or the subsurface for the whole year, except in the August - September period, when they are located next to the bottom in the above mentioned separated layer, where the highest values of primary production are also recorded.

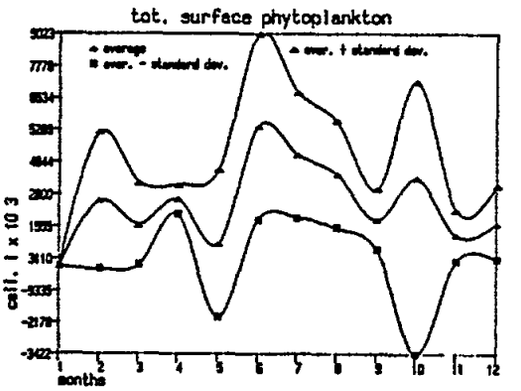


Fig. 16

The taxonomic composition of the phytoplanktonic populations is quite similar at the different depths: the population is dominated by "Microflagellates" (nanoplankton) (comprising small size Euglenophyceae, Prasinophyceae, Clorophyceae and Dinophyceae) throughout the year, except in April and from July to November (Fig. 17) when Diatoms (*Skeletonema costatum, Leptocylindrus danicus, Chaetoceros* sp.p., *Rhizosolenia* sp.p. and *Nitzschia* sp.p.) prevail. In June the highest percentage of Dinoflagellates (with genera *Gymnodinium, Gyrodinium, Peridinium, Scrippsiella, Gonyaulax* and

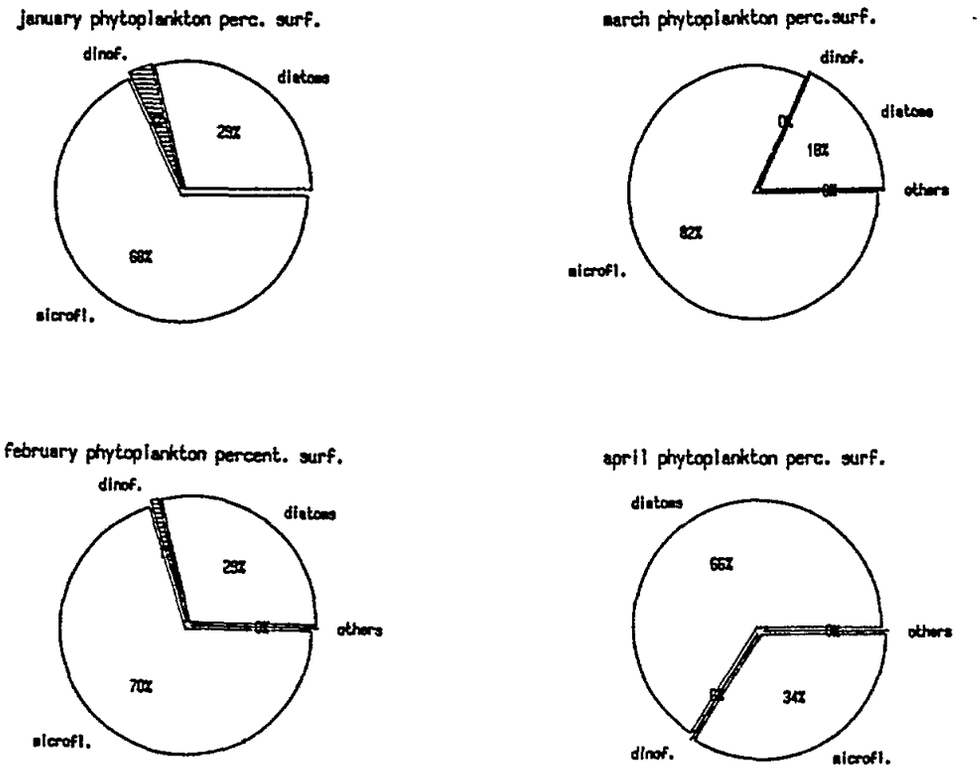
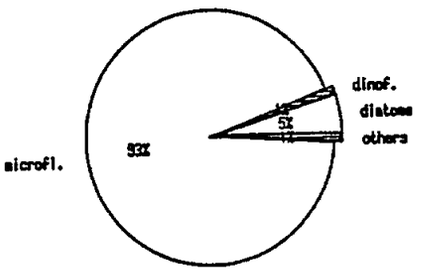
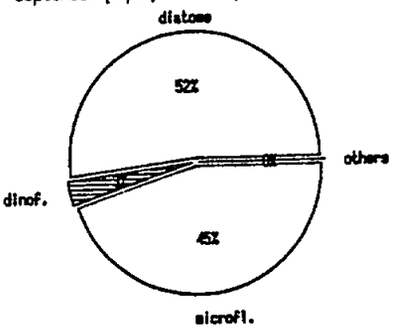


Fig. 17 a

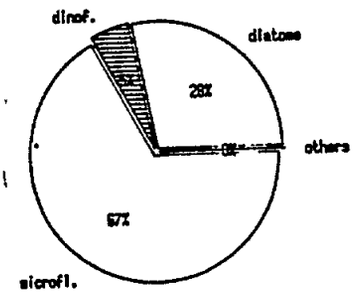
may phytoplankton perc. surf.



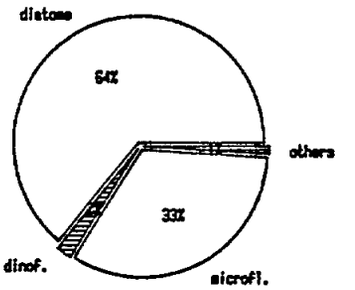
september phytoplankton perc. surf.



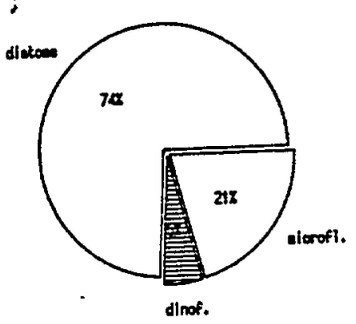
june phytoplankton perc. surf.



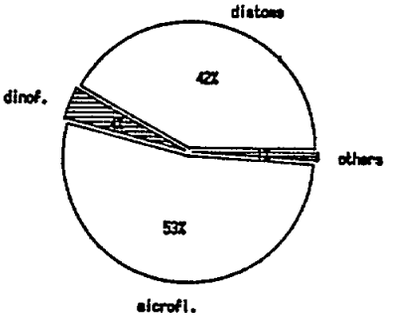
october phytoplankton perc. surf.



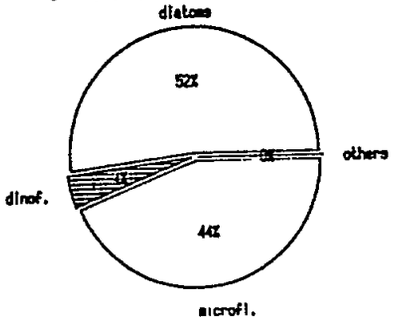
july phytoplankton perc. surf.



noveaber phytoplankton perc. surf.



august phytoplankton perc. surf.



deceaber phytoplankton perc. surf.

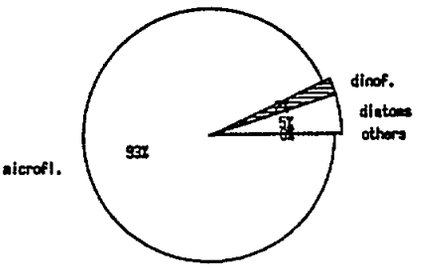


Fig. 17 b

Prorocentrum) is recorded. Only in May the group formed by Silicoflagellates and Coccolithophorids ("Others") reaches 1%, their percentage being lower throughout the whole year.

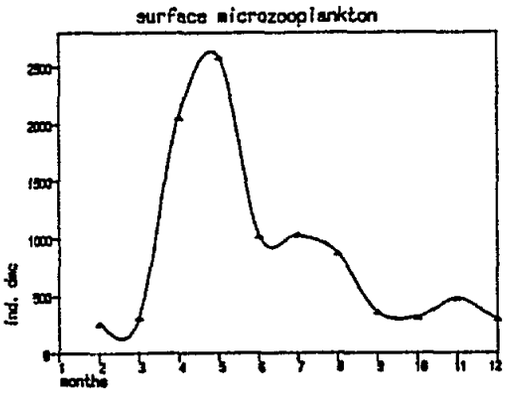


Fig. 18

Microzooplankton

During 1986/1987 the microzooplanktonic population reaches the absolute maximum on the surface in May (Fig. 18), the minimum occur from December to March.

Even the microzooplankton quantitative trend at lower depths (5m, 10m and 15m) reflects the surface one, though generally maintaining at lower values.

At the surface, from February to September, the population is dominated by the Ciliates other than Tintinnids (the genus *Strombidium* often prevails) (Fig. 19), while in October, November and December the Tintinnids, always present in percentages higher than 8%, prevail. In autumn, spring and winter the

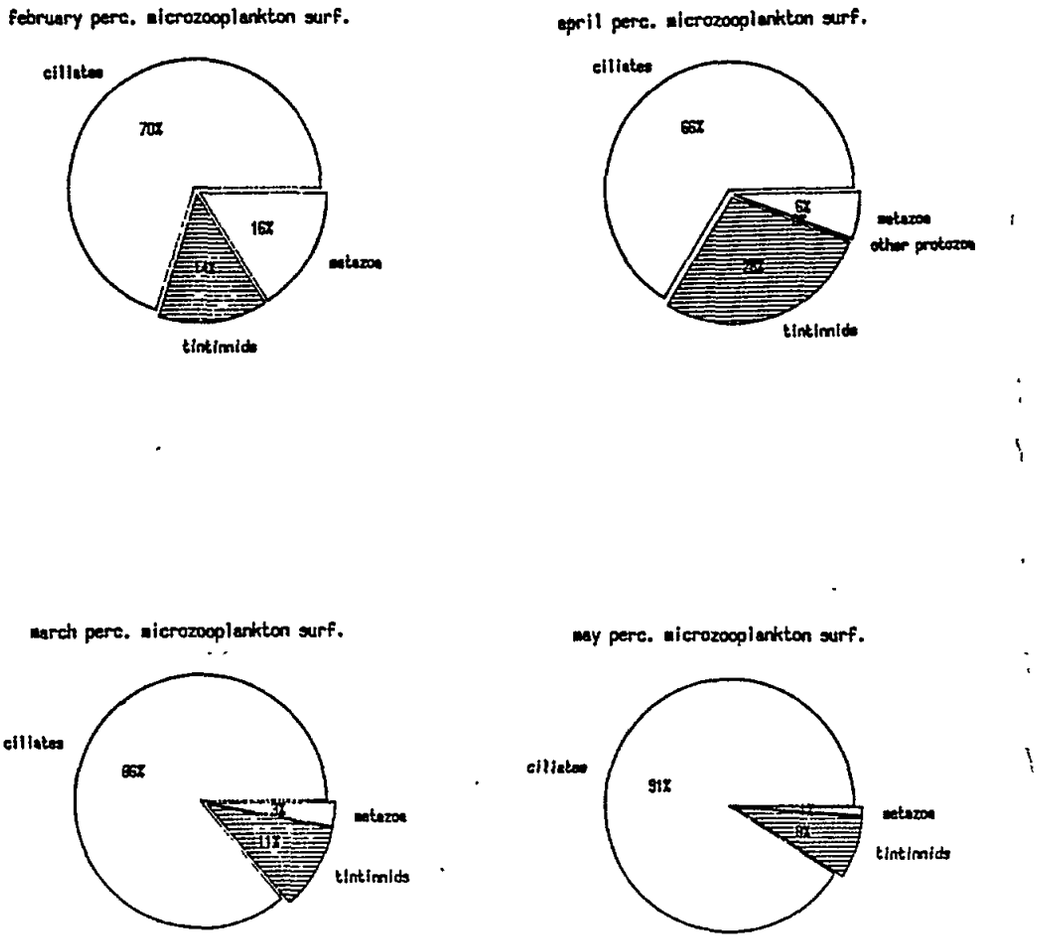


Fig. 19 a

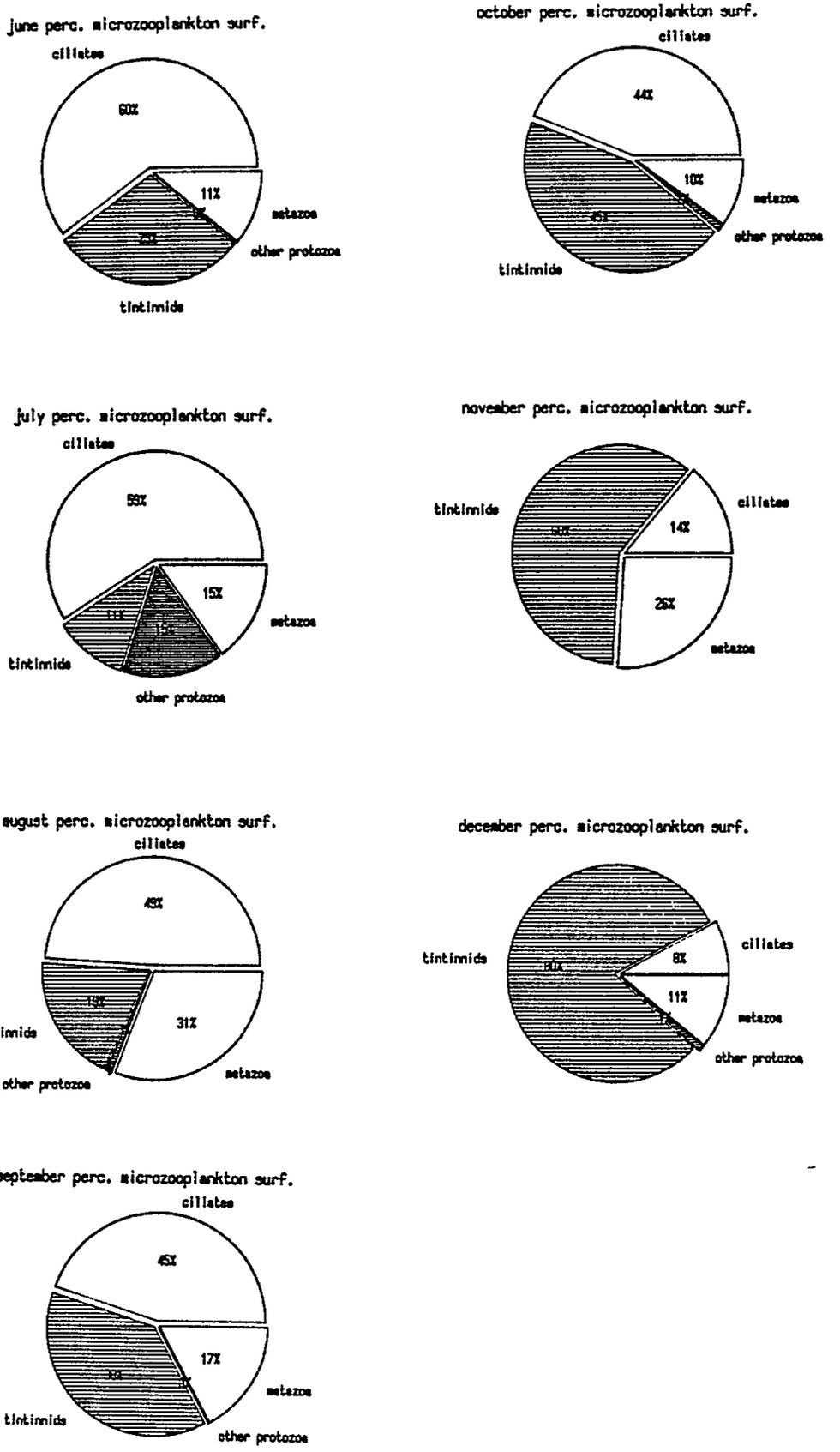

june perc. microzooplankton surf.
ciliates
60%
11%
metazoa
other protozoa
tintinnids
october perc. microzooplankton surf.
ciliates
44%
10%
metazoa
other protozoa
tintinnids
july perc. microzooplankton surf.
ciliates
59%
15%
metazoa
tintinnids
other protozoa
november perc. microzooplankton surf.
tintinnids
ciliates
14%
25%
metazoa
august perc. microzooplankton surf.
ciliates
49%
tintinnids
31%
other protozoa
metazoa
december perc. microzooplankton surf.
tintinnids
ciliates
8%
11%
metazoa
other protozoa
september perc. microzooplankton surf.
ciliates
45%
17%
metazoa
tintinnids
other protozoa

Fig. 19 b

genus *Tintinopsis* prevails, and the genera *Eutintinnus, Salpingella and Helicostomella* are dominant in summer.

The "other Protozoa", comprising Foraminifera, Flagellates and Radiolaria are well represented only in July, while the larvae of Metazoa ("Metazoa") are important over the whole year, particularly in February and from June to the end of the month of December.

The percent monthly composition just described is reflected at the other depths, though the Tintinnids and the larvae of Metazoa are often more abundant than in the surface layer.

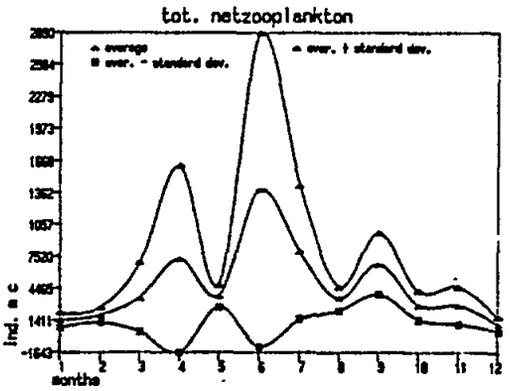


Fig. 20

Net zooplankton

The total quantitative trend, expressed as individuals / m^3 (Fig. 20), indicates an absolute maximum in June and minima in winter.

The taxonomic composition of the Gulf population - already described by Ghirardelli (1975, 1983) Specchi *et al.* (1981), Fonda Umani *et al.* (1982a, 1984) - is dominated by the Copepods for most of the year. In fact their percentage decrease under 50% (Fig. 21) only from July to September.

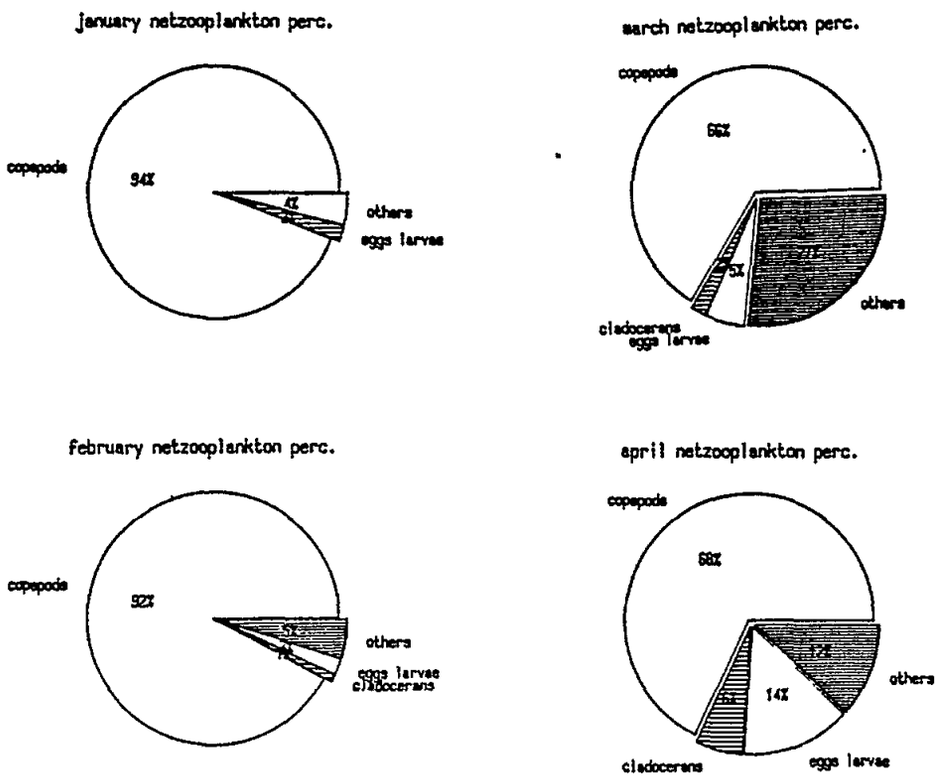
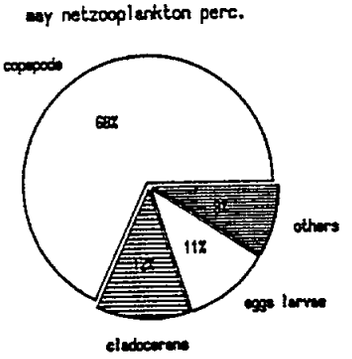
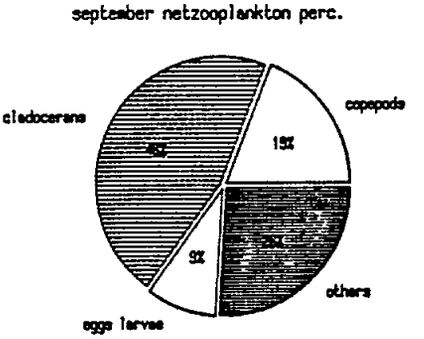
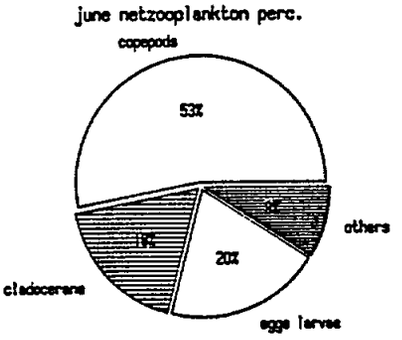
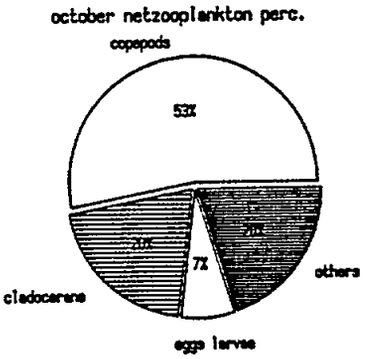


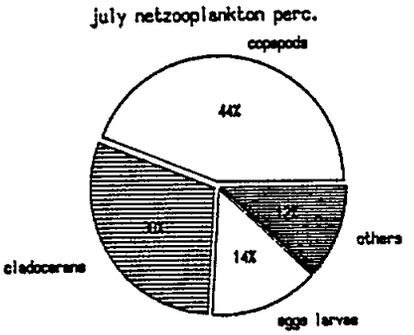
Fig. 21 a

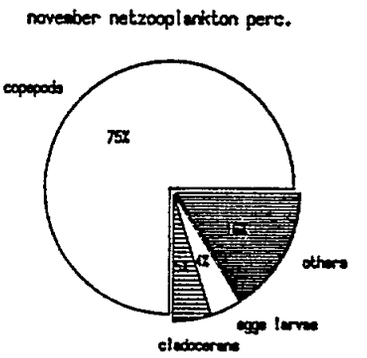

may netzooplankton perc.
copepods
68%
others
11%
12%
eggs larvae
cladocerans

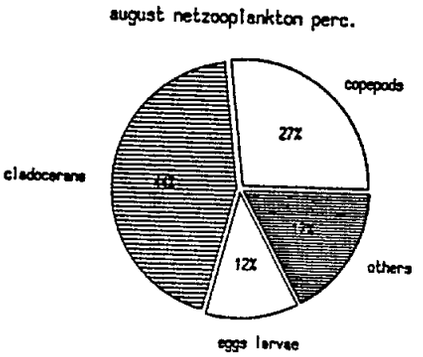

september netzooplankton perc.
cladocerans
copepods
15%
9%
others
eggs larvae


june netzooplankton perc.
copepods
53%
others
19%
20%
cladocerans
eggs larvae


october netzooplankton perc.
copepods
53%
20%
7%
others
cladocerans
eggs larvae


july netzooplankton perc.
copepods
44%
others
14%
cladocerans
eggs larvae


november netzooplankton perc.
copepods
75%
others
cladocerans
eggs larvae


august netzooplankton perc.
copepods
27%
cladocerans
others
12%
eggs larvae

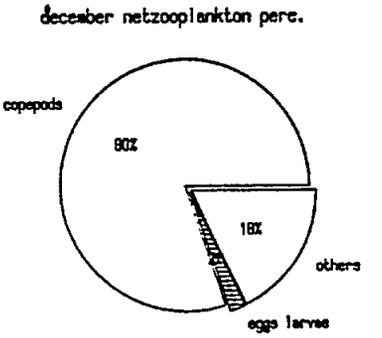

december netzooplankton perc.
copepods
80%
others
eggs larvae

Fig. 21 b

The typical neritic species, with a widely ecological range such as *Oithona nana, O. helgolandica, O. plumifera, Paracalanus parvus, Ctenocalanus vanus, Pseudocalanus elongatus, Centropages kroyeri, C. typicus, Temora longicornis, T. stylifera*, the genus *Clausocalanus (C. arcuicornis, C. pergens, C. furcatus)* and *Acartia clausi* (neritic or estuarine for Hure *et al.* (1980)), are prevalent. In some period of the year *A. clausi* alone can even reach 90% of the whole population of Copepods (Specchi *et al.*, 1981) and as dry weight, it may contribute for more than 80% to the total zooplankton biomass (Fonda Umani, 1985).

The other holoplanktonic group, which is fairly well present in the Gulf waters, is formed by the Cladocera, of which the six Mediterranean species are observed (i.e. *Evadne spinifera, E. tergestina, E. nordmani, Podon polyphemoides, P. intermedius* and *Penilia avirostris*). Their percentage ranges between a minimum at 0.3% in December and a maximum at 46% in September, when they are numerically the most important fraction as it occurs in August. In these two months *P. avirostris* prevails in number; it begins its swarming as early as June (Specchi and Fonda Umani, 1974) when population of *Acartia clausi*, which tends to decrease only in July, is still considerable.

"Others" are the remaining holoplankton organism such as Cnidaria (Siphonophora, Anthomedusae, Hydromedusae), Tunicata (*Oikopleura, Doliolum*), Chaetognatha (*Sagitta*) and by the sole species of the Protozoa (*Noctiluca miliaris*) whose dimensions are such as to be easily catched with the nets used for zooplankton.

The total percentages of the other holoplanktonic organisms vary from the minima at 4-5% in January-February to the maxima of 27% in March.

"Eggs and Larvae" consist of all the larval stages of the planktonic and benthic organisms, larger than 200 μm, i.e. ephyre of Schyphomedusae, larvae of Antozoa, nauplius of Copepods, cipris, zoae and metazoae of Decapods, veliger of Bivalves and Gastropods, pilidium, larvae of Polychaeta, trocophorae, auricolariae, bipinnariae, plutei, larvae of Ascidiacea, eggs and larvae of Teleosteans.

This fraction is particularly considerable in June, when it represents 20% of the whole population, mostly due to the amount of anchovy eggs.

Biomass

The monthly average means, expressed in mg / m^3 of dry weight (Fig. 22) show the highest values in the period April-June, and in September/November, the lowest values in March and December. The described trend is similar to the one reported by Benovic *et al.*, (1984) with an annual average value slightly lower (16 mg / m^3 instead of 18.5 mg / m^3).

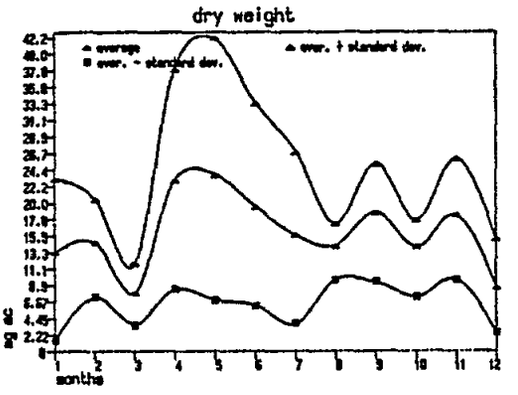


Fig. 22

The net zooplankton biomass is generally at steady high level during the whole year, never falling below 7.7 mg / m^3, but, on the other hand, it never reaches extremely high levels (maximum monthly average value 23.8 mg / m^3 in May).

Besides, the trend of the biomass as dry weight differs considerably from the total zooplankton trend expressed as individuals / m^3, mostly in summer when the highest density of "light" species (i.e. *Penilla avirostris, Noctiluca miliaris* and juvenile forms of Copepods) occurs.

In winter, very low densities correspond to the somewhat high values of biomass because the population is sustained by large-size mature Copepods like *Centropages typicus, Calanus helgolandicus, Temora* sp.p., etc.

Variations and anomalies

Up to now, average trends and taxonomic composition have been described; they are mainly referred to series, sometimes long ones, of sampling carried out in different years. In the reality, the planktonic system of the Gulf of Trieste generally reflects these trends, but it may present even considerably differences from one year to another.

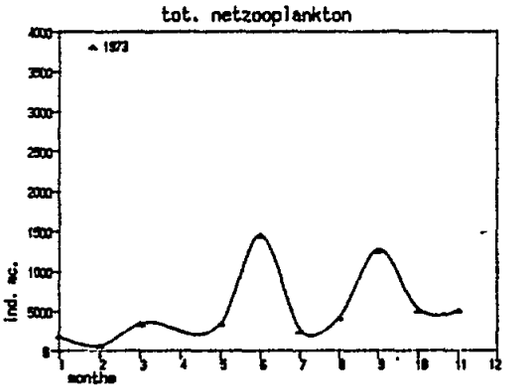


Fig. 23

The most evident anomalies are the "discoloured waters", a phenomenon occurring in this area since 1973 (Bussani, 1974). After this first report, in June 1977 there is evidence of a red tide caused by *Noctiluca miliaris* (Cassinari *et al.*, 1979); in September 1978 there is a first evidence in the Gulf of discoloured waters of *Gonyaulax polyedra*, though not very intense (Fonda Umani, 1985). In June 1980, some other discoloured waters of *N. miliaris* are reported, in June 1981 of *Prorocentrum lima* (*Exuviella marina*) which is responsible for a certain discolouration, though restricted to the harbor area; in September 1982 a brown discolouration due to *G. polyedra* is observed again; at the end of May 1983 in the areas with scarce vertical and horizontal mixing a bloom of *Scrippsiella faeroense* (*trochoidea*) (Fonda Umani and Honsell, 1984) is observed and again in 1983, in September, *G. polyedra* blooms again. Farther on, at the end of the summer 1984, a greenish discolouration due, according to some Authors, to *Gymnodinium cori* affects the whole High and Middle Adriatic (Artegiani *et al.*, 1985) and, to a lesser extent, the Gulf of Trieste.

Another revelant fact is the occurrence, during the period spring - summer, of swarms of *Pelagia noctiluca* which first reached the Gulf waters in 1977 and came back in the following years, with an increasing intensity until 1984 (Rottini Sandrini *et al.*, 1980; Rottini Sandrini and Stravisi 1981; Rottini Sandrini, 1982).

These events may be well assumed to be the most evident result of the modification which the whole planktonic system structure underwent during the same period.

If the total net zooplankton trends are analyzed, for the years 1973, and from 1977 to 1980, it can be observed that the values reach two maximum peaks of the same intensity in June and September of the first year (Fig. 23); in 1977-1978 the first peaks become intense and longer (Fig. 24) and in 1980 only one absolute maximum is observed during the summer (Fig. 25).

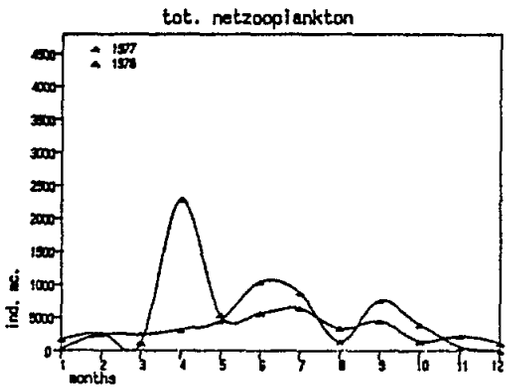


Fig. 24

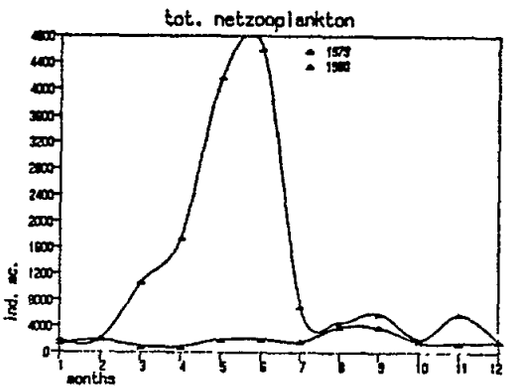


Fig. 25

These modification in the total trends are due to the variations in the quantities and to the period of occurrence of the single species which form the community: the trends of *Temora longicornis* (Fig. 26, 27) and *Acartia clausi* (Fig. 28, 29) for the years 1970 to 1973 and from 1977 to 1980 are reported as an example. Both populations characterized by two maximum periods (spring and late summer) tend towards a sole, more evident maximum in summer.

Also for the net zooplankton biomass, substantial variations are observed from year to year: in 1973 (Fig. 30), 1977 and 1978 (Fig. 31), in 1979 and 1980 (Fig. 32) we observed that from the two or three peaks of spring and summer maxima the overall situation tends to be a sole maximum in autumn.

In 1984 (Fig. 33) the trend is still different, in fact the highest value is observed in January and this is due to an important number of large-size mature Copepods from the deep Mid - Adriatic. The biomass decreases in May-June.

The lack of the summer maximum peak in 1980 and 1984 can be easily related to the massive presence in the Gulf of *P. noctiluca*, which is a very active predator of zooplankton.

Furthermore, the decrease in zooplankton and its consequent lower grazing activity cause an important increase in the vegetable biomass. The maxima abundance of phytoplanktonic cell in 1980, 1984 and 1985 (Fig. 34) are actually recorded in May and June. On the contrary (Fig. 35) three maxima are observed in the spring of 1986, high percentages of Diatoms being responsible only for the first one.

Therefore, a reversal trend seems to have occurred in 1986, with increase in the spring and autumn maximum values with respect to the summer one. As a matter of fact, the considerable invasion of medusae of the previous years disappear and the zooplanktonic populations which is longer heavily preyed upon by them, is likely to have grazed on the vegetable fraction again.

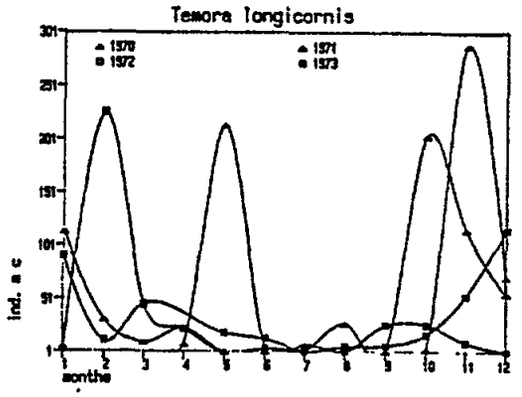


Fig. 26

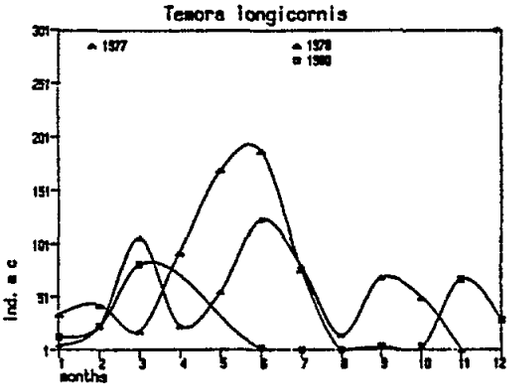


Fig. 27

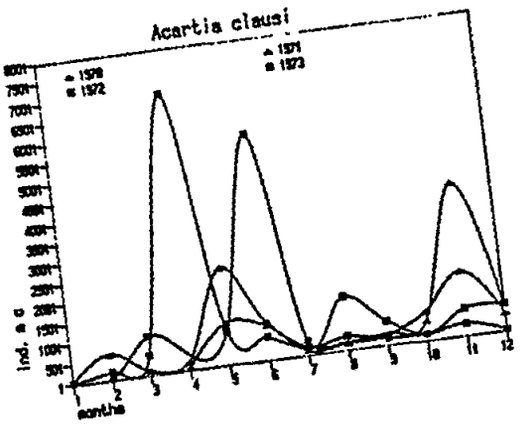


Fig. 28

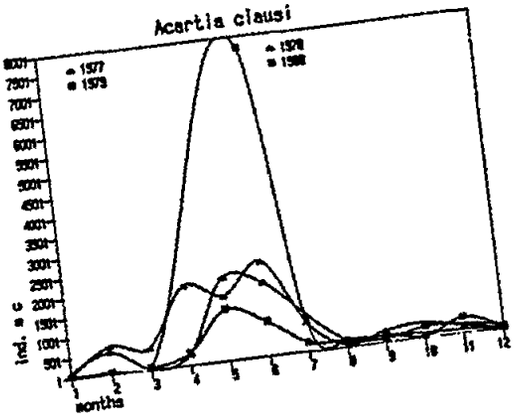


Fig. 29

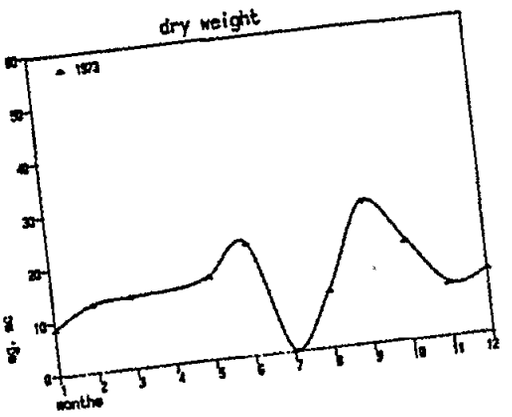


Fig. 30

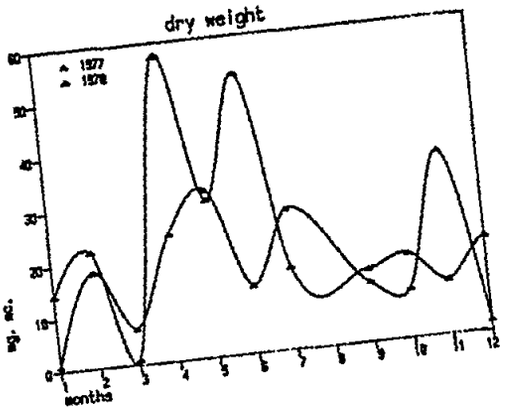


Fig. 31

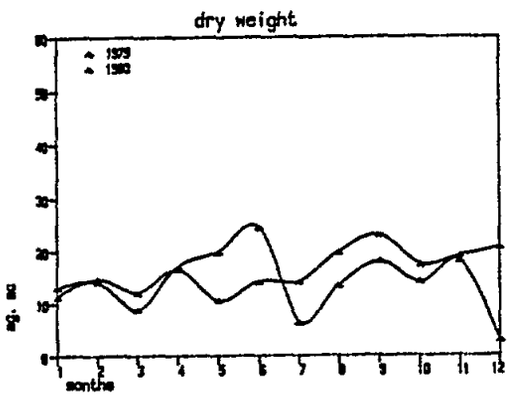


Fig. 32

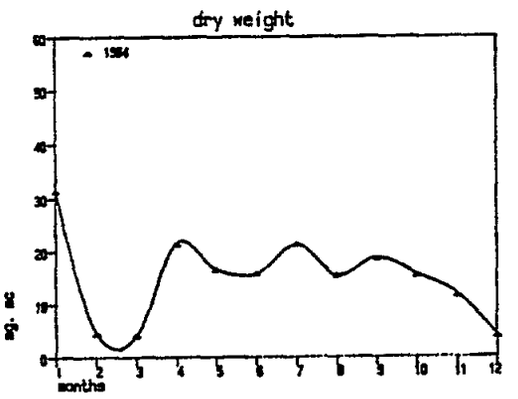


Fig. 33

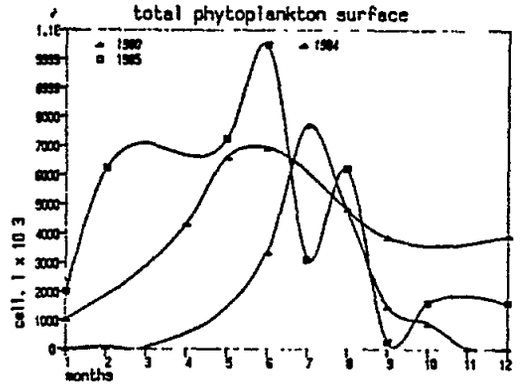


Fig. 34

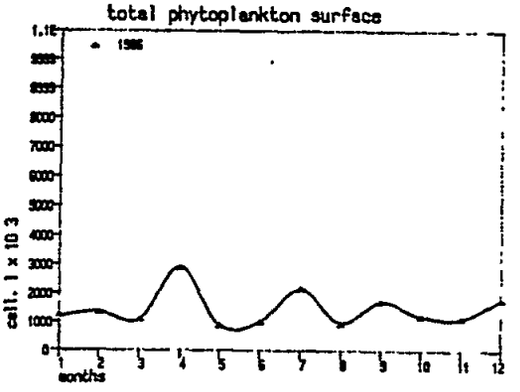


Fig. 35

4. CONCLUSIONS

The relatively high latitude of the Gulf of Trieste -it is the northernmost north part of the whole Mediterranean-, its climatic characteristics and the peculiar hydrodynamism, all contribute to exasperate the environmental conditions of the North Adriatic, which are already extremely severe, e.g. thermic annual variations of 19 °C and haline variations up to 10.4 p.s.u. are sometimes observed in the region.

The wide variability of the physical conditions is responsible for the intense selection on the vegetal and animal populations of the Gulf, thus favoring few, highly euriythermic and euryhaline species.

The considerable nutrient supplies from the coastal area, where anthropic interventions are extensive, together with the nutrients left by sediments (Faganeli and Malej, 1981) which circulate on the whole water column for most of the year, determine high contents of biogenetic elements.

The primary production, ascertained by the ^{14}C method, is not particularly high as well as the phytoplanktonic density expressed as biovolume or in C content. Therefore, the presence of a substantial picoplanktonic biomass may be hypothesized. This biomass would contribute to support the microzooplanktonic populations which, at least in some periods of the year, do not seem to have enough food available (Cabrini *et al.*, in press).

The phytoplanktonic populations are mainly represented by nanoplankton throughout most of the year; only in spring (April) and autumn Diatoms are more abundant (especially *Skeletonema costatum* and *Nitzschia* sp.p.).

Dinoflagellates are never abundant, yet some of them - i.e. *Gonyaulax polyedra, Noctiluca miliaris, Scrippsiella faeroense* - have been responsible for intense monospecific blooms in June and September of some years.

The abnormal blooms of late spring have been related to the formation on the sea surface of a layer of water diluted by precedent rainfalls and, at the same time, suddenly warmed. The reproductive blooms of a single species, favoured by the environmental conditions, may begin in this surface nucleus, which is deeper than 2 m, unsalted, warm and with no turbulence.

The September blooms, instead, are part of wider phenomena concerning the whole inshore area of the North Adriatic Sea; they are transported into the Gulf of Trieste by the diluted waters which flow on the surface from west to east.

From 1980 to 1984, the maximum abundance of phytoplankton is recorded in summer; this trend has been related both to nutrients availability and to the reduced grazing pressure by the zooplankton, which, on its turn is intensely preyed by consumers of a superior order, i.e. *P. noctiluca*.

The microzooplanktonic fraction has a fundamental role in the energy transfer from the smaller primary producers (pico - and nano - plankton) to the subsequent links of the trophic net. It is mainly formed by Ciliates, other than Tintinnids, typical organisms of highly trophic environments (Revelante, 1981). This fraction reaches its maximum abundance immediately after the spring phytoplanktonic maximum.

The net zooplankton is dominated by few, highly euryvalent, generally mixed feeder species (i.e. *A. clausi*) for most of the year; only in winter, less strictly neritic species are more abundant due to the intrusion in the Gulf of deep waters from the south. The maxima values are observed in June, two weeks later than the phytoplanktonic ones.

The net zooplanktonic biomass is quite constant during the whole year and its values are highest in the Adriatic, with the exception of the area just close to the river Po mouth (Fonda Umani *et al.* 1982b), and among the highest in the Mediterranean Sea.

From 1977 to 1984/85, when our research studies were carried out, an increase in the general trophism of the system was observed. This increase may be caused by environmental variations due to local meteorological modification, or by larger inputs from the highly urbanized areas discharging into the Gulf. It could also be caused by structural modifications which the whole Adriatic basin underwent during this period. The latter have provoked more or less important alterations in its farthest north - eastern part, such as the circulation of water massively, prolonging its permanence periods; the characteristics of their conservation and non-conservation properties, etc. These fluctuations of the basin may be themselves imputed to long-term oscillations of meteorological factors concerning all Europe and the positions of the Icelandic cyclone and the Siberian anticyclone as Pucher - Petkovic and Zore Armanda (1973) hypothesized.

Whichever is the course, the years 1977 to 1980 witnessed both a steady increase in the surface annual average values of the main nutrients and, as stated above, an increase in the vegetale biomasses, mostly in summer. More precisely, the zooplanktonic biomass increases up to 1980 then it decreases for the greater number of predators during the summer, thus producing a further increase in the algal biomass.

The available data for the last year suggest a trend inversion since the phytoplankton reaches its absolute maximum values in spring and the summer peaks are mainly due to nanoplankton.

This might be the end of a phase, characterized by highly trophic situations - sometimes at the limit with distrophism - equivalent to the ascending trend period of a rather long cyclic phenomenon. This phenomenon is similar to the others which may have developed in earlier times and of which the most evident marks are left. Even then, algal blooms and medusae invasions were reported, together with the global configurations of zooplanktonic population structure which later were no longer recorded.

The data of the next years will either support this hypothesis or the ones shared by a number of researchers, suggesting that the whole Adriatic Sea is going towards an irreversible generalized situation of eutrophication.

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FEEDING OF Pelagia noctiluca IN OPEN SEA

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ABSTRACT

The diet in the open sea environment of *Pelagia noctiluca*, holoplanktonic scyphomedusa, is analyzed in this study through the observation of its gastrovascular contents and parallel samplings of the open sea meso- and macroplankton. Results show that *Pelagia* exhibits a non-specific predation in relation to the local availability of food. The greater part of the gastric contents is represented by Crustacea, mainly Copepoda and Cladocera.

1. INTRODUCTION

Pelagia noctiluca (Forsskal), open sea scyphomedusa, together with other pelagic Cnidaria and Ctenophora, forms the carnivorous gelatinous macrozooplankton; it thus plays an active role in the pelagic ecosystem.

Analyses of its metabolism as well as physico-ecological studies were mainly carried out in the laboratory (Russell, 1970; D'Angela *et al.*, 1985; Malej and Vukovic, 1986a,b; Faganeli *et al.*, 1986; Morand *et al.*, 1987), whereas open sea data on the predatory impact of this species are still lacking. Investigations on the natural predation of gelatinous zooplankton are available for Ctenophora (Larson, 1987), Hydromedusae (Larson, 1987), Siphonophora (Purcell, 1981a,b; Purcell and Kremer, 1983), Chaetognatha (Feigenbaum and Maris, 1984), Urochordata (King *et al.*, 1980) and for other species of Scyphomedusae (Cargo and Schultz, 1967; Clifford and Cargo, 1979; Lindahl and Hernroth, 1983; Hernroth and Gröndahl, 1983, 1985; Möller, 1984a,b; Hernroth, 1986; Stoecker *et al.*, 1987).

This study is thus meant to examine the diet of *P. noctiluca* (Forsskal) (Scyphozoa, Semaeostomeae) by analyzing the contents of the gastrovascular cavity with respect to the meso- and macrozooplankton distribution observed in parallel samplings.

2. MATERIALS AND METHODS

Collection of samples

Samples of medusae and plankton were collected during cruises by the Laboratory of Marine Biology and Fishery of Fano as part of the monitoring programme on the ichthyoplanktonic stock, supported by the Ministero della Marina Mercantile. The samples of the "VOLA" cruises, September 1985, stations 35 and 45, and of the "O" cruises, January 1986, station 48 (Fig. 1) were made available for examination.

Samplings were carried out with a 235 µm BONGO-20 plankton net with 10-minute double-oblique hauls at an average speed of 2-knots. The samples were collected at a depth of 70 metres in September and 55 metres in January. Once on the boat, they were immediately fixed in neutralized formaldehyde 10% in seawater.

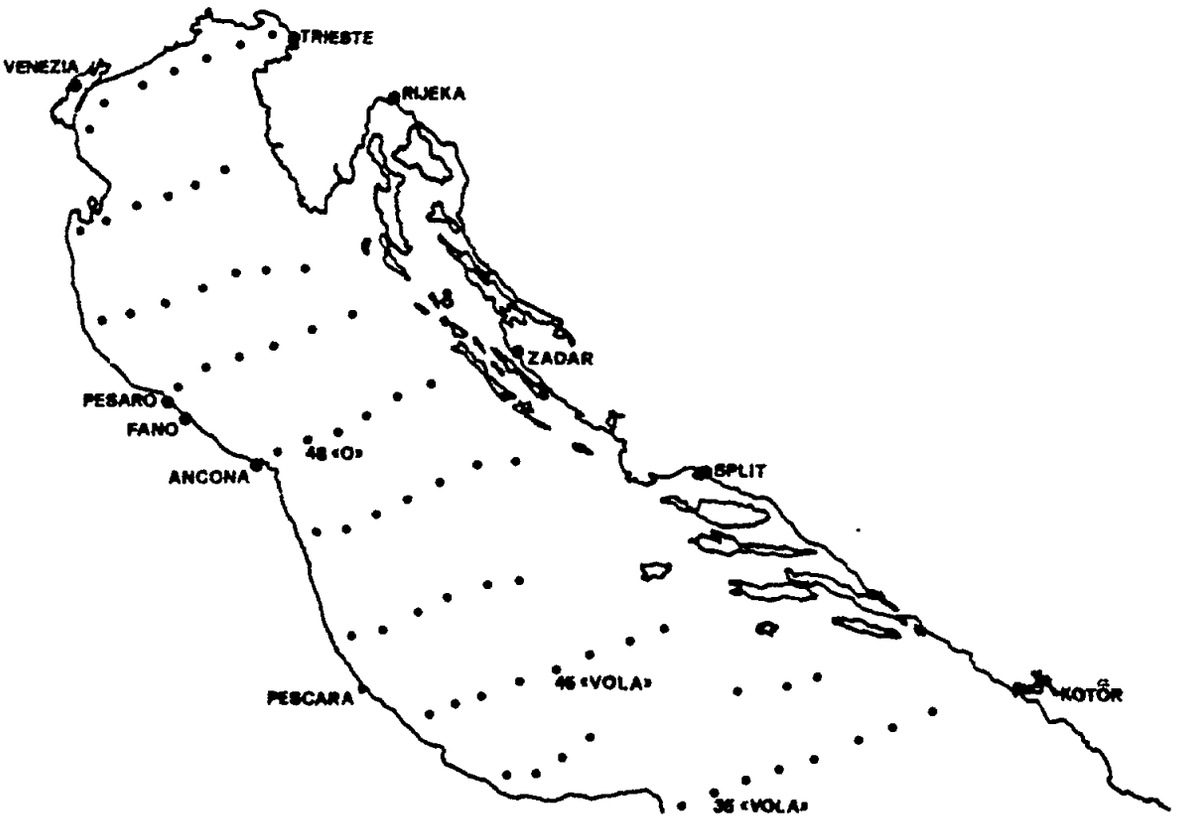

Fig 1. Distribution of the sampling stationsd in the Adriatic Sea. Stations 35 and 45, cruise "Vola", September 1985; Station 48, cruise "O", January 1986. (Figure taken with the kind permission of Mrs. G. Piccinetti Manfrin and Mr. C. Piccinetti, Lab. of mar. Biol. and Fishery, Fano, Italy).

Observation of the gastric contents

Before examining the gastric contents, interrhopalian diameter measurements were obtained for each medusa. The oral arms and the manubrium of each individual were excised; the plankton found in these structures (quite abundant) was not counted since it may have resulted from forced swallowing during the catching phase.

The contents of the stomach and of the gastric pouches were subsequently analyzed. For the reasons mentioned above, only those individuals which showed some signs of digestion, even partial, were counted. Due to the type of sampling, nanoplankton and microplankton were not analyzed.

The data collected were expressed as total number, as number of individuals/medusa, and as percentage, grouped for medusae with diameter < 4.5cm and 4.5cm, respectively, so as to show possible differences in predation in medusae of different sizes.

Observation of plankton samples

Meso- and macro-zooplankton specimens were counted, classified and expressed both as No m^{-3} and as a percentage of the total number.

3. RESULTS

Fifty one (51) individuals of *P. noctiluca* were collected and examined in summer 1985 (September, "VOLA" cruise) and 38 in winter 1986 (January, "O" cruise). The data obtained for the different species are given in Tables 1 and 3 and for the taxa in Tables 2 and 4 and Figs. 2 and 3.

Table 1. Species found in the gastrovascular cavity of *Pelagia noctiluca* and in the open sea plankton. September 1985

PLANKTON SPECIES	No OF JELLYFISH DIAMETER	PLANKTON FOUND IN THE GASTROVASCULAR CAVITY 16 < 4.5 cm No	%	No/Spec.	16 > 4.5 cm No	%	No/Spec.	OPEN SEA PLANKTON No/m^3
CNIDARIA:								
HYDROZOA:	Obelia sp.	0	0.00	0.00	0	0.00	0.00	1.52
	SIPHONOPHORA CALYCOPHORA	0	0.00	0.00	0	0.00	0.00	4.57
SCYPHOZOA:	ephyrae	0	0.00	0.00	0	0.00	0.00	0.76
ANELIDA POLYCAETA:								
	larvae	0	0.00	0.00	0	0.00	0.00	2.28
	Tomopteris helgolandicus	0	0.00	0.00	0	0.00	0.00	0.76
ARTHOPODA CRUSTACEA:		0	0.00	0.00	4	0.81	0.25	0.00
	larvae ind.	2	1.55	0.13	8	1.61	0.50	0.00
CLADOCERA:	* Penilia sp.p.	7	5.43	0.44	35	7.06	2.19	0.00
	Evadne spinifera	3	2.32	0.19	9	1.81	0.56	0.00
	Evadne sp.p.	0	0.00	0.00	1	0.20	0.06	38.06
	* Podon polyphemoides	1	0.77	0.06	0	0.00	0.00	0.00
OSTRACODA:	species ind.	4	3.10	0.25	5	1.01	0.31	5.33
COPEPODA:	**Calanus helgolandicus	0	0.00	0.00	4	0.81	0.25	1.14
	Calanus sp.p.	7	5.43	0.44	9	1.81	0.56	305.99
	**Eucalanus elongatus	0	0.00	0.00	0	0.00	0.00	0.00
	Eucalanus sp.p.	0	0.00	0.00	0	0.00	0.00	67.74
	Clausocalanus arcuicornis	2	1.55	0.13	0	0.00	0.00	0.00
	Clausocalanus sp.p.	28	21.70	1.75	70	34.27	10.63	403.42
	**Euchaeta sp.p.	0	0.00	0.00	0	0.00	0.00	2.28
	* Diaxis sp.p.	0	0.00	0.00	0	0.00	0.00	17.51
	Temora stylifera	18	13.95	1.13	63	12.70	3.94	37.29
	Temora sp.p.	4	3.10	0.25	2	0.40	0.13	0.00
	**Pleuromamma sp.p.	0	0.00	0.00	0	0.00	0.00	2.28
	Centropages typicus	1	0.77	0.06	13	2.62	0.81	57.85
	Centropages sp.p.	2	1.55	0.13	0	0.00	0.00	0.00
	Lucicutia sp.p.	0	0.00	0.00	0	0.00	0.00	0.76
	Candacia sp.p.	0	0.00	0.00	1	0.20	0.06	21.02
	**Anomalocera patersoni	8	6.20	0.50	29	5.85	1.81	6.85
	**Pontella sp.p.	0	0.00	0.00	0	0.00	0.00	1.52
	* Acartia clausi	0	0.00	0.00	0	0.00	0.00	3.04
	* Oithona sp.p.	3	2.32	0.19	13	2.62	0.81	51.76
	Microsetella sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	* Euterpina sp.p.	0	0.00	0.00	1	0.20	0.06	0.00
	Oncea sp.p.	2	1.55	0.13	7	1.41	0.44	8.37
	Sapphirina sp.p.	2	1.55	0.13	5	1.01	0.31	0.00
	Corycaeus sp.p.	0	0.00	0.00	8	1.61	0.50	29.68
	Copepodites ind.	5	3.88	0.31	12	2.42	0.75	0.00
MYCIDACEA:	species ind.	1	0.77	0.06	8	1.61	0.50	0.00
AMPHIPODA:	larvae	0	0.00	0.00	2	0.40	0.13	0.38
	species ind.	0	0.00	0.00	2	0.40	0.13	0.00
EUPHASIACEA:	species ind.	1	0.77	0.06	14	2.82	0.88	0.76
DECAPODA:	larvae	1	0.77	0.06	4	0.81	0.25	27.78
MOLLUSCA:								
GASTROPODA:	larvae	2	1.55	0.13	17	3.43	1.06	0.00
	eggs	0	0.00	0.00	0	0.00	0.00	6.09
BIVALVIA:	larvae	1	0.77	0.06	0	0.00	0.00	1.52
PHORONIDA:	larvae	0	0.00	0.00	0	0.00	0.00	0.00
CHAETOGNATHA:	Sagitta sp. p.	20	15.50	1.25	44	8.87	2.75	39.58
ECHINODERMATA:	Echinopluteus	0	0.00	0.00	0	0.00	0.00	0.00
INVERTEBRATE EGGS		1	0.77	0.06	0	0.00	0.00	0.00
CHORDATA:								
UROCHORDATA:	Appendicularia sp.p.	0	0.00	0.00	0	0.00	0.00	33.11
	Doliolum sp.p.	0	0.00	0.00	0	0.00	0.00	1.90
TELEOSTEA:	eggs	0	0.00	0.00	0	0.00	0.00	4.81
	larvae	3	2.32	0.19	6	1.21	0.38	4.57
	TOTAL	299			496			1192.28
	MEAN VALUE/SPECIMEN	8.06			31.00			

* : Coastal species ** . Deep water species

Analysis of the data shows that the predatory activity of the medusae < 4.5 cm in diameter medusae is always inferior to that of > 4.5cm diameter, both in January and in September. No significant qualitative differences are observed between predation by small-size medusae and larger individuals. A remarkable increase in predation in September compare to January was recorded. This may be due to both the higher density m^{-3} of plankton in September and to the increase in *Pelagia* metabolism, which is directly related to seawater temperature.

The taxa most preyed upon are Crustacea, which alone represent 94.67% in January and 85.01% in September of the total, followed by the Chaetognatha, 2.35% in January and 10.24% in September. In addition, Teleostea are always present (even if the percentages are small), both in gastric contents (2.99% in January and 1.43% in September) and in parallel zooplankton samples (0.13% in January and 0.70% in September).

Within Crustacea, the most preyed upon taxa are Copepoda and Cladocera; this agrees with the quantities available for zooplankton. An uncommon peak of Decapoda was recorded in January (39.66% of the total); this does not correspond to the relative quantity of zooplankton (0.82% out of a 2.33% availability in the plankton).

The Cladocera and Copepoda species comprise both inshore species, such as *Penilia* spp., *Podon polyphemoides, Oithona* spp., and open sea forms; among the latter, deep species (Scotto di Carlo *et al.*, 1984) such as *Calanus helgolandicus, Eucalanus elongatus, Anomalocera patersoni* and *Pontella* spp. were also observed.

Table 2. Plankton found in the gastrovascular cavity of *Pelagia noctiluca* related to the plankton samples. September 1985

No OF JELLYFISH	32			PLANKTON
GASTRIC CONTENTS	No	%	No/ spec.	%
1 CNIDARIA	0	0.00	0.00	0.57
2 ANELLIDA POLYCHAETA	0	0.00	0.00	0.26
CRUSTACEA				
3 LARVAE IND.	4	0.67	0.13	0.00
4 CLADOCERA	66	10.55	2.06	3.19
5 OSTRACODA	9	1.43	0.28	0.45
6 COPEPODA	419	67.02	13.09	85.42
7 MUSIDACEA	9	1.43	0.36	0.00
8 AMPHIPODA	4	0.67	0.13	0.03
9 EUPHASIACEA	15	2.42	0.47	0.06
10 DECAPODA	5	0.82	0.16	2.33
MOLLUSCA				
11 GASTROPODA	19	3.02	0.59	0.51
12 BIVALVIA	1	0.15	0.03	0.13
13 PHORONIDA	0	0.00	0.00	0.00
14 CHAETOGNATHA	64	10.24	2.00	3.32
15 ECHINODERMATA	0	0.00	0.00	0.00
16 Invertebrate eggs	1	0.15	0.03	0.00
CHORDATA				
17 UROCHORDATA	0	0.00	0.00	2.94
18 TELEOSTEA	9	1.43	0.28	0.79
TOTAL	625	100.00	19.53	100.00
TOTAL OF TAXA	13			13

Table 3. Species found in the gastrovascular cavity of *Pelagia noctiluca* and in the open sea plankton. January 1986.

PLANKTON SPECIES	No OF JELLYFISH DIAMETER	PLANKTON FOUND IN THE GASTROVASCULAR CAVITY						OPEN SEA PLANKTON
		11 < 4.5 cm			18 > 4.5 cm			
		No	%	No/Spec.	No	%	No/Spec.	No/m^3
CNIDARIA:								
HYDROZOA:	Obelia sp.	0	0.00	0.00	0	0.00	0.00	0.00
	SIPHONOPHORA CALYCOPHORA	0	0.00	0.00	0	0.00	0.00	0.00
SCYPHOZOA:	ephyrae	0	0.00	0.00	0	0.00	0.00	0.00
ANELIDA POLYCAETA:								
	larvae	0	0.00	0.00	0	0.00	0.00	0.34
	Tomopteris helgolandicus	0	0.00	0.00	0	0.00	0.00	0.00
ARTHOPODA CRUSTACEA:								
	larvae ind.	1	2.56	0.09	2	2.06	0.11	0.00
CLADOCERA:	* Penilia sp.p.	0	0.00	0.00	0	0.00	0.00	67.35
	Evadne spinifera	0	0.00	0.00	0	0.00	0.00	6.29
	Evadne sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	* Podon polyphemoides	5	12.82	0.45	5	5.00	0.28	2.72
	species ind.	0	0.00	0.00	0	0.00	0.00	0.00
OSTRACODA:	species ind.	0	0.00	0.00	0	0.00	0.00	6.12
COPEPODA:	**Calanus helgolandicus	6	15.38	0.55	8	8.25	0.44	5.44
	Calanus sp.p.	4	10.26	0.36	5	5.15	0.28	4.76
	**Eucalanus elongatus	0	0.00	0.00	2	2.06	0.11	0.00
	Eucalanus sp.p.	0	0.00	0.00	13	13.40	0.72	1.36
	Clausocalanus arcuicornis	0	0.00	0.00	0	0.00	0.00	0.00
	Clausocalanus sp.p.	0	0.00	0.00	3	3.09	0.17	22.46
	**Euchaeta sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	* Diaxis sp.p.	0	0.00	0.00	0	0.00	0.00	2.04
	Temora stylifera	3	7.69	0.27	1	1.03	0.06	56.42
	Temora sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	**Pleuromamma sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	Centropages typicus	2	5.13	0.18	6	6.19	0.33	11.22
	Centropages sp.p.	1	2.56	0.09	1	1.03	0.06	0.00
	Lucicutia sp.p.	0	0.00	0.00	0	0.00	0.00	0.68
	Candacia sp.p.	0	0.00	0.00	0	0.00	0.00	1.02
	**Anomalocera patersoni	0	0.00	0.00	2	2.06	0.11	2.04
	**Pontella sp.p.	0	0.00	0.00	1	1.03	0.06	0.00
	* Acartia clausi	0	0.00	0.00	0	0.00	0.00	0.68
	* Oithona sp.p.	0	0.00	0.00	0	0.00	0.00	21.43
	Microsetella sp.p.	0	0.00	0.00	0	0.00	0.00	0.68
	* Euterpina sp.p.	0	0.00	0.00	0	0.00	0.00	0.00
	Oncea sp.p.	0	0.00	0.00	0	0.00	0.00	22.79
	Sapphirina sp.p.	0	0.00	0.00	0	0.00	0.00	1.70
	Corycaeus sp.p.	0	0.00	0.00	0	0.00	0.00	6.12
	Copepodites ind.	0	0.00	0.00	2	2.06	0.11	0.00
MYCIDACEA:	species ind.	0	0.00	0.00	0	0.00	0.00	1.36
AMPHIPODA:	larvae	0	0.00	0.00	1	1.03	0.06	0.00
	species ind.	0	0.00	0.00	1	1.03	0.06	0.00
EUPHASIACEA:	species ind.	0	0.00	0.00	0	0.00	0.00	1.36
DECAPODA:	larvae	15	38.46	1.36	39	40.21	2.17	3.06
MOLLUSCA:								
GASTROPODA:	larvae	0	0.00	0.00	0	0.00	0.00	0.00
	eggs	0	0.00	0.00	0	0.00	0.00	2.72
BIVALVIA:	larvae	0	0.00	0.00	0	0.00	0.00	0.62
PHORONIDA:	larvae	0	0.00	0.00	0	0.00	0.00	0.68
CHAETOGNATHA:	Sagitta sp. p.	2	5.13	0.18	1	1.03	0.06	15.99
ECHINODERMATA:	Echinopluteus	0	0.00	0.00	0	0.00	0.00	0.34
INVERTEBRATE EGGS		0	0.00	0.00	0	0.00	0.00	0.00
CHORDATA:								
UROCHORDATA:	Appendicularia sp.p.	0	0.00	0.00	0	0.00	0.00	5.44
	Doliolum sp.p.	0	0.00	0.00	0	0.00	0.00	2.72
TELEOSTEA:	eggs	0	0.00	0.00	3	3.09	0.17	0.49
	larvae	0	0.00	0.00	1	1.03	0.06	0.00
	TOTAL	39			97			378.44
	MEAN VALUE/SPECIMEN		3.55			5.39		

*: Coastal species ** : Deep water species

Table 4. Plankton found in the gastrovascular cavity of *Pelagia noctiluca* related to the plankton samples. January 1986.

No OF JELLYFISH	29			PLANKTON
GASTRIC CONTENTS	No	%	No/ spec.	%
1 CNIDARIA	0	0.00	0.00	0.00
2 ANELLIDA POLYCHAETA	0	0.00	0.00	0.09
CRUSTACEA				
3 LARVAE IND.	3	2.13	0.10	0.00
4 CLADOCERA	10	7.25	0.34	20.18
5 OSTRACODA	0	0.00	0.00	1.62
6 COPEPODA	60	44.14	2.07	68.93
7 MUSIDACEA	0	0.00	0.00	0.36
8 AMPHIPODA	2	1.49	0.07	0.00
9 EUPHASIACEA	0	0.00	0.00	0.36
10 DECAPODA	54	39.66	1.86	0.81
MOLLUSCA				
11 GASTROPODA	0	0.00	0.00	0.72
12 BIVALVIA	0	0.00	0.00	0.16
13 PHORONIDA	0	0.00	0.00	0.18
14 CHAETOGNATHA	3	2.35	0.11	4.23
15 ECHINODERMATA	0	0.00	0.00	0.09
16 Invertebrate eggs	0	0.00	0.00	0.00
CHORDATA				
17 UROCHORDATA	0	0.00	0.00	2.16
18 TELEOSTEA	4	2.99	0.14	0.13
TOTAL	136	100.00	4.69	100.00
TOTAL OF TAXA	7			14

Table 5. Number of specimens of *Pelagia noctiluca* with the gastrovascular cavity with or without preys.

JELLYFISH		SEPTEMBER		JANUARY	
		No	%	No	%
DIAMETER < 4.5 cm	EMPTY	19	54.29	7	38.89
	WITH FOOD	16	45.71	11	61.11
	TOT.	35		18	
DIAMETER > 4.5 cm	EMPTY	0	0	2	10
	WITH FOOD	16	100	18	90
	TOT.	16		20	
TOTAL	EMPTY	19	37.25	9	23.68
	WITH FOOD	32	62.75	29	76.32
	TOT.	51		38	

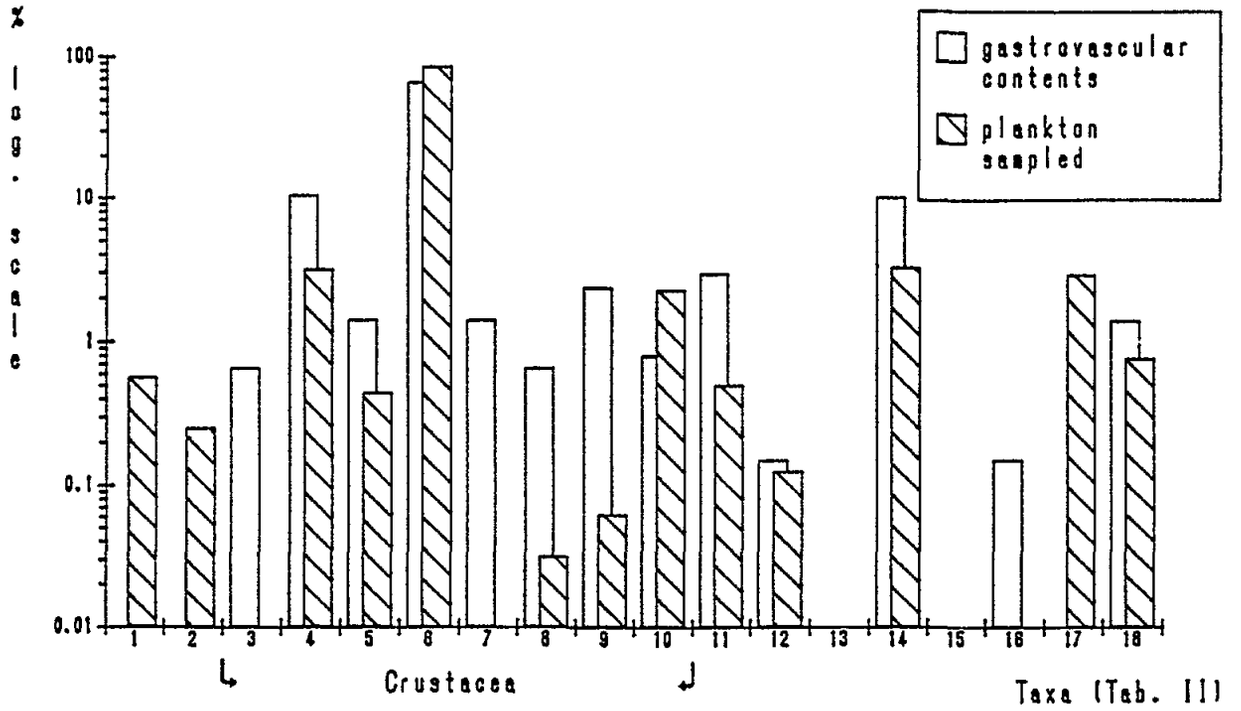

Fig. 2. Correlation between the taxa of plankton caught by *Pelagia noctiluca* and the plankton sampled. September

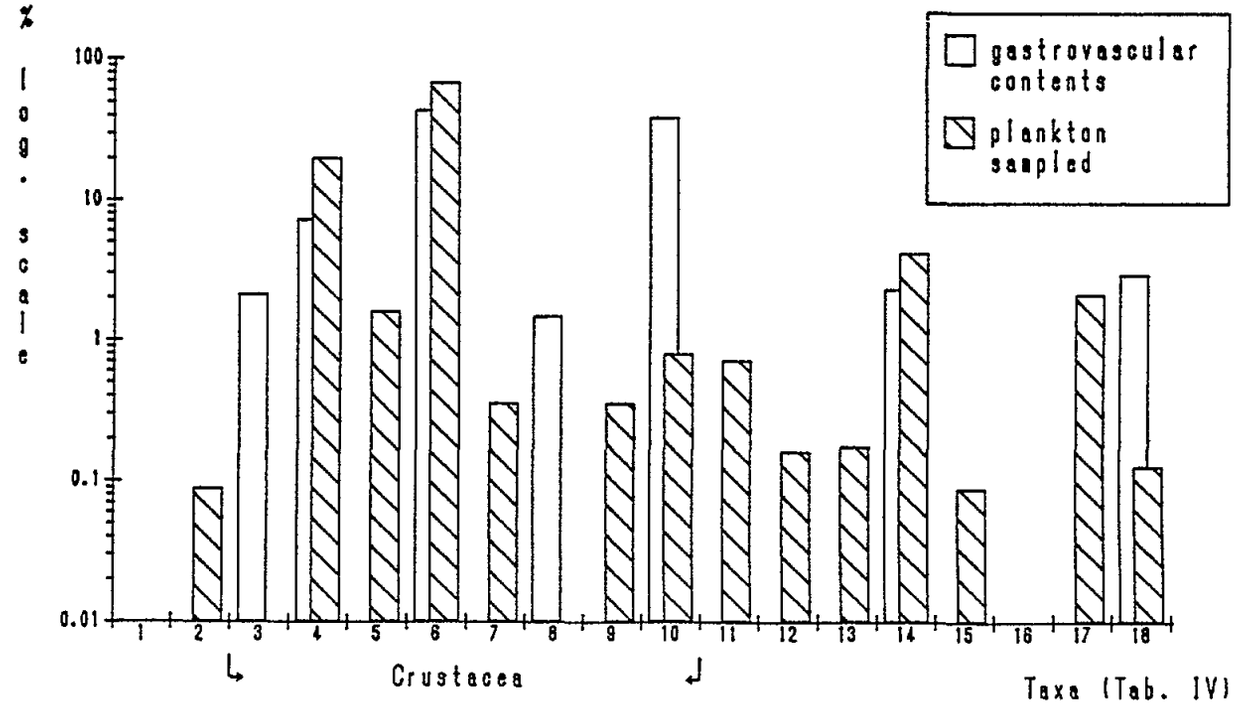

Fig. 3. Correlation between the taxa of plankton caught by *Pelagia noctiluca* and the plankton sampled. January

In September, the analysis of *Pelagia* gastric contents showed the presence of Gastropoda larvae (3.02% on a 0.51% availability in the plankton), while the presence of Cnidaria, larvae of Anellida, Phoronoidea, larvae of Echinodermata and Urochordata was not observed, regardless of whether they were available in the plankton or not. Specimens of Ctenophora were absent both from gastrovascular cavities and in plankton samples.

The analysis of the ratio between medusae without food contents (classifiable) and medusae with preys in their gastrovascular cavity gave the following results (Table V):

-61.11% of medusae with a diameter < 4.5cm contained preys in January and 45.71% in September;

-90% of medusae with a diameter of > 4.5cm contained preys in January and 100% in September.

On the whole, 76.32% of medusae contained classifiable food in January and 62.75% in September.

4. DISCUSSION AND CONCLUSIONS

The aim of this study was to examine the diet of *P. noctiluca* in the open sea at two different periods of the year (winter and summer), since a number of studies had shown that both the biological cycle (Rottini Sandrini and Avian, 1983; Rottini Sandrini *et al.*, 1985; Avian, 1986; Avian *et al.*, 1987) and the metabolism of the scyphomedusa are related to meteo-climatic conditions (Malej and Vukovic, 1986a, b; Morand *et al.*, 1987).

Our results indicate that the main feeding source of *Pelagia* is represented by Crustacea, mainly Cladocera and Copepoda (94.67% in January and 85.01% in September), followed by Chaetognatha (2.35% in January and 10.24% in September), eggs and larvae of Mollusca (0.00% in January and 3.17% in September), and eggs and larvae of Teleostea (2.99% in January and 1.43% in September). Small fish (1 to 4-5cm long) are rarely found in the gastrovascular cavity. Laboratory experiments have proved that *P. noctiluca* can paralyze small fish, but can hardly swallow them. Open sea observations show that small-size fish shoals can avoid contact with the jellyfish tentacles thanks to their mobility, even inside aggregations of the latter with 1-10 specimen m^{-3} densities (Avian, personal observations, Gulf of Trieste, 1982, 1983, 1984).

The fact that the taxa observed in the plankton samples were absent in gastric contents does not indicate that they cannot actually be preyed upon; we believe that larval forms are more rapidly digested than adult individuals and in addition their availability in the plankton is rather low (Tables II and V).

As for gelatinous plankton (Cnidaria and Ctenophora), its total absence can also be ascribed to its consistency. In fact, inshore and laboratory observations (Avian and Rottini Sandrini, unpublished observations) have pointed out an active predation on ctenophore *Pleurobrachia rhodopis;* in laboratory this species begin to disaggregate as soon as it comes in contact with the marginal tentacles of *Pelagia*, even before it is swallowed. On the contrary, cannibalism or predation on adults or ephyrae of other species of scyphomedusae was never observed.

By analyzing seasonal predation with respect to size, it is possible to observe a higher predatory activity in medusae with a diameter of < 4.5cm in January (61.11%) than in September (45.71%); medusae with a diameter of > 4.5cm give inverse results (90% in January and 100% in September). This apparent discrepancy can be ascribed to two factors: (i) The decrease in metabolism, due to the cooling of seawater temperature (Rottini Sandrini, 1982) in January, mainly concerns larger specimens, while smaller-size medusae are less affected; (ii) the high metabolism and the consequent higher predatory activity of medusae in September bring about competition over food within the aggregations (Legovic and Rottini Sandrini, 1986) and small-size medusae are at a disadvantage.

The data obtained show that *P. noctiluca* is mainly a non-selective predator of meso- and macrozooplankton as shown by Morand *et al.*, (1987). The type of predation observed seems to be related to food availability rather than to possible preference. The capacity of *Pelagia* to perform daily wide vertical migrations (Franqueville, 1971) makes predation possible even on species considered as deep water species.

5. ACKNOWLEDGMENTS

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DYNAMIQUE D'UNE POPULATION DE Pélagia noctiluca (CNIDARIA, SCYPHOZOA) EN MER LIGURE

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RESUME

Les très fortes pullulations de la scyphoméduse *Pélagia noctiluca* (Forsskal, 1775) enregistrées en Méditerranée, tant dans le Bassin oriental depuis 1977, que dans le Bassin occidental depuis 1982, ont suscité beaucoup d'observations grâce aux remarquables efforts d'animation du PNUE concrétisés par de très nombreuses réunions (Athènes 1983, Triestre 1984, Lucerne 1984, Naples 1985, Trieste 1987).

En Mer Ligure en particulier, l'équipe constituée autour de ce thème a très vite orienté ses recherches dans trois directions pour mieux cerner la biologie de cette espèce en ne privilégiant aucun aspect:

-sur le long-terme pour analyser les fluctuations des blooms de *P. noctiluca*,

-sur le moyen terme pour relier la repartition des populations aux structures hydrologiques,

-sur le court terme pour étudier la croissance individuelle et sa répercution dans l'écosystème pélagique.

1. Analyse sur le long-terme des fluctuations de P. noctiluca : chronologie des années à *Pélagia* en Méditerranée occidentale

Au colloque d'Athènes (UEP, 1984), Stravisi (1984) pour l'Adriatique et Goy (1984a; 1984Bb) pour la Mer Ligure ont avancé l'hypothèse d'un déterminisme climatique des fluctuations de cette espèce mettant en cause soit la douceur de l'hiver, soit la faiblesse de l'amplitude thermique annuelle.

Cette relation Climat-Méduses a été reprise en l'isolant du contexte hydrologique environnemental, et même biologique, par manque de données. La chronologie de l'évennement "Pélagia", établie sur deux siècles, a fait apparaître immédiatement une agglomération des "années à méduses" et des "années sans méduses" depuis le début de la série en 1775. Les années à méduses n'ont pas un caractère exceptionnel, elles peuvent perdurer jusqu'à 7 ans et représentent plus de 40% du temps sur un siècle.

La méthode du périodogramme de contingence (Legendre *et al.*, 1981) codant ce phénomène en données binaires présence-absence années après années fait apparaître une périodicité de 12 ans pour les 111 dernières années les plus fiables (Morand 1989, Goy *et al.*, 1989).

Le cycle de 12 ans (Fig. 1) peut se décomposer en 5 années successives où la probabilité d'apparition de "*Pélagia*" est faible, 5 années où cette probabilité est forte, les 2 années suivantes montrent des probabilités proches de l'espérance observée sur l'ensemble de la série.

Ainsi, cette pullulation de *P. noctiluca*, déjà reconnue par les auteurs anciens qui les decrivent "par million autour du bateau" ou "soupe de méduses" n'est pas due à l'accroissement de la pollution en Méditerranée mais doit être recherchée dans des modifications cycliques de son environnement marin.

Le recul sur les données hydrologiques ne dépasse pas une cinquantaine d'années. Il a donc fallu utiliser d'autres series, en l'occurrence la série climatique de Gènes choisie pour sa remarquable continuité sur un siècle. Les 3 paramètres sélectionnés expriment le mieux le climat: température, pression atmosphérique et pluviosité (Morand 1984).

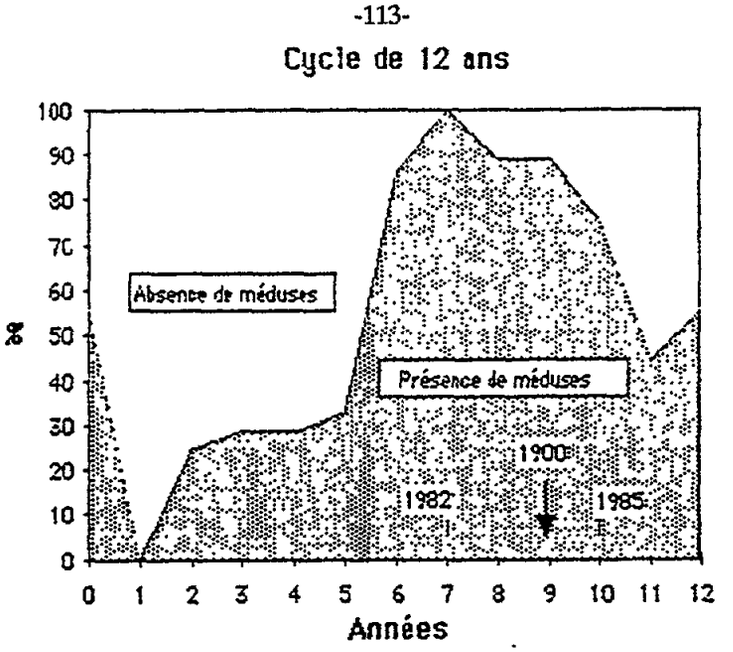

Fig. 1 -Pourcentage d'année a méduses observées entre 1876 et 1986 en Méditerranée occidentale présentés suivant la périodicité dominante de 12 ans.

Ce fichier de 3 x 365 x 100 données a d'abord été condensé en calculant des moyennes par paires de mois successifs. Les variables transformées par la méthode des retards échelonnés ont été ajustées aux données présence-absence annuelles de méduses, puis on est revenue aux paramètres météorologiques en calculant leur poids relatif dans la fonction de probabilité (Morand 1989).

Sur les Figures 2, 3 et 4 où les variables sont centrées, des poids négatifs signifient que des valeurs faibles augmentent la probabilité qu'il y ait des méduses l'année (ou les années) suivante. Au contraire avec des poids positifs, ce sont les valeurs fortes qui jouent ce même rôle. L'examen pour chacune des variables météorologiques permet de définir un type de " **temps de méduses** " (expression de Serge Dallot !):

Il s'agit d'années sèches, à conditions anticycloniques très accusées et avec des températures précocement fortes, conditions observées dans les trois années qui précédent un bloom.

On peut raisonnablement penser que si la sécheresse actuelle se maintient encore en 1991, les "*Pélagia*" réapparaîtront bientôt en Mer Ligure.

2.Analyse inter-bloom d'une population de Pélagia noctiluca: relations entre la répartition des méduses et les structures hydrologiques du Bassin Ligure.

Par analyse sur le moyen terme, on entend étudier les variations des populations de méduses lors de la dernière période de pullulation de 1982 à 1986. De courtes campagnes océanographiques entre Nice (Riviera française) et Calvi (Corse) ont permis de localiser et de suivre les méduses.

La partie la plus spectaculaire en période de pullulations, est l'envahissement des plages qui à lui seul a motivé toutes les études. Mais ce n'est qu'un phénomène sans grande signification écologique car les méduses moribondes sont incapables de retourner vers la haute mer. Il s'agit plutôt d'exportations sporadiques à partir du stock situé au large et transportées par advection horizontale ou par les courants dûs aux vents locaux (Morand 1989).

En 1984, on a pu étudier la répartition des *Pélagia* adultes par des comptages visuels en mer et par des récoltes de plancton. L'abondance des méduses est, en moyenne, plus forte et plus stable au large qu'à la côte. On a pu également reconnaître une localisation liée aux structures hydrologiques - à savoir: une zone périphérique située près de la côte et parcourue par le courant cyclonique Liguro-provençal, une zone centrale où les courants sont faibles mais la salinité maximale. Entre ces deux zones, existe un front de densité - le Front Liguro-provençal - qui est le siège d'une intense production biologique (Boucher *et al.*, 1987).

Il apparaît que *Pélagia* est une océanique. En période de bloom elle est permanente dans la zone centrale, légèrement plus abondante de part et d'autre du front et nettement moins abondante dans la

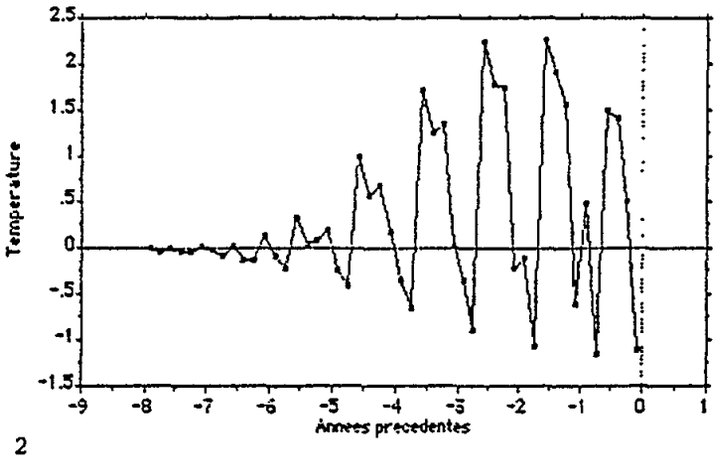

Fig. 2

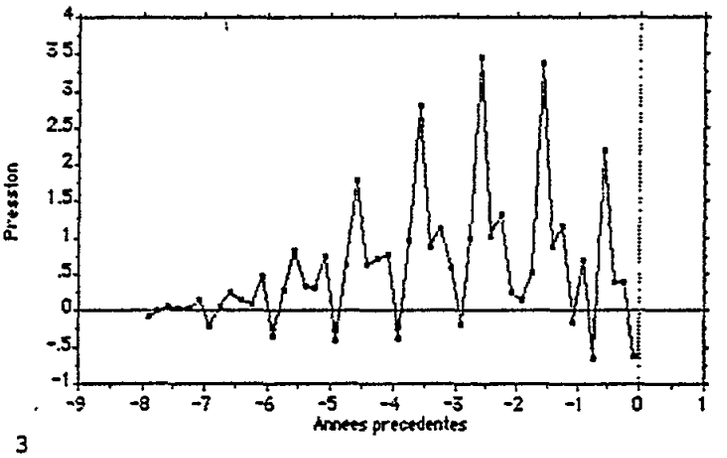

Fig. 3

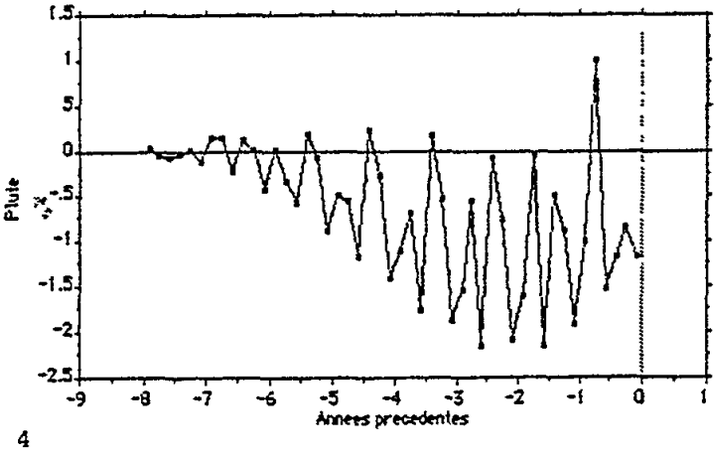

Fig. 4

Fig. 2,3,4 -Poids relatifs des variables météorologiques: température (2), pression atmosphérique (3) et pluviosité (4) sur les 8 ans avant un bloom de *Pélagia noctiluca* (voir le texte).

zone périphérique (Fig. 5). Les "évasions" seraient alors provoquées par les sortes de méandres, allant jusqu'à l'individualisation, qui dérivent en essaims d'adultes vers la côte.

Saisonnalité:

L'étude de l'abondance de cette éspèce fait apparaître une saisonnalité, déjà signalée à partir de la compilation des archives de comptages quotidiens retrouvés à la Station Zoologique de Villefranche-sur-mer (Morand et Dallot 1985). L'existence d'une saisonnalité n'est pas étonnante, ce type de structure temporelle est de régle chez la plupart des éspèces du plancton et a conduit autrefois à l'élaboration de nombreux "calendriers planctoniques". Mais le profil saisonnier médian le *Pélagia* est original: parmi les espèces présentant un cycle annuel significatif elle est la seule dont le maximum saisonnier corresponde à la période chaude de l'année (Morand et Dallot 1985).

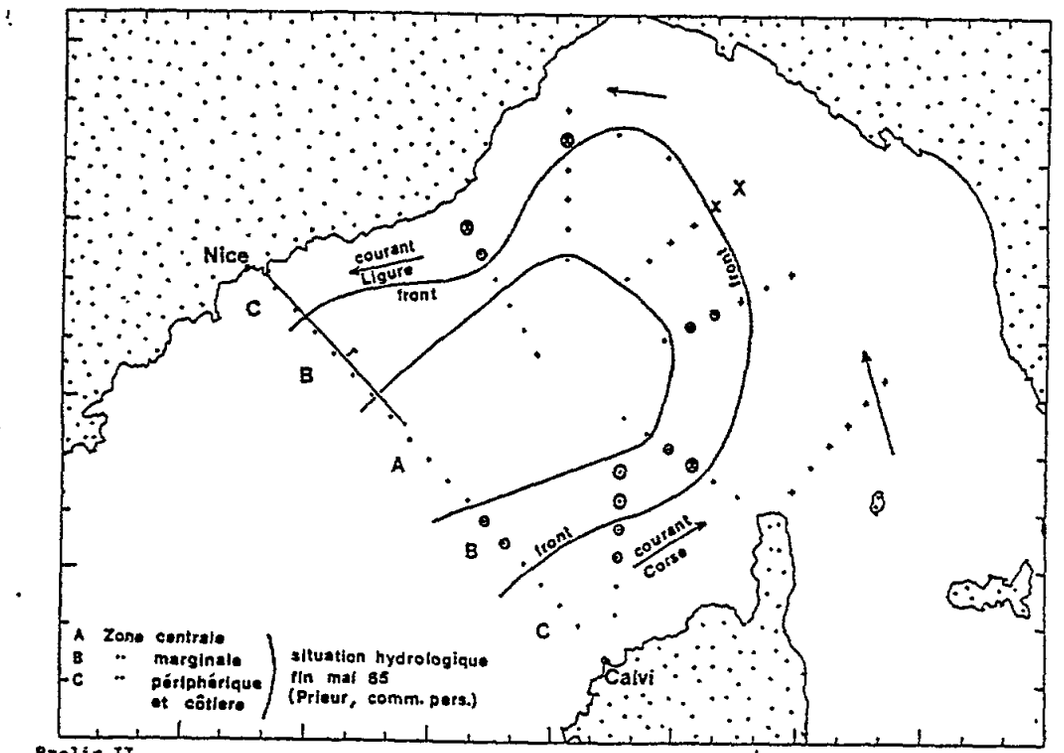

Fig. 5 -Répartition des *Pélagia noctiluca* dans le contexte hydrologique de la Mer Ligure au cours de la Mission PROLIG (23 mai - 2 juin 1985).

Enfin, l'examen d'échantillons planctoniques collectés avec des filets de 200 µm de vide de maille à la sortie de la rade de Villefranche-sur-mer vers le large à révélé l'existence d'un cycle annuel assez régulier de l'abondance de très jeunes stades larvaires éphyrules avec un pic estival (Fig. 6).

La présence de tous les stades de développement dans une zone restreinte comme la rade de Villefrance-sur-mer et son environ immédiate au large indique bien que ce n'est pas une intrusion sporadique mais bien une population en place qui se stabilise et se reproduit.

3. ETUDE SUR LE COURT TERME DE LA CROISSANCE INDIVIDUELLE:

Le court terme consiste à étudier les variations individuelles au cours des différents stades de développement pour connaître les effets des paramètres de l'environnement tant physiques (ici la température) que biologiques (nourriture et compétition) sur la croissance.

Contrairement à toutes les autres scyphoméduses, le cycle de vie est hypogénétique, c'est-à-dire qu'il n'y a pas de stade fixe scyphistome. Les oeufs sont particulièrement gros: 300 µm. Un développement

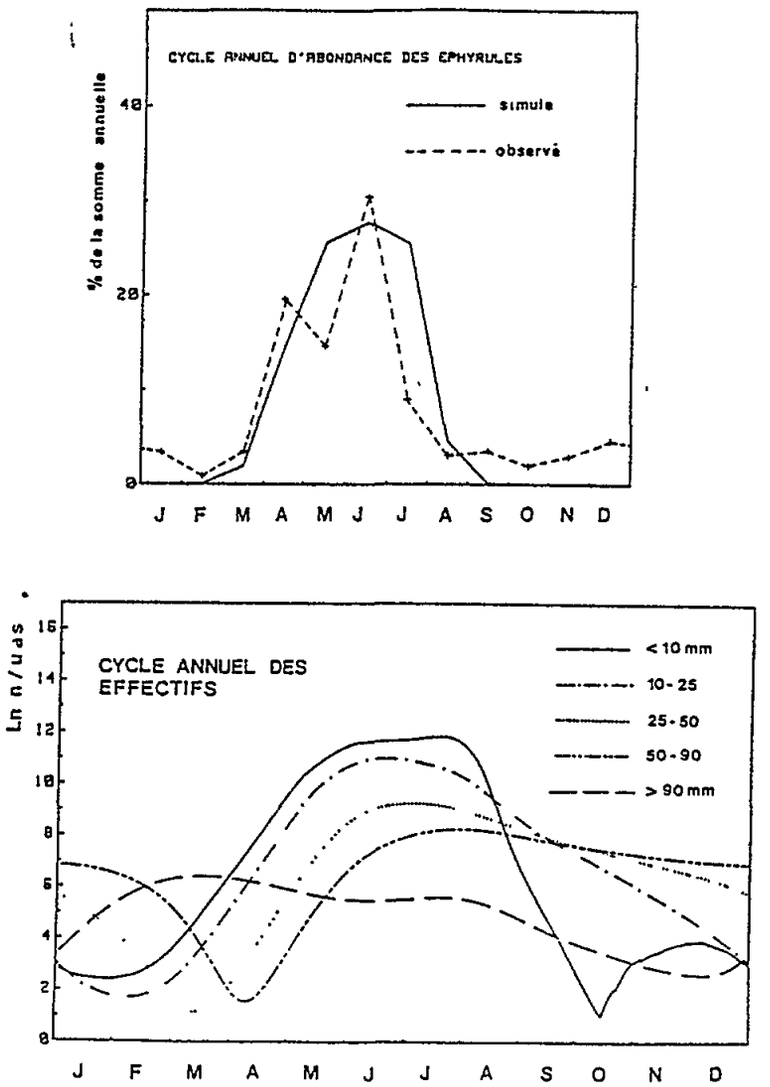

Fig. 6 -Cycles annuels des effectifs d'éphyrules (en haut) et des classes de taille (en bas) établis avec toutes les données disponibles.

direct a également été décrit chez *Aurelia aurita* par Haeckel (1881) et par Yasuda (1979) à partir d'oeufs anormalement gros.

Le développement larvaire, étudie depuis Krohn (1855), passe par différents stades éphyrules définit par le nombre de lobes ombrellaires et le nombre de filaments gastriques, on suppose qu'il se réalise en un an ce qui, en Méditerranée, signifie que l'éspèce est eurytherme. Les méduses sont capables de se reproduire en aquarium quand le diamètre atteint 50 mm.

C'est peut-être ce cycle holoplanctonique qui permet aux *Pélagia* de coloniser la haute mer, il est certain que l'absence de stade fixé et des oeufs bourres de réserve favorisent la vie en zone océanique.

Le suivi de la croissance a permis la détermination:

des taux de croissance,
des taux de respiration,
des taux d'excrétion ammoniacale
et de la ration journalière

exprimes en fonction de la taille suivant un modèle allométrique (Morand *et al.*, 1987).

On a également montré que les basses températures allongeaient les temps des différentes phases larvaires et ralentissaient le métabolisme. Si on envisage les migrations verticales des adultes, on voit que l'éspèce passe une partie de son cycle en "vie ralentie" sous la thermocline.

4. MODELISATION DEMOGRAPHIQUE:

Finalement, les paramètres métaboliques acquis expérimentalement ont été utilisés dans une modélisation de la population de *Pélagia* au cours d'un cycle annuel, les méduses étant reparties en 50 classes de taille de la larve aux adultes. On a introduit 2 variables forçantes: la concentration de nouriture (zooplancton) et la température, en faisant l'hypothèse de migrations verticales nycthémérales d'amplitude croissante avec la taille (on capture effectivement des éphyrules en surface le jour; au contraire les adultes ne sont visibles en surface que la nuit dans la zone centrale de la Mer Ligure).

Le modèle permet de calculer le bilan métabolique des différentes classes de taille et les changements de leur distribution d'abondance au cours du temps. Si les variables forçantes ont un comportement moyen pour la région, les résultats conduisent à une importante conclusion: avec un seul pic printanier de biomasse utilisable par les méduses et une oligotrophie estivale et automnal typique, le bilan métabolique global de la population, exprime en mg d'azote par mètre-carré et par jour, est négatif entre août et novembre. On doit suspecter alors une interruption possible du recrutement annuel avec disparition des jeunes stades moins résistants.

Ce calcul ne tient compte ni des prédateurs ni des amphipodes parasites. Mais le modèle permet également d'estimer la prédation de la population de *Pélagia* sur le zooplancton. Les méduses peuvent consommer une grande variété de proies (copépodes, euphausiacés, ptéropodes, oeufs et larves de poissons), elles sont euryphages.

5. CONCLUSION

Une interprétation biologique est possible si l'on décompose le cycle en trois phases:

1. une phase printanière voit pondre et disparaître l'ancienne génération, tandis qu'émérge la nouvelle représentée d'abord par des éphyrules puis par des individus de plus en plus grands capables de se reproduire vers 50 mm de diamètre dès le début de l'été;

2. à partir de fin juin-début juillet, l'évolution se ralentit: les éphyrules sont de moins en moins nombreuses, le transfert progressif vers les classes de taille supérieures se ralentit faute de nouriture mais la température élevée favorise la maturation sexuelle qui échoue toujours par absence de nourriture;

3. fin décembre, le réfroidissement retarde ou même stoppe la reproduction ce qui favorise la survie en vie ralentie des individus tout au long de l'hiver. Dès l'approche du bloom printanier zooplanctonique, un ultime effort de reproduction est cette fois couronné de succès.

Ce scénario un peu simpliste ne fait intervenir qu'une génération par an Mer Ligure ce qui est compatible avec l'oligotrophie estivale de la Méditerranée.

La mise en évidence de l'existence de conditions météorologiques associées au déclenchement des pullulations de méduses pose le problème des relations entre climat - dynamique océanique et production pélagique. En d'autres termes, on peut attribuer les pullulations périodiques de la méduse *P. noctiluca* à des fluctuations hydroclimatiques qui influencent le bilan halin de la Méditerranée et qui contribuent à augmenter la production des zones frontale et centrale. Une espèce carnivore de grande taille peut alors développer d'importantes populations et persister pendant quelques années en occupant une position très dominante dans l'écosystème pélagique. Toutefois l'extinction d'une période de bloom suppose que des compétiteurs de même niveau trophique provoquent l'effondrement des populations de *Pélagia*.

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AGGREGATIONS OF THE SCYPHOMEDUSA Rhizostoma pulmo IN THE LEBANESE COASTAL WATERS DURING THE SUMMER OF 1986

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ABSTRACT

Among the Scyphomedusae present in Lebanese coastal waters, *Rhizostoma pulmo* is the largest and most abundant. This jellyfish may reach a bell diameter of 40 cm during its maximum development during the summer peak. The usual appearance of this species is from late May to early June when the surface sea water temperature increases suddenly from 23°C to 27.50°C as was the case in summer 1986. *R. pulmo* swarming remained from June till mid-August when it disappeared completely. During the few weeks preceding this swarming, a phytoplankton bloom was recorded followed by an outburst of zooplankton characterized by Chaetognata (*Sagitta friderici, S. enflata*), Appendicularia (*Oikopleura* spp.), Cladocera (*Evadne spinifera, E. tergestina*) and many meroplanktonic larvae. This exceptional *Rhizostoma* swarming seems to be correlated with the high temperature and nutritional factors, since this Scyphomedusa is mostly a microphagous predator feeding mainly on zooplankton organisms.

RESUME

Parmi les Scyphoméduses présentes dans les eaux côtières libanaises, *Rhizostoma pulmo* semble être la plus grande et la plus abondante. Cette méduse acalèphe peut atteindre 40 cm. de diamètre durant son maximum d'abondance estival. L'espèce commence à apparaître entre fin mai et début juin lorsque la température de surface de l'eau de mer augmente brusquement de 23°C à 27,5°C, comme c'était le cas en été 1986. Cette abondance extraordinaire de *R. pulmo* continue jusqu'à la mi-août où elle disparaît subitement. Une floraison du phytoplancton précédait de quelques semaines cette poussée de *Rhizostoma*. Un développement printanier très fort de zooplancton succède à la poussée phytoplanctonique et se caractérise par une abondance particulière de Chaetognathes (*Sagitta friderici, S. enflata*), d'Appendiculaires (*Oikopleura* spp.), de Cladocères (*Evadne spinifera, E. tergestina*) ainsi que de plusieurs larves méroplanctoniques. Cette invasion extraordinaire de Rhizostoma semble ne se manifester qu'en raison de facteurs nutritionnels, cette espèce étant connue pour être un microphage se nourrissant au dépens d'organismes zooplanctoniques.

1. INTRODUCTION

The Hydromedusae and Scyphomedusae of the Lebanese coastal waters have been the subject of regular surveys since 1970; data concerning their composition, distribution and annual cycle have been published (Lakkis, 1971; Lakkis & Zeidane, 1985). Twenty one species of jellyfish were recorded from neritic waters and among them three Scyphomedusae: *Rhizostoma pulmo* Agassiz, *Cotylorhiza tuberculata* Agassiz and *Cassiopea polypoides** Keller.

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*Caught in September 1987 with small aggregates, this Indo-Pacific Scyphomedusa is a new record for the Mediterranean Sea

Further study (Goy, Lakkis & Zeidane in prep.) will provide more information on the Medusae of the Levantine Basin. Aggregations of *R. pulmo* which is the most common of the three in the area, have occurred a few times during summer causing damage to fishermen and panic among swimmers. This was the case during the summer of 1986.

2. METHODS AND HYDROGRAPHIC FEATURES OF THE AREA

Within the framework of the general monitoring survey of the plankton ecosystem along the coast of Lebanon, regular monthly samples were collected from different stations along the Lebanese coast between 1985 and 1987 with a Bongo plankton net of 60cm diameter and 200 and 500 microns mesh size. Samples with a 50 micron standard plankton net were also taken simultaneously in order to obtain information concerning the composition and abundance of microplankton (Fig. 1). The main purpose of collecting the samples was to study the composition and distribution of the Ichthyoplankton and Decapod larvae.

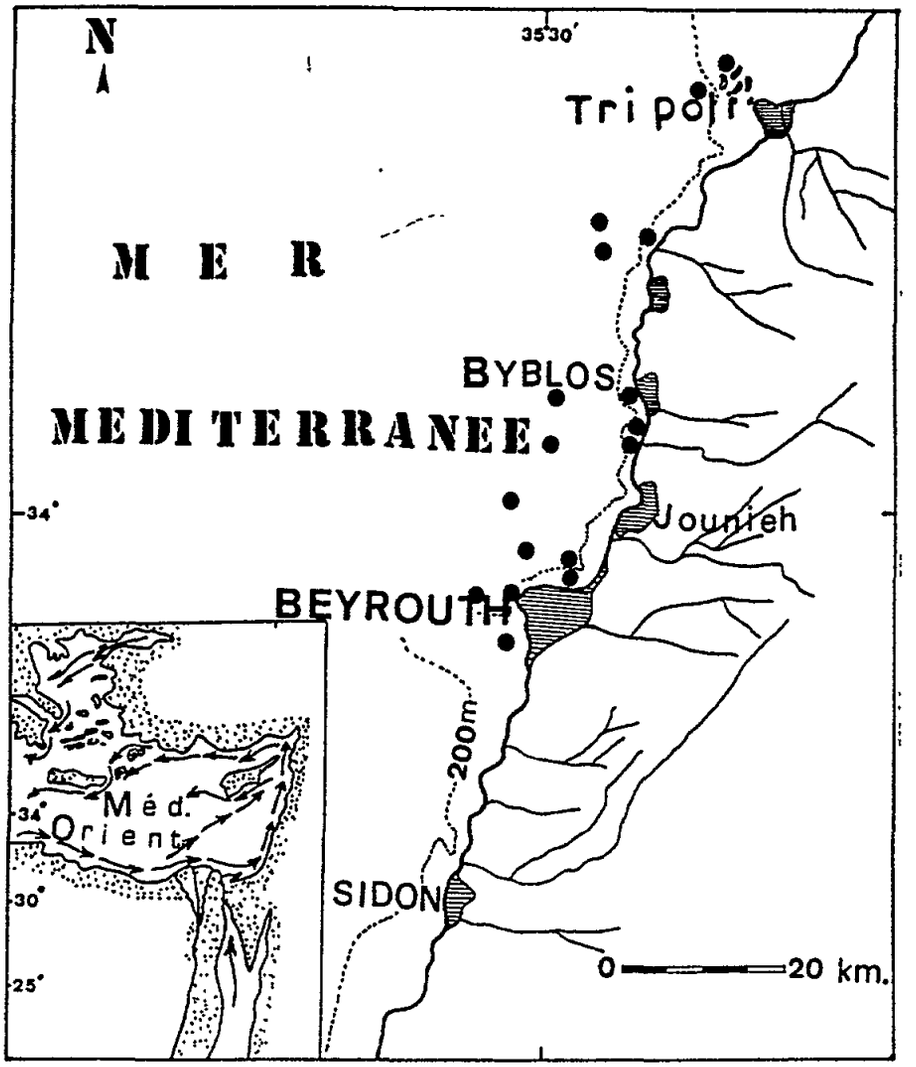

Fig. 1. Position of inshore and offshore stations along the coast of Lebanon between 1979 and 1987. The limit of the narrow contintal shelf is shown with the dotted line. The insert shows the general circulation pattern in the Eastern Mediterranean.

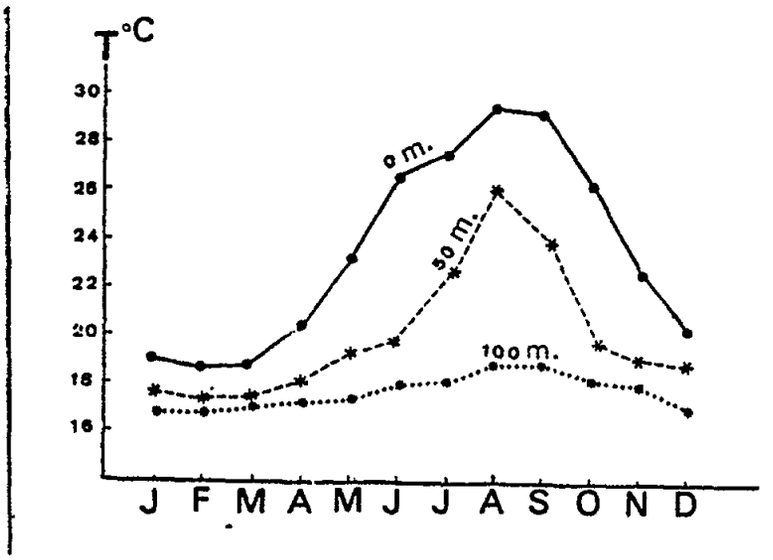

Fig. 2. Monthly nariations of the temperature at 0m, 50m and 100m in the offshore station By2 during 1986.

Vertical (50-0m) and surface tows were carried out from the SETA III research vessel equipped for hydrographic measurements. Data on temperature, salinity, water transparency, dissolved oxygen and nutrient concentrations were obtained along with the sampling process; these data have already been published in detail (Lakkis & Zeidane, 1987).

The Lebanese coastal waters are characterized by a large temperature range (minimum 17 °C in February maximum 30 °C in August). The winter period (December-March) is characterized by a vertical homothermy and the long summer period (May-October) by a stratification of water layers and a strong thermocline (Figs. 2 and 3). As far as salinity is concerned, the seasonal variations in the offshore waters are very small, ranging between 38.50 °/oo during the rainy winter and 39.50 °/oo during the dry summer. Vertical changes of the salinity values depend on the vertical water mixing, but in general a certain homogeneity is observed betwen 75 and 100m (Fig. 4). The surface T-S diagram shows a clear separation between the two seasonal water masses, the summer mass (the upper one) being characterized by high temperature and salinity, and the winter one by moderate values of the two parameters (Fig. 5).

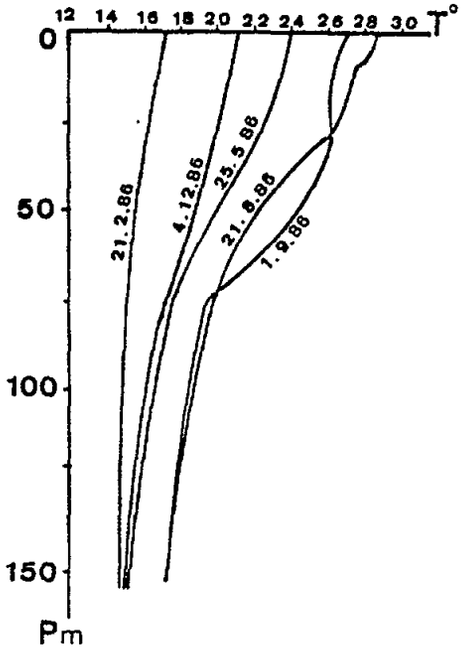

Fig.3. Vertical distribution of the temperature and thermocline profile at the station By2 during 1986.

The general circulation pattern prevailing along the coast of Lebanon is mostly northward. The surface current is for most of the year parallel to the coastline with some eddies separating from the main branch to form inshore cyclonic clockwise local currents namely in Jounieh bay and other coastal embayments (Fig. 6). Near the shore currents are less strong than in the offshore water. In November, the average surface current speed is 0.15m s^{-1} (Goedicke, 1972).

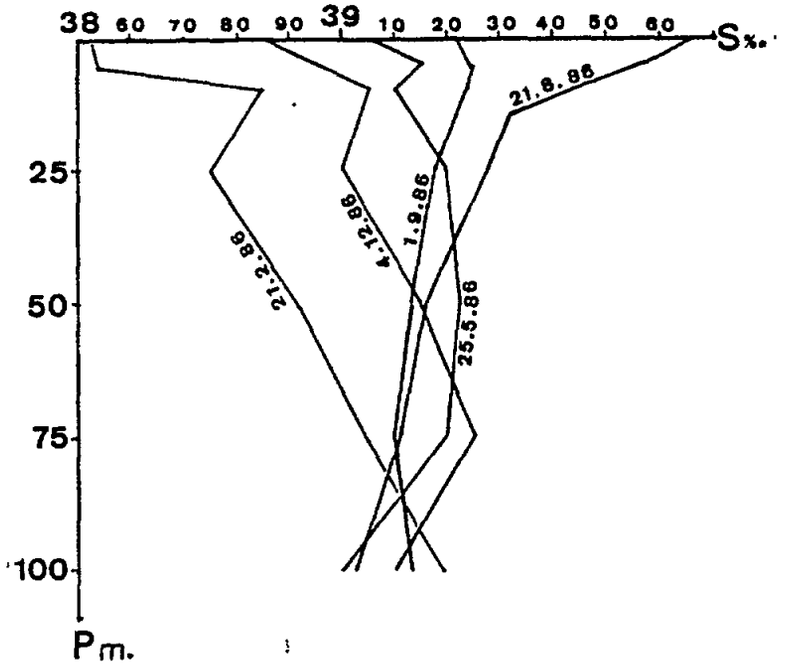

Fig. 4. Vertical distribution of the salinity at the offshore station By2 during 1986.

The plankton samples, formalized in 4% buffered solution, were analyzed for qualitative and quantitative purposes. The biomass of fresh plankton was measured and expressed as $cm^3\ m^{-3}$ of sedimented organisms and as a number of individuals per m3, counted in a Dollfus counting plate under a stage stereoscopic microscope. The large Scyphomedusa which could not be caught with the plankton nets were roughly estimated by counting them directly from the boat and expressed in number per $100m^2$.

3. RESULTS AND DISCUSSION

(1) Structure and population density of the plankton

The plankton of the Lebanese coastal waters is characterized by a high taxonomic diversity, most of the species belonging to the Mediterranean temperate fauna. However, many species occurring regularly in the area are of subtropical and Indo-

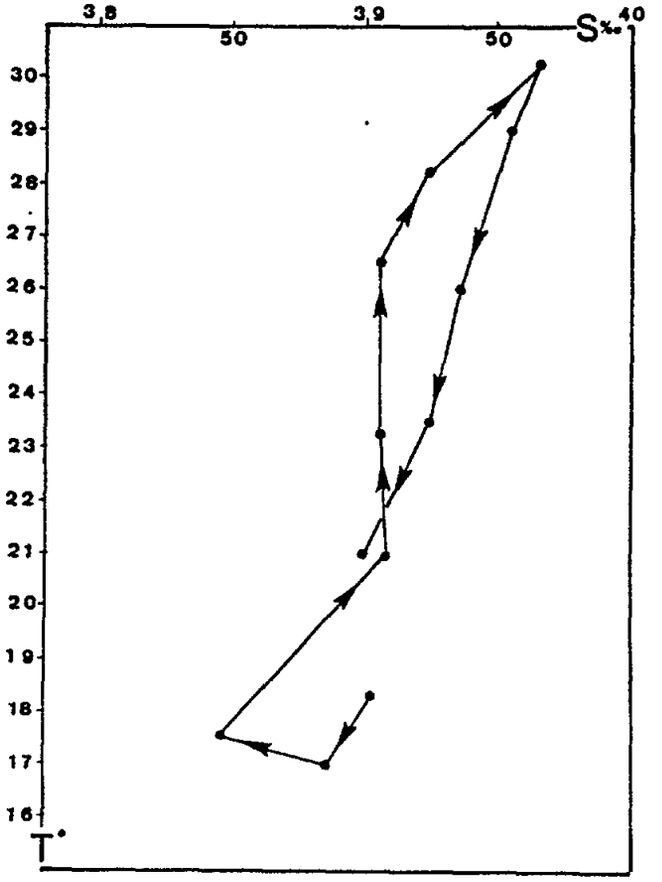

Fig. 5. Diagram T-S at the station By2 during 1986.

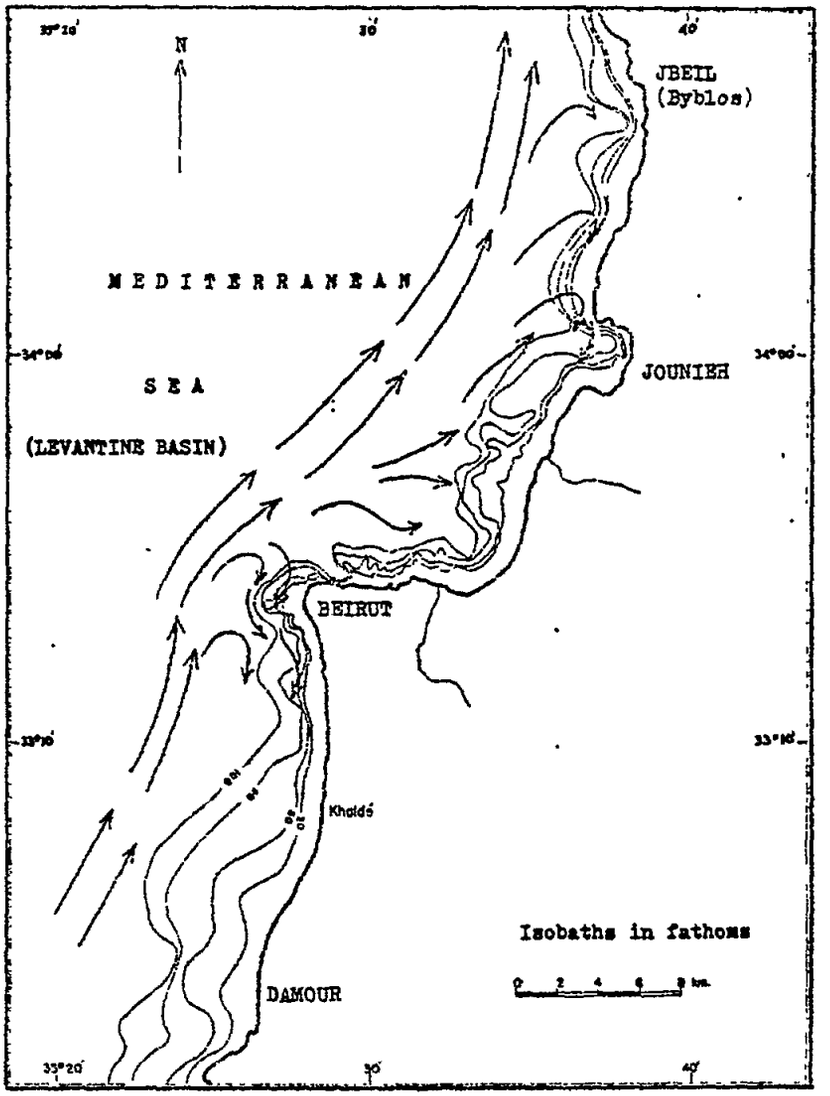

Fig. 6. General aspect of the surface current along the coast of Lebanon. From the main current parallel to the shore line eddy currents separate to form clockwise gyres (according to Goedicke, 1972).

Pacific origin (Lakkis, 1971b). In Table 1, the seasonal distribution of abundance of the main planktonic groups is given. We always observe a maximum average value in biomass production in May-April ($2cm^3\ m^{-3}$), coinciding with an average maximum number of organisms (6000 ind. m^{-3}). In April when sea water temperature is around 21-22°C, the annual spring phytoplankton bloom contains a high density of Diatoms and Dinoflagellates and a high species diversity (Lakkis and Novel-Lakkis, 1981). The high zooplankton production is mainly due to the Copepod development forming about 70% of the total number. In addition to this important group, the meroplankton is increased by the development of planktonic larvae, namely those of Decapoda Echinodermata' Crustacea and Mollusca. In May and June the plankton biomass is at its maximum and then it starts to decrease progressively until reaching its minimum value in September. However, several groups remain abundant in summer such as the Cladocera with dominance of *Evadne spinifera, E. tergestina* and *Podon polyphemoides*. The Appendicularia enrich the plankton with the development of *Oikopleura longicauda* (65% of the group), *O. dioica* and other *Oikopleura* spp. as well as *Fritilaria* spp. Among the Chaetognatha, *Sagitta friderici* (85% of the group) and *S. enflata* are the most common. The gelatinous planktonic organisms such as the Siphonophora, Ctenophora, Thaliacea and Hydromedusae are very abundant in summer and autumn, and sometimes the clogging of plankton nets is due to the abundance of these organisms.

Table 1. Composition and seasonal distribution of the main planktonic groups in Lebanese coastal waters during 1986.

	J	F	M	A	M	J	J	A	S	O	N	D
T°C	18	17	18	20	22.5	27.5	29	29.5	30	25	23.5	21
S‰	38.7	38.6	38.5	38.9	39.2	39.3	39.3	39.3	39.4	39.5	39.3	39
Biovol cc m^{-3}	0.2	0.4	0.9	2.2	0.7	1.9	0.9	0.3	0.5	0.7	0.1	0.7
N ind. m^{-3}	160	67	1657	6014	3595	1915	953	1590	1162	532	609	497
Hydromedusae $N \cdot m^{-3}$	1	2	5	6	3	1	3	1	2	2	66	26
Siphonophora	4	5	11	13	19	5	41	1	3	3	7	11
Ctenophora	x	x	x	-	-	-	5	6	7	9	10	2
Polychaeta	8	1	1	5	1	1	1	x	x	2	4	4
Cladocera	-	-	2	x	82	29	193	513	5	5	5	2
Ostracopoda	1	x	x	x	x	x	x	1	1	3	x	x
Copepoda	127	40	1500	5800	3367	1566	481	600	1020	450	460	380
Amphipoda	x	x	x	x	x	x	x	x	x	x	x	x
Decapod larva	1	1	1	15	5	43	8	104	16	10	2	2
Pteropoda	3	7	1	9	26	68	140	210	19	40	2	4
Heteropoda	x	x	x	x	x	x	x	-	-	-	x	x
Chaetognatha	4	2	14	92	43	26	28	23	28	4	31	15
Appendicularia	6	7	30	36	35	45	50	29	36	34	66	70
Echinopluteus	x	3	3	x	x	1	1	5	10	10	x	x
Nauplii	3	x	40	50	20	10	10	1	3	2	2	x
Lamellibranch.	1	4	10	4	100	16	24	4	3	x	x	x
Thaliacea	1	1	1	10	4	x	x	1	1	3	5	1
Fish eggs and larva	1	1	3	8	2	5	5	4	3	3	1	1
Other larvae	8	5	5	15	5	6	5	1	1	x	x	x
Phytoplankton x 100 cel l^{-1}	20	50	90	300	400	200	150	100	80	200	200	40
Rhizostoma pulmo	-	-	-	-	R	A	C	x	x	-	-	-

Table 2. Composition and seasonal distribution in abundance of Hydromedusae and Scyphomedusae species found in Lebanese coastal waters between 1970 and 1987. Symbols used: A = abundant (frequency 100-60%), C = common (60-40%), R = rare (< 40%), x = occasional or single specimen, - = absent.

SPECIES	J	F	M	A	M	J	J	A	S	O	N	D
ANTHOMEDUSAE												
*Dipurena ophiogaster	-	-	x	x	x	-	-	-	-	-	-	-
*Sarsia gemmifera	-	-	x	x	x	-	-	-	-	-	-	x
*Euphysa flammea	-	-	-	-	x	x	x	-	-	-	-	-
*Zanclea sessilis	-	-	x	x	x	C	C	R	x	-	-	-
**Paracytaeis octana	-	-	-	-	-	-	-	-	-	x	x	x
*Oceania armata	x	x	x	-	-	-	-	-	-	-	-	x
*Podocoryne carnea	-	-	R	R	C	C	R	x	x	-	-	-
*Podocoryne minuta	-	x	x	R	R	R	x	x	x	-	-	-
*Amphinema dinema	-	-	x	x	x	-	-	-	-	x	x	x
*Halitiara formosa	-	-	-	-	-	-	-	x	x	x	x	-
**Niobia dendrotentaculata	x	x	x	-	-	-	-	-	-	-	-	x
LEPTOMEDUSAE												
**Laodicea undulata (v. ocellata)	x	x	x	x	-	-	-	-	-	-	-	x
Obelia spp	x	x	C	A	A	A	C	R	R	R	x	x
*Phialidium hemisphaericum	x	R	R	C	C	R	R	x	x	-	-	-
*Cirrholovenia tetranema	-	-	x	x	x	-	-	-	-	-	-	-
*Eucheilota paradoxica	-	x	x	x	x	-	-	-	-	-	-	-
*Eucheilota ventricularis	x	x	x	x	x	-	-	-	-	-	-	x
LEPTOMEDUSAE												
Eirene viridula	-	-	-	-	-	x	R	R	R	x	x	-
Helgicirrha schulzei	-	-	x	x	x	-	-	-	-	x	x	x
LIMNOMEDUSAE												
**Moerisia carine	-	-	-	-	-	-	-	-	x	x	x	x
*Pochella oligonema	-	-	-	-	-	x	x	x	x	-	-	x
*Proboscidactyla ornata	-	-	-	x	x	x	-	-	-	-	-	X
TRACHYMEDUSAE												
Geryonia proboscidalis	x	x	x	-	-	-	-	-	-	-	x	x
Liriope tetraphylla	R	R	R	C	C	A	A	A	C	x	x	R
Aglaura hemistoma	-	-	-	x	x	x	R	x	-	-	-	-
Rhopalonema velatum	-	-	R	R	A	C	R	x	x	-	-	-
**Tetrorchis erythrogaster	-	-	-	-	-	-	-	-	-	x	x	x
NARCOMEDUSAE												
Solmundella bitentaculata	-	-	R	R	C	C	R	x	x	x	-	-
Cunea sp	-	-	-	-	-	-	-	x	x	R	R	x
*Solmissus albescens	x	x	x	R	x	-	-	-	-	-	-	x
SCYPHOMEDUSAE												
**Cotylorhiza tuberculata	-	-	-	-	-	x	R	C	C	R	x	-
*Rhizostoma pulmo	-	-	-	-	R	A	A	R	x	-	-	-
**Cassiopea polypoides	-	-	-	-	-	-	x	R	C	x	-	-

* Mentioned for the first time in the Eastern Mediterranean
** New records for the Mediterranean Sea

Table 3. Spearman's correlation coefficient analysis between the abundance of *Rhizostoma pulmo* and some environmental factors. * Significance at 95%.

Factors	Rhizostoma pulmo
Temperature °C	0.8*
Salinity S‰	0.8*
Water transparency	0.9*
Dissolved oxygen	0.2
Wind speed	0.5
Surface current speed	0.4
Phytoplankton biomass	0.5
Zooplankton biomass	0.7*

(2) Composition and seasonal distribution of Medusae

In a previous study on Hydromedusae (Lakkis & Zeidane, 1985), 22 species were determined, three of them new records for the Mediterranean Sea. *Paracytaeis octana, Tetrorchis erythrogaster* and *Moerisia carine.* Further investigations on the Medusae of the Eastern Mediterranean (Goy *et al.*, in prep.) provided more information on composition and distribution; 33 species are determined from the samples collected (Table 2): 11 Anthomedusae, 8 Leptomedusae, 3 Limnomedusae, 5 Trachymedusae, 3 Narcomedusae and 3 Scyphomedusae.

The seasonal distribution of medusae shows maximum abundance in April-May and again in November-December. Scyphomedusae are mostly abundant between May and November, with a maximum in July-August. Among the three species present in our waters *C. tuberculata, C. polypoides* and *R. pulmo* the latter is the most abundant; in some years e.g. June-July 1986, the swarms have invadedcoastal waters. In early June 1986, following the outburst of phytoplankton and zooplankton blooms, *R. pulmo* appeared suddenly and by the beginning of July the swarms had spread along the coast, causing panic among swimmers and affecting fishing activities. Many people claimed to have been stung by *Rhizostoma* after having been in contact with it in the water. Despite the fact that this scyphomedusa is not mentioned among the strong stinging species, Halstead (1965) listed it among venomous marine animals. We estimated the density of the *Rhizostoma* population at 1 ind. m^{-2} all along the coast, with an aggregation tendency near the shoreline. The bell diameter varied between 15 and 40cm.; floating occurred between 1 and 5m from the surface, and the medusae were carried by the drift in spite of their strong beating. The swarms started to decrease in density by the end of July and disappeared by mid-August.

(3) Relationship between Rhizostoma and environmental factors

This exceptional swarm of *Rhizostoma* was observed in June-July 1986 and was due to special environmental factors prevailing at that time, namely the high production rate of phytoplankton, followed by considerable zooplankton development. In addition to these biotic factors, some abiotic factors seem to have affected this swarming. They include high temperature and salinity values, water transparency and surface current induced by wind speed and northward direction. Spearman's rank correlation coefficient analysis was used to quantify the relationship between these parameters and the abundant distribution of the *Rhizostoma* population. The results given in Table 3 show a distinctly positive significant correlation between the abundance distribution of *Rhizostoma* and temperature ($r = 0.8$), salinity ($r = 0.8$), water transparency ($r = 0.9$) and zooplankton biomass ($r = 0.7$). Correlations of other factors (dissolved oxygen, wind speed, surface current and phytoplankton biomass) are not significant although they are low positive.

In conclusion, it can be stated that the *Rhizostoma* swarms in Lebanese coastal waters are not a regular periodic phenomenon. Since 1968, our regular survey has recorded 3 summer swarms: in 1972, 1979 and

1986. The Rhizostoma presence in our waters, however, is rather regular and its appearance in June-July every year is a familiar phenomenon on the coast. Environmental factors, namely temperature, salinity, hydroclimatic and plankton biomass are of great importance. Only a long-term monitoring survey could provide more information concerning this swarming phenomenon which affects the pelagic system.

4. ACKNOWLEDGMENTS

I would like to thank Miss Raymonde Zeidane for her scientific assistance in analyzing and counting the plankton samples. Miss Nada Matar brought specimens of *Cassiopea polypoides* to my laboratory for identification. A travel grant was offered by the UNEP, MEDPOL Programme to attend the 2nd Workshop on Jellyfish in the Mediterranean Sea, where I delivered this paper.

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CAUSES, CONSEQUENCES AND POSSIBLE CONTROL OF MASSIVE OCCURRENCES OF JELLYFISH Pelagia noctiluca IN THE ADRIATIC SEA

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SUMMARY

The most likely causes and some consequences of the massive occurrence of *Pelagia noctiluca* in the Adriatic Sea have been identified and discussed. The former are separated into natural anomalies (identified by other researchers, they include a change in the transport of jellyfish into the Adriatic Sea and a rise in minimum winter temperature of sea water in the northern Adriatic) and anthropogenic influence (two potential causes are identified: nutrient enrichment of coastal waters and more intensive fishing of fishes that serve as predators and competitors of jellyfish). Using a mathematical model, the qualitative behaviour of jellyfish under each of the potential causes has been calculated. The control of jellyfish populations in coastal waters should include a decrease in nutrient enrichment and a decrease in fishing intensity for fishes that compete with jellyfish and those that feed on jellyfish.

1. INTRODUCTION

The massive occurrence of *Pelagia noctiluca* in the Adriatic Sea has been documented since 1977 by several researchers (Maretic, 1980; Malej, 1981; Rottini-Sandrini and Stravisi, 1981). Earlier, from 1913 until 1977, *P. noctiluca* regularly appeared in much smaller numbers and did not arouse any concern.

In the rest of the Mediterranean, *P. noctiluca* appears regularly but rarely in large numbers. Historical records from Villefranche-sur-mer reveal irregularities that have not yet been fully explained, although a possible connection with higher winter temperatures of the sea has been pointed out (Goy, 1984). It seems that recent massive occurrences of *P. noctiluca* have become a more common phenomenon, the causes of which have not yet been identified.

The appearance of large numbers of *Pelagia* near the coast, especially near beaches, is considered a deterrent for tourists in such areas. This was the reason that States around the Mediterranean Sea launched a thorough study of this unusual phenomenon with a view to understanding the causes of the occurrence and finding solutions for possible control.

This paper touches upon some consequences of the massive occurrence of *P. noctiluca*. The potential causes are discussed next. A third part deals with possible control strategies and finally, the state of present knowledge is assessed and some remaining problems are elucidated.

2. MATERIALS AND METHODS

The methods used during this study consist of statistical analysis of data, construction, simulation and analysis of one predator-prey model in the form of a system of non-linear, ordinary differential equations.

3. RESULTS AND DISCUSSION

Consequences of massive occurrence

The massive occurrence of *P. noctiluca* in coastal waters and near beaches is a nuisance and presents a danger to swimmers. Problems arousing stinging by *P. noctiluca* have been documented and they range

from minor to major burns depending on the number of contacts with the jellyfish, the place of contact on the body and the sensitivity of the individual. Fishermen have also experienced burns when cleaning their net of jellyfish or taking fish which were caught together with it. In addition, such fish are not suitable for human consumption.

The massive occurrence of jellyfish in an area also means that smaller zooplankton, ichthyoplankton and small fish will be consumed in part by jellyfish. This food source is otherwise left for consumption by other fish.

Causes of massive occurrence

Based on the research so far, four potential causes are worth considering. They are:

(1) Transport of Jellyfish to Coastal Areas;
(2) Higher Minimum Winter Temperature of Sea Water near the Coast;
(3) Nutrient Enrichment from Land-based Sources and
(4) Decreased Competition and Predation Pressure on Jellyfish.

The first two potential causes may be considered as a natural deviation from normal conditions. Consequently, if one or both operate without the contribution of potential causes (3) and (4), then the massive occurrence is a natural phenomenon that will disappear with a return to the normal oceanographic conditions. The potential causes (3) and (4) are of anthropogenic origin and if it is shown that they are significant then a control of massive occurrence should obviously lead to modification of fishing practices and to a treatment of wastes from land-based sources.

Transport

A hypothesis put forward by Vucetic, (1982), is that a documented stronger than usual ingression of Mediterranean water has brought about a higher concentration of jellyfish into the Adriatic Sea and especially in the northern Adriatic. An implicit assumption of this hypothesis is that in the central Mediterranean jellyfish are common and may be found in larger swarms.

The net result according to this hypothesis is that regarding jellyfish concentration, the Adriatic Sea has become more like the central Mediterranean. Higher concentrations of jellyfish near other northern Mediterranean coasts could then be attributed to the same cause. The validity of this hypothesis can not be fully checked due to the lack of continuous current measurements. However, the ingression into the Adriatic Sea has been documented by existing temperature and salinity measurements. It should be noted that historical records show several earlier ingressions but no concurrent massive occurrence of jellyfish has been documented.

According to this hypothesis the phenomenon is natural and arises from anomalies in water circulation patterns. Details of the entrance of jellyfish into the Adriatic and transport of swarms may be found in Legovic and Benovic, (1984). The formation of swarms and their stability are discussed by Legovic and Rottini-Sandrini, (1987).

Minimum winter temperature of sea water

Stravisi, (1984), investigated temperature time series measured in the port of Trieste and concluded that the minimum sea water temperature during winter was higher than 6 °C for 14 consecutive years (1966-1980). Temperature deviation of 1-3 °C supposedly allowed jellyfish ephyrae to survive the winter in the northern Adriatic and, since jellyfish breed in the northern Adriatic, to produce more offspring than normal. The fact that jellyfish breed in the northern Adriatic was discovered by Malej (1982), and later confirmed on a larger pool of data by Rottini-Sandrini *et al.*, (1984). Jellyfish are indeed very sensitive to temperature and 6 °C seems to be lethal at least to ephyrae (Rottini-Sandrini, 1982). The explanation for a higher minimum (and mean) winter temperatures of sea water is found in the correlation with more frequent southerly winds (Rottini-Sandrini *et al.*, 1980).

Unlike the first, this hypothesis can not be extended to cover the whole Mediterranean because the minimum sea water temperature during winter in the southern part of the Adriatic Sea and in the central Mediterranean is well above the critical range.

It seems that minimum winter sea water temperature can not be the only factor responsible for massive occurrences because in the last fifty years there have been similar, although shorter, periods of such temperatures; however historical samples do not contain numerous ephyrae. In addition, in the winter of 1984-85, minimum sea water temperature was very low, yet in the subsequent spring and summer many jellyfish swarms were observed (UNEP, 1986) although this could be due to high concentrations in preceding years.

Nutrient enrichment from land-based sources

The higher concentration of jellyfish in some coastal waters may be explained by the fact that jellyfish can take advantage of a higher concentration of nutrients found in large areas around waste water outflows (Wilkerson and Dugdale, 1984). Apart from direct absorption of DOC which, in high DOC concentration, may account for up to 10-40%, some jellyfish are accompanied by symbiotic algae the growth of which is enhanced in conditions of high nutrient concentration. In addition, jellyfish have a very high maximum specific feeding rate so that, compared with other zooplankton predators, they profit more from an increase in the concentration of the food types they feed on. Finally, jellyfish are able to decrease in size when there is a food shortage and increase again when a food source is found. A smaller size distribution in the Adriatic versus the central Mediterranean suggests that undernourishment in the Adriatic is more likely.

It has been shown recently (Justic *et al.*, 1987) that land-based nutrient sources in the northern Adriatic have increased in the last fifty years, implying an increase in primary production above the thermocline.

If we combine the finding that jellyfish can utilize nutrient sources with the finding that nutrient sources have increased in the northern Adriatic we are led to the hypothesis that recently jellyfish have bred in the northern Adriatic more successfully than ever before.

Increase in catch of jellyfish competitors and predators

It has been found that the catch of jellyfish predators and competitors in the Adriatic Sea has increased at least four-fold between 1965 and 1980 (Legovic *et al.*, 1987). Assuming the same birth rate of fish, this means less standing stock of these fishes and consequently less competition and predation pressure on jellyfish. Although based on data from the Adriatic Sea only, this hypothesis may be extended to all coastal areas of northern, central and western Mediterranean.

According to this hypothesis, the increase in fishery catches seems to be at least one of the contributing factors to the massive occurrences of this jellyfish.

A model of jellyfish and their prey

In order to investigate the effect of the above factors that might have caused a recent increase in jellyfish population, a simple predator-prey model was used (Legovic, 1987). According to the model, a higher nutrient inflow causes an increase in the steady state of jellyfish population and no change in jellyfish prey. Qualitatively the same effect is obtained when the population of predators competing for jellyfish prey decreases. A decrease of predators on the jellyfish population causes an increase in jellyfish population and a decrease in jellyfish prey. Sufficiently high nutrient enrichment or a decrease in jellyfish predators may cause the appearance of a stable limit cycle, i.e. asymptotically periodic fluctuations of both prey and jellyfish population. If persistent periodic fluctuations are a natural phenomenon then the above change will increase the amplitude of periodic fluctuations.

Possible control

Two types of control strategies are of interest: local and global. Local control, i.e. protection of beaches, can be achieved by placing nets around beaches. The nets should span the entire water column, including tides and waves. Global control of jellyfish in coastal sea depends on identifying the causes and understanding the contribution of each factor to the increase of jellyfish populations. Each of the above

mentioned potential causes probably contributes to the increase in jellyfish populations. The extent of the contribution of each factor is, unfortunately, not known. This situation will probably not improve significantly in the near future. The two relevant anthropogenic factors subject to control in coastal waters are a decrease in nutrient enrichment and a reduction of catches of fish that serve as jellyfish predators and competitors.

4. CONCLUSIONS

The most likely causes and some consequences of the massive occurrence of *P. noctiluca* in the Adriatic Sea have been discussed. The causes may be divided into natural anomalies and anthropogenic influences. Natural anomalies include a change in transport of jellyfish into the Adriatic Sea and a rise in minimum winter teperature of sea water in the northern Adriatic. The latter implies the survival of jellyfish during winter in much larger numbers and a greater reproduction rate in the following season. From the group of anthropogenic influences two potential causes were identified: nutrient enrichment of coastal waters and more intensive fishing of species that serve as predators and competitors of jellyfish. Unfortunately, the extent of the effect of each cause has not been determined. The control of jellyfish populations in coastal waters includes a decrease in nutrient enrichment and a decrease in fishing intensity for fishes that compete with jellyfish and those that feed on jellyfish.

5. ACKNOWLEDGMENTS

This research was supported by the Authority for Scientific Research of SR Croatia and UNEP/MAP.

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CONSIDERATIONS SUR LA DISTRIBUTION DE Pelagia noctiluca (Forskal) DANS L'ADRIATIQUE DE 1976 A 1987

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RESUME

Dans le cadre du programme de recherche sur la biologie des méduses des mers italiennes, une étude sur la distribution de *Pelagia noctiluca* dans l'Adriatique a été faite.

La distribution de cette méduse en fonction des années et saisons considerées figure dans les études ichthyoplanctoniques de 1976 à 1987.

1. INTRODUCTION

Le laboratoire de Biologie Marine et de Pêche de Fano a réalisé, en collaboration avec le Département de Biologie de l'Université de Trieste et avec l'Institut d'Océanographie et de Pêche de Split, dans le cadre d'un programme de recherche sur l'ichthyoplancton une série de campagnes en haute et moyenne Adriatique (Fig. 1).

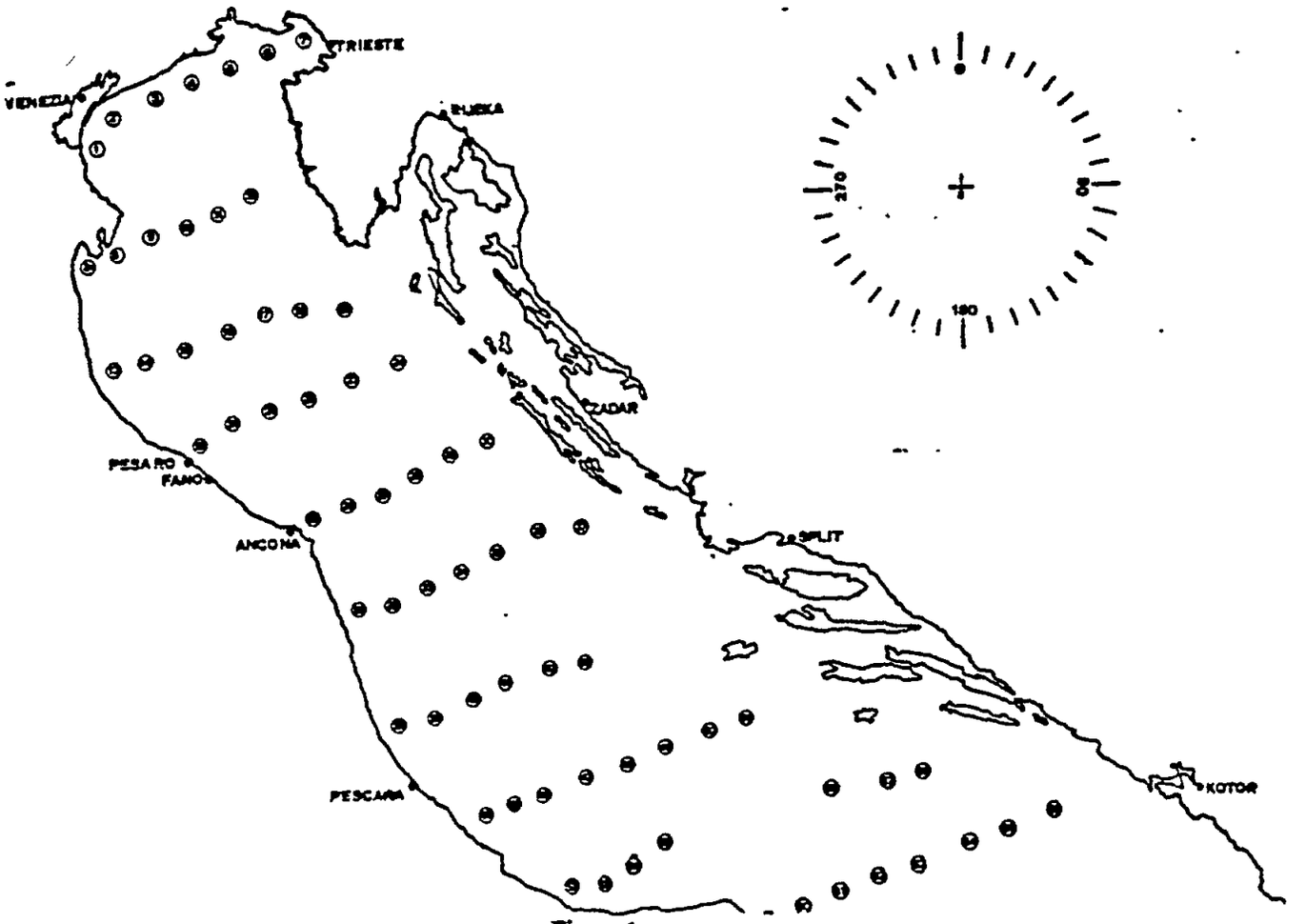

Fig. 1

Ces campagnes ont commencé en 1976 et en avril 1987, 26 ont été menées à bien.

Bien qu'au départ, la recherche n'ait pas été dirigée vers l'étude des méduses, une partie des échantillons, en particulier ceux qui avaient été prélevés avec le filet à plancton conico-cylindrique (modèle FAO), a été utilisée pour déterminer les indices de présence et d'abondance de la méduse *Pelagia noctiluca*. Au cours des premières campagnes, l' étude présente un caractère essentiellement qualitatif, tandis que par la suite on a appliqué à l'épuisette (modèle FAO) un fluxmètre et un profondimètre pour déterminer le volume d'eau filtrée, et la profondeur atteinte, ce qui a rendu possible le calcul de certains indices d'abondance.

Les résultats de l'examen du matériel récolté dans l'Adriatique de 1976 à juillet 1984 ont été en partie publiés (G. Piccinetti-Manfrin and C. Piccinetti, 1983; 1983-1984; 1984).

Le présent rapport présente les résultats des campagnes de juillet 1984 à avril 1987, tout en se rattachant aux séries de données précédentes pour fournir une vue complète de la situation dans l'Adriatique ces douze dernières années quant à la présence, la distribution et l'abondance de la méduse *P. noctiluca*.

2. MATERIEL ET METHODES

Le mode d'opération en mer est resté fondamentalement le même pendant toute la période considérée: sur un réseau de stations (voir figure no. 1), souvent completé vers les eaux yougoslaves par des campagnes réalisées en même temps par les collègues yougoslaves, des pêches quantitatives de zooplancton ont été effectuées en double oblique avec un filet modèle Bongo 20 à mailles de 235 à 335 microns, entre la surface de l'eau et une profondeur de 70 mètres, lorsque c'était possible. En parallèle on procédait à une pêche avec un filet FAO d'un mètre de diamètre et des mailles de 500 microns. On mesurait ensuite, grâce à une sonde, la stratification de température et la salinité et on effectuait un prelèvement d'eau de surface en vue d'une analyse des sels nutritifs et du plancton.

Pour chacune des 26 campagnes le nombre de stations varie, dans la mesure que, parfois du fait de conditions météorologiques, pendant les mois d'hiver en particulier, toutes les stations prévues n'ont pas été réalisées; dans l'ensemble 1431 stations ont été visitées, à savoir en moyenne 55 par campagne.

En laboratoire les échantillons prélevés avec le filet à plancton modèle FAO ont été examinés. On a compté toutes les méduses de l'espèce *P. noctiluca* de 2 à 3 mm (efire) et plus.

Le nombre d'individus obtenu par échantillon, a été rapporté au m^3 d'eau filtrée et au m^2 de surface, compte tenu du volume d'eau filtrée et de la profondeur attente.

En effectuant l'échantillonage de jour comme de nuit et en sachant que la distribution verticale de *P. noctiluca* varie en fonction de l'heure de la journée, les valeurs quantitatives obtenues doivent être considérées comme des indices d'abondance approximatifs et non comme des valeurs réelles.

Le grand nombre de campagnes effectués et la quantité de stations réalisées, en suivant toujours la même méthode, permettent d'obtenir des indications sur l'évolution de la situation.

3. RESULTATS

Les figures 2, 3, 4, 5 représentent la distribution quantitative de *P. noctiluca* pour les campagnes de décembre 1984, mars 1985, septembre 1985 et mars 1986. On constate que la distribution jusqu'en mars 1986 ne présente pas de grosses différences par rapport aux années précédentes; les stations marquant la plus grande présence se trouvant toujours à proximité de la ligne Ancone-Zadar, où les courants provoquent probablement une concentration de méduses accrue. Pendant les campagnes de septembre 1986 et avril 1987, alors que la distribution des stations restait identique, on n'a capturé aucune méduse de l'espèce *P. noctiluca*.

Le tableau I indique certaines données pour les 26 campagnes effectuées, en particulier le nombre total de stations, le nombre de stations positives pour *Pelagia noctiluca* et, depuis qu'on utilise un fluxmètre et un sondeur sur le filet modèle FAO également, un indice d'abondance correspondant au nombre moyen de *Pelagia* par unité de superficie. Le tableau montre que, de juillet 1978 à mars 1986 la présence de *Pelagia* et sa distribution sont restées similaires, même en présence de fluctuations saisonnières et annuelles. Pour ce qui est des indices d'abondance, on note que c'est dans la période juillet 1982 - juillet 1983 que l'on a obtenu la densité maximale de *Pelagia* en haute et moyenne Adriatique alors que, par la suite et jusqu'en septembre 1985 sa présence n'était pas très élevée. Toutefois en mars 1986, elle tend à augmenter et enfin à partir de septembre 1986, *Pelagia* disparaît totalement du matériel récolté.

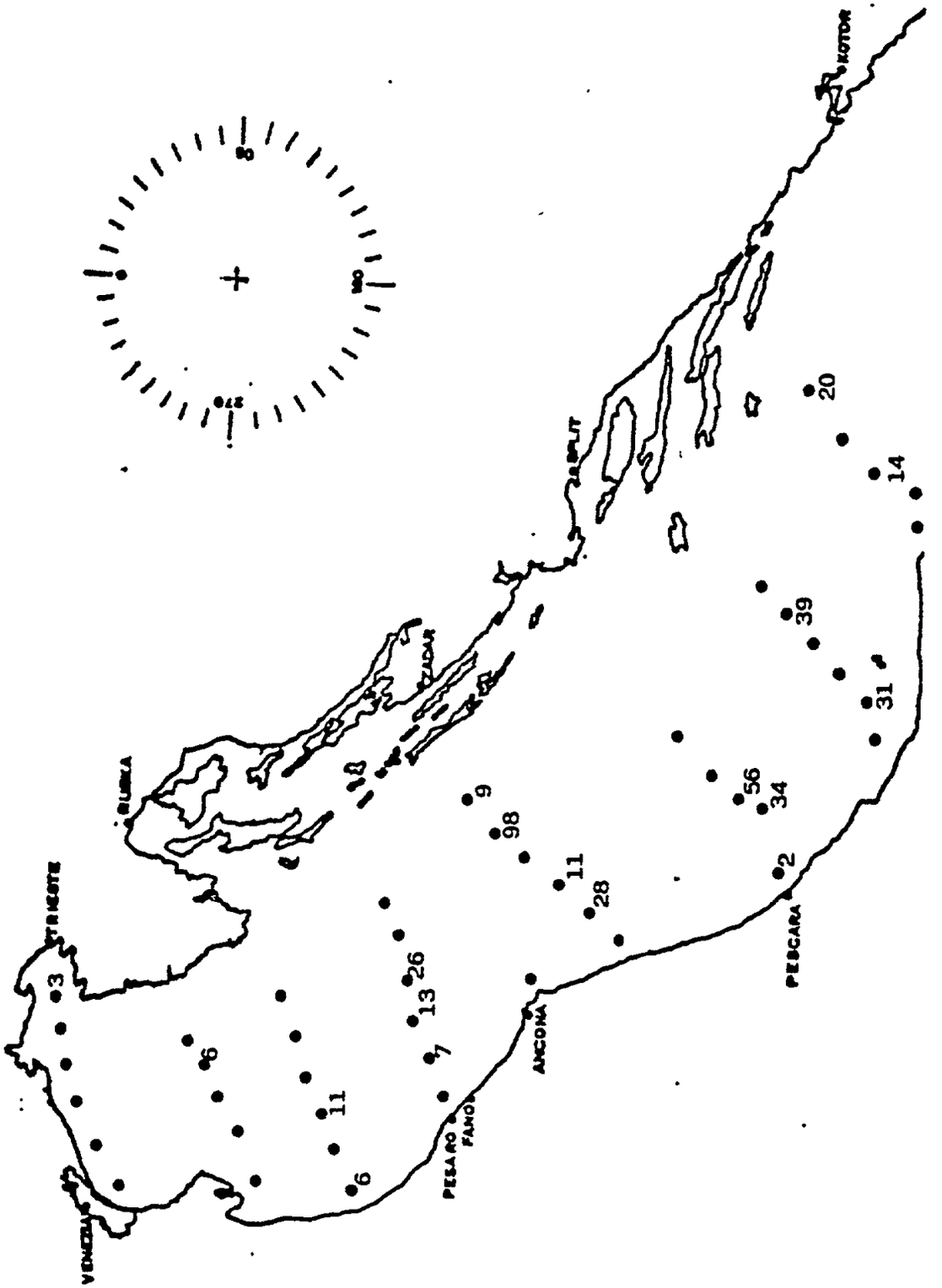

Fig. 2. Décembre 1984. Nombre de méduses / 100 m^2

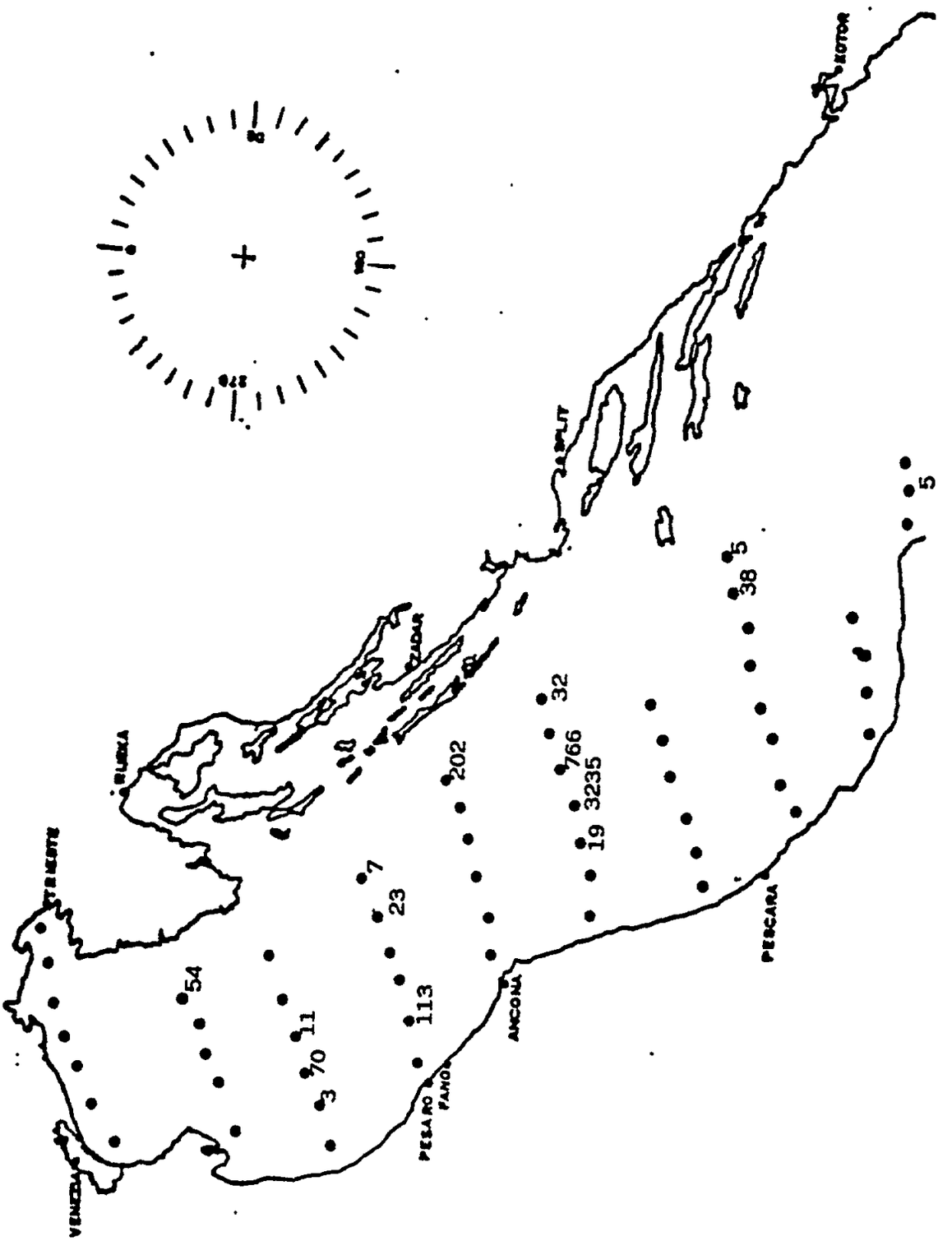

Fig. 3. Mars 1985. Nombre de méduses / 100 m^2

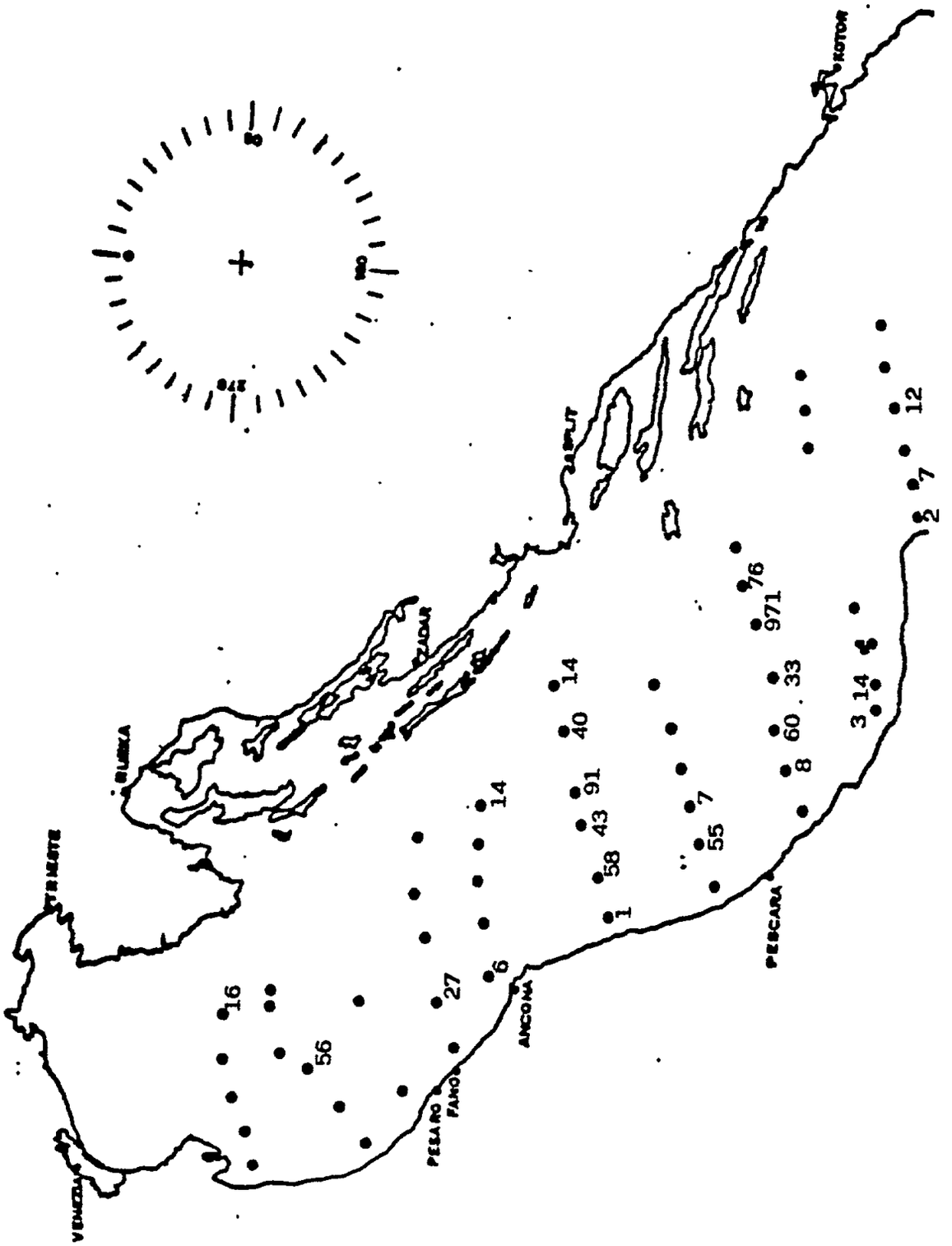

Fig 4. Septembre 1985. Nombre de méduses / 100 m^2.

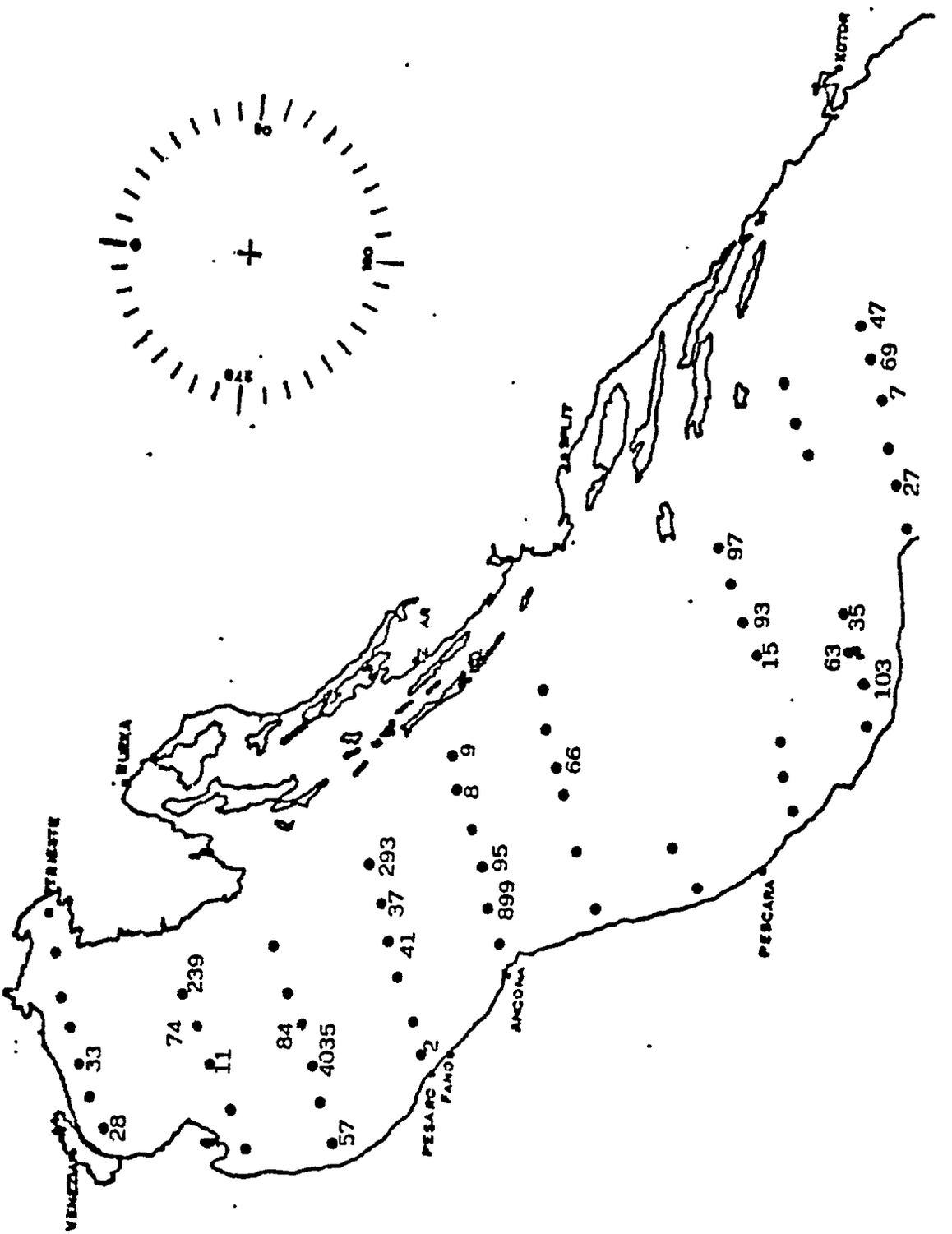

Fig 5. Mars 1986 Nombre de méduses / 100 m^2

Tableau 1. Résumé des données sur la présence de *Pelagia noctiluca* en haute et moyenne Adriatique

Date	Nombre total de stations	Nombre de stations positives	% stations	Nombre moyen méduse/m^2
Juillet 1976	63	2	3,2	-
Septembre 1976	68	3	4,4	-
Septembre 1977	58	3	5,2	-
Juillet 1978	64	26	40,6	-
Mars 1979	64	28	43,7	-
Juillet 1979	64	29	45,3	-
Décembre 1979	36	9	25,0	-
Février 1980	43	11	25,6	-
Juillet 1980	66	41	62,1	-
Mars 1981	43	17	39,5	-
Juillet 1981	64	28	43,7	0,15
Décembre 1981	37	16	43,2	-
Mars 1982	37	14	37,8	-
Juillet 1982	63	18	28,6	1,78
Mars 1983	64	42	65,6	12,88
Juillet 1983	65	39	60,0	4,42
Décembre 1983	60	24	40,0	0,10
Mars 1984	54	32	59,2	0,75
Juillet 1984	64	24	37,5	0,80
Décembre 1984	46	18	39,1	0,09
Mars 1985	58	15	25,9	0,79
Juin 1985	24	12	50,0	0,22
Septembre 1985	55	23	41,8	0,29
Mars 1986	58	27	46,6	1,13
Septembre 1986	63	0	0	0
Avril 1987	50	0	0	0

Tableau 2. Valeurs de certains paramètres environnment aux durant les campagnes de septembre 1985 et 1986

	Septembre 1985	Septembre 1986
Température à la surface		
Moyenne de la campagne	23,16	23,06
Moyenne stations positives	23,11	-
Moyenne stations négatives	23,19	23,06
Salinité à la surface		
Moyenne de la campagne	37,32	36,82
Moyenne stations positives	37,59	-
Moyenne stations négatives	37,13	36,82
Nitrates à la surface		
Moyenne de la campagne	25,27	9,59
Moyenne stations positives	19,05	-
Moyenne stations négatives	29,55	9,59

4. DISCUSSION ET CONCLUSIONS

On peut retirer de l'ensemble des 26 campagnes une image assez indicative de la distribution et de l'abondance de *P. noctiluca* en haute et moyenne Adriatique. Les campagnes de 1976 et 1977 ont montré le pénétration de cette méduse dans l'Adriatique, en provenance de la mer Ionienne. Par la suite, on assiste à une rapide augmentation et une distribution sur tout le bassin, marquant des différences, mais rela-

tivement homogène d'une campagne à l'autre, avec une moindre présence dans les eaux côtières et une densité plus forte en haute mer, en particulier là où le jeu des courants permet l'accumulation des organismes transportés, comme les méduses.

Pendant les deux dernières campagnes (septembre 1986 et avril 1987), l'absence totale de *Pelagia* des échantillons récoltés indique une brusque variation de l'abondance des populations, dans le sens inverse de celle de 1977-1978. Lors de la campagne de mars 1986, rien ne laissait prévoir une telle variation, dans la mesure où la vaste distribution, la densité non négligeable et la présence d'un nombre élevé de petites méduses n'annonçaient pas une disparition rapide.

Cette brusque variation, intervenue entre mars et septembre 1986, mérite d'être analysée, en particulier pour en repérer les causes, que l'on pouvait peut être relier, en sens contraire, à la fluctuation positive de 1977-1978. Pour tenter une première vérification, nous avons mesuré les températures, la salinité et a concentration moyenne de nitrates pendant les deux campagnes de septembre 1985 et septembre 1986 pour faire ressortir d'eventuelles différences liées au cycle thermique ou à la masse d'eau dont la salinité et les nitrates peuvent être de bons indicateurs.

Ces données, reparties en fonction des stations positives et négatives figurent sur le tableau No. II. La température ne marque pas de différence entre les deux campagnes ou entre stations positives et négatives, la salinité en septembre 1985 est légèrement plus élevée pour les stations positives que pour les stations négatives, ce qui confirme ce que l'on a déjà mentione' auparavant, à savoir une présence accrue de *Pelagia* dans des eaux à salinité plus élevée; en 1986 la salinité moyenne est inférieure, mais cela pourrait être lié à la moindre présence de stations en 1985 en haute Adriatique, où les salinités sont plus élevées.

La quantité inférieure de nitrates relevée en septembre 1986 pourrait constituer un indice à relier à une moindre productivité de l'environnement, à son tour liée à l'abondance des méduses. Confirmant ce qui a déjà été signalé (Tegaccia 1983-1984) la méduse *P. noctiluca* ne semble pas être étroitement conditionnée par la température et la salinité, ou directement par les nitrates. Il est donc nécessaire d'examiner d'autres facteurs environnementaux et biologiques pour comprendre leur influence sur les fluctuations d'abondance de cette espèce.

En utilisant d'autres prélèvements de plancton effectués par le Laboratoire de Biologie Marine et de Pêche de Fano, dans une zone limitée de haute Adriatique, nous avons essayé de mieux préciser la période de la disparition de la méduse. Après la campagne de mars 1986, même dans les prélèvements de mai 1986 ces méduses étaient abondantes, alors qu'à partir de juillet 1986 on n'en a plus capturées. Cela pourrait indiquer que c'est entre la fin mai et juillet 1986 qu'est intervenu un facteur qui a provoqué la disparition de *Pelagia*.

Les données présentées illustrent l'évolution d'un phénomène; l'augmentation énorme d'une population suivie de sa disparition, et le fait de connaître l'évolution dans le temps de ce phénomène est à la base d'un approfondissement de la recherche des causes de ces fluctuations, ce qui sera la ligne de nos activités de recherche à l'avenir.

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OBSERVATIONS ULTERIEURES SUR LA DYNAMIQUE DE *Pelagia noctiluca*

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RESUME

Dans le cadre du programme de recherche sur la biologie des méduses des mers italiennes, des recherches sur la dynamique de *Pelagia noctiluca* ont été effectuées. Tous les spécimens de *Pelagia* capturés au cours de plusieurs recherches ichthyoplanctoniques menées par le Laboratoire de Biologie Marine et de Pêche de Fano dans le nord et le centre de l'Adriatique ont été étudiés.

De la distribution fréquence-largeur de la population pour chaque étude on a déduit certaines indications quant aux paramètres biologiques de cette espèce.

1. INTRODUCTION

La forte fluctuation positive constatée à partir de 1978 de la population de *Pelagia noctiluca*, avec ses conséquences sur certaines activités humaines, comme la baignade et la pêche, a donné lieu à de nombreuses recherches, dont, en 1984 une première enquête sur la dynamique de la population de cette espèce en Adriatique (Piccinetti *et al.*, 1984).

En suivant la distribution de l'espèce, nous avons constaté sa disparition des échantillons recueillis en Adriatique au cours de l'été 1986.

Afin de vérifier si certaines situations anormales dans la composition de la population se trouvaient à l'origine de cette fluctuation négative et en vue d'une vérification ultérieure des paramètres biologiques précédemment déterminés, nous avons examiné la série d'échantillons de 1979 à 1987.

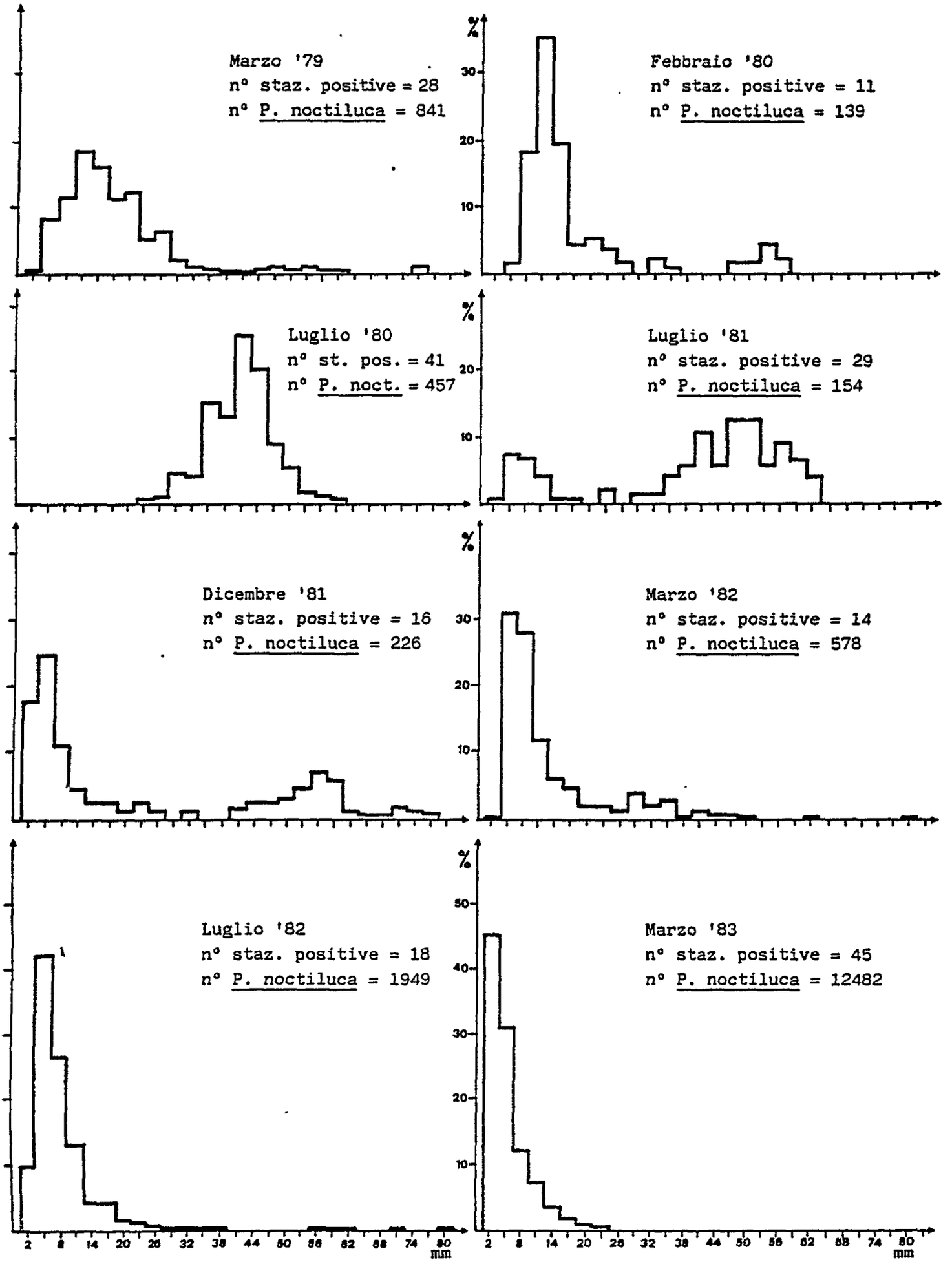
2. MATERIELS ET METHODES

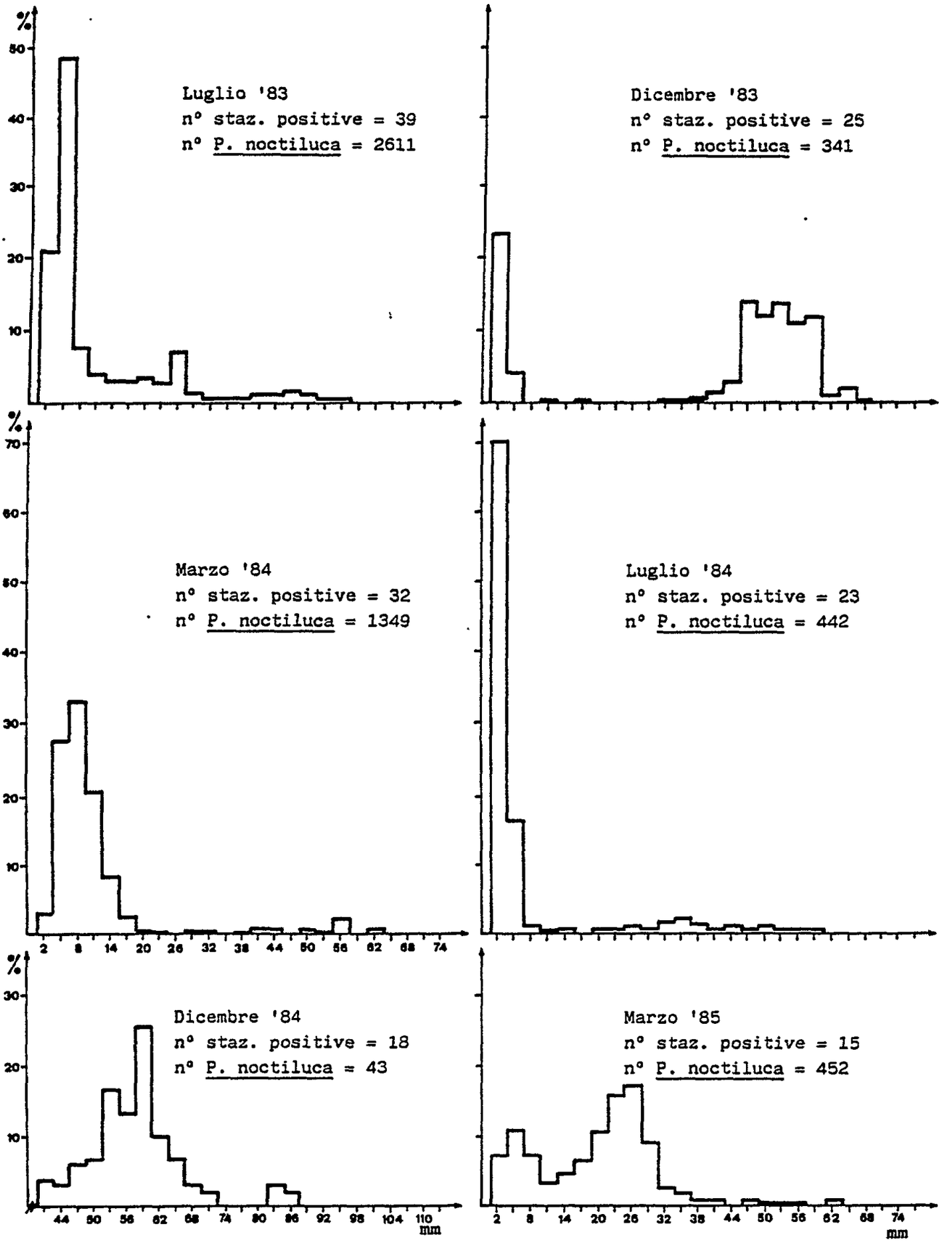
Les échantillons de plancton prélevés de façon quantitative grâce à un filet à planton modèle FAO d'un mètre de diamètre à mailles de 500 microns lors d'une série de croisières effectuées par le Laboratoire de Biologie Marine et de Pêche de Fano dans l'Adriatique entre Trieste et le Gargano ont été examinés. Les méduses de l'espèce *P. noctiluca* ont été isolées, comptées, et leur mesuré au millimètre près. Pour chaque croisière on a fait la somme des données de chaque station pour 100 m^3 d'eau filtrée, en les subdivisant par ordre de taille, afin d'obtenir un échantillonnage représentatif de la composition par taille de la population pour toute la région et pour chaque campagne.

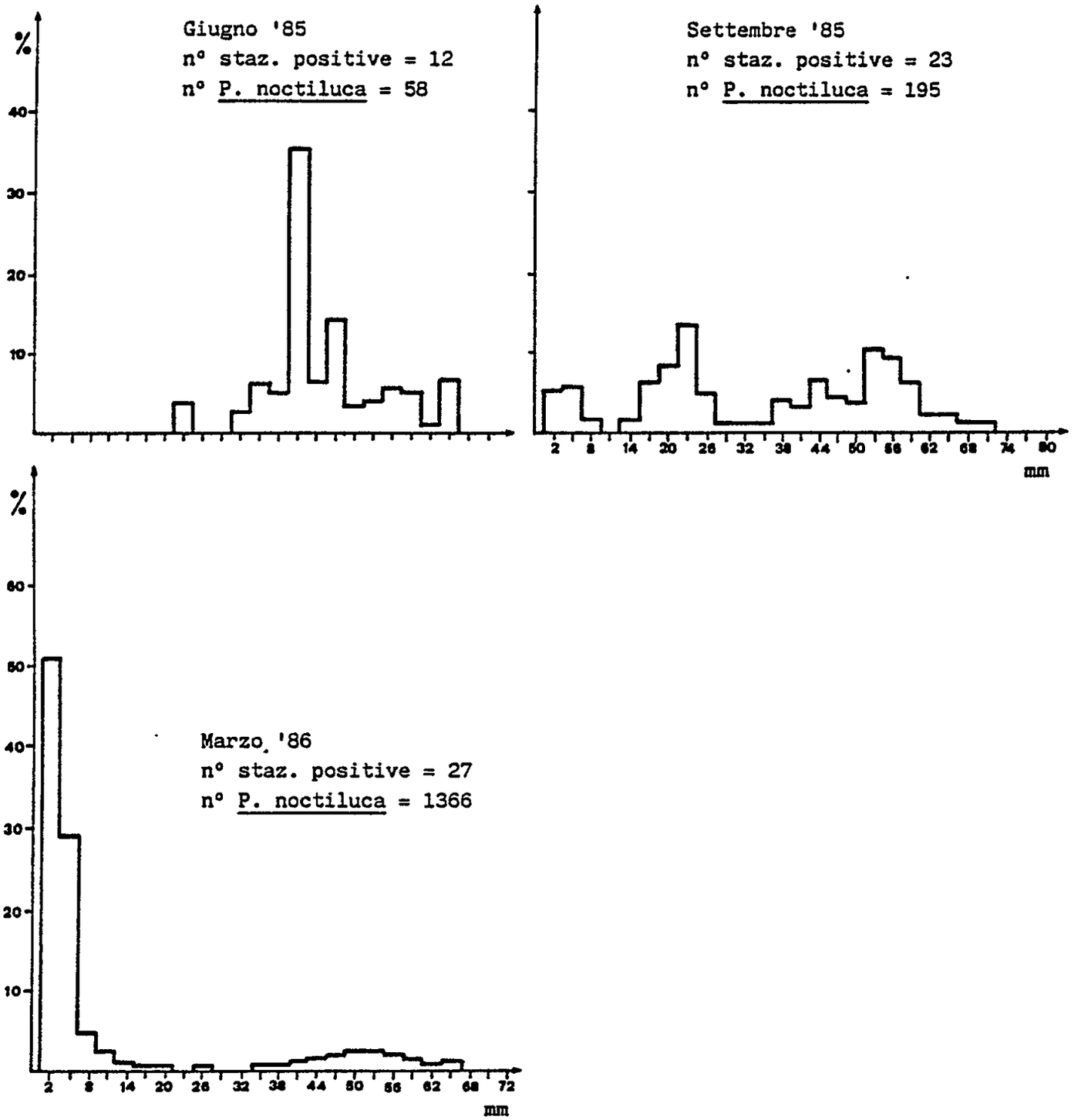
A l'inverse de la recherche précédente, nous avons préféré regrouper les tailles en classes de 3 mm de largeur, afin d'éviter une dispersion excessive des données et de faciliter les comparaisons. Les prélèvements par campagne varient de quelques dizaines à plus de 10.000 exemplaires.

3. RESULTATS

Les compositions par taille des 17 campagnes effectuées de mars 1979 à mars 1986 figurent sur les tableaux en annexe (Figs. 1, 2, 3). Les données des campagnes de 1976 à 1978 ne sont pas homogènes parce que recueillies au moyen du filet modèle FAO sans fluxmètre. Nous ne les avons donc pas reprises ici.


Marzo '79
n° staz. positive = 28
n° P. noctiluca = 841
Febbraio '80
n° staz. positive = 11
n° P. noctiluca = 139
Luglio '80
n° st. pos. = 41
n° P. noct. = 457
Luglio '81
n° staz. positive = 29
n° P. noctiluca = 154
Dicembre '81
n° staz. positive = 16
n° P. noctiluca = 226
Marzo '82
n° staz. positive = 14
n° P. noctiluca = 578
Luglio '82
n° staz. positive = 18
n° P. noctiluca = 1949
Marzo '83
n° staz. positive = 45
n° P. noctiluca = 12482
%
mm
2 8 14 20 26 32 38 44 50 56 62 68 74 80


%
Luglio '83
n° staz. positive = 39
n° P. noctiluca = 2611
Dicembre '83
n° staz. positive = 25
n° P. noctiluca = 341
Marzo '84
n° staz. positive = 32
n° P. noctiluca = 1349
Luglio '84
n° staz. positive = 23
n° P. noctiluca = 442
Dicembre '84
n° staz. positive = 18
n° P. noctiluca = 43
Marzo '85
n° staz. positive = 15
n° P. noctiluca = 452
mm



Durant les campagnes de septembre 1986 et d'avril 1987 aucune méduse de l'espèce *P. noctiluca* n'a été capturée.

La distribution quantitative de *P. noctiluca* dans la région, ainsi que les variations de densité au cours de chaque campagne figurent dans un autre ouvrage (Piccinetti-Manfrin and Piccinetti 1987).

4. DISCUSSION

Les diagrammes indiquent une présence constante pendant toute l'année de méduses de petite taille avec toutefois une augmentation pendant les campagnes de mars.

Si on compare les campagnes effectuées pendant la même saison à différentes années, on note en général une concordance dans la composition par taille, à l'exception de mars 1985 où les classes juvéniles sont peu représentées.

En mars 1986, dernière campagne avant la disparition de *P. noctiluca*, on constate la présence d'un fort pourcentage d'états juvéniles à côté de la présence d'exemplaires adultes, alors que la composition par taille est similaire à celle du mois de mars des autres années.

Les campagnes effectuées en été présentent une plus grande variabilité dans la composition par taille par rapport à l'importance des classes plus jeunes; au cours des étés 1980, 1981 et 1985 les formes adultes l'emportent alors que pour les étés 1982, 1983 et 1984 ce sont les formes juvéniles qui sont les plus nombreuses.

Le nombre d'exemplaires capturés est sensiblement plus élevé lorsque les phases juvéniles sont présentes.

Les campagnes effectuées en décembre donnent des résultats qui varient d'une campagne à l'autre: en 1981 et 1983 on trouve deux groupes de tailles, jeunes et adultes alors qu'en décembre 1984 on ne trouve que les adultes, les specimens jeunes étant totalement absents.

De l'ensemble de ces diagrammes, subdivisés par saison, il ressort qu'à côté d'une certaine répétition au fil des ans de situations similaires, existent quelques variantes qui assouplissent le cycle biologique sans pour autant qu'il y ait un cycle saisonnier précis.

Si l'on considère la fréquence temporelle des campagnes qui permet de suivre l'évolution d'un groupe d'individus au cours de leur cycle biologique, on obtient des indications qui révèlent, au moins pour quelques années, l'augmentation de l'espèce.

Les méduses des classes de 8 à 14 mm de février 1980 semblent atteindre la taille de 35 à 44 mm en juillet 1980. Les méduses des classes 5 à 11 mm de juillet 1981 semblent atteindre les tailles de 44 à 59 mm en décembre 1981 avec une croissance plus rapide.

Les méduses des tailles de 5 à 14 mm de mars 1984 semblent atteindre les tailles de 32 à 44 mm en juillet et les tailles de 53 à 62 mm en décembre 1984.

Ces indications confirment les données précédentes pour l'année 1983 (Piccinetti *et al.*, 1984) et montrent une courbe de croissance identique.

Les tailles maximales de *Pelagia noctiluca* capturées sont de la classe de 85 mm, prélevées au mois de décembre 1984.

5. CONCLUSIONS

L'ensemble de ces données confirme certains aspects de la biologie et de la dynamique de la population de *P. noctiluca* dans l'Adriatique. La période de reproduction s'étend sur toute l'année avec une plus grande intensité pendant les mois d'hiver.

Le cycle biologique est rapide, dépassant de peu un an, avec une croissance qui ne varie pas beaucoup en fonction de la saison de naissance; comme c'est le cas chez toutes les espèces à cycle biologique court, on note une très forte mortalité naturelle. La dimension maximale constatée est de 85 mm.

La composition par taille de la population en mars 1986 ne présente pas d'anomalie par rapport aux années précédentes et ne peut expliquer la disparition de *Pelagia* à partir de juillet 1986, dans la mesure où les états juvéniles présents en grand nombre en mars auraient dû être également présents en juillet, septembre et décembre de la même année avec des tailles supérieures, alors qu'on n'en a capturés que jusqu'au mois de mai.

Ceci indique que la cause de la disparition de *Pelagia* à partir de l'été 1986 ne peut être attribuée à une variation de natalité liée à la reproduction; il faut la rechercher dans des facteurs liés à l'élimination rapide de tous les individus de la population jeune et adulte, ce qui a rendu impossible la reproduction successive dans la mesure où en avril 1987, on ne retrouvait même plus les nouvelles formes juvéniles dans les échantillons.

Quant à la cause de cette rapide disparition, il est impossible de l'identifier pour l'instant car elle pourrait être liée à des facteurs océanographiques, comme les courants, ou à des facteurs biologiques comme la prestation ou le manque de nourriture.

Les résultats des recherches du Laboratoire de Biologie Marine et de Pêche de Fano nous permettent de conclure que la disparition de *P. noctiluca* de haute et moyenne Adriatique a été provoquée par l'élimination rapide de la population présente (jeunes et adultes) et que cette disparition a eu lieu dans la période allant de mai à juillet 1986.

Les recherches ultérieures tendront à déterminer ce qui s'est passé pendant cette période.

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MED POL II PROGRAMME "JELLYFISH IN THE MEDITERRANEAN SEA" C.I.M.A.M. FINAL REPORT

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ABSTRACT

The increased frequency since 1977 of surface swarmings of Scyphomedusae in the Mediterranean Sea since 1977 prompted the Department of Biology of Trieste University to set up the International Centre for the Environment and Jellyfish in the Mediterranean (Centro Internazionale Mediterraneo Ambiente Meduse - C.I.M.A.M.) as a division of the Laboratory of Marine Biology in Trieste. The aim of CIMAM is to plan and coordinate studies related to (i) the ecology, biology and physiology of these organisms; (ii) injuries to human health and damage to fishing activities caused by *Pelagia noctiluca*; (iii) correlations between jellyfish occurrence and behaviour with environmental conditions (physical and chemical seawater characteristics, hydrodynamical conditions, meteorology and climate).

Research carried out over recent years has shown that *P. noctiluca* is reproducing throughout the year at different rates depending on climatic conditions. Maturation of oocytes is faster during the warm months and slower during the cold period. Reproduction in the Gulf of Trieste occurs between March and October, owing to the peculiar winter meteoclimatic conditions (water mixing by strong winds, seawater temperature between 6 °C and 15 °C). Many observations carried out in the natural environment further explained the offshore swarming mechanisms of this species. Reproduction occurs inside large active swarms, which contain animals at all different development stages and which can withstand to some extent the hydrodynamic agents. These swarms are characterized by large daily vertical displacements, probably related to the daily migrations of the zooplankton representing the main food resource. The gradual depletion of the food stock inside the swarm, together with possible variations in the optimal seawater conditions (e.g. temperature and salinity) produces a reduction of jellyfish motility and the disaggregation of the swarm itself, leading to a number of smaller surface "patches" which passively follow

the current field. Jellyfish patches, or single specimens can therefore be observed near the coast: the animals, at the end of their biological cycle, sink to the bottom and die.

The coastal swarming of *P. noctiluca* is therefore caused essentially by the local meteorological conditions and hydrodynamics and by coastal morphology, i.e. by natural environmental conditions. On the other hand, the increased number of jellyfish swarms observed in recent years can be related to the catch effort exerted since 1974 on the stock of jellyfish predators, which affected the natural predator-prey equilibrium.

The damages to fishing activitites caused by scyphomedusae are mainly due to large stocks of jellyfish, mainly *Rhizostoma pulmo*, trapped in the nets and to the alteration of the organolectic characteristics of fish caused by contact with *P. noctiluca*.

P. noctiluca has been monitored, and its biological cycle studied, in its natural environment. Furthermore, laboratory experiments have been conducted in order to investigate the effects of the hydrological parameters on its reproduction, development, behaviour and metabolism. These experiments, compared with data collected in the natural environment, demonstrated that seawater temperature greatly affects the *Pelagia*'s reproductive potential, motility and metabolism. Motility and metabolism appear to slow down above 19 °C and below 16 °C. As regards reproduction, at lower seawater temperatures both vitellogenetic processes and the release of fertilizable oocytes slackened. Below 5°C *P. noctiluca* does not reproduce.

The results mentioned above refer to the Adriatic Sea.

In order to study the vitellogenetic processes and gonadic maturity, studies have been performed on gonad histology, both in *P. noctiluca* and in other schyphomedusae.

The health problem of the accidental contact between jellyfish and man has been approached along two main lines of study: the first consists in (i) the separation and study of the cnidocysts and (ii) the separation of toxins from cnidocysts; the neurotoxic activity of the single surnatant fractions so obtained are therefore studied. The second line is based on problems related to the jellyfish dermotoxicity: (i) methods are studied to isolate the venom contained in the nematocysts in its active form, without contamination by extra-nematocystic material; (ii) experimental models are defined in order to estimate, both in man and in experimental animals, the dermotoxic effects experimentally reproduced.

1. INTRODUCTION

The Project "Jellyfish in the Mediterranean Sea" was launched in the framework of MED POL-Phase II because large swarms of Schyphomedusae, in particular *P. noctiluca* (Semaeostomeae, Pelagiidae), were sighted in several coastal areas of the Mediterranean since 1977 (Axiak and Civili, 1986). *Pelagia* is typical of offshore waters in warm seas; it does not present the scyphistoma polypus phase. A bibliographic study by Goy (1984) demonstrates that the surface swarming of *P. noctiluca* was well known at the end of the eighteenth century. At that time, only simple observations of such coastal swarms were quoted in the literature. In the mid-nineteenth century, interest in marine studies increased. Many centres began their activities, such as the Zoological Stations in Naples, Messina, Villefranche, the Oceanographic Museum of Monaco in the Tyrrhenian Sea and the Zoological Station of S. Andrea in Trieste, subsequently moved to Rovigno d'Istria in the Adriatic Sea. Important oceanographic cruises were performed at that time, leading to a scientific collaboration between European Universities and the marine centres mentioned above.

The first studies on the biological cycle of *P. noctiluca* were carried out at that time. The absence of the scyphistoma phase was then discovered (Krohn, 1855) as well as the presence of an endodermic structure (the "Krone") which appears during the maturation of the oocyte (Hertwig and Hertwing, 1879); the development and organization of the jellyfish were described (Claus, 1883); studies on jellyfish embryology were carried out (Metschnikoff, 1883); the description of the first segmenting phases of the egg was also given at that time (Goette, 1893); accurate observations were made on the reproductive period by means of a qualitative analysis of the coastal swarms (Lo Bianco, 1888, 1909). Vanhöffen (1896) made the first accurate observations of the surface swarms in the Atlantic ocean.

The scientists of that time stressed that it was possible to carry out suitable research on *P. noctiluca* only during the occurrence of coastal swarming which represented, and still represents, by night or day a casual event of short duration, mainly during spring and summer and which generally cannot be predicted. Studies on *P. noctiluca* today are as fortuitous as they were then (Steuer, 1902; Delap *et al.*, 1907; Mayer, 1910; Stiasny, 1912, 1914; Babic, 1913; Szüts, 1915; Neppi, 1922; Kramp, 1924; Cole, 1952; Hunt, 1952;

Fraser, 1954; Russell, 1938, 1967, 1970; Franqueville, 1971; Malej, 1981; Vucetic *et al.*, 1980; Rottini Sandrini *et al.*, 1980, 1981, 1982, 1983-84; Rottini Sandrini and Stravisi, 1981, 1982, 1983; Vucetic and Rottini Sandrini, 1983; Tegaccia *et al.*, 1983-84; Piccinetti *et al.*, 1986; Piccinetti Manfrin and Piccinetti, 1983-84, 1984, 1986; Stravisi, 1984; Legovic and Rottini Sandrini, 1986; Legovic *et al.*, 1987).

The new occurrence of *P. noctiluca* during 1976 and its first appearance in the northern Adriatic Sea in 1977 was not an isolated phenomenon. During the following years, jellyfish swarms were observed with increased frequency during summer, raising the interest of the mass media on account of the negative impact on tourism. The Adriatic coast was indeed infected by these small animals, capable of producing bad stings to swimmers and to fishermen when cleaning their nets filled with jellyfish. All this of course renewed the interest of scientists; in particular, the "Centro Internazionale Mediterraneo Ambiente Meduse - C.I.M.A.M." was created at Trieste, in the framework of the Marine Biology Laboratory, in collaboration with the Universities of Trieste and Bologna, the CNR Istituto Talassografico of Trieste and other Institutions. In 1984 the "Jellyfish Programme" became part of the UNEP/MAP MED POL Programme. C.I.M.A.M. planned and coordinated research along the following axes:

(1) **Bio-ecological**

(a) Monitoring
(b) Biological cycle and reproduction: analysis of the biological cycle and of the reproductive potential both in the natural environment and in the laboratory. Influence of seawater temperature and other hydrological parameters on reproduction.
(c) Behaviour: laboratory studies on the influence of temperature, salinity and organic substances on *Pelagia* motility and the pulsation rate of its umbrella.
(d) Metabolism: study of the isotopic variations of the constituent water with respect to seawater for different animal sizes.

(2) **Biochemical, toxicological and medical**

(a) Optimization of methods for the purification of cnidocysts.
(b) Morphological and morphometric analysis of cnidocysts of *P. noctiluca* and their use in taxonomy.
(c) Tests of dermal damage by cnidocysts on animals and man; monitoring of damages on man at the Dermatological Clinic of Trieste University.

(3) **Environmental Physics and Climate**

(a) Physical seawater characteristics: study of the in situ properties of the temperature, salinity and density fields, of the underwater irradiance, seawater transparency and sea currents. Sea level.
(b) Meteorological parameters: air pressure, temperature and humidity, wind, precipitation and evaporation, solar radiation.
(c) Climate: interannual variability of the environmental parameters and their correlation with jellyfish occurrences.

2. MATERIALS AND METHODS

Bio-Ecological Studies

MONITORING

Since 1976, the Marine Biology and Fisheries Laboratory of Fano, Bologna University, directed by Prof. Piccinetti, has collected seasonal data on the quantitative distribution of *P. noctiluca* in the Adriatic Sea and the Eastern Mediterranean. Jellyfish monitoring has been carried out during the 3-4 seasonal cruises supported by the Ministero della Marina Mercantile in the framework of the blue-fish monitoring programme.

Samples were collected by means of WP2 plankton nets (mouth surface 0,25 m^2, length 261 cm, bucket diameter 7.5 cm, vol. 500 ml) for vertical hauls, and by means of 60 cm Bongo nets (300 and 500 m mesh-size) for double oblique hauls (0-30m). Nets were equipped with flow meters in order to compute the sampled volume. The samples collected were fixed in formaldehyde 10%; all specimens were counted and measured (diameter between opposite rhopalia) in the Laboratory. The training ship "A. Vespucci" of the Italian Navy collected data on the offshore swarming of *P. noctiluca* during the 1977-78-79 cruises; these data were used for studies on aggregation dynamics.

The correlation between jellyfish and caught fish in the central part of the Gulf of Trieste has been studied as follows: Daily catches were performed by means of a fishing boat by the Marano Lagunare Fishermen Co-operative with the aid of a CIMAM researcher. On board, after each haul, both fish and jellyfish were weighed (wet weight); furthermore, jellyfish were classified and counted. These data have been statistically described.

Statistical data of the fish catch in the Adriatic Sea, from 1960 to 1983, are taken from the ISTAT Roma annual reports.

BIOLOGICAL CYCLE

Monthly vertical plankton hauls were made at a fixed station in the Gulf of Trieste (Lat. 13° 42'E; Long. 45o 39'N) from 1977 to 1986, by means of a Nital nylon plankton net (180 m mesh-size, mouth diameter 40 cm, 7.5 cm diameter Tregouboff bucket). During the occurrence of jellyfish aggregations, four vertical hauls were made in 24h, both in the centre and at the edges of the aggregation. Swarm dimensions and surface jellyfish density were evaluated; the pulsating rate of some specimens was measured randomly. Furthermore, some specimens were collected for laboratory experiments.

The samples collected were treated as follows: All the observable developmental stages and the adults of *P. noctiluca* were separated with the aid of a stereo microscope; the remaining sample was stored in neutralized formaldehyde 4%. The planulae and ephyrae were measured and counted *in vivo* and therefore fixed in neutralized formaldehyde 3%. Male and female gonads were excised from the adult specimens after determining the umbrella diameter, and immediately fixed for histological studies for both light and electron microscopy. Specimens with a diameter of 2.5 cm were put in suitable tanks (Cargo, 1984) for reproduction and behavioural experiments (thermal and haline shocks, response to N-urea).

As regards the studies on the reproductive potential of *P. noctiluca* in the Adriatic Sea, 100 specimen (diameter 4+/- 0.5 cm) were selected and weighed (wet weigth) each month. Each ovary was measured, weighed and cut in two parts; the first was fixed for histological analysis, the second was fixed in neutralized formaldehyde 3% for ovocyte count, used to evaluate the seasonal influence on the vitellogenetic processes.

Samples for histological analysis were fixed in Karnowsky, Zamboni-De Martino or in glutaraldehyde 2-2.5% (2-3 h, 5°C); buffers were phosphate 0.1 M and/or cacodylate 0.1 M, pH = 7.2, 7.3 Tonicity was adjusted to seawater values with NaCl, sucrose and $CaCl_2$ (1-3 mM); 3-6 washes in the buffer; postfixation in OsO_4 in the vehicle (3/4 - 1 h, 5°C); 2 washes in the buffer, 1 in distilled water; dehydration in acetone or ethanol, propylene oxyde; embedding in Epon-Araldite or Spurr resin.

Semithin sections were observed with a light microscope; ultrathin sections contrasted with uranyl acetate and lead citrate and observed with a TEM.

Samples for SEM were fixed as above, dehydrated in acetone, dried to the critical point and shadowed with gold-palladium.

Two methods were employed in order to obtain fertilization and the early developmental stages in laboratory:

(a) 15 specimens (8 male and 7 female) were put in an aquarium filled with 84 l of seawater filtered with 180 m mesh-size nylon Nital, stored at 19 °C, salinity 36.9 psu and dissolved oxygen 5.8 ml l^{-1}. After 24h the adult specimens were fixed as described above, the seawater was filtered and the spawned eggs counted and placed into 200ml glass basins under the same hydrological conditions.

(b) Ripe gonads were taken from four adult specimens, a part of which was fixed as described above. Another part was put immediately into glass basins filled with 200 ml of sterilized seawater (Millipore filters, 0.22 m mesh-size) and cut into pieces, at temperatures of 13.5 and 4.5 °C respectively (salinity 37.7 psu, dissolved oxygen 5.8 ml l^{-1}. After 24h the gonads were removed and the remaining eggs counted. Controls under a stereomicroscope were made every 4h in both experiments, in order to evaluate the percentage of the fertilized eggs and the development of the larval stages. Every measurement was taken on

living specimens in order to avoid the contraction due to fixatives (Möller, 1980). Some specimens were fixed at every development stage. The seawater was changed every 24h, with the same hydrological parameters, with the addition of liquid food and nauplia of *Artemia salina* after the metamorphosis from planula to ephyra.

BEHAVIOUR

Behaviour experiments were performed in order to study the motility of *P. noctiluca* at different temperatures, salinities and in the presence of organic compounds. Motility was evaluated in relation to the umbrella rhythm of pulsations and the real movement of specimens. These experiments were performed in tanks with fixed hydrological parameters in a cold room. The specimens employed were gathered in the Gulf of Trieste and immediately put in acclimatization tanks, in order to avoid shocks due to strong changes of the hydrological parameters. The behaviour was continuously observed during the experiments and data were collected at fixed intervals.

METABOLISM

Metabolism was studied by means of the isotopic composition of the body water of *P. noctiluca*. 56 specimens were used for this research. Tentacles, oral arms and gonads were removed after measuring the diameter between opposite rhopalia and the specimens were then frozen. Samples were then vacuum dried and the body water separated quantitatively by freezing into a trap at liquid nitrogen temperature. Body water was used for measuring $^{18}0:^{16}0$ ratios while organic matter was processed to measure $^{13}C:^{12}C$ ratios. Both the carbon and the oxygen isotopic compositions are expressed in the delta (δ) terminology, where is defined as:

$$\delta = \{(R\ sample - R\ stand) / (R\ stand)\} \times 1000$$

where R is the studied isotopic ratio ($^{13}C:^{12}C$ or $^{18}O:^{16}O$) compared to the same ratio in the international standard.

Biochemical, Toxicological and Medical Studies

PRELIMINARY PURIFICATION OF CNIDOCYSTS

The marginal tentacles and oral arms were taken from specimens of *P. noctiluca* immediately after the collection: jellyfish frozen in toto were used as well. This material was soaked in distilled water at 4 °C for 24h and broken up mechanically. The resulting suspension was filtered through a 120 m plankton net and the filtrate was centrifuged for 10 min. at 4000 rpm. The pellet obtained was washed several times by suspending it in distilled water and centrifuging. A crude nematocystic fraction (CNF) was thus obtained. Parts of this suspension were conserved at -80°C.

ANALYSIS OF PELAGIA NOCTILUCA CNIDOCYSTS

The suspension of cnidocysts, both undischarged and discharged, was fixed as previously described, in order to analyze their structure under the scanning electron microscope. The cnidocysts were also measured *in vivo* by a videoanalyzer. The discharge of cnidocysts was induced by ions of the lyotrophic series, by acids, bases and by tripsin.

ANALYSIS OF THE TOXINS PRESENT IN THE CAPSULAR FLUID OF *PELAGIA* CNIDOCYSTS

A purified preparation of cnidocysts was homogenized in potter and ultracentrifuged at 20,000 rpm for 30 min. at 4 °C. The surnatant was fractionated on a Sephadex G-75 column and eluted with distilled water. The pooled fractions were freeze-dried. A part of these fractions was used for toxicity tests in animals after dissolution in PBS buffer. The various buffers were also submitted to a SDS-Page electrophoresis, in order to determine the molecular weights.

Activity of the capsular fluid on the myocardium: The supernatant and the various pools were injected into the jugular vein of five adult rats of both sexes, weighing about 300g. Before treatment the rats were anaesthetized by i.p. Katamine (500 mg). For the electrocardiographic recording, two needles were introduced at the insertion of the fore limbs. Control values of the heart rate were taken before treatment with the substances under testing.

Activity of the capsular fluid on the neuro-muscular synapse: Both the whole fluid and the pools were tested on the sciatic nerve-sartorius muscle preparation of *Rana esculenta*, in the usual way. The preparate was dipped in buffered saline (pH 7.4) and partial block of the neuromuscular transmission was reached by decreasing to 1 mM the concentration of Ca^{++} in the bath and adding Mg^{++} (5-10 mM). Then the plate potential (e.p.p.) and the plate current (e.p.c.) were recorded by means of glass microelectrodes (5-10 MΩ) filled with 3 M KCl.

DERMOTOXICITY TESTS

The C.N.F. was purified by means of a succession of centrifugations or sucrose gradient, at various speeds and for different times, until a purified nematocystic fraction (P.N.F.), devoid of broken or discharged nematocysts and of extranematocystic material was obtained. The suspension in water of P.N.F. was lyophilized for storage. After rehydration, the lyophilized nematocysts were submitted to ultrasounds in order to provoke their discharge or breakage and the release of the soluble contents. This discharged nematocystic fraction (D.N.F.) was also lyophilized for storage. The suspension obtained after ultrasonic treatment was centrifuged in order to separate the soluble fraction (S.F.) from the insoluble fraction (I.F.) made up of the "ghosts" of nematocysts. All these steps of purification were checked by optical microscopy. The degree of discharge obtained was evaluated by the usual colorimetric protein-measurement techniques.

Dermotoxicity tests in mice: Hairless female mice of a Charles River strain were used. This strain is genetically devoid of hair and is therefore the most suitable for dermotoxicity tests. The sensitivity of this strain to the *P. noctiluca* venom was evaluated by submitting the animals to a direct contact with living jellyfish, after the plasma had been coloured with Evans Blue in order to highlight oedematous phenomena. To test the dermotoxic activity of the various fractions, they were suspended in saline buffer solution and injected intradermically. The effects were observed macroscopically and histologically.

Dermotoxicity tests in humans: The tests were carried out on healthy volunteers. The activity of the various nematocystic fractions was evaluated on the basis of three different testing procedures:

(a) **Patch test:** the test suspension is applied on the intact skin and protected with a patch (observation of the effect after 1, 24, 48 and 72h).

(b) **Prick test:** application of the test suspension on the intact skin followed by scratching without patching (observation after 20 min).

(c) **Scratch-patch test:** application on the scratched skin followed by patching (observation after 30 min, 48 and 72h).

Orientation tests were carried out preliminarily with ten-fold diluted suspensions.

3. RESULTS

Bio-Ecological Studies

Three years of research demonstrated that *P. noctiluca* reproduces all year round in the Adriatic Sea, at different rates depending on meteoclimatic conditions: the maturation rate of oocytes is faster during warm months and slower during cold months. In the Gulf of Trieste, the peculiar winter climatic conditions stop reproduction.

Laboratory experiments confirmed observations in the sea as regards reproduction. Other laboratory experiments demonstrated that seawater temperatures affect (i) reproductive potential, (ii) pulsation rate, (ii) motility and (iv) the metabolism of *P. noctiluca*.

The increase of the *P. noctiluca* population in the Adriatic Sea since 1976-77 is mainly due to (i) favourable trophic conditions, (ii) the decrease in the predator population following greater fishing efforts, (iii) favourable hydrological and meteoclimatic conditions.

The surface coastal jellyfish swarming is due to local marine dynamics related to coast morphology.

MONITORING

The analysis of plankton samples collected in the Gulf of Trieste and in the middle Adriatic in the years 1970-1976 did not show any specimen of *P. noctiluca* or other forms of the biological cycle of *Pelagia* itself or of other schyphozoa. All the forms of the biological cycle of *P. noctiluca* were found to be reversed since 1977: the population increased until 1984 and decreased from 1984 to 1987 (Rottini Sandrini *et al.*, 1980, 1981, 1982, 1983a,b; Piccinetti Manfrin and Piccinetti, 1983-84, 1984, 1986; Tegaccia *et al.*, 1983-84; Piccinetti *et al.* 1986). While *Pelagia* has been found almost everywhere in the offshore Adriatic waters (e.g. Tremiti Islands, 1984), it has never been present in front of the Po Delta and very few specimens have been found in the coastal waters of Emilia-Romagna.

Aggregations of *Pelagia* both offshore, in coastal waters and in harbours, have been documented by means of films and pictures; plankton samples, hydrological data and data on dynamics have been collected as well. The following results were obtained:

(i) Aggregations occur offshore, in the surface layer (10 m), with seawater temperature normally in the range of between 16 and 20 °C; the interested surface is of the order of 1 km^2, the density is of the order of 10 specimens per cubic meter.

(ii) All forms of the biological cycle are present in the aggregations; the diameter of the umbrella of the adult specimens is in the 2.5-6.5 cm range.

(iii) The aggregations begin around a food source, the main finality being reproduction. This is an active stage which is called "swarm". Individuals in the swarm actively move. Their horizontal motion is, on average, centripetal and capable of withstanding the sea (Legovic and Rottini Sandrini, 1986). Their vertical motion follows the daily displacements of their food source (micro and net plankton) to a depth of the order of 100m. The large scale horizontal displacement of the whole swarm is that of the marine layer where the swarm is located: swarms follow the sea currents. The histological analysis of the gonads demonstrated that individuals can reproduce when the diameter has reached 13cm (Rottini Sandrini *et al.* 1983a).

(iv) The active stage of a swarm is followed by a passive aggregation ("patch"): the individuals, reproductors, at the end of their biological cycle in particular, loose their motility. The patch is divided by waves, currents and winds into many minor patches; from this stage, the typical local meteorological and dynamics conditions are responsible for "coastal patching" of some duration (Stravisi, 1984).

The results of the monitoring performed by the Fishermen Co-operative of Marano Lagunare (Gulf of Trieste) are the following:

(i) The filling of trawler nets because of a great number of large jellyfish (*R. pulmo*) reduces the net catching surface. As a consequence, the fish yield can be considerably reduced and the net itself can be broken occasionally. The result is economically damaging for fishermen (Rottini Sandrini *et al.*, 1984).

(ii) The organolectic quality and the appearance of fish are altered by large amounts of jellyfish (*P. noctiluca*): this is true of both feeding and contact in the net. In this case, fish can hardly be sold and there is financial loss for the fishermen (Rottini Sandrini *et al.*, 1986b).

(iii) Damage to the health of fishermen is caused by accidental contacts with *Pelagia* during net hauling and washing.

BIOLOGICAL CYCLE AND REPRODUCTION

The analysis of the plankton samples demonstrated that in the central and northern Adriatic all developing stages of *P. noctiluca* are present throughout the year (Bratina *et al.*, 1981; Rottini Sandrini *et al.*, 1981; Rottini Sandrini and Vucetic, 1983; Piccinetti Manfrin and Piccinetti, 1983/1984, 1984, 1986; Tegaccia *et al.*, 1983-1984). An analysis of monthly samples collected in the Gulf of Trieste since 1976 demonstrated

that *Pelagia* is almost absent from this area during winter, with the exception of the winters of 1979 and 1980 when seawater temperatures were never below 7.6 °C approximately.

The above field observations led to a set of laboratory tests on the possible effects of some hydrological parameters on the biological cycle mainly of *P. noctiluca*, and to histological analyses of test specimens. Results are as follows:

As to the effects of water temperature on reproduction, the following was noted: at 4.6 °C fertilization occurs but oocyte segmentation stops at blastula. At 13.6oC reproduction and development stages are reached in about twice the time required at the optimal temperature of 19oC. The percentage of fertilized oocytes is 33% at 4.6 °C, 34% at 13.6 °C, 44% at 19 °C (Rottini Sandrini *et al.* 1982, 1983, 1986; Avian, 1986a). Histological and cytological analyses on male and female gonads of *Pelagia* are in progress. So far, the presence of an endodermal structure ("para-ovular body") with protein synthesis during vitellogenesis has been identified; furthermore, the rate of maturation of the ovary increases with seawater temperature (Bratina *et al.*, 1982; Rottini Sandrini and Avian, 1983; Avian, 1983; Avian, 1986a; Avian *et al.*, 1986).

Histological research has been carried out on the structure and cytology of the gonads of *Discomedusa lobata* (occasionally present in the Adriatic). A para-ovular body similar to that of *Pelagia* has been found and described for the first time (Rottini Sandrini *et al.*, 1986a).

During a study on the development from ephyra to young jellyfish of *Cotylorhiza tuberculata* the early formation of the sub-genital cavity in 10mm ephyrae was found; gonads are absent in young specimens up to 3-4cm (Avian, 1986b).

BEHAVIOUR

Laboratory tests demonstrated that *Pelagia noctiluca* stops its pulsating activity at seawater temperatures below 6 °C. The pulsating rate begins in the 7-8 °C range, and some motility begins as well. Arythmic and weak pulsations are observed in the range 8-18 °C; optimal pulsating conditions and active motility are observed between 18 and 20 °C. At higher temperatures arrhythmic pulsations and reduced motility appear again (Rottini Sandrini, 1982; Rottini Sandrini *et al.*, 1987).

As regards seawater salinity, the optimum for motility and pulsating rate is in the range 35-38 psu. At lower salinities the activities tend to stop; at higher salinities (39-40 psu) a difference in behaviour is observed, with arrhythmic pulsations and rotatory movements (Catalano *et al.*, 1988).

P. noctiluca is indifferent to inputs of N-urea in the laboratory tank (Rottini Sandrini *et al.*, 1983b).

METABOLISM

As regards the ^{18}O isotope, the constituent water of *Pelagia* is very similar to seawater. The isotopic characteristics of carbon in *Pelagia* increases with seawater temperature. Neither O nor C isotopic conditions are correlated with the dimensions of the specimens. As a result, metabolism does not depend on *Pelagia* size but only on seawater temperatures (D'Angela *et al.*, 1985).

Biochemical, Toxicological and Medical Studies

After the study of the structure of the cnidocysts of *P. noctiluca* and after the method for the purification of the cnidocysts themselves was developed, research work was carried out on (i) the dermotoxic effects produced by subcutaneous injections of *in toto* cnidocyst suspensions both in experimental animals and in man; (ii) the individualization and separation of toxins produced by nematocysts; (iii) the toxic effects of the single fractions both on the frog's sartorius muscle and the rat's cardiac rhythm (these studies are in progress).

ANALYSIS OF CNIDOCYSTS

The suspension of purified cnidocysts, both undischarged and discharged, shows the presence of five types (Weill, 1934; Mariscal, 1974; Quadrifoglio *et al.*, 1987):

Heterotrichous Microbasic Eurytele, with a well defined shaft with three helicoidal series of large spines and the thread with three helicoidal series of little spines.

I Holotrichous Isorhiza Haploneme, without a shaft, the thread of which shows three helicoidal series of well developed spines.

I Atrichous Isorhiza Haploneme, similar to the previous type, but with a thread without spine; it exhibits three helicoidal series of "V"-shaped notches. It is possible to distinguish this type from the previous one only by means of SEM. This type has never before been described.

II Holotrichous Isorhiza Haploneme, previously defined as "Atrichous", which exhibits three helicoidal series of spines.
II Atrichous Isorhiza Haploneme, with a capsular diameter of 3-8 μm and a smooth thread.

Moreover, a sixth type of cnidocyst, which has not been described as yet, has been found and its study is currently underway.

STUDIES ON TOXINS

Supernatant fractions: All the elution profiles show two absorption peaks. The first represents proteins with a molecular weight between 44 and 66 Kdal and the second is due to low molecular weight compounds, < 2 Kdal. The two peaks are separated by a series of fractions with low absorption at all wave lengths (220, 260, 280, 310 nm). As a consequence, the pools used for tests contain mainly the fraction related to the two major peaks.

Effects on rat myocardium: The unfractionated supernatant and the pools containing the first peak enhanced the heart rate within normal limits. No substantial changes of other electrocardiographic parameters were observed.

Effects on the synaptic transmissions: Ten minutes after the addition of the unfractionated supernatant, a marked decrease of the e.p.p. amplitude was observed. This effect on the amplitude is noticeably enhanced after 45 min. Also, an effect on the time course was observed, both on the ascending and the descending phases. Similar effects were recorded on the e.p.c. With the fraction pools the effects were not as spectacular as with the unfractionated fluid. However, the pools containing the first peak could modify the synaptic activity of the preparation. It follows that the active pools are related to the first absorption peak, with m.w. between 44 and 66 Kdal (Quadrifoglio *et al.*, 1987).

DERMOTOXICITY TESTS

Dermotoxicity in mice. "Hairless" mice are sensitive to *P. noctiluca* stinging. Shortly after contact with the tentacles of the jellyfish, a series of coloured spots, 2mm in diameter, appears on the treated skin of mice. They rapidly develop into papulae and after 30 min the whole back of the animals appears oedematous. After two hours the irritative reaction is still evident. Immediately after stinging some transient signs of neurotoxicity, such as tremors and hyperexcitability, are observed. We can deduce that the "hairless" mice react to the *Pelagia* venom in a similar way to humans. They are therefore suitable as animal models for our research. The dermotoxic activity of the C.N.F. is evaluated by intradermal injection of 0.05 ml of buffered suspension on the right thigh of the mice. One and a half hours after the treatment some vasodilatation is observed and after 24h an oedematous response takes place, reaching a peak after 24h. Three days later a necrotic lesion appears at the injection point reaching a diameter of 7-8 mm after 6 days. Twelve days later the lesion clears up and is replaced by a granuloma.

Our data show that the C.N.F. maintains the irritating properties of the starting material. The higher severity of the observed reaction may be due to the high number of injected nematocysts. The delayed appearance of the effects is probably due to a slower discharge of the nematocysts (Della Loggia, 1984; Del Negro *et al.*, 1986;1987). The limited availability of the material collected and the losses during purification procedures made us keep the remaining fraction for experimentation on humans.
Dermotoxicity tests on humans. In order to verify that during the purification procedures no loss of activity takes place, the following fractions were tested on healthy volunteers: C.N.F., P.N.F., D.N.F. The

other fractions (S.F., I.F.) are at present being tested. All the fractions tested are active if tested in the prick test and mainly in the scratch-patch test, whereas they appear almost inactive in the patch tests.

From these data it can be concluded that the prepared purification procedure does not cause a relevant loss of activity of the *Pelagia* venom. However, the nematocysts, after having separated from their cellular matrix, appear unable to penetrate the intact skin (Scarpa, 1984; Scarpa *et al.*, 1986;1987).

Environmental Physics and Climate

This part of the research is the result of collaboration between CIMAM and the Istituto Talassografico of Trieste of the National Research Council (CNA-ITTS).

PHYSICAL SEAWATER CHARACTERISTICS

About 150 stations in the Gulf of Trieste were set up in the years 1979-1985 with the ITTS M/S Thalassia II. Vertical profiles of *in situ* seawater temperature and conductivity were measured by means of a Mark VII Martek CT profiler. Seawater salinity and density were computed according to the 1978 Practical Salinity Scale and the 1980 International Equation of State for Seawater. The results are reported by Stravisi (1983c). Surface spring seawater heating, thermocline development, autumn-winter mixing and late winter dense water formation are well described. The heat and buoyancy fluxes at sea surface in the Gulf of Trieste were computed by Stravisi and Crisciani (1986). Underwater irradiance profiles were measured by means of a Kahlsico irradiance metre in the PAR band. Seawater transparency was measured by means of white and black Secchi disks, showing correlations with the phytoplancton annual cycle (Stravisi, 1983a). Current velocity vertical profiles were constructed by means of Ekman-Mertz and Hydro-Products current metres (Stravisi, 1983b). The characteristic large scale gyres of a mainly two-layer circulation in the Gulf of Trieste were described. The interannual sea level variations recorded at ITTS were reported and described by Stravisi and Ferraro (1986).

METEOROLOGICAL PARAMETERS

The conventional meteorological parameters (air pressure, temperature and humidity, wind, precipitations and evaporation, global sun irradiance, were continuously recorded at the ITTS Meteorological Station. Hourly data were stored on magnetic diskettes at the ITTS and CIMAM Data Banks. ITTS internal reports with hourly data and graphs in the years 1981-1985 were prepared by Stravisi *et al.* (1986b;1986c;1986d;1986e;1986f). Correlations between meteorological parameters and the occurrence of *P. noctiluca* were studied by Rottini Sandrini *et al.*, (1980) and by Stravisi (1984).

CLIMATE

Historical data of the meteorological parameters recorded at Trieste since the last century have been stored on magnetic diskettes at the CIMAM Data Bank. Some data not known till recently were discovered and published (Stravisi and Zorzenon, 1986). The interannual variability of the climatological parameters at Trieste has been studied by Stravisi (1986a). The existence of the quasi-biennial fluctuations and the presence of a 50-year cycle in the wind frequencies of bora and southerly winds in the Adriatic Sea are the main results. Furthermore, the 1965-1985 period characterized by a marked reduction of bora and by a corresponding increase of southerly winds frequency has been illustrated.

4. CONCLUSIONS

The three-year research programme initiated by UNEP/MAP within the framework of the Project "Jellyfish in the Mediterranean Sea" is not long enough in order to throw light on the complex phenomenon of jellyfish aggregations, which have interested certain Mediterranean regions since 1977. However, some significant results were achieved after the Trieste CIMAM-LBM was founded.

From the bio-ecological point of view, as regards reproduction, behaviour and metabolism, the comparison between the results of monitoring, laboratory experiments and motion pictures show that the offshore aggregations of *P. noctiluca* follow a well defined temporal evolution depending on trophic and reproductive factors, which are influenced by seasonal hydrological and hydroclimatic conditions (Legovic

and Rottini Sandrini, 1986; Rottini Sandrini *et al.*, 1987; Avian *et al.*, 1987). The offshore aggregations of *P. noctiluca* represent a natural phenomenon of its biological cycle. Movements of the aggregations and the coastal swarming in particular follow the characteristic local marine dynamics and hydrological conditions (Stravisi, 1984).

It must be stressed that, however, both the laboratory experiments and the observations in the field of *P. noctiluca* are very difficult because this species does not have the scyphistoma stage like most of the scyphozoa (Möller, 1980; Hernroth and Gröndahl, 1983; Cargo, 1984).

The histological analyses of the gonads demonstrated that *Pelagia noctiluca* reproduces throughout the year, at different rates, depending on seawater temperature, the optimum period covering the warm season (Rottini *et al.*, 1983-84; Piccinetti *et al.*, 1986; Avian *et al.*, 1987). The summer surface swarming represents the best condition for reproduction, since reproductors and food are gathered in a restricted area.

As can be seen from the literature, the aggregations of *P. noctiluca* and other jellyfish have been known since the end of the 1700's in the Mediterranean and in other seas as well (Vanhöffen, 1986; Goy, 1984). On the other hand, *P. noctiluca* is not affected by substances like organic phosphorus, *E. coli*, heavy metals, hydrocarbons, N-urea and nitrogen compounds, in other words by marine "pollution" *stricto sensu*. But if the term pollution is used to indicate a general modification of a natural equilibrium (Odum, 1973), then we can consider that the blooms of jellyfish which have occurred in the last few years are related to the man-induced predator-prey alteration following the intensification of fishing efforts and to anthropogenic pollution as well. Anthropogenic pollution (in the broad sense) together with a favourable meteoclimatic situation has led, in recent years, to the intensification of a natural phenomenon. The decrease in the jellyfish population since 1986 appears to be related to a climatic change in the Adriatic Sea (Stravisi, 1986a; 1986b; Stravisi *et al.*, 1986a) and to a diminished fishing effort, as stipulated in the Italian Law of 5 April 1985 of the Ministero Marina Mercantile, which provided for protected areas on the basis of the stipulations of the earlier Law of 31 December 1982, No. 979, "Disposizioni per la difesa del mare". During the next few years it will be interesting to see what the new environmental equilibrium will be, given the climatic change and human activities.

The biochemical, toxicological and medical studies led to new results as regards damage to human health caused by *P. noctiluca*. Six types of cnidocysts were identified, demonstrating the complexity of this phenomenon and the possibility that different types of toxins may exist in different cnidocysts. Neurotoxic activity has been demonstrated. It would be useful to continue research along these lines in order to reach a better understanding of these biochemical processes. A problem at this point is the supply of fresh *Pelagia* samples.

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JELLYFISH IN THE MEDITERRANEAN SEA. FIRST RESULTS

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ABSTARCT

In recent years numerous of shoals of jellyfish have been observed throughout the Mediterranean basin with consequent problems for fishing and for tourists activities.

In order to understand the causes which determine the fluctuations in the numbers of jellyfish and their arrival on shore, the Institute of Zoology and Comparative Anatomy of the University of Bari has taken part in the UNEP/MAP project "Jellyfish in the Mediterranean Sea". To this end, since 1985, it has organized studies on the ecology and biology of the jellyfish found in the Lower Adriatic and the Upper Ionian. First a census of sightings of jellyfish shoals was carried out through the use of appropriate forms, which were distributed to the principal nautical clubs and groups along the coast of Puglia and also to the fishermen and to the divers' groups of the area, in order to get a first indication of the areas where the shoals were present and of their size. In July 1985 surveys were organized off the Tremiti Islands (Province of Foggia) and in various zones of the Lower Adriatic. These surveys measured the number of sightings, the density of the shoals, the physico-chemical state of the water; samples were also taken. The data observed were analyzed and, even though limited, they seem to support the hypothesis that shoal fluctuations are clearly related to the ciculation of the currents created in the Lower Adriatic.

There are considerable difficulties in carrying out these studies, because it is certain that many major fluctuations are not specifically linked to exact phenomena which can be easily quantified. Studies of the fluctuations in shoals of jellyfish are very important and may be examined in depth through a large scale programme of international collaboration among the Mediterranean countries. However, such a coordinated study would require large financial resources which at present are virtually non-existent.

1. INTRODUCTION

In recent years huge shoals of jellyfish have occurred on a large scale in the Mediterranean Sea. The appearance of the shoals and the frequency with which they have been observed near the coast has attracted the attention of scientists grouped around the project "Jellyfish in the Mediterranean Sea". The numerous participants in the project have been attracted to it by the need to understand the causes which determine the development of such massive shoals of jellyfish. Many species were observed but major attention has been given to *Pelagia noctiluca* (Forskal).

P. noctiluca is a small jellyfish which seriously affects tourism because of its negative effects on swimmers; for example, in 1978-1979, 250,000 tourists fell victim to this species along the coasts of Yugoslavia. The first information about the fluctuations of this species was gathered approximately 100 years ago (Lo Bianco, 1888, 1909; Delap, 1906; Mayer, 1910; Babic, 1913; Neppi, 1922). *P. noctiluca* is a species which suddenly occurs in huge shoals, sometimes appearing for a number of years; these shoals present large variations, mostly as concerns their density, but also their frequency. They may suddenly disappear and then reappear at a later time (Franqueville, 1971; Rottini Sandrini *et al.*, 1982; Piccinetti Manfrin and Piccinetti, 1983-'84; Goy, 1984; Tegaccia and Tegaccia, 1985).

2. MATERIALS AND METHODS

At the beginning of 1985 the Institute of Zoology and Comparative Anatomy of the University of Bari began a programme of research on the ecology and biology of the various species of jellyfish widely dis-

tributed in the coastal waters of the Lower Adriatic and the Upper Ionian, namely *Rhizostoma pulmo, Cotylorhiza tuberculata, Aurelia aurita, Chrysaora hisoscella* and in particular *P. noctiluca.*

In order to obtain a first set of data on the presence of jellyfish, forms were distributed to the main nautical clubs and groups both of the Adriatic and Ionian coasts of Puglia. This was done because of the need to identify a phenomenon, the location and the size of which cannot be predicted from the present state of knowledge. This simple form contained a list of identifying characteristics of the species under study based on the characteristics distinguishable through a macroscopic observation from aboard boat. The information requested could easily be provided by non-specialized observers using the instruments normally found on leisure craft (compass, anemometer, thermometer, etc.).

In order to carry out more detailed observations and to acquire data which might be used as a control of the experimental census made by the non-specialized observers, a collecting survey was carried out off the Tremiti Islands (Province of Foggia) using equipment which the local authorities of those islands kindly provided. Part of the samples collected during that survey in July 1985 were fixed in 5% formol and the rest in glutaraldehyde-cacodylate buffer. They were later studied in the laboratory of the Institute of Zoology at Bari. The diameter of jellyfish was measured and at the same time gonads, pieces of tentacles and the umbrella were embedded in paraffin and epoxy resin. The pieces thus embedded in paraffin and epoxy resin were then cut up to obtain 5-7 μm sections for histological examination by light microscope and also ultra thin sections to examine by a Zeiss 109 electron microscope.

3. RESULTS

The number of properly filled in forms received in 1985 was small and far below what we expected (some 10% of those distributed). This very low figure may be due not only to poor cooperation of the non-specialized observers, but also to the limited number of sightings made in that year. In 1986 the results were very similar while the sightings were much scarcer. In these two years there was a major reduction in the number of shoals of *P. noctiluca* with a complete absence of sightings in the early months of 1987. On the other hand shoals of *R. pulmo* were noted, particularly in the Lower Adriatic in the early months of 1987. The results of the studies of the samples taken in 1985 off the Tremiti Islands are however more interesting. This group of small islands off the Gargano promontory seems to be particularly interesting as concerns the appearance of shoals numbering thousands of individuals mostly *P. noctiluca* (density up to 50 individuals per cubic metre for an area of approximately 3 square nautical miles). The appearance of such conspicuously large shoals seems to be frequent during the summer, but only occasional during the cold months, according to the information given by fishermen and islanders. During the observation period (1st-7th July 1985) no sightings of jellyfish were made off the mainland coast opposite the Islands. During this survey ephyrae of *P. noctiluca* were caught near the coast at S. Domino using a model WP-2 plankton net. The data obtained by direct observation during the survey were later compared with the information provided in the forms turned in by vacationers who frequent that area.

It seems that there is a valid correlation between the appearance near the coast in summer of individuals which are mostly entire and have a motor activity of the umbrella (equal or greater than 70 contractions a minute at a water surface temperature of about 23 °C) and the persistence in the area of winds of a least 10 knots rising from the first quadrant (NE).

In September 1986 shoals of jellyfish were sighted some miles off Manfredonia and the Tremiti Islands; these shoals were however smaller than those observed in 1985. Other samples of *P. noctiluca* were taken off Torre a Mare (Province of Bari) only in April and September 1986; no specimens were found in the other months of that year.

The histological examination of the male and female gonads of the specimens caught off the Tremiti Islands in July 1985 and off Torre a Mare in April and September 1986 showed that they were all sexually mature.

4. CONCLUSIONS

The data gathered on the distribution of jellyfish shoals along the Adriatic and Ionian coasts of Puglia are very limited; thus we can only formulate a hypothesis to explain the formation of the shoals.

It seems probable that there is a strict cause and effect relationship between the existence of certain environmental conditions and the appearance of the phenomenon at least in its initial stages before interaction among individuals can take place.

It seems that a very important part is played by the general circulation of currents in the Lower Adriatic. During the summer, currents of deep water circulate in a SE-NW direction along the Yugoslavian coast and in the opposite direction along the coast of Puglia. The Tremiti Islands are located in an area of the Adriatic where a part of the ascending current changes direction, moving in a SE direction, in a semicircle until it reaches the Adriatic coastline of Puglia.

From the investigations carried out the hypothesis of a "deep level" entry (below 100-150 metres) of jellyfish into the Adriatic appears probable. This entry would take place particularly during the cold months when the ascending currents are, by far, predominant in the Canale d'Otranto.

The appearance of shoals of jellyfish along the coast of Puglia might therefore have as one of its causes the rising to the surface level of these organisms at the time of the change of season. Thus the jellyfish found in areas such as the Tremiti Islands could be circulated along with the surface water towards the SE because of the influence of the winds.

Further experimental studies are needed in order to understand the large scale fluctuations of the shoals of jellyfish. Research of this kind is necessarily difficult because of the variations of the phenomenon. In fact in recent months it has no longer been possible to find these large shoals in the Lower Adriatic, but only some shoals of *R. pulmo*.

Although this investigation lies within the framework of the project "Jellyfish in the Mediterranean Sea" the funds provided by UNEP covered only part of the expenses incurred during the sampling at the Tremiti Islands, Torre a Mare, etc. Additional funds to cover the rest of the expenses were supplied by M.P.I. for the study of the plankton and benthos in the Lower Adriatic. Since this research is of major importance for the acquisition of knowledge on the fluctuations of the shoals of jellyfish in the entire Mediterranean basin, it is necessary to develop international cooperation among the Mediterranean States in order to arrive at a precise and accurate definition of the phenomenon. We hope therefore that the level of financing will allow not only the continuation of research, but also the unification of methodologies through an exchange of expertise and the collaboration of all the universities and research bodies of the Mediterranean area involved in the study of this problem.

Moreover a careful cost-benefit analysis would fully justify a more adequate financial support if the damage to public health and tourism were to be taken into account.

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OBSERVATIONS OF SURFACE CURRENTS IN THE GULF OF TRIESTE

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ABSTRACT

A set of lagrangian surface current measurements along the coast of the Gulf of Trieste between Trieste and Miramare is presented. Statistical current distributions are given, depending on the wind direction and on the astronomical tidal phase. The coastal surface circulation is in general parallel to the coast, directed towards W or SE according to the wind occurring in the Gulf (from the East or from the West) with a mean velocity of about 10 cm*s $^{-1}$. Tidal currents of about 3 cm s^{-1} can hardly be detected from the wind generated noise; modal directions are towards WNW, SE, ESE, NW during high water, ebb tide, low water and flood, respectively.

The coastal surface circulation described here is in line with the general circulation of the Gulf of Trieste.

1. MARINE CIRCULATION IN THE GULF OF TRIESTE

The Gulf of Trieste, the northernmost end of the Adriatic Sea, can be assimilated to a square with sides of about 20km oriented along NW-SE and NE-SW axes. The basin is closed along three sides: the NW sandy shore with very shallow water, the NE rocky shore and, SW from Trieste, the SE coast with the Bays of Muggia and Koper; the fourth SW side, between Grado and Savudrija, is open towards the Adriatic. The mean depth is 17m; the maximum depth of 25m is in the central southern part of the Gulf, along the border between Italian and Yugoslav waters.

The marine currents in the Gulf of Trieste have been studied since 1951 both by means of eulerian measurements (Stravisi *et al.*, 1981; Mosetti, 1972; Berger, 1979; Stravisi, 1983a) and lagrangian devices (Pocecco, 1973; Bidorini, 1974). The main results achieved so far can be summarized as follows:

(i) Tidal currents have mean velocities of about 3 cm s^{-1}, up to 10 cm s^{-1} along the open boundary and the NW coast (Mosetti, 1972; Michelato, 1973). The associated periodic tidal transport simply moves forward and backward, with a run of the order of 1 km, almost the same water mass; a residual tidal current of the order of 1 cm s^{-1} results from numerical computations (Princi *et al.*, 1980). The tidal contribution to the renewal of the Gulf water is in conclusion very poor.

(ii) Currents associated with local or Adriatic seiches of normal amplitude, according to numerical computations (Stravisi, 1973), have velocities up to 3 cm s^{-1}.

(iii) The mean velocity of density gradient currents is about 2 cm s^{-1} (Mosetti, 1972).

(iv) The large scale circulation in the Gulf of Trieste, with a mean vertical velocity of about 10 cm s^{-1}, is mainly wind-driven (Mosetti, 1972; Stravisi *et al.*, 1981).

(v) A strong velocity gradient is normally observed at the sea surface: on average, (from 0 to 1m depth), the current speed decreases to 3 cm s^{-1} and the current direction rotates by 45° (Stravisi, 1983b).

(vi) The circulation model for the Gulf of Trieste resulting from the observations is the following (Stravisi *et al.*, 1981; Stravisi, 1983a): A bottom layer, below about 10m and therefore concerning only the SE part

of the Gulf. rotates counterclockwise with a mean velocity of about 2-5 cm s^{-1}. This circulation, even if weak, is almost a permanent feature, so that it can be computed that the Adriatic water entering into the Gulf of Trieste at SE rotates to exit again, under normal meteorological conditions, after about ten to fifteen days. The surface layer (about 5m) is mainly driven by the local wind field; a large scale gyre normally rotates clockwise with westerly sea breezes, stops or rotates counterclockwise with easterly land breezes or bora. Velocity is 10 cm s^{-1} or greater. An inversion of the velocity direction is therefore generally observed at a depth of about 5m, which is normally above the characteristic thermocline (Stravisi, 1983a; 1983b). The bora driven circulation is counterclockwise from the surface to the bottom: this condition is the most efficient for the renewal of the whole water mass in the Gulf of Trieste (Stravisi. 1977b). Proof of this is also given by the seawater temperature: during strong summer bora events, a seawater temperature diminution of about 5 °C can be observed at 2m depth in 24h, indicating a replacement of warm surface water by colder bottom water.

The large scale gyre in the Gulf of Trieste drives small scale coastal eddies; the horizontal turbulence is such that the current velocity at a particular point is strongly variable. As a consequence, it is very difficult to predict the lagrangian path of different objects. It also depends very much on the depth at which these objects are located and if they can actively move vertically (like plankton or jellyfish) through dynamically different layers. Furthermore, a separate study must be devoted to the dynamics of the surface film, which generally moves at a different speed and direction than the surface layer (v).

2. OBSERVATIONS OF COASTAL SURFACE CURRENTS

The circulation model of the Gulf of Trieste described in the preceding section is based on measurements performed at fixed stations and at fixed depths from below the surface (10 cm) to the bottom. The off-shore lagrangian measurements were taken mainly at a depth of 2m and 10m. The experiment demonstrates the existence of high velocity variations just below the sea surface and a set of observations has been initiated to study the current field of this thin surface layer. The use of lagrangian devices is appropriate, since conventional current metres are too large and their measurements biased by surface waves. In the beginning, three stations (Barcola, Cedas and Miramare) were chosen along the NE coast of the Gulf of Trieste. More than two hundred measurement were taken between February and August 1987 at 20m from the coast. Pine-cones (!) were used as an ideal low-cost ecological lagrangian device, representing the current field of the 0-5cm surface layer. After the launch, the position of the lagrangian was determined from the coast by means of bearing compasses and clinometers; in this way, mean velocities in a time of 2-5 minutes with an accuracy of 10% were obtained. The velocity direction of the three stations is normally concordant so that, in this context, the corresponding measurements will be grouped into a single sample. A preliminary description of the results obtained so far is now given.

The current speed distribution at the three stations, for a total of 231 measurements, is shown in Fig. 1. The mode is between 1-5 cm s^{-1}, the mean speed is 11.6 cm s^{-1}. These figures are in line with the average offshore vertical current speed profile described by Stravisi *et al.* (1981), which is exponentially damped from 12.5 cm s^{-1} at 0m to 2.9 cm s^{-1} at 20m depth. The distribution of the velocity directions is shown in Table 1 and Fig. 2: the current is, with few exceptions, parallel to the nearby coast, directed along a NW-SE axis. Similar results were obtained 1 mile offshore between Barcola and Miramare, by Bidorini (1974).

CORRELATION WITH THE WIND.

Observations have been grouped according to wind direction recorded at the meteorological station of the Nautical Institute at Trieste. Since the characteristic period of the Gulf of Trieste is one hour, the prevailing wind direction during the hourly interval preceding the measurement was considered. Winds were classified as easterly winds (E) when blowing from NE, ENE, E, ESE and SE, as westerlies (W) if blowing from SW, WSW, W, WNW and NW. E winds at Trieste represent land breezes and "bora", W winds mainly sea breezes. The directional distribution of the coastal current direction in the presence of E, W winds is given in Table 1 and Fig. 2. With few exceptions, the surface current is clearly depends on the wind. indicating a counterclockwise coastal circulation with easterlies and a clockwise circulation with westerlies. depending on the main offshore gyre already described. The mean current speeds in the two cases are 13.5 cm s^{-1} and 10.0 cm s^{-1} respectively (Table 2); the corresponding resultant vectorial mean

current velocities are 9.8 cm s^{-1} towards 293° (WNW) and 6.3 cm s^{-1}, 139° (SE). The percentual ratio between vectorial and scalar mean velocities is an indicator of the stability of the current direction; rather high values are obtained (Table 2), 73% and 63% for E and W winds respectively.

Table 1. Distributions of the surface current direction along the coast at Barcola, Cedas and Miramare (Trieste). Whole sample (TOT); subsamples with easterly (E) and westerly (W) winds; subsamples at (1) high water, (2) ebb tide, (3) low water and (4) flood. No: Number of measurements.

	TOT	E	W	(1)	(2)	(3)	(4)
N	0.9	1.0	0.0	0.0	2.4	0.0	0.0
NNE	0.4	0.0	0.8	0.0	0.0	0.0	1.0
NE	1.3	1.0	0.8	2.6	0.0	8.3	1.0
ENE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E	2.6	0.0	4.2	0.0	6.0	0.0	1.0
ESE	6.9	1.0	11.0	2.6	7.2	25.0	6.3
SE	23.4	2.9	40.7	21.1	33.7	8.3	17.7
SSE	5.2	3.9	5.9	7.9	2.4	8.3	6.3
S	3.0	1.0	5.1	5.3	0.0	16.7	3.1
SSW	2.6	1.0	4.2	5.3	3.6	0.0	1.0
SW	1.7	0.0	3.4	0.0	2.4	8.3	1.0
WSW	2.6	2.9	2.5	5.3	3.6	0.0	1.0
W	7.4	15.7	0.8	13.2	4.8	0.0	8.3
WNW	16.5	30.4	5.9	21.1	9.6	25.0	18.8
NW	20.3	32.4	11.0	15.8	19.3	0.0	25.0
NNW	5.2	6.9	3.4	0.0	4.8	0.0	8.3
No.	231	102	118	38	83	12	96

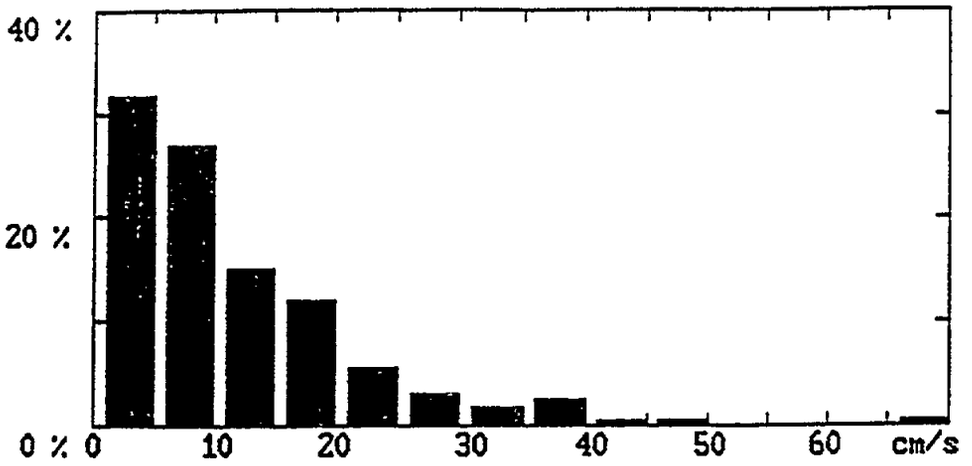

Fig. 1. Distribution of the surface current speed at three coastal stations (Barcola, Cedas, Miramare) in the Gulf of Trieste

CORRELATION WITH THE TIDE

In order to investigate the tidal dependence of the coastal circulation, current measurements were grouped into four subsets, according to the phase of the astronomical tide (Stravisi *et al.*, 1986) during the hourly intervals of the observation: (1) high water, (2) ebb tide, (3) low water and (4) flood. The corresponding distributions of the current directions are shown in Table 1 and Fig. 3. It can be seen that the bimodal NW-SE distribution is mainly present also in the (1,2,3,4) subsets; modal directions can hardly be indicated as WNW at high water (1), SE during ebb tide (2), ESE at low water and NW during flood. The corresponding scalar and vectorial mean velocities are given in Table 2; resultant means are about 3 cm s^{-1}. The stability parameters are low, from 11% to 43%. The result is therefore that the coastal tidal current, of the order of 3 cm s^{-1}, is strongly biased by the wind driven current.

3. CONCLUSIONS

The preliminary results of a new set of observations indicate that the circulation of the 5cm surface layer along the coast NW of Trieste is in line with the general circulation of surface waters in the Gulf. The actual current surface velocity is mainly the result of the wind driven (75%) and tidal components (25%). The surface seawater layer is characterized by a gyre in the Gulf. Rotation is clockwise under westerly sea breezes and counterclockwise with easterly land breezes and bora. Strong easterlies, bora in particular, drive the whole water column cyclonically. The water mass resident in the gulf exits along the NW coast and the Adriatic water enters along the SE coast.

Considering the normal wind frequency distribution at Trieste (Stravisi, 1977a), with 52% (4,500 hours per year) easterlies and 20% westerlies (1,700 h a^{-1}), and the mean speed of the corresponding marine currents (0.5 km h^{-1} WNW, 0.3 km h^{-1} SE) from Table 2, an annual counterclosk wise path of about 1,700 km comes out, about 70 times the distance from Miramare to the Gulf entrance: these figures indicate a renewal time of about 5 days, under normal meteorological conditions, for the surface water in the Gulf of Trieste.

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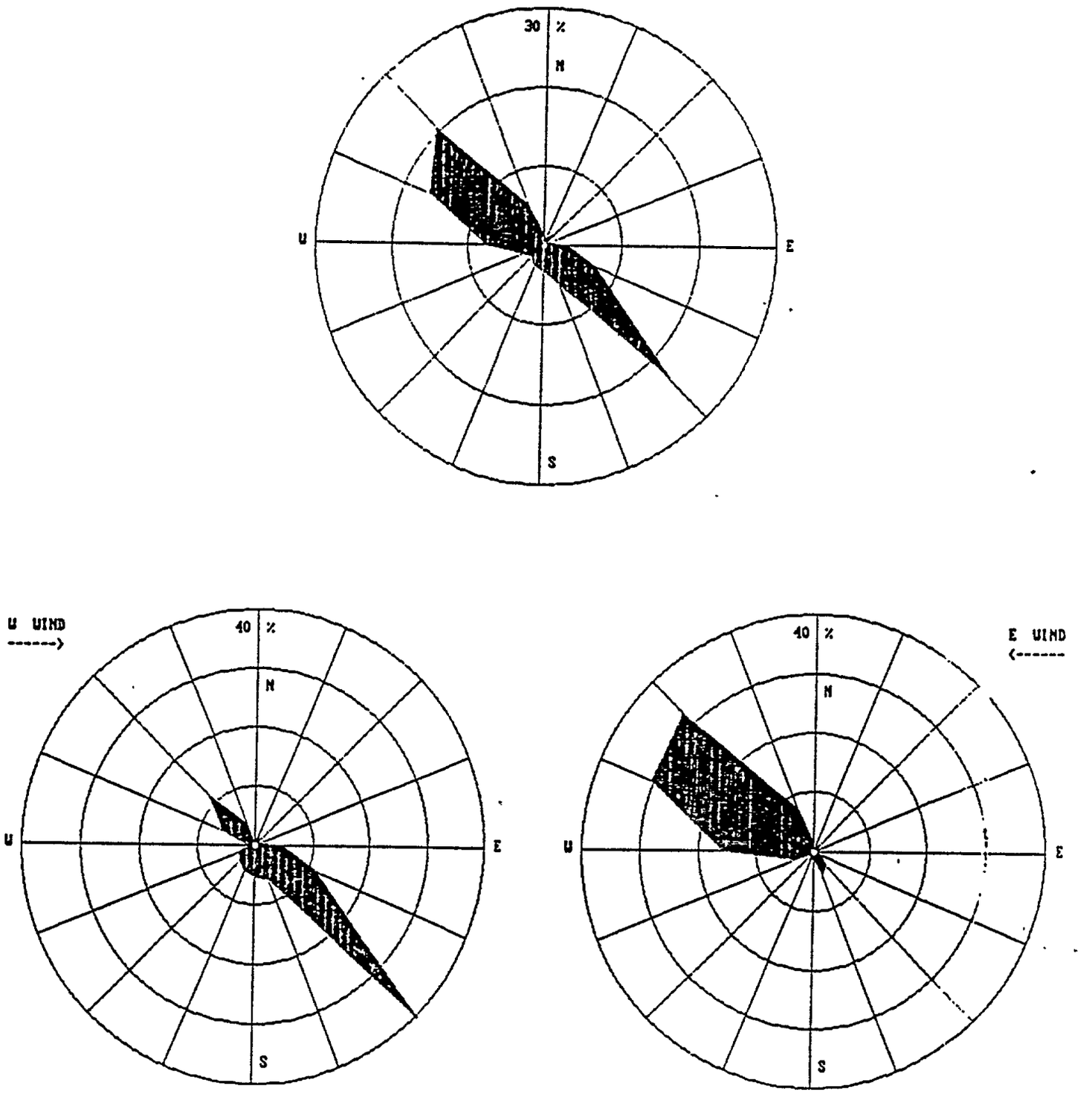

Fig. 2. Distributions of the surface current direction at three coastal stations (Barcola, Cedas, Miramare) in the Gulf of Trieste. All measurements (231) on top; currents with westerly (118) and easterly (102) winds (bottom).

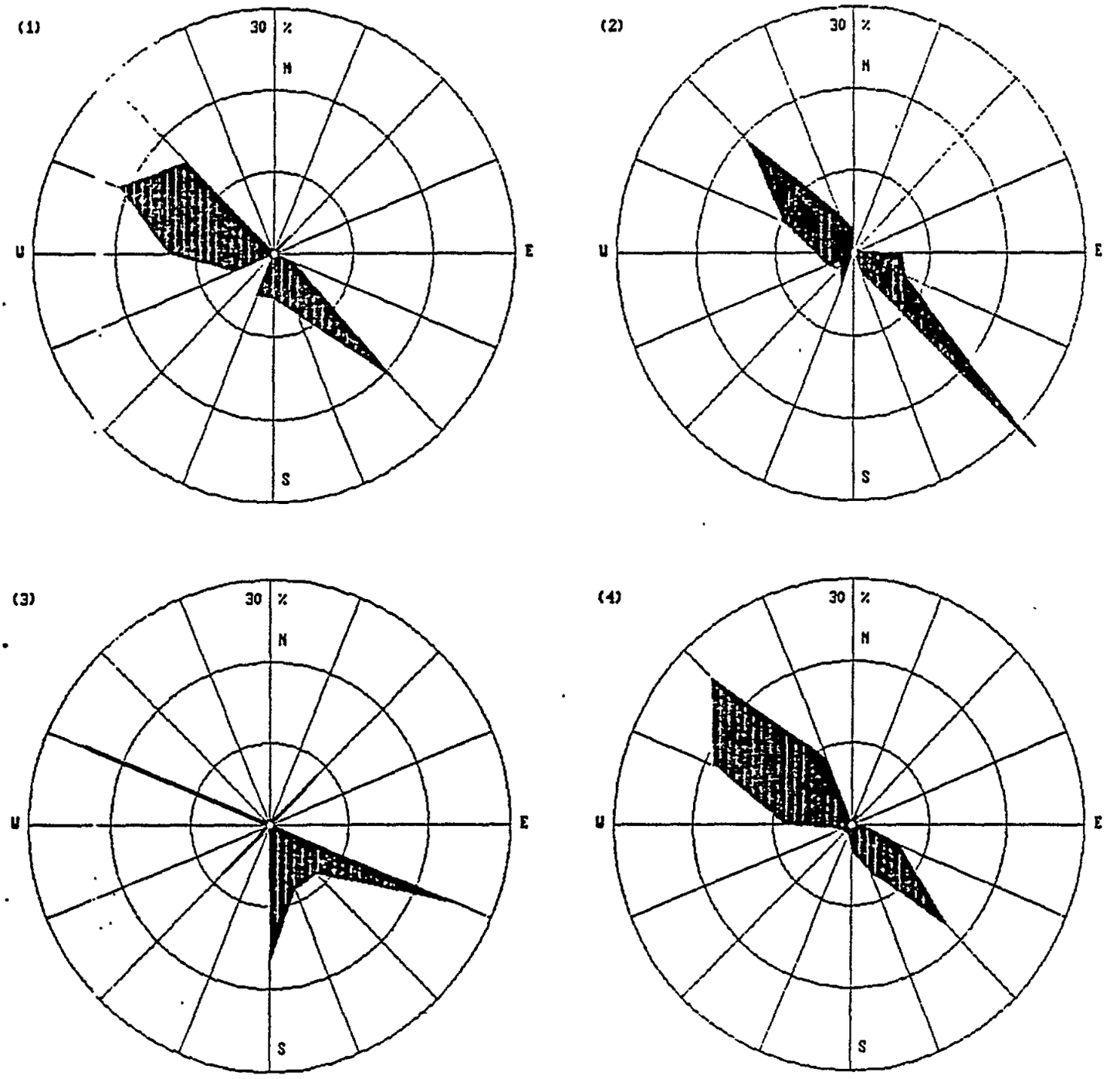

Fig 3. Distributions of the surface current direction at three coastal stations (Barcola, Cedas, Miramare) in the Gulf of Trieste. (1) High water, (2) ebb tide, (3) low water and (4) flood.

Table 2. Surface coastal currents at Barcola, Cedas and Miramare (Trieste). Number of measurements (a); mean wind velocity, (b); scalar mean current seed, (c); vectorial mean current velocity, (d); prevailing current direction (e); percentual stability (f) as function of the wind direction and of the tidal phase.

	(a)	(b)	(c)	(d)		(e)	f)
	No.	km h^{-1}	cm s^{-1}	cm s^{-1}		mode	stab.
Easterly winds	102	11.6	13.5	9.8	293°	NW	73%
Westerly winds	118	5.9	10.0	6.3	139°	SE	63%
1) High water	38	6.9	10.6	3.2	219°	WNW	30%
2) Ebb tide	83	8.2	13.1	1.4	163°	SE	11%
3) Low water	12	6.4	7.7	3.3	153°	ESE	43%
4) Flood	96	9.4	11.2	3.6	275°	NW	32%
Total	231	8.4	11.6	1.8	241°	SE	16%

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INTERANNUAL CLIMATIC VARIATIONS IN THE NORTHERN ADRIATIC SEA

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ABSTRACT

The climatic characteristics of the Adriatic Sea and of the Gulf of Trieste in particular are described. The time series of the conventional climatic parameters and of the seawater temperature recorded at Trieste are presented and analyzed with respect to the interannual variations. The climatic events which mainly interest the marine dynamics are the decrease of the annual frequency of the dominant "bora" wind in the years 1869-1872, 1922-1927 and 1965-1985, when a corresponding increase of southerly winds frequency was observed.

The climatic variations observed in the years 1976-1980 are discussed, since this period is characterized by the appearance of unusual marine biological phenomena in the northern Adriatic.

1. CLIMATIC CHARACTERISTICS OF THE ADRIATIC SEA AND OF THE GULF OF TRIESTE

The climate of the Adriatic basin has been described by Stravisi (1983c) on the basis of normal data from the conventional coastal meteorological stations. The mean atmospheric pressure over the sea is 1014 hPa: its spatial distribution is characterized by a permanent low pressure area in the central Adriatic, deepening during the cold season, with a resultant atmospheric circulation contributing to the large scale cyclonic gyre of the marine currents. The normal air temperature is 16 °C, decreasing from 18oC over the southern Adriatic basin to 14oC over the Gulf of Venice; the sea heating effect against the cold air continental input, mainly from the Po Valley, is evident. The annual normal amount of precipitations over the Adriatic is 500mm, increasing from about 300mm over the central 40% of the sea surface towards the coast, reaching 1400mm at the SE coast and 1000mm at Trieste. The relative humidity and the cloud amount increase from the western (69% and 4.4/10 respectively) to the eastern Adriatic coast (75% and 5.3/10).

The Adriatic basin plays an important climatological role on the synoptic scale, since it represents a communication channel between the Mediterranean region and continental Europe. Through this "climatic channel" heat is transferred northwards by sea currents and released into the atmosphere, while sea water is cooled and the characteristic winter dense water (6.6°C, salinity 38, density 1030 kg m^{-1} is formed (Stravisi, 1983d). Computations by Stravisi and Crisciani (1986) indicate an annual mean heat flux of 65 W m^{-2} from the sea surface in the Gulf of Trieste. The sea water column there is strongly cooled from September to February, and heat is advected by means of southerly marine currents to compensate for the net emission. During late summer and autumn the surface flux takes away mainly the local heat storage and the meridional heat transport is reduced. The northern Adriatic is furthermore a basin of dilution, mainly thanks to the coastal runoff, since precipitations over the sea and evaporation from the sea almost balance each other (Stravisi and Crisciani, 1986).

Large scale heat transports also occur by means of atmospheric motions, mainly due to southerly winds along the Adriatic basin and to the easterly "bora" descents, characteristic and prevailing in the northern region (Stravisi 1977a). These dominant winds furthermore contribute to the general circulation of the marine surface layer.

The Gulf of Trieste has a surface of about 20 x 20 km^2 and a mean depth of 17m; the maximum depth (25m) is in front of its SE coast. Because of its location (the northernmost Mediterranean water) and shallowness, the climatic "continentality", characteristic of the Adriatic basin, is here enhanced. The

seawater has a mean annual temperature decreasing almost linearly from the surface (16.0 °C) to the bottom (13.1 °C), the mean being 14.5 °C: the seawater column is characterized by a large vertical temperature gradient (a difference of up to 8 °C between sea surface and bottom) during spring and summer and by the vertical mixing produced by the bora winds during autumn and winter (Stravisi, 1983d). The directional wind statistics at Trieste through the year (in the period 1951-1975) are described by Stravisi (1977a) and represented in Fig. 1: the ENE bora turns out to be the dominant wind, with 41,000 km a^{-1}, a frequency of 21.3% (78 days per year) and a mean velocity equal to 5.6 m s^{-1}. Local winds in the Gulf are the sea and land breezes, almost along the direction WNW-ESE respectively; the southerly winds at Trieste, from "scirocco" (SE) to "libeccio" (SW), generally affect the whole Adriatic basin. The annual cycles of easterly winds and westerly winds are opposite in phase: easterlies and bora have a maximum during autumn and winter, sea breezes during spring and summer. The main effect of the bora descents on the northern Adriatic is the setting up of a large scale cyclonic gyre (Stravisi, 1977b) with horizontal and vertical mixing of the seawater mass; the whole water column circulates counterclockwise in the Gulf of Trieste (Stravisi, 1983b) producing an efficient seawater renewal.

The sea level variations in the northern Adriatic, and in the Gulf of Trieste in particular, are the largest in the Mediterranean (with the exception of the Gulf of Gabes). This characteristic is due to the dimensions, shape and bottom profile of the basin. The astronomic tide at Trieste is mainly semidiurnal with a mean range of 86cm at syzygies and 22cm at quadratures (Polli, 1950). The average monthly range of the observed sea level is 160cm (from 80cm below to 80cm above msl), the average annual range 219cm (from 97cm below to 122cm above msl); data from ITTS (1980) refer to the years 1976-1980. The first longitudinal Adriatic seiche (free oscillation), with a period of 21.5h and an amplitude up to 0.5m, is excited by meteorological perturbations, mainly by southerly winds on the basin; in this case, large surges can occur when seiche and tide are in phase (Stravisi *et al.*, 1986).

In conclusion, the Gulf of Trieste is characterized by a continental climate; large tides, coastal fresh water inputs, bora and strong winter seawater cooling are the most relevant features. Climatic data for Trieste are extensively reported in the literature (e.g. Polli, 1970; Stravisi, 1976); some useful figures are given in Table 1.

Table 1. Normal climatic data for Trieste, years 1931-1960(1),1972-1982(2) and 1951-1980(3).

	January	July	Year
Atmospheric pressure hPa	1016.7	1014.2	1015.5 (1)
Air temperature °C	4.7	23.9	14.3 (1)
Relative humidity, %	66.2	60.9	64.7 (1)
Wind velocity (ms^{-1})	2.7	3.5 (1)	
Precipitations mm	77	953 (1)	
Cloud cover (1/10)	6.2	3.7	5.4 (1)
Sunshine h	97	308	2131 (1)
Global solar irrad. (MJ/m^2)	126	658	4508 (2)
Global solar irrad. (cal/cm^2)	3014	15705	107881 (2)
Seawater temperature (°C at 2m)	8.9	23.3	15.7 (3)

2. THE CLIMATIC SERIES AT TRIESTE

Meteorological observations and measurements were begun in Trieste in 1819 at the local Nautical and Commerce Academy. The description of the older stations is reported by Polli (1942). Since 1920, with the exception of some years at the end of the Second World War, the meteorological station has been located at the site now occupied by the new seat (1951) of the Istituto Sperimentale Talassografico of Trieste (ITTS), recently part of the Italian National Research Council (CNR). Reports with the meteorological

data of Trieste have been regularly published. Recent summaries of annual data and related statistics are given by Stravisi (1976, 1986b). Secular linear trends computed by Stravisi (1986b) are reported in Table 2: a climatic modification occurred in the sense of a warmer atmosphere with lower humidity and reduced precipitations, less bora and more southerly winds. The sea level increase at Trieste (Stravisi and Ferraro, 1986) is of the order of the world oceanic level rise, 15 cm/century (Barnett, 1983).

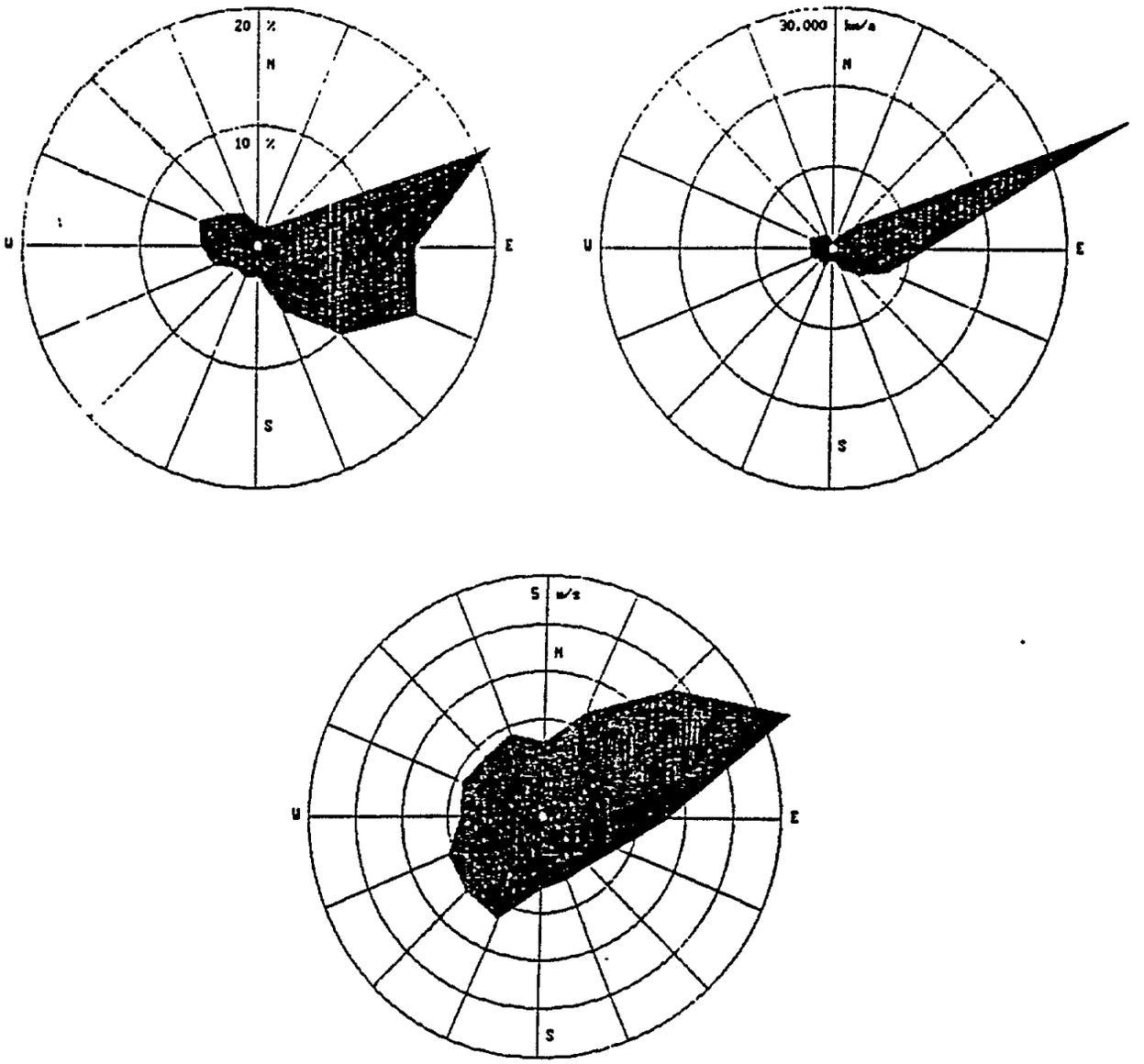

Fig. 1.Directional distribution of the wind percentual frequency, run and mean velocity at Trieste (1971-1975 averages)

Table 2. Secular linear trends of some climatic parameters at Trieste ("bora" includes NNE, NE, ENE, E; southerly winds SE, SSE, S, SSW, SW).

Atmospheric pressure	(1871-1985):	-0.03	hPa century
Air temperature	(1871-1985):	+0.32	°C century
Relative humidity	(1871-1985):	-2.7	% century
Annual precipitations	(1871-1985):	-146	mm century
Annual sunshine duration	(1886-1985):	-156	h century
Annual "bora" duration	(1903-1985):	-28	d century
Annual southerly winds duration	(1903-1985):	+18	d century
Sea level	(1890-1984):	+13.2	mm century

In this paper the Trieste climatic series related to the marine environment are considered: 1861 was chosen as the starting year. Annual data are reported in Table 3; sample means, standard deviations, skewness, kurtosis and extremes are also indicated as explained herebelow.

(1) The atmospheric pressure (unit: hectopascal, 1 hPa = 1 mbar) is reduced at sea level; data are taken from Stravisi (1976), ITTS (1977 to 1980, 1987) and Stravisi *et al.* (1986 a to f).

(2) The air temperature (unit: degree Celsius, °C) refers to the actual height (10m above msl); old data have been homogenized by Polli (1942); data are from Stravisi (1976), ITTS (1977 to 1980; ITTS 1987) and Stravisi et al. (1986 b; 1986f).

(3) Annual mean precipitations are given in millimetres per day (mm/d) (Stravisi, 1976; ITTS 1977 to 1980, 1987; Stravisi *et al.*, 1986 e,f).

(4) The annual percentual frequency of "bora" here includes winds from NNE, NE, ENE and E: this has been done to account for the variations of the mean direction of bora during different events (the normal ENE direction sometimes turns to E or NE), for personal differences during records reading and for small changes in direction at different station sites. NNE has also been included: its normal frequency (1.4%) is however low. Only wind durations have been considered, not velocities, since this series is not homogeneous owing to changes of anemograph and site during the years. Bora frequency data are taken from Stravisi (1986a) for the years 1884-1985 and from ITTS (1987). Data for the years 1869-1883, computed on the basis of the wind duration distributions reported by Osnaghi (1887), have not been published to date.

(5) The annual percentual frequency of the "southerly winds" here includes winds from SE, SSE, S, SSW and SW, generally affected by "scirocco" and "libeccio"; comments and data sources are the same as for bora.

(6) The climatic series of sunshine duration, according to conventional Campbell-Stokes recorders, began in 1886; annual percentual frequencies are taken from Stravisi (1986c) and ITTS (1987); frequency has been computed as the ratio between the total annual sunshine duration and the annual duration of astronomical daylight at Trieste (4401 hours per year, 4412 hours per leap year).

(7,8,9) The annual mean seawater temperature, the winter (January, February and March) mean temperature and the (winter) minimum temperature are computed on the basis of daily measurements taken since 1934 at Trieste from the seashore at a 2m depth (Stravisi, 1987; ITTS, 1987).

3. ANALYSIS OF THE CLIMATIC SERIES

A spectral analysis of the Trieste climatic series (annual values between 1871 and 1985) is reported by Stravisi (1986c): the main peaks of their root mean power spectrum correspond to 50, 24.1, 18.3, 12.7, 10.9, 7.8, 4.96, 4.62, 3.67, 3.42, 2.97 and 2.25 years. The short period harmonic components (below 5 years down to the quasi biennial oscillations) generally have rather large amplitudes.

In this paper, in order to show the long term variability of the climatic characteristics, the annual data (1-6) of Table 3 have been smoothed by means of the Tukey "53H" filter described by Kleiner and Graedel (1980). This filter, represented in Fig. 2, cuts off all periods below 5 years. The smoothed series are represented in Fig. 3 (pressure, air temperature, precipitation and percentual sunshine duration); the observed and smoothed percentual annual frequencies of bora and southerly winds are represented in Fig. 4. Sample averages according to Table 3 are indicated.

With reference to the secular trends reported in Table 2, the following can be included. The atmospheric pressure is almost stationary; a pseudo-period of about 9 years can be seen, with an average amplitude of about 1.5 hPa (correcting for the filter effect). The air temperature is generally lower than the average till about 1920, higher from 1920 to 1977. These features are in line with the temperature variations of the northern hemisphere according to Budyko (1977). The main pseudo-period, about 11 years, has an amplitude of about 1.5°C. Annual precipitations lower than the average are observed in the years 1936-1958. The pseudo-period is 10-11 years, average amplitude 300mm. The percentual annual sunshine duration has a period of about 11-12 years and an amplitude of 8%. Lower sunshine is found during the years 1966-1983. The monthly averaged daily amounts of the global solar irradiation for the years 1971-1986 are represented in Fig. 5.

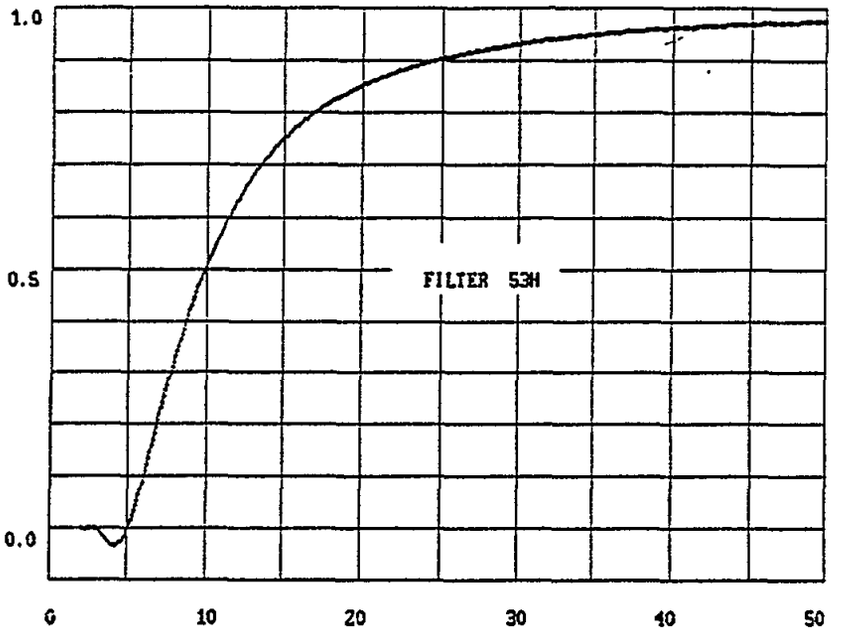

Fig. 2. Tukey filter "53H" as a function of period in time units

As regards the frequency of the characteristic winds (Fig. 4), it can be stated that the linear trends of Table 2 are reduced by the introduction of the older data (1869-1902). A periodicity of about 8 years with a filter corrected amplitude of 10% is observed. Years with maximum bora frequency can be located around 1890 and 1970: a mean recurrence time of 50 years comes out, in accordance with the spectral analysis (Stravisi, 1986b). The mean amplitude of the 50-year bora frequency cycle is about 8% or 30 days

Year	1	2	3	4	5	6
1861	1015.8	13.4	2.4			
1862	1014.6	14.2	3.2			
1863	1016.4	15.7	2.3			
1864	1015.4	13.1	3.3			
1865	1015.9	14.8	1.8			
1866	1015.6	14.5	2.7			
1867	1015.0	14.8	3.0			
1868	1016.0	15.0	2.4			
1869	1015.3	13.8	3.2	35.4	23.6	
1870	1014.7	13.2	3.3	41.8	21.7	
1871	1015.4	13.3	2.3	37.2	24.3	
1872	1014.8	15.0	3.8	25.5	27.4	
1873	1016.2	14.4	3.0	41.8	17.6	
1874	1016.0	13.6	2.5	44.8	19.0	
1875	1016.0	13.1	2.7	45.1	21.0	
1876	1014.7	13.5	4.0	49.0	20.5	
1877	1015.0	14.0	3.2	45.4	19.1	
1878	1014.5	13.9	3.6	42.9	19.8	
1879	1014.6	13.7	2.8	47.2	18.8	
1880	1016.8	14.1	3.4	47.6	18.7	
1881	1016.0	13.4	2.6	66.9	13.3	
1882	1016.8	14.6	3.1	55.3	21.8	
1883	1015.7	13.6	2.2	53.7	18.2	
1884	1016.7	13.7	2.6	44.2	22.5	
1885	1014.7	13.9	4.0	54.5	19.0	
1886	1015.0	14.2	3.0	52.6	17.3	48.9
1887	1015.9	13.5	3.0	45.4	20.1	50.7
1888	1016.0	13.4	2.6	37.8	26.1	46.8
1889	1014.8	13.6	3.7	58.4	14.7	49.8
1890	1015.6	13.7	2.2	60.4	13.6	54.6
1891	1016.4	13.7	2.6	44.0	23.6	54.2
1892	1014.6	13.9	3.3	39.8	24.5	51.6
1893	1015.8	13.7	2.4	45.1	20.1	52.0
1894	1016.2	14.2	2.3	53.9	17.1	54.4
1895	1014.0	13.9	2.3	50.7	18.9	48.6
1896	1015.9	13.8	3.8	48.5	20.4	50.9
1897	1016.0	14.5	2.5	48.8	18.5	51.1
1898	1016.0	15.1	2.4	49.6	18.5	47.3
1899	1016.5	14.0	2.9	50.6	18.0	44.4
1900	1014.2	14.8	3.4	57.1	15.6	46.4
1901	1014.9	13.7	3.1	52.8	21.7	47.1
1902	1015.6	13.7	2.5	47.2	18.3	48.2
1903	1016.4	14.3	2.8	44.4	17.4	44.9
1904	1015.8	15.0	2.3	54.2	13.7	46.0
1905	1016.1	13.7	3.4	48.3	16.3	47.1
1906	1015.3	13.9	2.7	45.2	17.1	49.1
1907	1015.9	14.0	2.7	48.0	14.7	47.9
1908	1016.8	13.7	1.9	47.0	14.7	52.9
1909	1014.5	13.7	2.9	42.1	20.2	49.3
1910	1013.9	14.1	3.8	42.7	20.4	45.1

Year	1	2	3	4	5	6	7	8	9
1911	1017.0	14.6	2.5	43.1	18.2	52.0			
1912	1015.8	13.5	2.8	40.4	19.0	40.3			
1913	1017.0	13.9	3.0	41.9	16.4	48.4			
1914	1015.6	13.9	3.1	43.2	18.3	49.5			
1915	1013.3	13.9	4.4	44.6	18.8	46.7			
1916	1013.7	15.0	3.9	37.8	24.3	48.4			
1917	1014.9	14.1	3.2	49.8	18.0	53.9			
1918	1016.8	13.8	3.5	41.1	23.0	50.7			
1919	1014.2	13.6	3.5	40.2	25.4	49.6			
1920	1017.3	14.4	2.0	39.6	20.0	50.2			
1921	1018.4	14.6	1.8	43.1	20.6	49.9			
1922	1015.1	13.7	2.7	36.3	26.7	44.0			
1923	1014.3	14.6	2.9	38.6	25.1	45.5			
1924	1015.3	14.0	2.8	40.5	25.2	43.2			
1925	1015.3	14.1	2.9	30.8	29.9	43.2			
1926	1015.2	14.6	3.6	36.5	28.2	38.2			
1927	1014.8	14.9	2.6	36.2	28.5	49.9			
1928	1015.8	14.4	3.2	42.9	23.7	48.8			
1929	1016.3	13.8	2.4	44.0	24.6	49.9			
1930	1014.6	14.7	3.6	37.5	27.7	44.9			
1931	1014.8	13.9	2.8	40.8	26.8	44.9			
1932	1016.9	13.8	3.1	38.2	29.7	47.4			
1933	1014.9	13.3	3.4	47.3	23.2	42.4			
1934	1015.5	15.0	3.5	40.9	24.7	49.3	16.3	8.1	6.0
1935	1013.9	14.3	2.2	43.9	22.7	49.9	15.4	7.2	4.7
1936	1014.2	14.8	2.5	43.3	22.9	46.9	15.9	9.7	7.8
1937	1013.7	14.7	3.5	45.9	21.5	42.6	16.3	9.0	7.0
1938	1017.4	14.2	1.7	47.5	18.1	54.2	15.6	7.2	5.8
1939	1014.7	14.1	2.5	53.1	14.2	49.2	15.7	8.4	7.3
1940	1015.0	12.8	3.1	58.2	15.5	45.7			
1941	1014.9	13.0	2.5	51.7	19.2	46.1			
1942	1015.8	14.0	1.6	51.3	19.0	50.7	15.4	5.8	3.2
1943	1017.6	15.0	2.3	43.6	13.9	54.6			
1944	1015.2	13.9	2.1	50.7	17.0	48.5			
1945	1016.9	14.8	1.6	41.3	15.0	55.4	16.5	7.6	6.5
1946	1016.1	14.8	2.1	45.4	18.2	54.4	15.9	8.5	6.6
1947	1015.6	14.7	2.6	48.8	20.8	48.9	15.4	6.5	4.6
1948	1018.0	14.5	3.2	52.8	17.4	48.7	15.5	8.2	6.5
1949	1017.8	14.8	2.3	52.1	15.0	53.7	15.7	6.8	4.8
1950	1015.0	15.2	2.7	45.1	19.9	50.4	16.8	9.0	7.1
1951	1014.7	15.1	2.9	38.4	24.6	44.8	16.6	9.9	8.5
1952	1014.2	14.3	2.9	35.4	24.4	46.2	16.0	8.9	7.1
1953	1018.0	14.4	2.3	48.5	15.2	48.4	15.5	7.4	5.6
1954	1014.3	13.7	2.2	39.6	20.9	44.7	15.2	7.1	4.7
1955	1014.4	13.7	2.6	43.7	15.5	43.5	15.2	8.8	6.7
1956	1016.0	13.1	2.7	45.1	20.6	45.3	15.0	6.9	4.0
1957	1016.2	14.3	2.1	42.1	23.8	50.0	15.4	8.2	6.3
1958	1014.8	14.5	2.5	37.7	23.3	50.6	16.1	8.6	7.1
1959	1016.0	14.5	2.8	44.8	17.6	47.2	15.6	9.7	8.4
1960	1013.7	14.3	3.7	40.5	22.6	45.6	16.2	8.9	6.4

Year	1	2	3	4	5	6	7	8	9
1961	1016.5	15.0	3.1	38.2	22.5	55.0	16.6	10.2	8.2
1962	1015.2	13.8	2.9	47.3	19.3	52.4	14.9	8.3	6.4
1963	1014.5	13.9	3.3	39.2	25.1	50.9	15.2	6.0	4.0
1964	1016.9	14.2	2.7	39.4	25.5	51.6	15.7	8.2	6.3
1965	1014.3	13.7	3.0	32.8	29.7	48.1	15.7	8.6	6.5
1966	1013.9	14.7	2.8	36.5	24.6	43.6	16.5	8.9	7.3
1967	1016.6	14.7	2.2	36.3	27.4	46.4	15.8	8.5	6.9
1968	1015.2	14.3	3.1	36.6	26.5	46.1	15.9	8.0	6.3
1969	1014.2	14.2	3.0	39.7	24.0	43.9	15.8	8.1	6.2
1970	1015.2	14.0	2.9	30.9	29.4	44.1	15.6	8.6	7.5
1971	1016.1	14.2	2.4	38.5	25.1	48.1	15.9	8.4	6.0
1972	1016.1	14.1	2.8	39.5	25.7	39.9	15.6	9.4	7.7
1973	1016.4	14.3	2.3	39.4	23.7	45.9	15.6	8.5	7.3
1974	1015.5	14.4	2.8	38.3	28.9	42.6	15.9	9.8	9.0
1975	1016.6	14.8	3.2	36.9	30.7	43.6	15.8	9.2	8.2
1976	1015.5	14.0	2.7	40.1	23.5	44.0	15.3	8.4	7.0
1977	1015.9	14.3	3.2	31.2	31.6	41.5	15.9	10.1	8.9
1978	1014.9	13.5	3.2	32.2	30.3	42.6	14.9	8.7	7.1
1979	1014.8	14.2	2.9	39.2	26.7	45.8	15.7	8.8	7.5
1980	1015.2	13.2	3.1	41.3	25.2	40.3	14.9	8.8	7.6
1981	1015.5	14.0	2.8	37.5	25.4	44.3	15.1	.4	5.2
1982	1016.9	14.6	2.6	42.7	23.1	47.2	15.7	6.1	7.2
1983	1017.5	14.4	1.9	36.1	29.5	50.6	15.9	8.8	7.2
1984	1015.6	13.8	2.8	37.8	31.2	43.9	15.4	7.9	6.5
1985	1015.6	14.8	2.4	33.6	32.4	48.3	15.7	7.9	5.6
1986	1016.2	14.3	2.5	43.4	25.0	54.1	15.8	8.2	6.2
1987								7.7	6.4
mean	1015.56	14.13	2.83	43.58	21.77	47.86	15.72	8.38	6.65
s	0.90	0.55	0.55	6.83	4.66	3.77	0.46	0.93	1.18
skew.	0.43	0.11	0.20	0.46	0.22	-0.04	0.27	-0.27	-0.31
kurt.	4.60	2.60	2.81	3.50	2.20	2.52	2.73	2.89	2.77
min	1013.3	12.8	1.6	25.5	13.3	38.2	14.9	5.8	3.2
max	1018.4	15.7	4.4	66.9	32.4	55.4	16.8	10.2	9.0

Table 3 - Annual mean climatic data for Trieste. (1) atmospheric pressure /hPa at mean sea level; (2) air temperature /°C; (3) precipitation rate /(mm/d); (4) "bora" (NNE,NE,ENE,E) and (5) "southerly winds" (SE,SSE,S,SSW,SW) percentual frequency; (6) percentual sunshine duration; (7) annual, (8) winter mean and (9) minimum seawater temperature /°C (2 m depth).

per year. The 1963-1985 period is characterized by a marked reduction of the bora frequency and by a corresponding increase of the southerly winds. Similar situations, but of a much shorter duration, occurred in 1925 and 1872 when, as during 1977, bora and southerly winds had the same frequency. A reversal of this recent unusual situation can be expected for the last decade of this century.

The observed annual values of the seawater temperature at Trieste (2m depth) are shown in Fig. 6. The annual mean temperature (a), the winter (January to March) mean temperature (b) and the minimum temperature (c) are listed in Table 3. The summer (July, August and September) mean (d) and maximum (e) temperatures have been plotted as well. Average temperatures are indicated. The bar plot (f) on the bottom shows the annual number of (winter) days with seawater temperature below 6.5%°C. Summer mean and maximum temperatures appear to be higher than the average (23.1 °C and 26.5 °C respec-

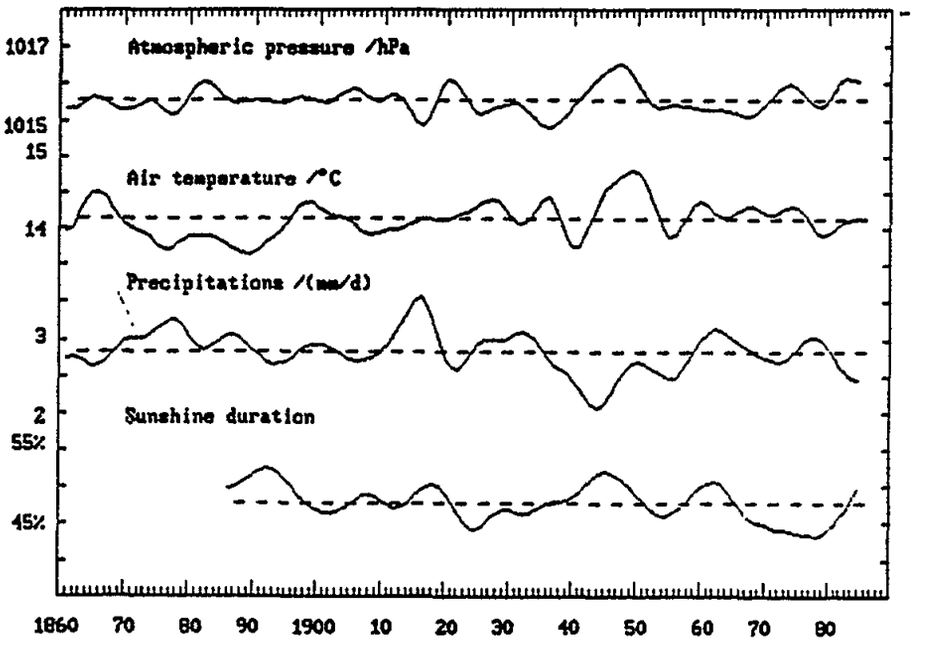

Fig. 3. Filtered (53H) climatic series and mean values at Trieste. 1961-1986: atmospheric pressure (1015.56 ± 0.90 hPa), air temperature (14.13 ± 0.55 °C), precipitations (2.83 ± 0.55 mm d^{-1}; 1033 ± 200mm a^{-1}). 1886-1986: sunshine percentual duration (47.9 ± 3.8%)

tively) before about 1960 and lower after that year. Winter mean and minimum temperatures are rather regularly higher than the average from 1972 to 1983, with the exception of 1981. This period corresponds to the years of shorter bora duration and increased southern advection. Looking at the number of "cold seawater" days (Fig. 6,f), it can be noted that before 1972 there were no more than three consecutive "warm" years; during the whole period 1972-1980 seawater temperature never cooled below 6.5°C.

To summarize the recent climatic variations in the Gulf of Trieste it can be said that (i) the decade 1940-1950 has been characterized by high pressure, warmer air, more sunshine, reduced precipitations, much Bora and scarce southerly winds; (ii) the decade 1970-1980, on the contrary, by scarce bora and many southerly winds, reduced sunshine and as regards the sea warm winters and colder summers.

4. CLIMATIC CONDITIONS BETWEEN 1976 AND 1980

The years from 1977 to 1980 have been characterized by the appearance of some unusual planktonic organisms in the northern Adriatic and in the Gulf of Trieste in particular. Climatic conditions favouring this phenomenon reported by Rottini Sandrini et al. (1980) and by Stravisi (1984). These conditions are (i) the enhanced southern marine water advection due to the increased frequency of southerly winds, (ii) the scarce water mixing and renewal in the Gulf of Trieste owing to the diminution of the bora duration, (iii) the increased survival probability of some species in the Gulf because of warmer winter seawater and to some extent of summer seawater temperatures lower than usual.

It seems therefore interesting to compare some climatic data of this period, including 1976 as a preconditioning year, with the corresponding long term reference data. The starting year 1977 is considered separately.

Table 4 shows the seasonal differences recorded at Trieste between 1976 and 1980 and the 1977 atmospheric pressure and air temperature as well as the corrresponding 1871-1970 secular averages (Stravisi, 1976); the seasonal differences between the seawater temperature (2m depth) and the reference period 1951-1980; the seasonal ratios of the global solar irradiation, precipitations and mean wind velocity with respect to the reference periods (1971-1986 for irradiation; 1871-1970 for precipitations and wind).

The climatic conditions of the Gulf of Trieste during the years 1976-1980 are the following: winter: low pressure (especially February 1978), warmer air and sea (March 1977), abundant precipitations (January and March 1979), scarce Bora (1977). Spring: colder air and sea (May and June 1980), less precipitations (May 1979). Summer: cold air and sea (August 1976) and somewhat greater precipitations (344mm - a record! - during August 1977). Autumn: scarce Bora (October and November 1977). Year 1977: warm winter and cold summer air and seawater temperatures, much abundant winter and summer and scarce spring and autumn precipitations, a marked diminution of the wind velocity, owing to scarce Bora, mainly during winter, scarce winter sun irradiance.

5. SEAWATER TRANSPARENCY

Seawater "transparency" is a simple and useful indicator of the marine environmental and ecological conditions. This parameter is commonly represented by the depth of disappearance of a horizontal white disk - the Secchi disk - vertically lowered in the sea.

Secchi disk measurements in the Gulf of Trieste have been performed since 1951; the average Secchi depth is 5m in the near shore harbour waters, 7 to 10m along the NE coast, 12 to 15m in the off-shore waters (Stravisi, 1983a).

Table 4. Seasonal differences or ratios between climatic elements of the years 976-1980, 1977 and the reference periods.

1976-80	Pressure hPa	Air t. °C	Sea t. °C	Sun irr. %	Prec. %	Wind %
Winter	-1.3	+0.8	+0.3	97	122	82
Spring	-0.2	-0.5	-0.5	102	84	98
Summer	+0.4	-1.3	-0.8	98	116	92
Autumn	+0.1	0.0	-0.3	98	106	89
Year	-0.2	-0.3	-0.4	99	107	90
1977	Pressure hPa	Air t. °C	Sea t. °C	Sun irr. %	Prec. %	Wind %
Winter	-0.3	+1.1	+1.5	84	142	58
Spring	0.0	-0.2	+0.5	107	69	86
Summer	-0.4	-1.7	-0.6	94	203	93
Autumn	+2.1	+0.8	-0.4	92	58	81
Year	+0.4	+0.2	+0.4	97	118	78

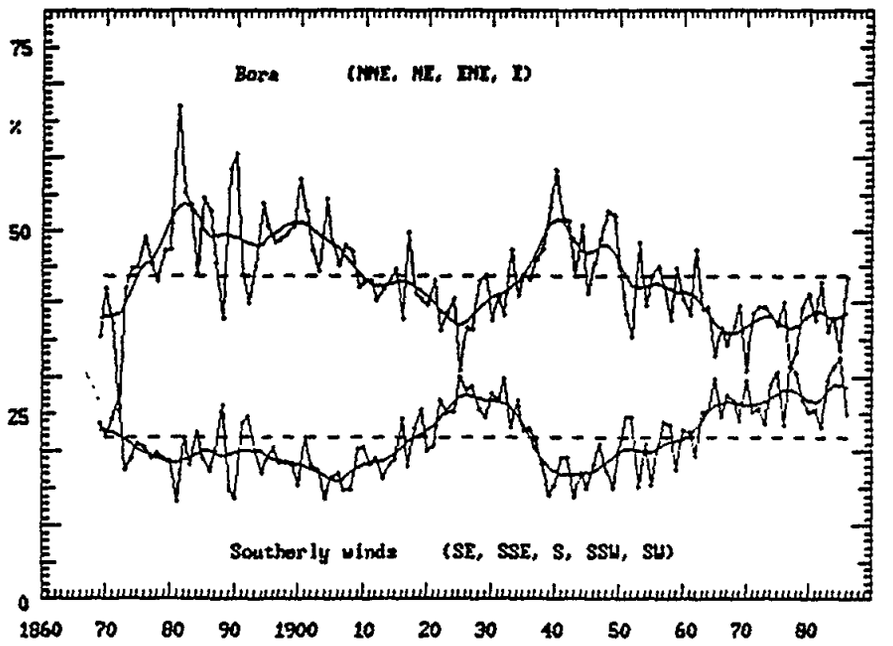

Fig. 4. Observed and filtered (53H) time series of the bora and southerly winds annual percentual frequencies at Trieste (1869-1986). Mean values and standard deviations are 43.6 $\pm$ 6.8% (159 $\pm$ 25 d a^{-1}) and 21.8 $\pm$ 4.7% (79 $\pm$ 17 d a^{-1}) respectively

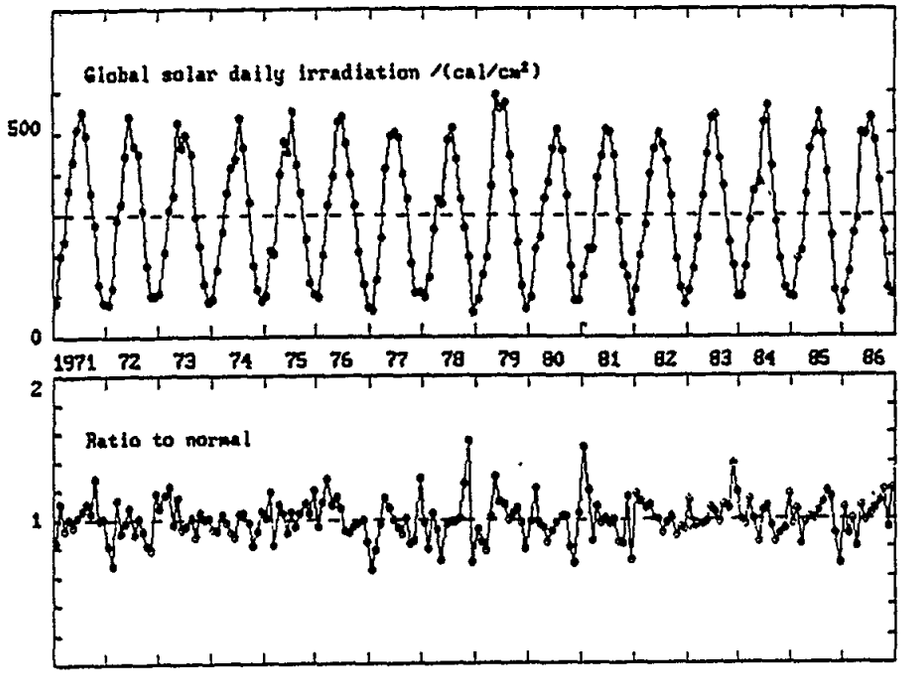

Fig. 5. Global solar daily irradiation at Trieste (monthly mean values 1971-1986; the annual average is 298 $\pm$ 10 cal.$cm^{-2}d^{-1}$) and ratios with respect to the 1971-1986 mean annual cycle

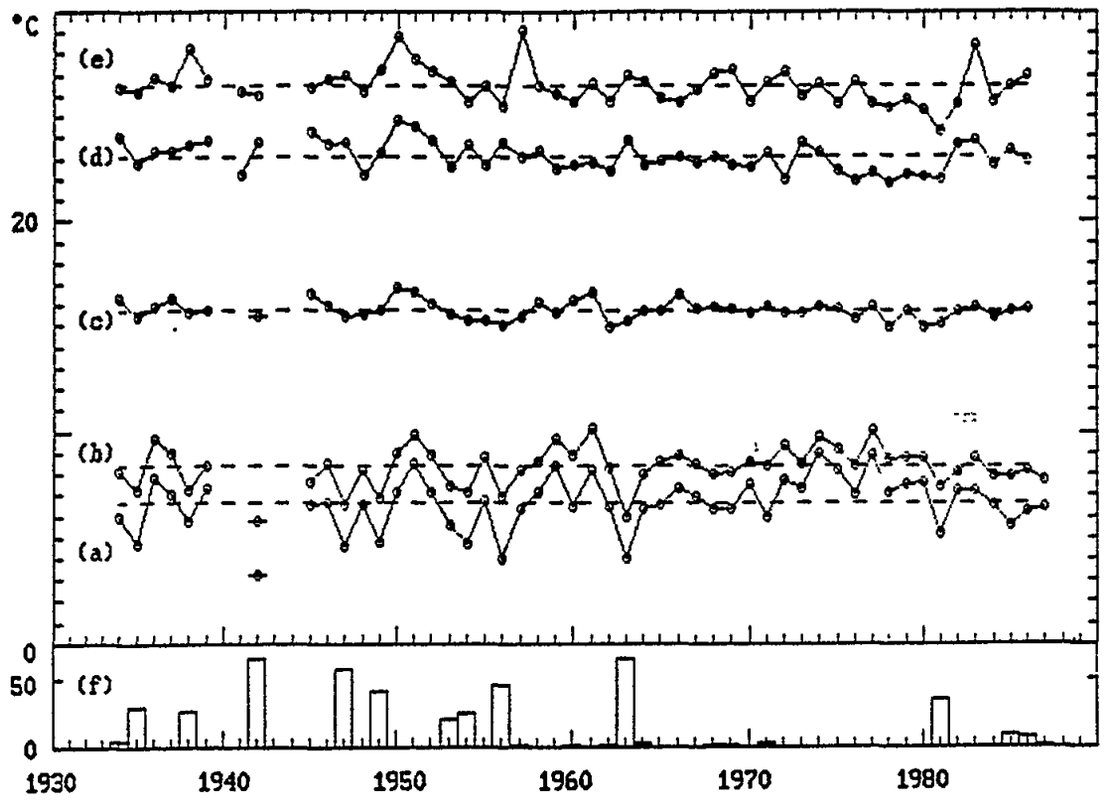

Fig. 6. Trieste 1934-1986: annual mean seawater temperature (2m depth) and (1934-1939, 1945-1986) averages. Winter (a) minimum (6.6 $\pm$ 1.2°C) and (b) average (8.4 $\pm$ 0.9 °C); (c) annual mean (15.7 $\pm$ 0.5 °C); summer (d) mean (23.1 $\pm$ 0.7 °C) and (e) maximum (26.5 $\pm$ 0.9 °C). Number of winter days (f) with seawater temperature below 6.5 °C)

The longest homogeneous time series at a fixed station has been collected mainly by Specchi and Fonda Umani near Miramare during the years 1970-1976 and 1983-1986; monthly and annual means and standard deviations are reported in Table 5. The corresponding mean annual seawater transparency cycles are shown in Fig. 7. The annual mean Secchi disk depths are the same in the two periods, about ten years apart: a significant trend cannot be detected. The phase of the semiannual cycle exhibits a shift of about one month. On average, minimum transparencies occur during May and December, the maximum in August. Seawater in the Gulf of Trieste can be classified, from the optical point of view, as a type 3 coastal water according to the Jerlov (1968) classification.

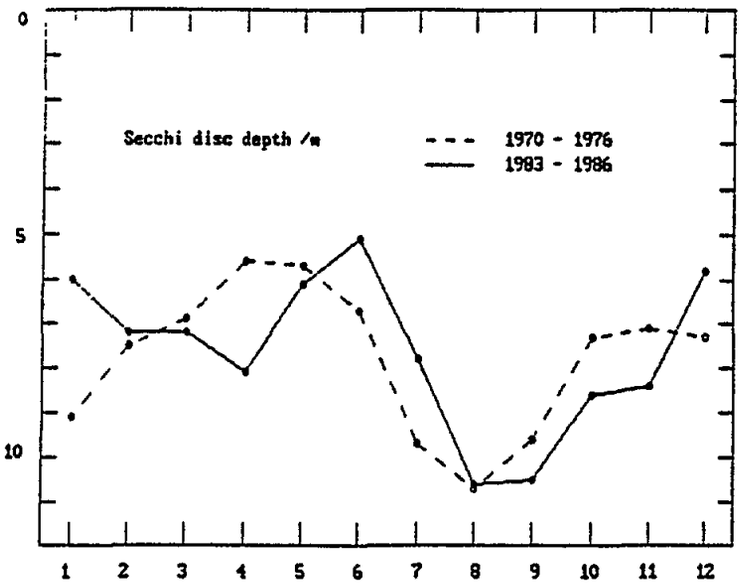

Fig. 7. Annual cycle of the Secchi disk depth m^{-1} at Miramare (Trieste). Periods 1970-1976 (7.8 $\pm$ 1,6 m) and 1983-1986 (7.6 $\pm$ 1.8 m).

Table 5. Secchi disk depth in m near Miramare (Trieste): monthly and annual means and standard deviations (number of measurements).

	1970–1976			1983–1986			1970–1986		
JAN	9.1	2.5	(7)	6.0	0.5	(3)	8.2	2.1	(10)
FEB	7.5	1.8	(11)	7.2	3.3	(3)	7.4	2.0	(14)
MAR	6.9	2.4	(14)	7.2	1.3	(5)	7.0	2.2	(19)
APR	5.6	1.7	(18)	8.1	5.3	(7)	6.3	3.0	(25)
MAY	5.7	1.5	(14)	6.1	2.2	(5)	5.8	1.6	(19)
JUN	6.7	2.0	(13)	5.1	1.8	(9)	6.0	1.9	(22)
JUL	9.7	2.7	(10)	7.8	2.9	(6)	9.0	2.7	(16)
AUG	10.7	2.4	(10)	10.6	3.6	(6)	10.7	2.8	(16)
SEP	9.6	3.3	(10)	10.5	1.9	(5)	9.9	2.8	(15)
OCT	7.3	2.2	(11)	8.6	2.5	(5)	7.7	2.2	(16)
NOV	7.1	1.3	(10)	8.4	1.0	(4)	7.5	1.2	(14)
DEC	7.3	2.0	(10)	5.8	2.4	(3)	7.0	2.0	(13)
mean	7.8		(138)	7.6		(61)	7.7		(199)
s	1.6			1.8			1.5		

6. ACKNOWLEDGMENTS

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Special thanks are due to the C.N.R. Thalassographic Institute of Trieste and to its current director Davide Bregant; to the UNEP Co-ordinating Unit for the Mediterranean Action Plan, and to F. Saverio Civili in particular, for the interest in and support for, the Trieste CIMAM activity; to Laura Rottini Sandrini who stimulated and gave support to the CIMAM research projects during these last few years.

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HYDROBIOLOGICAL VARIABILITY IN THE MIDDLE ADRIATIC IN RELATION WITH UNUSUAL DISTRIBUTION OR BEHAVIOR OF Pelagia noctiluca

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ABSTRACT

This paper brings some new data on hydrobiological changes in the Adriatic during the "Pelagia years" (1976-1985).

In the discussion, special attention was given to the dynamics of water masses and the oxygen drop recently recorded from the bottom layers, as a possible stress affecting Pelagia population dynamics.

1. INTRODUCTION

The increased abundance and unusual swarming of *Pelagia noctiluca* recently observed (1977-1986) in the Adriatic and in many parts of the Mediterranean, has elicited interest for the study of the phenomenon. It is obvious that the size of the population of the *Pelagia* has recently increased and the causes of this are being investigated. It is quite apparent that fluctuations in numbers also occurred in the past (Vucetic, 1982; Goy, 1984), but it is still not clear whether they are due to the environmental changes or if they are in some degree intrinsic to a physiological control of the population.

A comparative study of the hydrographic characteristics of the Adriatic, the Mediterranean and the Atlantic, based on historical and recently published data has been carried out in relation to *Pelagia* distribution and biology. Great attention was given to the survey of general Adriatic ecosystem modifications with special emphasis to the middle Adriatic. Great effort was also exerted to discover as many historical data as possible on *Pelagia* records and distribution, with parallel hydrographic or environmental data.

In this paper an attempt is made to synthesize all collected historical and recent data for *Pelagia* records in parallel with the hydrological and biological changes in the Adriatic.

2. MATERIALS AND METHODS

The work was realized through "Monitoring" and "Research" activities. Monitoring was realized to survey the general ecosystem modifications and the long-term plankton fluctuations in the middle Adriatic, with special emphasis on *Pelagia* bloom occurrence. Permanent monthly observations (samplings) were carried out at three stations: Kastela Bay (coastal region N 25), Pelegrin (channel area N8) and at the open sea station N9 Stoncica, and the seasonal observations at 5 stations (N25,8,9,11,13) on the profile Split-Mt. Gargano. (Fig. 1).

Researches included the analytical work on all the historical (from 1911-1985) and recently published data on environmental changes of hydrographic or biological parameters as possible indicators of ecosystem modifications in the middle Adriatic area. In order to give an explanation or interpretation to the jellyfish phenomenon, about 10000 hydrographic data have been computed (Zore-Armanda *et al.*, 1987).

On the most frequented profile (station N9, Stoncica) about 350 Secchi disc and 7500 salinity, temperature and nutrients data were obtained (Fig. 1). A smaller number of data on the biological parameters, such as ^{14}C, chlorophyll, phyto-zooplankton and pelagic fish population density (catch and fishing effort), were collected (Pucher-Petkovic *et al.*, 1988; Vucetic and Alegria-Hernandez, 1986;1988).

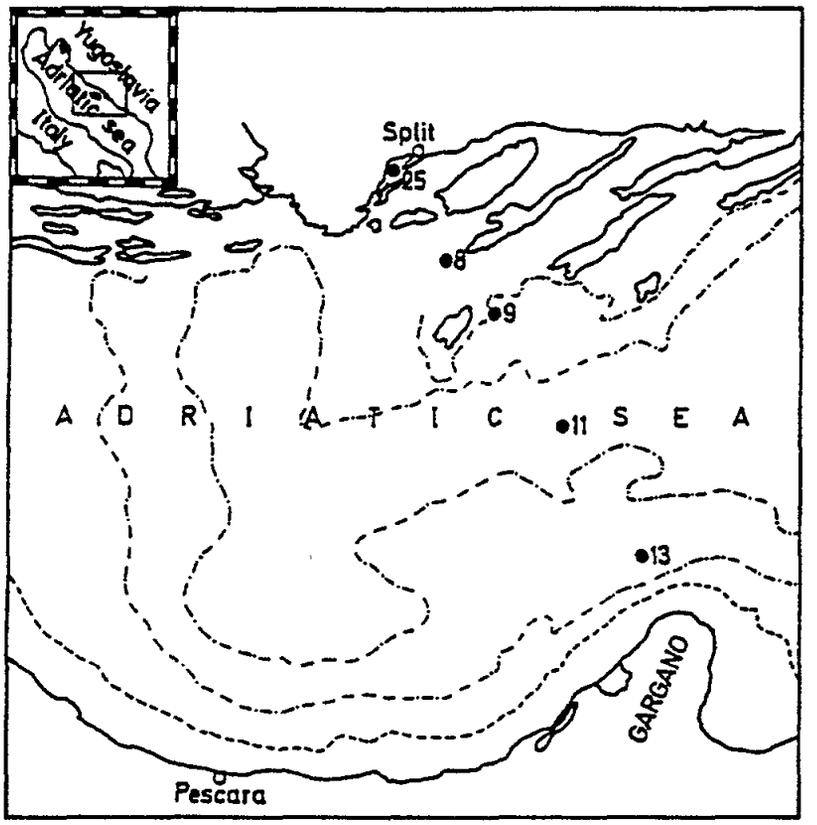

Fig. 1. Investigated area-stations No 25- Kastela Bay; No 8-Pelegrin; No 9-Palagruza and No 13- Mt. Gargano.

3. RESULTS

Analyzing all available historical and recent collected data it was possible to remark that a significant change in some parameters in the last decade had taken place in the areas of the open Adriatic. (Vucetic, 12983; Benovic *et al.*, 1987; Zore-Armanda *et al.*, 1987).

Vucetic (1983) found, a salinity increase in the surface layers of the Northern Adriatic, in "*Pelagia*" years, as salt water advection. Zore-Armanda *et al*, (1987) also noted the same phenomenon, taking complete data, or stations means, for the Split-Mt. Gargano profile (Fig. 2,a,b).

Temperature data (Fig. 3) show, strong oscillations if the mean value of all profile stations is observed (Zore-Armanda *et al.*, 1987). The observation of all the stations shows that in some of them a slight increase appears. In Kastela bay a sudden drop of temperature was registered in 1978 and, later, a continued increase. The same situation was found in the stations Pelegrin, Stoncica, Palagruza and Mt. Gargano (Vucetic, 1988).

In the General Adriatic surface layer the yearly fluctuation of the oxygen has been less important for the last decade with a slight increase from 1976 onwards (Fig. 4,a). The saturation at 50 m reaches the values found on the surface layers. Meanwhile, the saturation at the 100-m layers shows clear decreasing trend with minimal value in June 1977. This drop is exceptionally strong (visible) in the station N9, Stoncica (Fig. 3b). Benovic *et al*, (1987) found a similar situation in the Northern Adriatic.

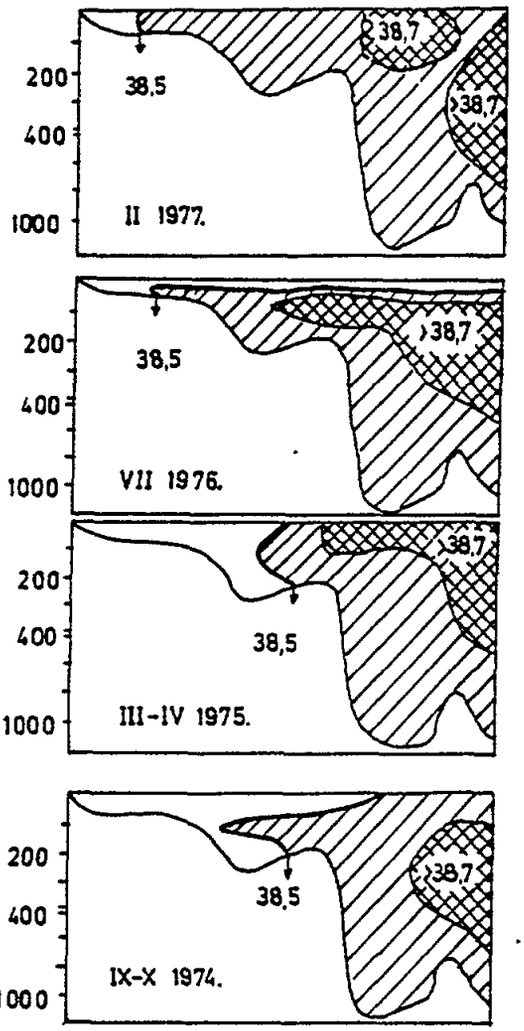

Fig. 2a. Salt water advection in the Adriatic in the period 1974-1980 (Vucetic, 1983)

In the Central Adriatic phosphate shows drastic decrease partly attributed to methodology changes (Fig. 5). According to Ivancic and Degobbis (1987) the low organic phosphorus (1980-1984), and the decrease of concentrations in the Northern Adriatic observed in the fall-winter period, was due not only to a prevailing of regeneration over assimilation processes in the early fall, but also to the more intense water exchange with the central Adriatic regions.

Secchi transparency, after very low values observed in some months of 1960, has shown clear trend of decrease (Fig. 6a,b) starting from 1970.

In this period the phytoplankton has shown a strong increase in biomass (Fig. 6b; Fig. 7). Particularly an increase in primary production is observed from 1980 on, so that the mean for 1980-1983 period is about 38% higher from that of 1962-1979 period. With regards to the WSPC (World sea productivity classification), the Adriatic productivity changed from category II to productivity category III, and at the same time the horizontal distribution of less productive water (zone) is reduced according to the data obtained measuring chlorophyll a (Purcher-Petkovic *et al*, 1988).

The zooplankton biomass, as annual mean value, has shown decrease trend in "*Pelagia* years" but some higher maximal values were recorded in 1974 (Fig. 6b). At the same time some composition differences appear (Vucetic and Morovic, 1987). Vucetic (1980) recorded a strong increase in *Penilia avirostris* population as typical neritic species on the open station Stoncica (Fig. 7). Benovic *et al*, (1987) have

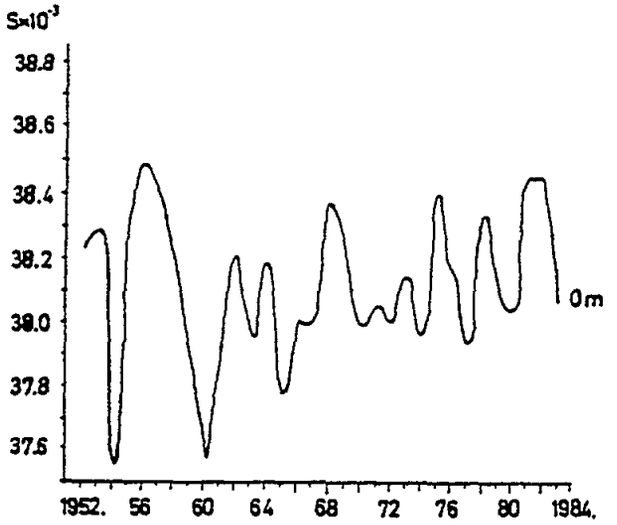

Fig. 2b. Surface salinity fluctuartion (annual mean) on the Split-Gargano profile (Modified after Zore-Armanda *et al.*, 1987

pointed out the disappearance of some hydromedusae species, and Malej (personal communication) an increase of gelatinous animals.

The plankton feeder pelagic fish catch data show a permanent increase which alone does not necessary mean a population density increase, if echotrace or strong increase have not shown the same trend (Vucetic and Alegria-Hernandez, 1986;1988; Azzali and Luna (in press) (Fig. 8). The registered echotrace number increase could be partly due to fish schooling behavior and feeding migration to the coasts, and not necessary a picture of population density increase.

The transparency decrease has been attributed to eutrophication, increase of oxygen saturation on the surface and at 50 m depth due to increased photosynthetic activity, and decrease of nutrients due to the increase in primary and secondary productivity.

Some authors attempted to associate all these changes with the influence of the Nile damming and partly to pollution, i.e. the increased disposal of waste into the sea (Zore-Armanda and Gacic, unpublished data). Vucetic (1980), writing of eutrophication or "neritisation" of station Stoncica, is more willing to at-

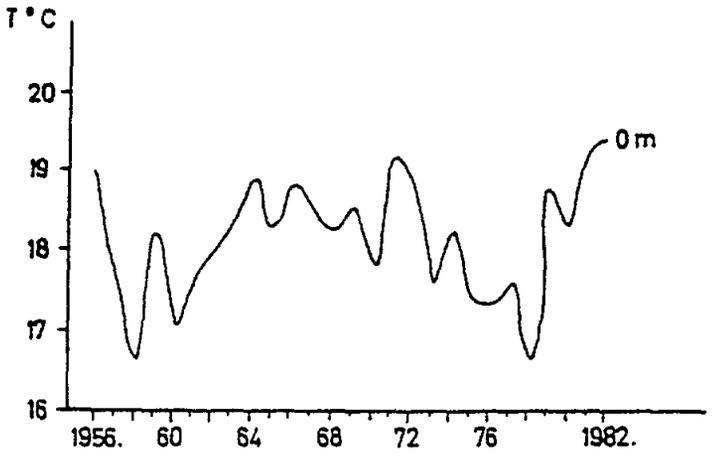

Fig. 3a. Surface temperature (°C) fluctuation (annual mean) on the Split-Gargano profile (Modified after Zore-Armanda *et al.*, 1987)

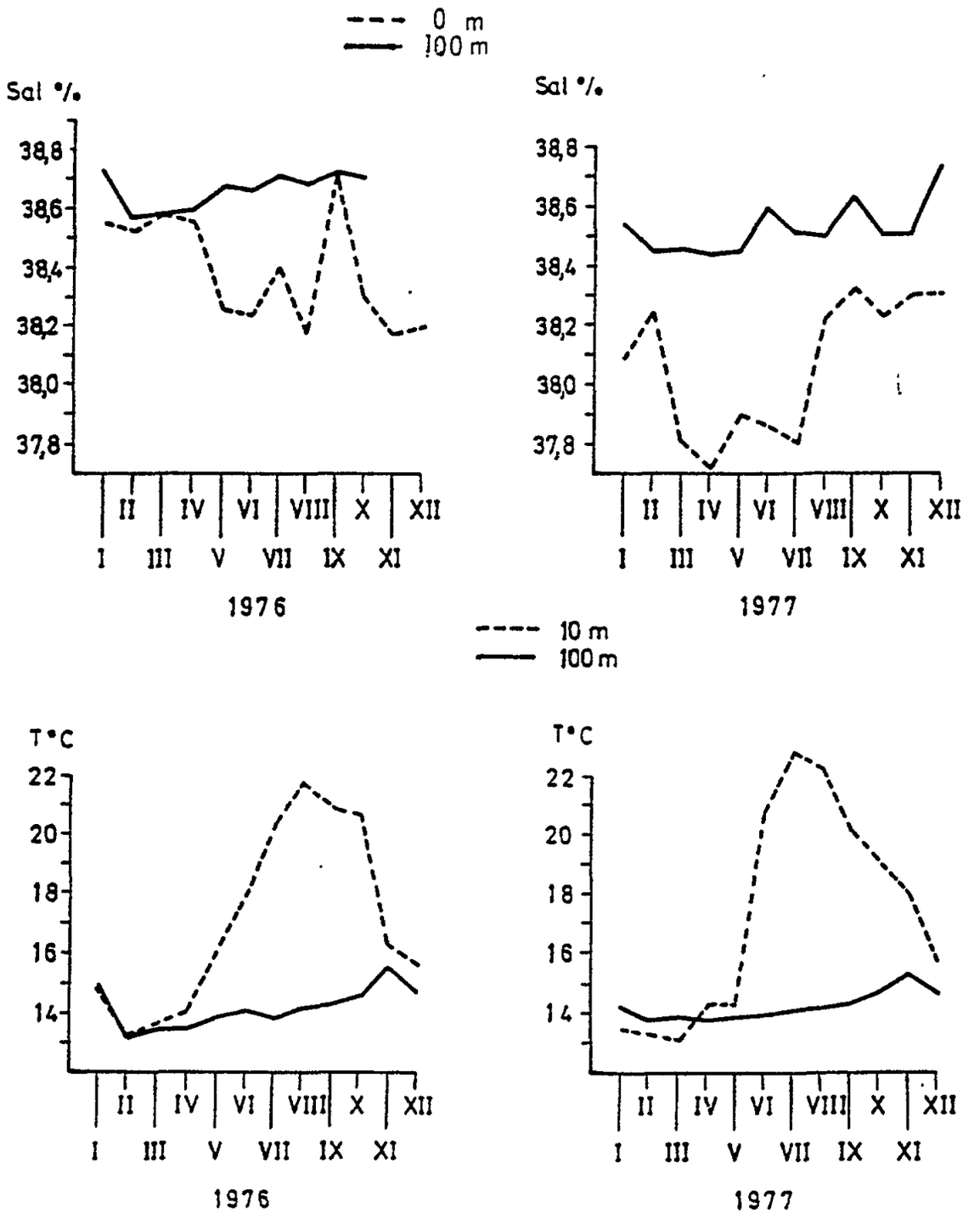

Fig. 3b. Salinity-temperature variations on the station Stoncica (No 9) in the middle Adriatic (1976-1977).

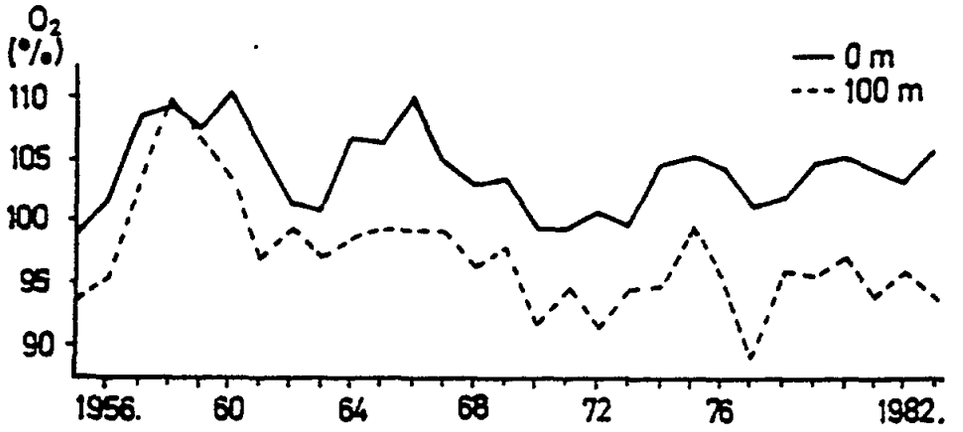

Fig. 4a. Surface and bottom oxygen fluctuation (annual mean) on the Split-Gargano profile (Modified after Zore-Armanda *et al.*, 1987)

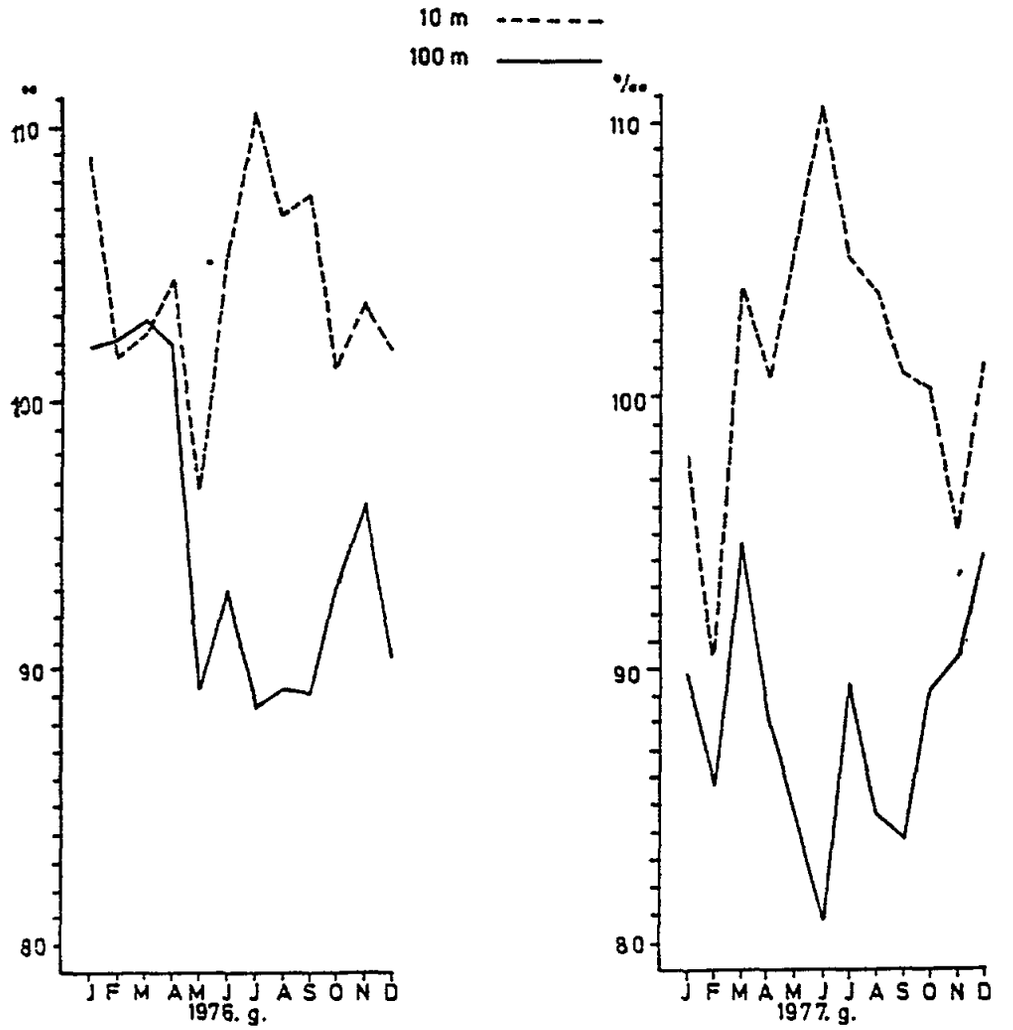

Fig. 4b. Surface and bottom oxygen fluctuation on the station Stoncica (No 9) in the middle Adriatic in the 1976-1977)

tribute all these changes to water masses dynamics stronger than earlier, which is now called in some papers "natural fluctuations" (Pucher-Petkovic and Marasovic, 1987).

4. DISCUSSION

As published earlier by Vucetic (1982) and Goy (1984), it was possible to establish a periodical appearance of *P. noctiluca* from historical data. For this reason Vucetic (1983) tried to give an answer to the question; are we presently seeing a difference in distribution or a difference in population density? For the middle Adriatic coastal area it was possible to establish both; the difference in distribution and the difference in population density. Vucetic (1982) related this phenomenon to hydrographic changes and has given some of the answers or explanations for that. The differences in distribution due to different water masses distribution have been confirmed by the data of changes in hydrographic properties, i.e. increase of salinity in the "*Pelagia* years" from the South to the North (Vucetic, 1982; Zore-Armanda et al, 1988). Salinity increase (vertically and horizontally), due to inflow of Mediterranean water, and also oxygen drops in the bottom layer (Benovic *et al*, 1987), has been found in "*Pelagia* years" not only in the period 1976-1985 but also in 1911-1914 period (Fig. 2a,9). Between these two periods some salinity increase has been registered but without *Pelagia* blooms. This fact shows that some special conditions need to be present and we need to discover them.

Perhaps some special "pulsation" of Mediterranean water exist or one ascendental year with strong in-

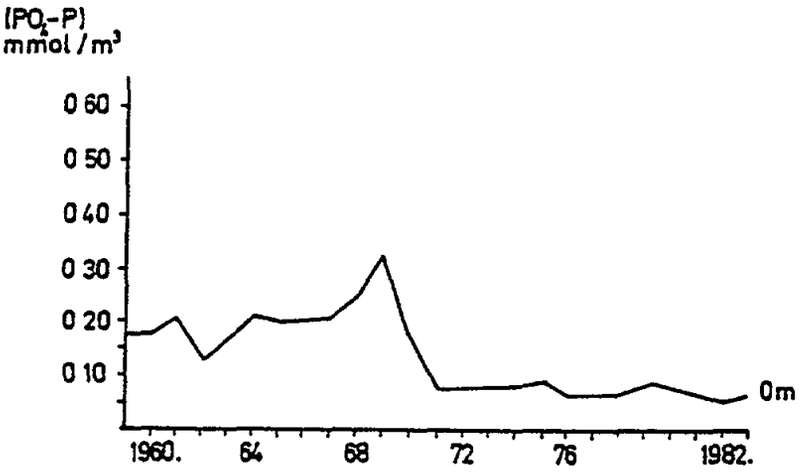

Fig. 5. Surface phosphate fluctuation on the Spilit-Gargano profile (Modified after Zore-Armandna *et al.*, 1987

flow "Buljan's ingression year", (Buljan and Zore-Armada, 1976) may need to be followed with a "descendental" (outflow) one. From existing data it appears that in the years between 1911-1914 and 1976-1985 after a year of strong inflow (1911 and 1976) a "regression" year followed with not such a strong influence of salinity in the North. In that way, the North Adriatic "descendent" water, had obtained stronger power to push back the inflow of south water masses (Fig. 2a,9).

Perhaps the Po river discharge plays some important role when cooler and denser winter waters sink and become a deep outgoing Adriatic waters and in warm seasons the same phenomenon occur on the surface (Buljan and Zore-Armanda, 1976; Degobbis *et al*, 1979). Po river discharges were exceptionally strong in 1977, bringing a high quantity of phosphate (Fig. 10) which produced exceptional phytoplankton blooms which could be a cause of sudden drop of oxygen in the bottom layers of the Central Adriatic.

At lower salinity *Pelagia* showed changes in pulsation rates and often resulted in their sinking (Catalano *et al*, 1984) which has an ecological consequence since it could take animals deep excluding the possibility to come back to the surface, where the more movable layers of water masses could bring the animals to the North Adriatic. The opposite occurred in the advection years, when warmer (14-15 °C) and saltier water spread to the North Adriatic. These conditions may have allowed *Pelagia* to be active

Fig. 6a. Transparency (annual mean) on the Split-Gargano profile (Modified after Zore-Armanda *et al.*, 1987)

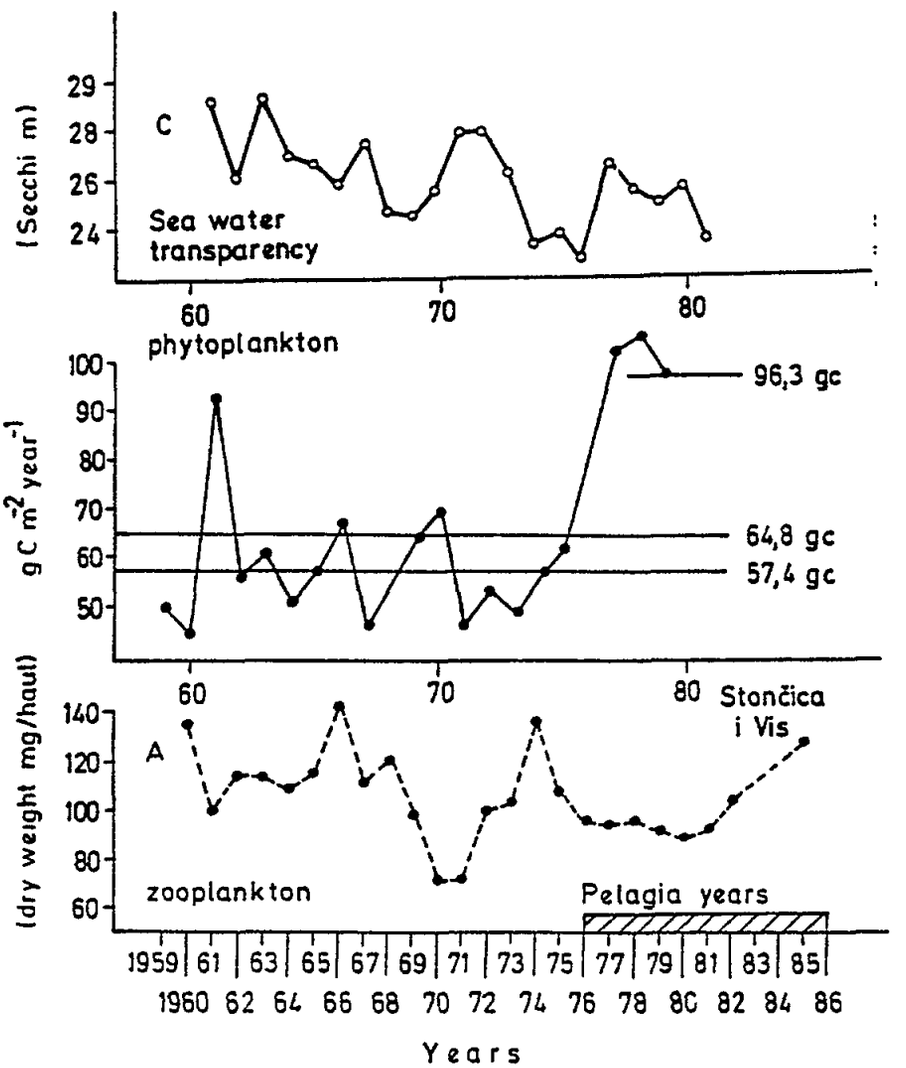

Fig. 6b. Trend of transparency, phytoplankton, zooplankton and "*Pelagia* years" (1960-1985) in the central Adriatic (Vucetic and Morovic, 1987; Pucher-Petkovic *et al.*, 1988)

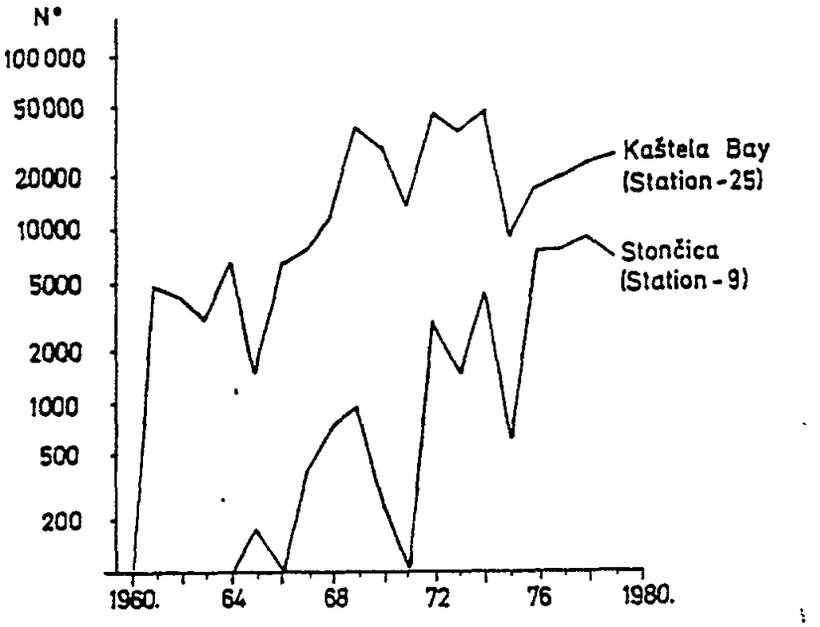

Fig. 7. Long-term fluctuation of *Penilia avirostris* in the east central Adriatic (Vucetic, 1981)

on the surface and not to sink to the bottom as it happened in years without such influxes, or in the cool (10-11 °C) water in the winter. In these warmer surface layers (14C) they can continue their biological cycles (Rottini-Sandrini, 1982) showing also a higher reproductive rate (Avian, 1984).

A year with higher primary and secondary production happened to be a period of stronger water masses dynamics in the Adriatic. So a positive correlation between *Pelagia* findings (or blooms) and high productivity could have two explanations. The first is that the observed population explosion in the Adriatic is due to good feeding conditions, and the second, that population explosion is due to "transport" distribution which includes passive horizontal drift by wind and current and active vertical migration due to stratification intensity or salinity and temperature differences between different water masses.

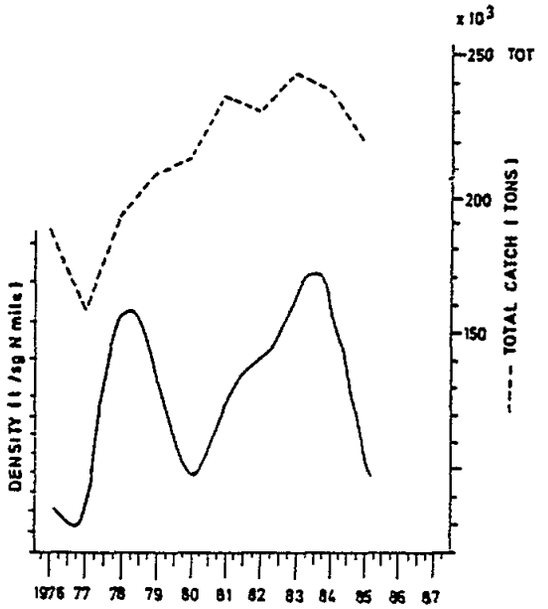

Fig. 8. Adriatic total catch and pelagic fish density fluctuation (echotrace, Azzali and Luna, in press)

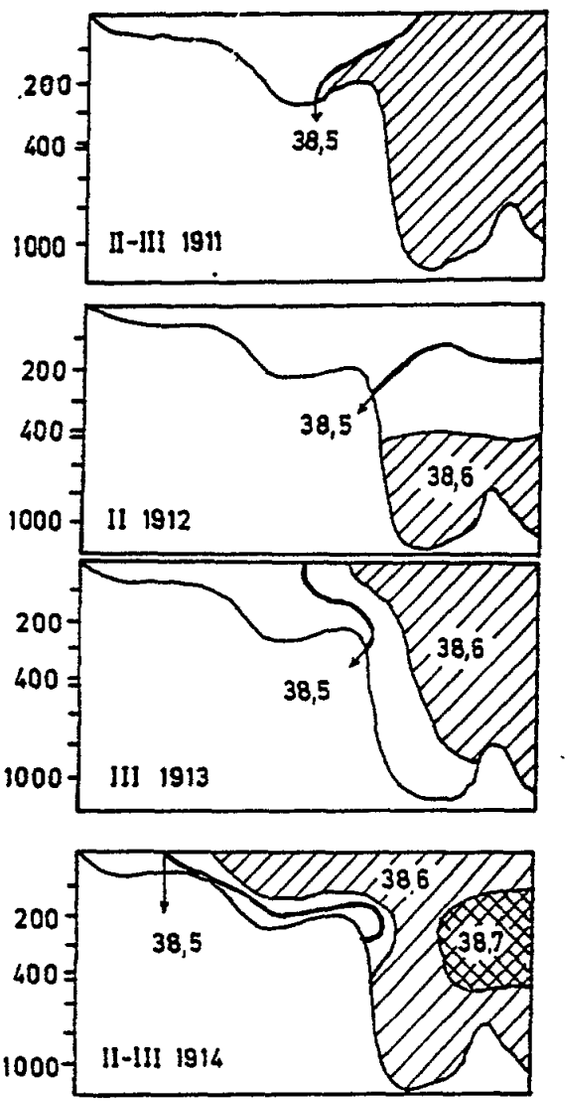

Fig. 9. Salt water advection in 1911-1914 period (Vucetic, 1982)

After Pucher-Petkovic *et al* (1988) data, the first explanation cannot be accepted as we still have high primary production and *Pelagia* completely disappeared. Why?

The second conclusion was based on two similar findings in Buljan's "ingression" or inflow years (1910-1914 and 1976-1985), however, some "ingression" years between these periods were without *Pelagia.*

The constant increase of oxygen in the surface and decrease in the bottom started sometime during the seventies (Benovic *et al*, 1987; Zore-Armanda *et al*, 1987). This is due to increased photosynthetic activity in the illuminated sea water column. The saturation at 100 m shows a clear downward trend. All this may be understood as an indication of higher productivity in the open waters, especially present from 1970.

Some authors (Legovic *et al*, 1986) tried to explain *Pelagia* bloom with the predator-prey relationship or absence of jellyfish predators. This cannot be accepted as Vucetic (1985) and Vucetic and Alegria-

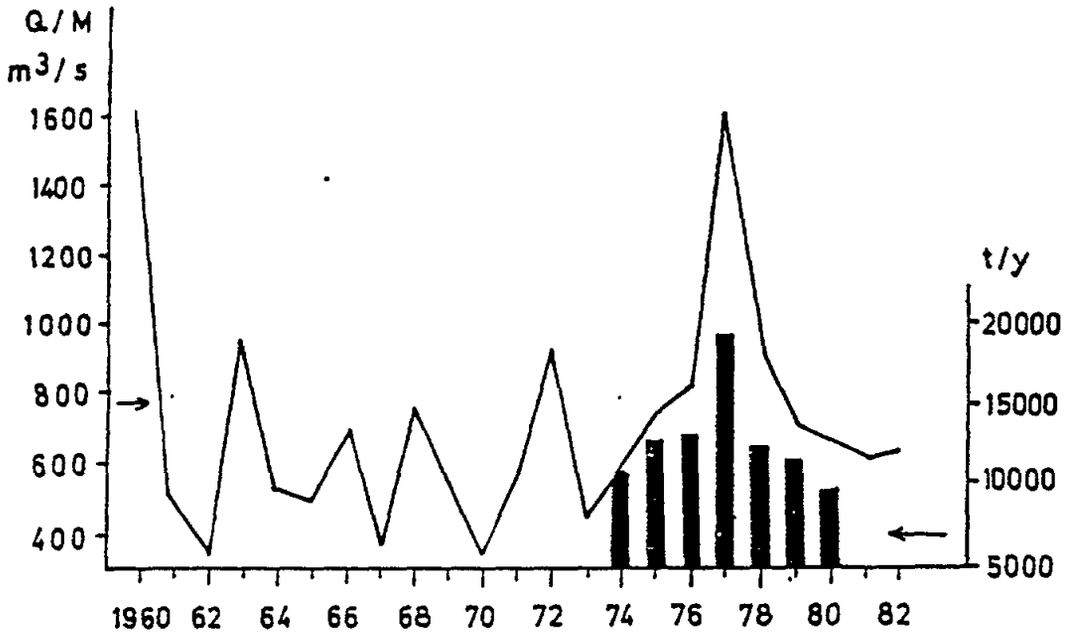

Fig. 10. Po river runoff in the period from 1960-82 and phosphate input (Marchetti, 1984)

Hernandez (1986;1988) show that a *Pelagia* "bloom" appeared at the time of higher or maximal pelagic fish population density (from catch and echotrace data (Fig. 8).

Benovic *et al,* (1987) brought out the hypothesis that the predator *Pelagia* made the hydromedusae population decrease, but the disappearance of some hydromedusan species before "Pelagia years" has attributed to the oxygen depletion in the bottom layer of the Northern Adriatic. Now, after *Pelagia* disappearance, hydromedusae should be back in the Northern Adriatic.

From hydrobiological data it looks that the year 1977 was an exceptional one not only for the Adriatic but also for the Atlantic, the North Sea and the Baltic Sea.

In the Central Adriatic an inexplicable sudden drop of oxygen in June 1977 has been registered in station Stoncica (Fig. 4a,b). Also, in the North Adriatic at the beginning of "*Pelagia* years", in June 1977, Degobbis *et al* (1979) recorded such unusual phytoplankton bloom that standing crop reached a level never observed before. At the same time a sudden low salinity and high pH values were registered. The authors concluded that all this could be a consequence of a set of meteorological conditions related to an increase in discharge of the nutrient-rich Po river. Later in 1977 they found a decrease in eastern advection and an increase in southern current along the Italian coast. It is easy to understand by looking at strong increase of Po river discharge and phosphate input in this year (Fig. 11).

In June of the same year (1977) more intense phytoplankton blooming and red tide appeared in many localities of the Northern Adriatic (Maretic *et al,* 1978). Along the east and west coast phytoplankton blooms are more frequent and in some areas now permanently present.

In this period "slime" or "mucus" was often seen on the bottom or floating in different layers, which was composed mostly of phytoplankton and other planktonic organisms (Pucher-Petkovic *et al*, 1987). Perhaps some of this mucus originated from deteriorated jellyfish as *Pelagia* was already present in enormous quantity at that time in the Adriatic.

It is necessary to analyze in detail what happened in the 1976 - 1977 period to discover which mechanism caused the sudden drop of oxygen concentration and how *Pelagia* and other plankton organisms reacted to this.

It is well known from the literature that the jellyfish and the other gelatinous organisms require less oxygen for swimming than the muscular species. Devenport and Trueman (1985) found that *Pelagia* uses

proportionally less oxygen for locomotion than muscular crustaceans *Phrosina semilunata*. This may explain why Malej (personal communications) found, in "*Pelagia* years" with oxygen decrease at the bottom, less crustaceans in the Northern Adriatic and more gelatinous organisms in zooplankton samples.

Usually *Pelagia* enter the Adriatic from the Ionian sea at the surface and at the intermediate water masses. The sudden drop of oxygen in this layers in 1977 (Fig. 4a.b) may have pushed *Pelagia* "in order to save the species" to invert all the energy in reproductive cells, which is reflected later by the population density increase. Or perhaps animals escaped from poor oxygen layers to the surface layers which, with the help of ascendental currents, have transported them to the Northern Adriatic.

It is not to be excluded that after strong inflow of south salty water into the north, the stratification increases as well as the oxygen differences between surface, intermediate and bottom layers. We believe that all that can stimulate the animal to produce more reproductive cells, may be the "dormient" ones like the phytoplankton spores. Thus, the year after this overwintering "seeds population", a bloom appears in a place where usually *Pelagia* was not present in a great number or was very scarce.

Perhaps it is worth mentioning that also in many parts of the Atlantic 1977 was an exceptional year. So Mc Cartney *et al* (1980) found anomalous water mass distribution in the North Atlantic, with intensification of the Gulf Stream after the winter of 1976-1977 (Worthington, 1977). In June 1977 Reid *et al* (1978) drew attention to an exceptional bloom in the North Sea with anomalous hydrographic conditions coinciding with strong winds from S and SW and heavy runoff from river Rhine. This was attributed to the existence of large overwintering seeds stock and to enhanced growth as response to the exceptional hydrographic and meteorological conditions. Reid et al (1983) explained that the juxtaposition of two very different water masses of the Dutch coast may, through frontal stratification, have reduced the depth of the mixed layer and thus increased the exposure of the phytoplankton to light. Vucetic (1986) supposed that something similar had happened in the Northern Adriatic since, in the same period, all the already mentioned changes which could result in more pronounced difference between two water masses and produced stronger frontal zones were observed. Stratification is therefore stronger in this dynamic years and all these findings are a consequence of that.

We agreed with the affirmation (Vucetic, 1982; Goy, 1984) that the recorded changes are the consequence of some global factors (climatic) influencing the ocean and sea ecosystems which in the case of the Adriatic, were added on local or regional trends of production increase or "neritisation" (Vucetic, 1980) of the middle Adriatic from the Northern part of this typical land-locked sea.

Recent climatic fluctuations have been recorded in many places. As to Israel, Striem (1985) states: "During the first half of this century the highest monthly winter precipitation occurred; something which never happened in the second half of the last century".

In conclusion, are all these changes natural cyclic phenomenon or they represent some new anthropogenic influence on our planet ?

5. CONCLUSIONS

Changes in population densities and distribution of *Pelagia noctiluca* have shown to appear at the same time with stronger water masses dynamics or input of Mediterranean waters in the South Adriatic and stronger discharges of the Po river in the North which resulted in higher phosphate input in the North (Fig. 11).

Pelagia started to be recorded in 1976 in the South and in 1977 up to the North Adriatic. In the same period a salinity increase has been recorded from the South to the North (Fig. 2a,b), and also temperature in some areas (Stoncica).

As from 1970 the oxygen saturation has shown constant decrease in bottom layers and increase trend at the surface (Benovic *et al*, 1987; Zore-Armanda *et al*, 1987). The year 1977 happened to be an exceptional one, as since all over the Adriatic, even in the station N9 Stoncica in June there has been a strong drop of oxygen level in the bottom layers (Fig.4a,b). Perhaps this sudden oxygen drop acted as a stress on *Pelagia* which resulted in an increase of fertility and fecundity by "hormesis" mechanism.

In this last decade also primary and secondary production started to increase but this was excluded as a cause for *Pelagia* population explosion. Namely, *Pelagia* disappeared in 1985 but productivity still showed increasing trend (Pucher-Petkovic *et al*, 1988). Predator-prey relationship was analyzed and the hypothesis (Legovic *et al*, 1986) that overfishing of predators of *Pelagia* may have produced population explosion has been excluded since a permanent increase has been noticed in the total catch and recently

especially in the pelagic fish stock of the Adriatic (Fig. 9). (Vucetic, 1985; Vucetic and Alegria-Hernandez, 1988; Azzali and Luna, in press).

The immediate objective of this research was to determine the causes and explain the mechanisms that resulted in the unusual recent blooms of the open-sea scyphomedusa *P. noctiluca*. We believe that the results are good since several patterns have been described, e.g. the response to large scale environmental forcing relating to hydrographic factors; however, the details of the mechanisms and processes have yet to be established.

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OCCURRENCES OF Pelagia noctiluca (SCYPHOZOA) IN NORTH ADRIATIC COASTAL AREAS

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ABSTRACT

In the research period 1984-86, *Pelagia noctiluca* has occurred in the whole northern Adriatic, in coastal and offshore waters. It was far more frequently observed and more abundant in the area of the outside chain of eastern Adriatic islands and the Istrian peninsula than in the channels and bays near the mainland. Jellyfish occurred mostly from spring to the end of autumn, although specimens were observed all year round. Swarms of *Pelagia* appeared irregularly in space and time. There are indications that swarms were sometimes heterogeneous in origin. It seems that the local swarm appearances and depth distribution of medusae have not been correlated with temperature and salinity, and the zooplankton standing crop. Local jellyfish aggregations are conditioned by active displacements and/or passive drifting caused by several hydrodynamic agents.

1. INTRODUCTION

The jellyfish *Pelagia noctiluca* (Forskal, 1775) has been known in the Adriatic Sea since 1910 (Babic, 1913) but until recent times it was considered a rather rare species (Riedl, 1970; Vucetic, 1983). Only since 1977 (Rottini Sandrini et al., 1980) *Pelagia* swarms have been reported in offshore and coastal waters (Malej, 1982; Stravisi, 1984; Piccinetti Manfrin and Piccinetti, 1983-84; Benovic, 1984; Malej and Vukovic, 1984; Vucetic, 1984, 1985; Zavodnik, 1987). As only few data were available from the shallow North Adriatic it seemed worthwhile to pay special attention to the regional distribution and the occurrence of jellyfish in the area, to check size distribution patterns, and establish abundance of jellyfish populations.

2. MATERIALS AND METHODS

Ten permanent sampling stations were established along two transects at a distance of 2 and 13 miles off the west coast of the Istrian Peninsula (Fig. 1). Also four permanent stations for coastal watch were established at Istrian lighthouses. The medusae were also sampled or watched, occasionally or repeatedly, at 77 accessory stations located at random along the mainland coast, or at several northern Adriatic islands. In the offshore waters, jellyfish were monitored at 14 accessory stations located along three transects running between the Italian and Yugoslav coasts (Fig. 1).Data on medusae were collected by means of inquiry data sheets, in situ diving observations, and plankton sampling. Inquiry data forms have been completed and returned by scientists and non-professionals, occasionally or at irregular intervals. At four permanent lighthouse stations a surface jellyfish watch was carried out daily except where prevented by storm conditions or for other reasons. Surface quantities of medusae were estimated visually as "non", "few", "moderate" and "abundant". While recording the data, personal differences in estimation were noted but comparative analyses of data collected simultaneously show that, in general, the observers' estimations coincided and were comparable.

In situ diving observations have been carried out by scuba divers from the Centre for Marine Research Rovinj in 52 locations, mostly around North Adriatic islands and in the National park "Kornati islands". Divings were effected at irregular intervals, under daylight conditions and at depths not below 65 metres.

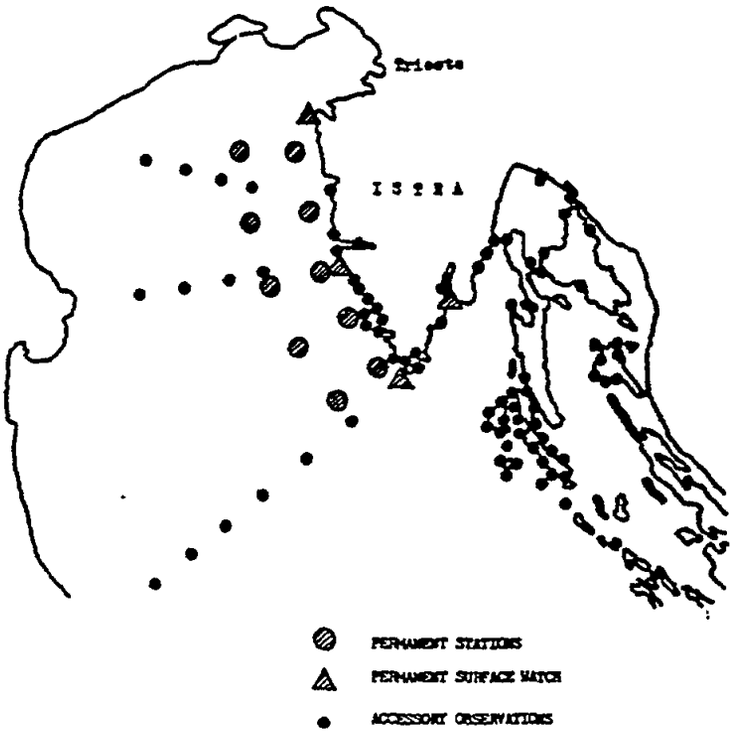

Fig. 1. Area and stations surveyed

At 10 permanent stations located off western Istria, zooplankton was collected by means of a standard Indian plankton net, which was towed vertically at a speed of 0.5m s^{-1}. At each survey, two hauls per station made from a depth of about 5m above the seabed up to the sea surface served as a composite sample. To enable comparison, the results were calculated to 60m3 sea water. Adult Scyphomedusae were sampled by means of an FAO net (diameter 100 cm, 500 μm mesh) (UNEP, 1983) with a mounted bucket of 3 l volume. The nets were towed horizontally at 0 and 5m depths, for 10 minutes at a speed of 2 miles per hour. Occasionally, oblique hauls from the bottom to the surface were made at the same speed and duration.

At each permanent field station, contemporary with plankton sampling, selected oceanographic parameters were measured, such as sea state and colour, transparency, temperature and salinity. Whenever required, scuba divers noted tidal phenomena and local current conditions.

3. RESULTS

Hydrographic data

Temporal and spatial variations of all parameters studied were within regional characteristic limits. For example, temperatures varied between 7.77 and 25.09°C, and salinity varied between 27.95 and 38.24 $S.10^{-3}$.

Zooplankton data

Noteworthy seasonal variations in plankton composition and zooplankton quantitites expressed in volume units occurred during the sampling period (Figs. 2, 3). Because of the enormous quantities of young *Pelagia noctiluca* at station ME-2 in October 1985, other zooplankton taxa could not be sampled quantitatively to enable proper measurements of the total zooplankton volume.

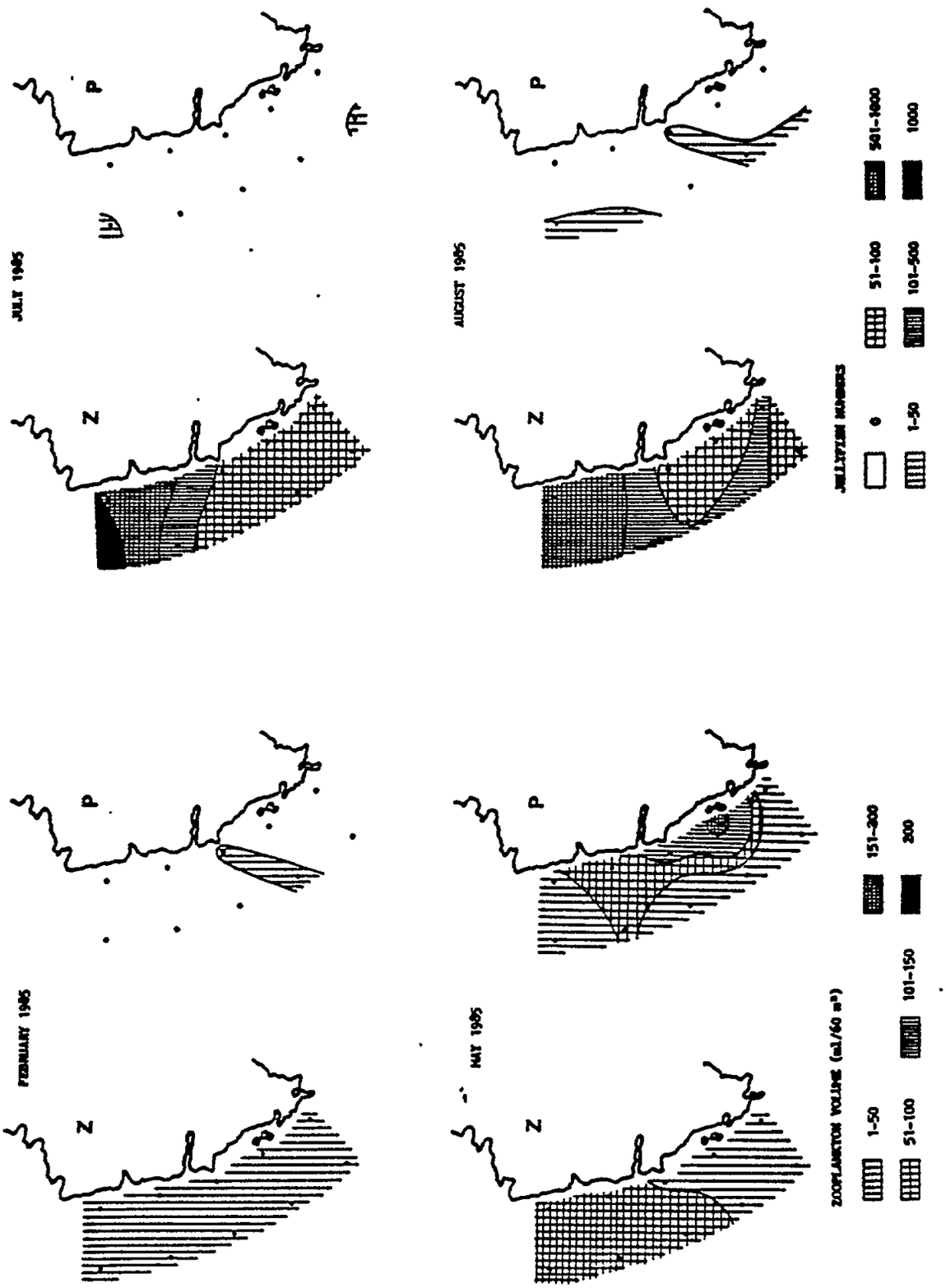

Fig. 2. Variations in zooplankton standing crop (left = z) and *Pelagia noctiluca* abundances (right = P) in the area surveyed

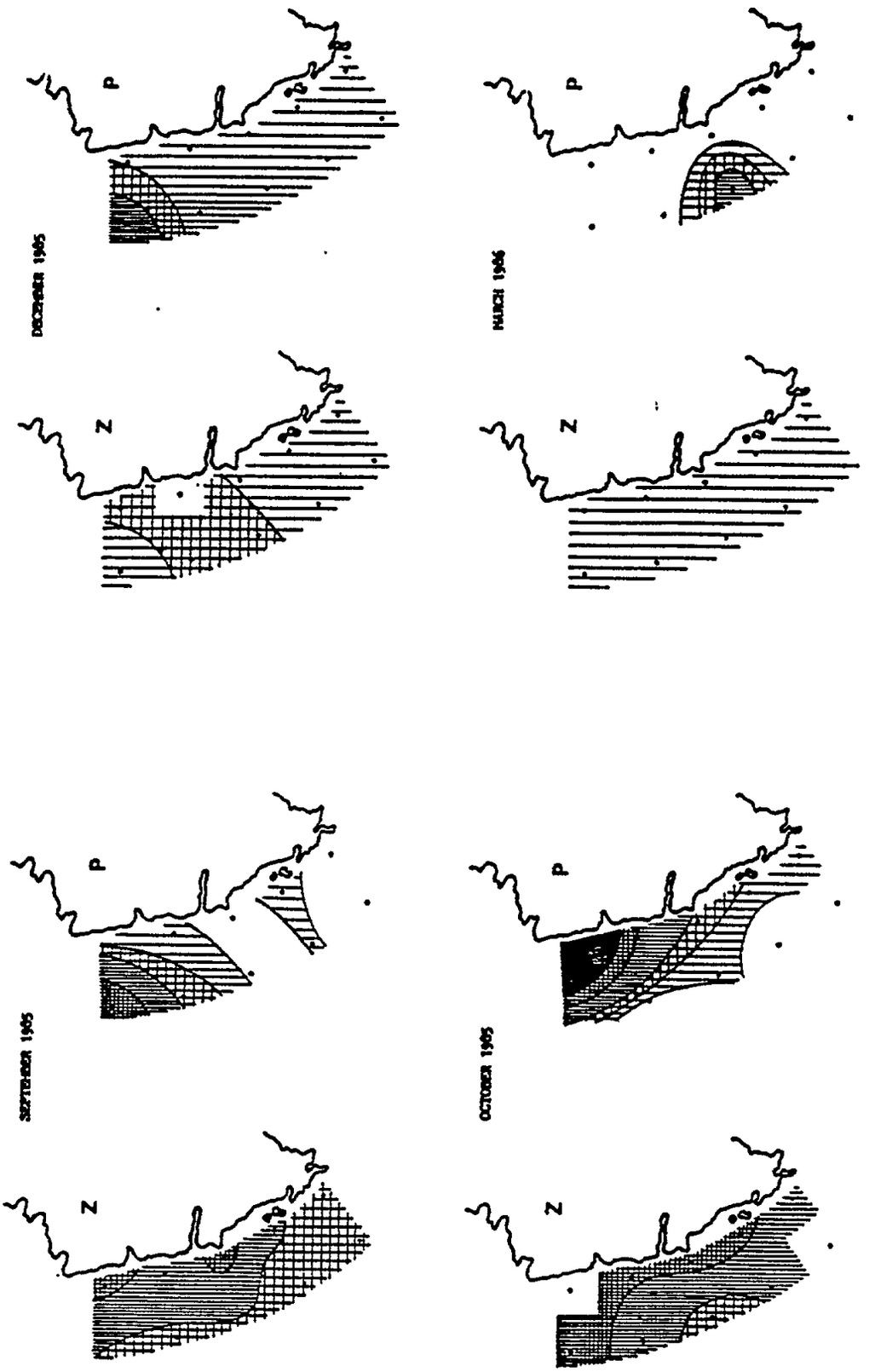

Fig. 3. Variations in zooplankton standing crop and *Pelagia noctiluca* abundances in the area surveyed. Legends as in Fig. 2

Table 1. Distribution of *Pelagia noctiluca* at permanent sampling stations in the surface and in 5 m layers.

Survey	1		2		3		4		5		6		7		8		9	
Month	Feb		Apr		May		Jul		Aug		Sep		Oct		Dec		Mar	
Depth (m)	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5
1	0	0			0	1	0	1	0	2	748	177	0	96	1	169	0	0
2	0	0	0	0	4	43	0	0	0	0	0	1	2320	2240	14	13	0	0
3	0	0			0	62	0	0	0	1	4	89	0	0	0	3	0	0
4	0	0	0	0	13	66	0	0	0	0	0	1	98	371			0	0
5	0	0			1	0	0	0	0	0	0	0	1	4	0	11	0	211
6	0	1	0	0	59	61	0	0	1	5	0	0	65	7	1	1	0	0
7	1	2			0	38	0	0	0	1	0	1	0	0	0	1	0	0
8	0	0	0	0	3	647	0	0	0	0	1	3	0	7	2	16	0	0
9	0	0			0	3	0	1	0	1	0	0			0	12	0	0
10	0	1			0	4	0	0	0	0	0	0	0	28	6	9	0	0

Jellyfish taxonomy

With regard to the scope of this research, only "macromedusae" were noted. The following species were identified:
Hydrozoa (Hydromedusae): *Aequorea aequorea* (Forskal), *Eirene viridula* (Peron et Lesueur).
Scyphozoa: *Rhizostoma pulmo* (Agassiz), *Cotylorhiza tuberculata* (Agassiz), *Chrysaora hisoscele* Eschholtz and *Pelagia noctiluca* (Forskal). According to the numbers of specimens collected, *Pelagia* dominated by far, by about 99.5%.

Pelagia noctiluca

OCCURRENCE

Pelagia noctiluca has been recorded at all localities surveyed, but in the research period from August 1984 to June 1986 it was not constantly present at any site surveyed repeatedly (Table 1, Figs. 2, 3, 4). The samplings and permanent surface watch suggested irregular seasonal appearances of jellyfish in the surface layer. It began to appear frequently in spring (about May) and was present in abundance until December or January.

Local occurrences of medusae mostly coincided with prevalent wind (and wave) direction. After each period (lasting several days) of continuous blowing of the scirocco (jugo) in the whole area, masses of jellyfish appeared along the mainland and islands' shores. The effects of bora blowing from the north east were quite contrary along the west Istrian coast. Medusae disappared in general, except from land-locked and sheltered coves. Jellyfish were however concentrated along the exposed eastern and northern shores of large islands.

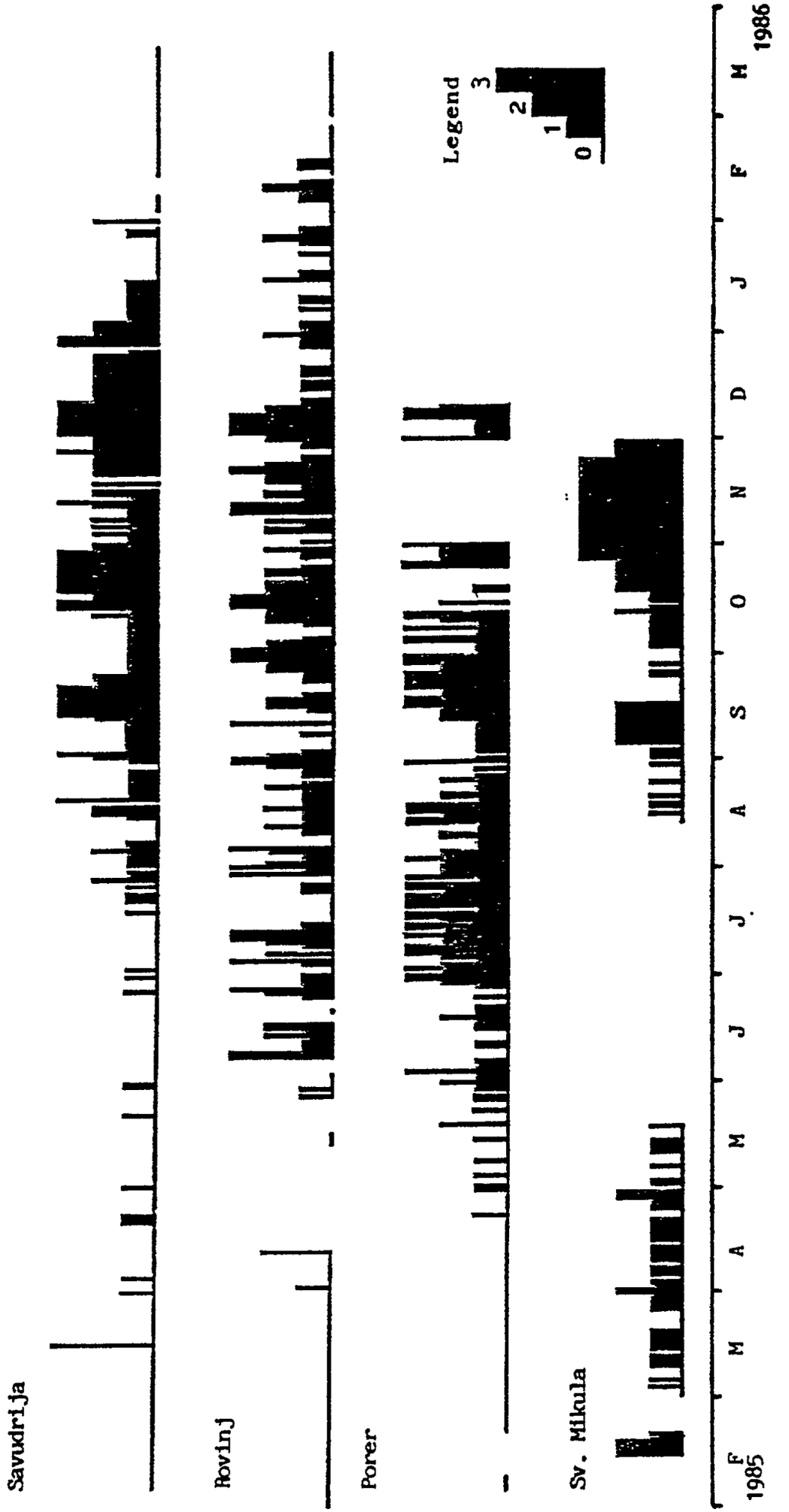

Fig. 4. Abundances of *Pelagia noctiluca* noted at surface watch stations. Legend: O = no medusae, 1 = few, 2 = moderate, 3 = abundant

The unequal distribution of jellyfish in the water column was suggested by the net sampling results, and noted by scuba divers. In daytime medusae were usually distributed between the sea surface and about 20-30m depth, but sometimes they accrued in the whole water column from the sea surface down to the bottom at 50-60m depth.

ABUNDANCE

In the period surveyed *P. noctiluca* appeared in some localities in irregular quantities varying from isolated and scattered specimens in the area to more than 500 jellyfish per cubic metre. The swarms could form in offshore areas, but could also be observed in the vicinity of the mainland or islands. According to diving and surface observations, in offshore "swarm" areas, jellyfish specimens were usually 5-10m apart, but in swarm nuclei the mutual distances could only be 1m or less. On the contrary, in coastal areas the swarms drifted by wind/waves and currents towards the shore and could reach densities of 100 or more (up to about 600) specimens per cubic metre of sea water in the upper 5m layer. When cast ashore, after retreating of the sea during ebb tide, the gelatinous layer of dead jellyfish sometimes reached 2-3 cm in thickness.

The jellyfish abundances were generally greater at sites directly exposed to wind and/or current action than in shore areas along which the swarms could pass by. Similarly, medusae were often abundant in sheltered parts of the sea behind a large pier, cliff or small islet, or in coves where jellyfish were trapped during violent wind or tidal displacements of the water body. The same abundance data at selected localities usually did not continue for more than a few days running, which suggests continuous displacements of thejellyfish community. Noteworthy are the high abundances of *Pelagia* which continued for a long time in the areas of the lighthouses Sv. Mikula and Savudrija (Fig. 4) which suggests that the swarms were "trapped" in the area.

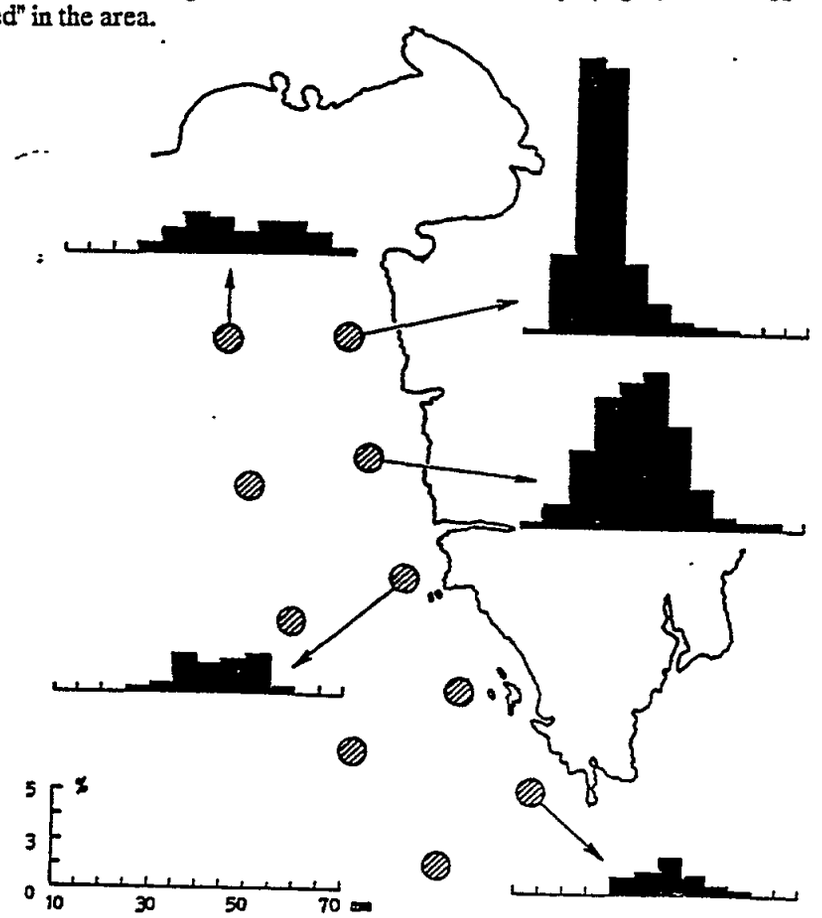

Fig. 5. Size distribution of *Pelagia noctiluca* off west Istria in October 1985

AGGREGATIONS

According to the notes of scuba and skin divers, *P. noctiluca* can aggregate by active moving and by passive drifting by abiotic factors, such as water dynamics. Several aspects could be distinguished in the aggregations: couples, surface aggregations, mid-layer clusters and bottom aggregations. Aggregations could be affected directly by wind, currents and topographical characteristics of the sea bottom and of the shore; this was described in detail elsewhere (Zavodnik, 1987).

SWARMING BEHAVIOUR

While drifting in free water, *Pelagia* would seldom stay at the sea surface for more than a few minutes, probably to avoid the possible damaging effects of waves. Except when coupled or clustered, just within nuclei of swarms, medusae would rarely be less than about 1m apart, thus holding enough room to maneuvre by active swimming. Generally, medusae collected in offshore areas were in a good ("healthy") condition, regardless of their age and maturity stage.

On the contrary, many medusae aggregated closest to the shore or the shallow bottom were in poor condition, as witnessed by lesioned umbrella surfaces, changes in characteristic colouring and in ruptured umbrella and manubrium parts and tentacles. Most of such heavy injuries were without doubt due to the whirling action of water and/or physical contacts of jellyfish with the bottom and shore cliffs. When concentrated on the sea surface, jellyfish were curtailed of their room to maneuvre. Mutual physical contacts within such aggregations could no longer be avoided, resulting perhaps in lesions of jellyfish umbrellas. Furthermore, lethal contacts of medusae with hard cliffs could not be avoided by active displacements of animals whose physical strength was too small to withstand the power of water movements. Thus, the surface swimming medusae aggregated near the coast are forced to remain at the water surface for a long period which can be fatal to them.

SIZE DISTRIBUTION

Diameters of *Pelagia* umbrellas ranged from 4-81 mm (Table 2). It is evident that jellyfish swarms were created usually by small and medium sized animals, and that swarms could be composed of several diameter classes (Fig. 5). It is interesting that at times of "few" populated offshore areas frequently only upper medium and big size classes of medusae were noted. Small sized (young) medusae were transparent

Table 2. Size distribution of *Pelagia noctiluca* collected in 1985-86.

Survey Month	1 Feb	3 May	4 Jul	5 Aug	6 Sep	7 Oct	8 Dec	9 Mar
No medusae	4	741	2	11	1062	881	267	243
< 5								7
5-9					71		1	69
10-14		16			309	3		130
15-19		72			475	47		30
20-24		184			163	161		3
25-29		262			28	184	2	
30-34		149			8	126	24	
35-39		47		2	4	128	30	
40-44		5	1	2		99	59	
45-49		2	1	3	1	55	46	2
50-54	2	3		2	2	43	54	2
55-59	1			2	1	21	24	
60-64						11	21	
65-69						3	5	
> 70	1	1					1	
# min	54	10	42	38	5	11	5	4
# max	72	81	45	59	58	67	75	52

and usually yellow greenish and brownish coloured. After the umbrella warts developed, the colour changed to pinkish which is characteristic of all animals whose umbrella diameter exceeds about 40mm.

4. DISCUSSION AND CONCLUSIONS

The occurrences of *P. noctiluca*, although irregular with regard to place and time, suggested a wide distribution of this species in all areas of the northern Adriatic, in coastal and offshore waters. The distribution pattern of jellyfish confirms the influence of the eastern Adriatic current system on the spreading of medusae as suggested by Vucetic (1984). Certainly, at the time of our surveys there were successive arrivals of *Pelagia* swarms in the area. However, jellyfish occurrences were neither correlated significantly with selected basic hydrographic parameters, as suggested previously by Piccinetti Manfrin and Piccinetti (1983-1984), nor correlated with the zooplankton standing crop (Figs. 2, 3).

From the size and abundance distribution patterns noted in October 1985 offshore from western Istria (Fig. 5), a conclusion can be drawn that there were various transportation routes of medusae taking various periods of time. It is also possible to speculate on the location of the different areas in which the spawning of *Pelagia* occurred.

Displacements of surface jellyfish populations could be however modified by a variety of surface abiotic agents such as wind, waves and tidal phenomena (Hamner and Schneider, 1986; Zavodnik, 1987). All these phenomena seem to be decisive in the aggregation of medusae in coves along the north Adriatic exposed coasts, and in sheltered areas which are not influenced by mid-layer and surface currents. While maximum abundances at these sites could reach about 600 specimens per cubic metre of sea water, the maximum swarm densities in free water offshore nuclei rarely exceeded 20 specimens per cubic metre. This last result based on the observations of divers is in accordance with a critical swarm density computed by Legovic and Benovic (1984).

Taking into consideration the appearance and condition of most jellyfish specimens nearing the shore, we cannot support the suggestion of Goy (1985), and Malej and Vukovic (personal communications) that specimens nearing the surface and coastal waters mostly appear moribund. It is true, however, that most (or perhaps all) animals might be injured or have lesions after repeated mutual contacts, or contacts with the bottom and/or shore cliffs which, due to the whirling action of the water body, the wave effects and similar phenomena, cannot be controlled physically and avoided by a weak medusa. Active swimming in search of food or because of other physiological demands, or a physiologically conditioned diminution of the animal specific density, seem to be of minor importance in surfacing *Pelagia*. Consequently, the reasons for mass jellyfish occurrences in coastal areas do not seem to be biologically conditioned but have to be searched for among abiotic environmental factors as suggested by Axiak (1983) and Kyrtatos (1985).

5. ACKNOWLEDGMENTS

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ON THE FOOD AND FEEDING IN THE NORTHERN ADRIATIC OF Pelagia noctiluca (SCYPHOZOA)

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ABSTRACT

The diet of seasonally collected *Pelagia noctiluca* was studied. It is very diverse and depends partly on plankton community composition, and partly on the agility of the prey. No correlation of coelenteron contents with regard to jellyfish size classes or population abundancies was established. No clear indication was found of pelagic fish population control by jellyfish feeding on fish eggs and larvae.

1. INTRODUCTION

The food and feeding behaviour of the Mediterranean *Pelagia noctiluca* are scarcely known. Little general information on the subject is available in the papers of UNEP (1983), Malej and Vukovic (1984), Goy (1985) and Vucetic (1985). No estimation on the effects of *Pelagia* feeding on fish stocks in the Adriatic Sea has been made. Therefore it seemed reasonable to consider the food preferences of jellyfish with special regard to planktonic fish eggs and larvae.

2. MATERIALS AND METHODS

In 1985 jellyfish were collected seasonally in the North Adriatic Sea at ten permanent stations located off the western coast of the Istrian Peninsula, and occasionally also at two stations located in the area of Rovinj and the Unije Island (Fig. 1).

Jellyfish were sampled by means of a FAO net (diam. 100cm, 500 μm mesh with a 3 litre volume mounted bucket) which was towed horizontally at a depth of 0 and 5 metres. Occasionally at coastal stations a hand net (diameter 14cm, 500 μm mesh) was used for surface sampling. The material was preserved in a 4% neutralized formol solution. The jellyfish were measured in the laboratory and their coelenteron content was inspected under a dissecting microscope.

3. RESULTS

Nine hundred and eighty two (982) *P. noctiluca* specimens collected in all seasons were studied for coelenteron contents. Their umbrella diameters ranged between 6 and 78 mm. In about 37% of the jellyfish no food particles were found, and in nearly 6% only unidentifiable detritus particles were encountered (Table I).

In other animals a great variety of pelagic fauna was noted which was mostly composed of holoplanktonic organisms. Developmental stages of some pelagic and benthic species were also encountered occasionally. Quite exceptionally a benthic nereide polychaete worm, insects (probably ants), fish postlarvae and juvenile fish were found in jellyfish coelenterons (Table II).

It seems that the diet composition was partly related to the diversity of contemporary zooplankton community. For example, in October 1985, in the whole area explored, copepods and phyllopods (especially *Evadne*) largely predominated in jellyfish coelenterons. In the summer season, the most frequently ingested fish eggs were anchovy eggs, while in December at southern stations sardine eggs were quite com-

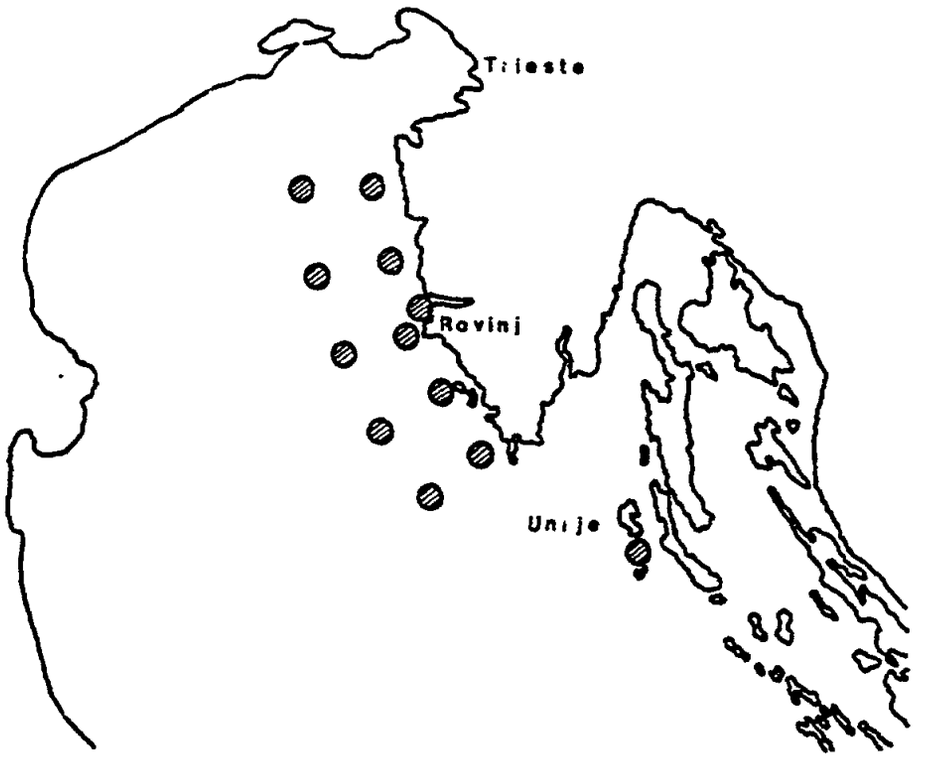

Fig. 1. Area and collection stations

mon. At the same time, jellyfish collected at northern permanent stations had not ingested sardine eggs but their diet was relatively rich in shellfish veliger larvae, especially of the genus *Lima* (Hrs-Brenko, pers. comm.).

Up to 79 ingested animals (arbitrary: food units) were found in the gastric system of a single jellyfish (Table III). The food consumption of a single *Pelagia* specimen was obviously not related to zooplankton diversity in the area. Thus, in the same patch of jellyfish whose umbrella diameter was 48mm, in the coelenteron of a peculiar specimen, 2 Copepods, 1 Phyllopod, 2 Siphonophores, 1 sardine egg, 2 Appendicularians and 1 Thaliacean (*Doliolum*) were found. The diet of the second specimen of the same umbrella size, consisted of 27 Copepods, 1 sardine egg, 7 Bivalvian veligers and 3 *Doliolum*. The coelenteron of the third 48mm *Pelagia* specimen was completely deprived of all food particles.

Table 1. Coelenteron contents in 982 *Pelagia* specimens

Coelenteron contents	No	%
Coelenteron empty	365	37.17
Detritus only	54	5.50
Detritus + Food	62	6.31
Food (Ingested animals)	501	51.02

Table 2. Coelenteron contents in 366 *Pelagia* specimens according to their size

Diameter class	No of medusae	Food units per 1 Pelagia	
(mm)		maximum	mean
< 10	2	3	2.0
10–14	17	15	2.7
15–19	19	19	3.9
20–24	46	35	11.0
25–29	46	43	15.4
30–34	34	44	11.0
35–39	44	79	12.7
40–44	45	33	8.0
45–49	46	38	11.8
50–54	37	33	7.3
55–59	15	39	12.8
> 60	15	23	5.1

The analysis of food unit frequencies showed no correlation with size classes of medusae (Table III), and no size or population abundancy correlation existed with regard to number of animals with empty coelenterons.

Most of the animals extracted from the jellyfish gastric system were in a relatively good condition and were identifiable. But in many shellfish larvae, for example, the shells were so damaged (possibly due to gastric juices) that genus identification was impossible. Likewise, more than 90% of sardine, sprat and anchovy eggs consumed could be classified as "dead", while at the same time in the zooplankton community only 10-25% of fish eggs were dead.

4. DISCUSSION AND CONCLUSIONS

Our analyses of coelenteron contents show that *P. noctiluca* feeds on all kinds of animals available, and that its diet is more diverse than previously supposed (Malej and Vukovic, 1984; Goy, 1985). Although generally speaking the jellyfish diet varied to some extent with regard to the season, there exist some indications of jellyfish individual voracity, and of their fastidiousness (or capture capabilities) conditioned probably by the agility of the prey. This was perhaps the reason for the rare presence in the jellyfish diet of quick Chaetognaths, Decapod zoeas, and fish post-larvae. On the other hand, a relatively high percent of fish eggs captured by jellyfish could perhaps be explained by immobility, i.e. passive drifting of eggs. No species selectivity of jellyfish with regard to eggs ingested was evident. It seems that medusae preferred to collect live prey rather than cadavers or parts of them.

The extracted coelenteron contents, however, were often influenced by jellyfish digestive agents, the actions of which have been most evident in veliger shells and fish eggs. While small animals were affected in their entirety, in large fish postlarvae or juvenile fish ingested by medusae only part of the prey (for example the head) was completely destroyed at the time of inspection, while the opposite part of the body (i.e. the tail) was still intact. Young fish (*Trachurus*) and unidentified Isopod Crustaceans were sometimes

Table 3. Food composition in 501 *Pelagia* specimens

Taxon	Pelagia specimens		MaximumNo / 1 specimen
	No	%	
Hydromedusae	5	1.00	2
Siphonophora	11	2.19	2
Gastropoda (veliger)	14	2.79	2
Bivalvia (veliger)	74	14.77	10
Polychaeta	2	0.40	1
Phyllopoda	287	57.29	77
Ostracoda	3	0.60	1
Copepoda	317	63.27	29
Decapoda	14	2.79	1
Isopoda	4	0.80	1
Amphipoda	11	2.19	1
Insecta	1	0.20	3
Chaetognatha	5	1.00	1
Appendicularia	46	9.18	4
Thaliacea	10	2.00	3
Pisces (ova)	195	38.92	23
Pisces (larvae, postlarvae)	7	1.40	1
Scyphozoa (ova, ephyrae)	4	0.80	+

found beneath umbrellas of collected medusae, but we could not conclude that these phenomena could be explained by a relation of mutualism as suggested elsewhere (Malej and Vukovic, 1984).

We have established no clear indication of pelagic fish population control by jellyfish feeding on their planktonic fish eggs and larvae, as suggested for northern seas (Möller, 1984). Among jellyfish specimens analyzed by us only about 20% contained fish eggs in their coelenteron system (mostly though not more than 1-2 eggs per animal). Fish larvae and postlarvae were present on extremely rare occasions. This supports the suggestion by Maso and Castellon (1985) that *Pelagia* is not an active fish predator. Among eggs consumed less than 10% was "live", i.e. freshly caught. A maximum of 23 fish eggs counted in a single medusa which indicated that passively drifting eggs were caught by chance and were available to jellyfish only when present in large quantities. On the other hand, it is known that eggs of some pelagic fish, such

as anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*), are distributed chiefly in the surface layer in offshore waters (Ghirardelli, 1967), i.e. in the water layer which under normal conditions is not inhabited by aggregated jellyfish (Zavodnik, 1987). Actively swimming fish larvae and postlarvae were evidently caught by jellyfish quite exceptionally. Consequently, in the area surveyed in 1985 the patchily distributed *P. noctiluca* had not, in all probability, influenced the pelagic fish stock through feeding. On the other hand, the reasons for increased landings of mackerel in Yugoslav harbours have not yet been scientifically explained and can only partly be accounted for in the abundances of jellyfish which is a fish food.

5. ACKNOWLEDGMENTS

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SIX TYPES OF CNIDOCYSTS IN Pelagia noctiluca IDENTIFIED BY MEANS OF LIGHT-SCANNING ELECTRON MICROSCOPY AND VIDEOANALYZER

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ABSTRACT

The analysis of the cnidocysts of *Pelagia noctiluca* (Forskal) by means of light and scanning electron microscopy shows the presence of six different types. Two of them had not been recognized in this species before and the others exhibit some structural differences from previous descriptions. All nematocysts were measured by means of a videoanalyzer (length, width and volume). The classification of these types is briefly discussed.

1. INTRODUCTION

The importance of the study of cnidocyst morphology was brought to light by many papers especially on Hydrozoa and Anthozoa (Weill, 1930, 1934; Carlgren, 1940; Werner, 1965; Picken and Skaer, 1966; Mariscal, 1974; Schmidt, 1972; Calder, 1974; Tardent and Holstein 1982; Ostman, 1979 a, b, 1982; Tardent *et al.*, 1985); it was shown that a correct identification of cnidocysts is essential for its taxonomy phylum based on : (1) Capsule structure, (2) structure of the discharged tubule, and (3) structure of the shaft. *Pelagia noctiluca* (Forskal) was the first scyphomedusa whose cnidocysts were observed (Wagner, 1841). Further studies described three types (Toppe, 1910; Krasinska, 1914; Alvarado, 1923; Weill, 1930, 1934; Russell, 1970).

The purpose of this paper is to review the morphological and morphometric characteristics of the various types of cnidocysts present in *P. noctiluca* by means of scanning electron microscopy for the morphological analyses and of a videoanalyzer for the morphometric analyses.

2. MATERIALS AND METHODS

Specimens of *P. noctiluca* (diameter between opposite rhopalia 3.5-5.5 cm) were caught in the Gulf of Trieste during:

-June 1985 (~ 30 specimens)
-September-October 1985 (6-700 specimens)
-November 1985 (2-300 specimens).

Marginal tentacles and oral arms were cut immediately after the catch and placed separately in distilled water at 4 °C for 24h.

We also examined nematocysts separated from whole specimens gathered in the Gulf of Napoli (3-400 specimens collected from May 1983 to May 1986; diameter between 3 and 6cm), frozen at -20°C.

Purification of the cnidocysts: After soaking in distilled water, the tissue was filtered through a graded series of plankton nets with decreasing mesh-size (from 1mm to 80), homogenized with a vortex and centrifuged several times (3500rpm, 15 min), removing the surnatant and suspending the pellet in distilled water, until a good purification was obtained. All these steps were made in a cold room at 4°C.

Light microscopy: About 1ml of the purified suspension was put on a glass slide and mounted with a water soluble medium, in order to avoid size reduction induced by fixation. The discharge of the nematocysts was obtained by means of ions of the lyotropic series (Salleo *et al.*, 1983b; Salleo, 1984), such as SCN-, I-, acids such as HCL, CH_3COOH or alkalis such as NaOH, or with Trypsin (Salleo *et al.*, 1983a). The electric induced discharge (Tardent and Holstein, 1982) does not occur in our isolated cnidocysts.

Scanning electron microscopy: 1ml of the suspension was placed on round cover slides (diam. 12mm), left there for 15 min in order to aid the adhesion and fixed for 2h at 4°C with glutaraldehyde 2%, paraformaldehyde 0.7% in cacodylate buffer 0.1M, pH 7.2, isotonic at seawater values (1100 mOsm) with NaCl 0.35M and $CaCl_2$ 2 mM. Washes were made in the vehicle (NaCl 0.46 M). Postfixation in OsO_4 in the same buffer, washes as above and graded series of acetone. The slides were mounted on stubs, critical point dried, shadowed with gold-palladium and observed under a Philips PSEM 400. Discharged cnidocysts were obtained either with lyotropic ions, or with pressure (Ostman, 1982) in order to avoid changes or wear due to acids or alkalis.

Measurement techniques: Measurements were made under a light microscope with a videoanalyzer, with a 100 x objective (total video magnitude 4000 x), on specimens which were not fixed. The following parameters were considered: length, width and volume of the undischarged capsules, length and diameter of the tubule and shaft of the discharged capsules. All measurements were made only on capsules which were not collapsed and whose length was similar to the microscope slide. When possible, populations of about 200 nematocysts of each type were analyzed.

3. RESULTS

From the samples obtained from the marginal tentacles and the oral arms six types of cnidocysts were identified. The qualitative distribution of these types is not related to the area of the jellyfish. On the other hand, there are quantitative differences among them, not characterized by size variations. The relative frequency of the various types (labelled A, B, C, D, E, F) is: A> E B C> D> F both in the tentacles and in the oral arms; however the types C and D are more frequent. For all types the size ranges are given in Table 1.

Type A - Heterotrichous Microbasic Eurytele

Capsule: Ellipsoidally shaped, with a protruding, discoidal operculum and a slightly sharpened distal apex (opposite the operculum) (Fig. 1a). The surface of the capsular wall is smooth at low magnitude and slightly granulous at a magnitude of 20,000 x. Under the light microscope the axial shaft is clearly visible and is surrounded by numerous transverse coils of the tubule. When the cnidocyst is discharged, there is a reduction in size, and the tubule is axial with the capsule length.

Tubule: The discharged tubule exhibits a larger, proximal section, the shaft, with a mean length of 11.9 μ, armed with three helicoidal series of 22-29 spines counterclockwise flattened, 2.5 μ long (Fig. 1b). The shaft diameter is 0.97 μ near the base and 1.06 μ in the distal region (Table 2). From this originates a tubule with a mean length of 568 μ, armed with three counterclockwise helicoidal series of little spines, thick and slightly curved towards the capsule, 0.25 μ long (Fig. 1c).

The diameter of the tubule ranges from 0.65 to 0.42 μ in the distal apex (Table 2).

Type B - Heterotrichous Isorhiza (new classification of the Large Atrichous Isorhiza).

Table 1. Data on undischarged nematocysts

Type of cnidoc.	No. of cnidoc.	Length (μ)		Width (μ)		Vol. (μ)	
		Range	X ± S.D.	Range	X ± S.D.	Range	X ± S.D.
A	200	10.11-16.17	14.13±1.39	8.17-12.98	10.72±1.08	365.61-1465.49	873.22±247.96
B	200	12.19-21.65	17.07±1.86	7.38-11.75	9.50±0.8	404.88-1370.45	820.48±196.00
C + D	251	15.20-30.14	23.81±2.67	13.87±28.78	21.81±2.43	1532.57-12952.00	6134.37±1962.11
E	150	4.35-7.88	6.51±0.58	3.31-5.05	4.20±0.37	26.32-96.11	61.06±13.37
F	136	30.83-52.58	39.63±4.35	5.66-10.36	7.65±0.77	564.48-2607.44	1238.54±332.34

X = mean value; S.D. = standard deviation.

Table 2. Data on nematocyst tubules

Type of cnidoc.	Length (μ)			Diameter (μ)		
	min.	med.	max.	min.	med.	max.
A shaft	11.43	11.90	12.86	0.97	1.05	1.06
tubule	526.22	568.03	607.38	0.42	0.54	0.65
B* tubule	-	192.04	-	0.42	0.44	0.46
C tubule	426.42	463.73	491.33	0.93	1.58	1.99
D* tubule	-	384.86	-	1.29	1.69	1.92
E tubule	90.52	123.38	148.16	0.43	0.51	0.52
F* shaft	-	12.43	-	1.1	1.2	1.3
* tubule	-	-	-	-	-	-

*Measurements made on a few samples

Capsule: The shape is variable, from ellipsoidal with a protruding operculum and opposite rounded apex, to a truncated cone with the abopercular side enlarged and nearly flat (Fig. 2a). The capsular surface is similar to the type previously described. Smaller ranges were observed in specimens with an umbrellar diameter of 3 cm (length 10.95 - 16.34 μ ; width 6.28-9.81 μ). There is thus a noticeable size variation related to the age and dimension of the jellyfish.

Tubule: The undischarged tubule is arranged as a tangle, with few clear coils visible near the operculum. The discharged tubule is axial with the capsule length, with a length of 192 μ, a proximal diameter of 0.46 μ and a distal of 0.42 μ (Table II). It is armed with three helicoidal series of spines countercloskwise, flattened and of a lanceolate shape in the proximal region of the tubule (about 1.5 μ in length), 0.4-0.5 μ long and narrower, thick and curved towards the capsule in the distal part, 0.2-0.3 μ long (Fig. 2b, c, d).

Type C - Holotrichous Isorhiza

Capsule: The shape is spherical, with the operculum slightly protruding, generally smooth, but it is not rare to find samples with a "plug" in the centre of the operculum, with a spherule of truncated cone shape (Fig. 3a, b).

Tubule: The undischarged tubule is clearly distinguishable under light microscope and is coiled regularly. The discharged tubule is axial with the capsular length 491 μ long, with a proximal diameter of 1.99 μ and a distal one of 0.93 μ (Table II). It is armed with three helicoidal series counterclockwise of flattened, triangular spines, slightly curved towards the capsule, with an enlarged basis. On the apex of this there is another thicker, triangular structure (Fig. 3d). The mean total length of the spine is 1.22 μ There is a proximal part of the tubule, 6-8 μ long, which is alwars free of spines (Fig. 3c).

Type D - Large Atrichous Isorhiza (new description)

Capsule: The undischarged capsule is quite identical to the one of type C, from which it is undistinguishable, under light microscope (Fig. 3a, b). For this reason measurements refer to the sum of types C and D (Table I).

Tubule: The only morphological difference is in the discharged tubule. The latter is axial with the capsule length, 384 μ long, with a proximal diameter of 1.92 μ and a distal one of 1.29 μ(Table II). There are no spines. This tubule exhibits a structure of three helicoidal strands countercloskwise, with slight "V"-shaped notches (Fig. 4a, b).

Type E - Little Atrichous Isorhiza

Capsule: It has a shape similar to that of types B or A but smaller (Table I). The discoidal operculum is slightly protruding (Fig. 2a).

Tubule: The arrangement of the undischarged tubule is similar to that of type B. The discharged tubule is axial with the capsule length 123 μ long, with a proximal diameter of 0.52 μ and a distal one of 0.43 μ (Table II). There is no structure or spiralization on it (Fig. 4c).

Type F - First observations and description

Capsule: It is shaped like a spindle, flattened and slightly curved (Fig. 5a, b). The operculum exhibits a discoidal, granulous surface, hollow at the top of the capsule. Under light microscope an axial structure is visible but no coils or tangles connected with a tubule.

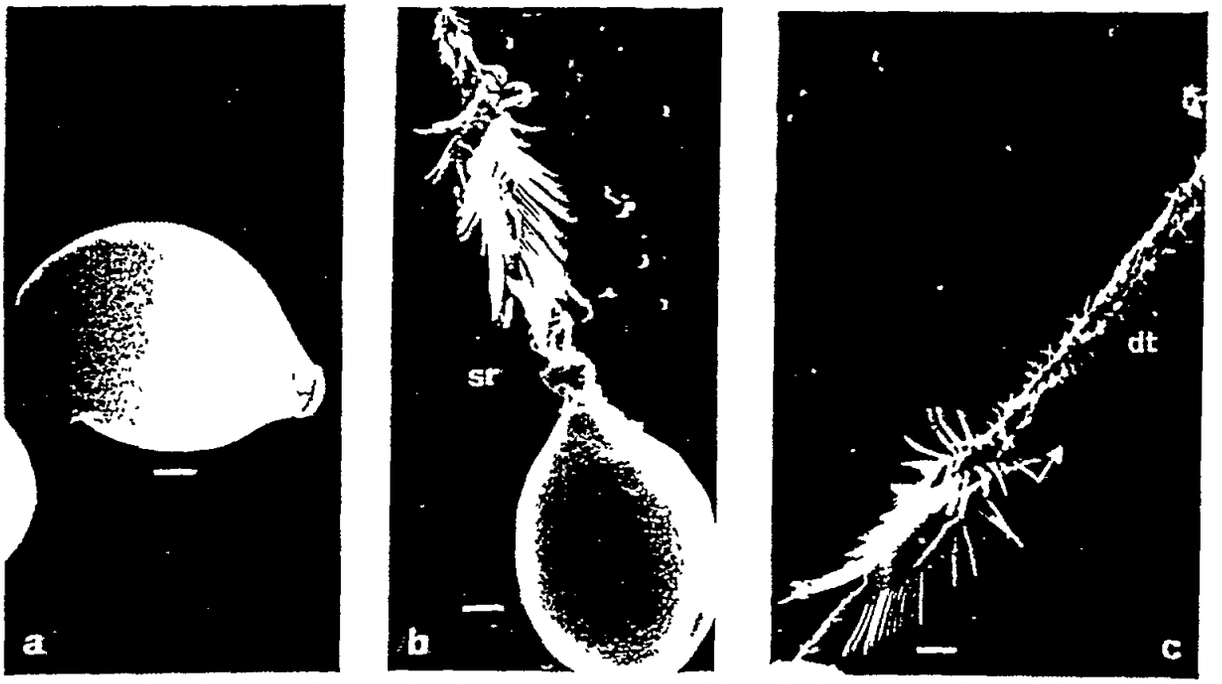

Fig. 1. Scanning electron micrographs of nematocyst type A. (a) undischarged capsule (scale bar = 1μ) (b) discharged capsule, showing the shaft with a proximal spineless region (sr) and the three distal series of spines (scale bar = 1μ); (c) discharged shaft and tubule (dt), showing the difference among spines (scale bar = 1μ).

Fig. 2. Scanning electron micrographs of nematocyst types B and E. (a) undischarged capsule of types B (b) and E (e) (scale bar = 1μ ; (b) discharged capsule - type B), showing a proximal spineless region (sr) and the armed proximal region of the tubule (apr) (scale bar = 1μ); (c) , (d) differences among the spines of the proximal region (c) and the distal region (d) of the tubule (scale bar = 1μ)

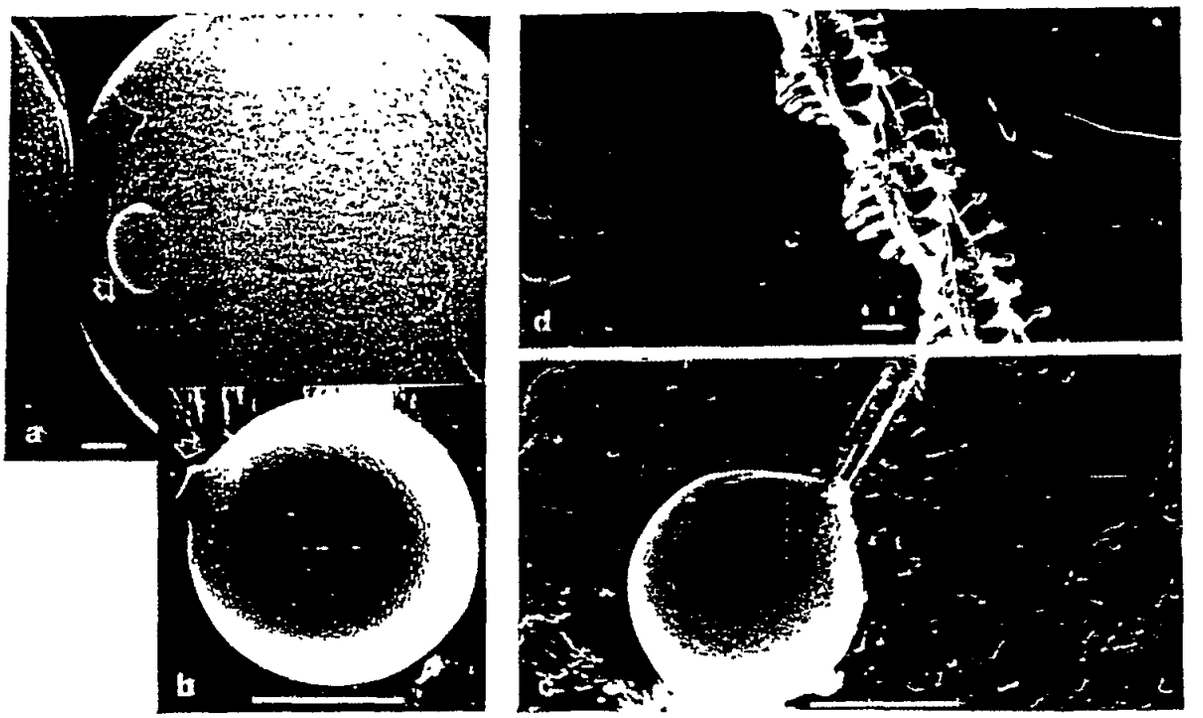

Fig. 3. Scanning electron micrographs of nematocyst type C. (a) undischarged capsule (type C or D) with a smooth operculum (arrow) (scale bar = 1μ); (b) undischarged capsule (type C or D) with an operculum showing a plug (arrow) (scale bar = 10 μ); (c) discharged capsule showing the proximal spineless region (sr) and the armature (scale bar = 10 μ); (d) detail of the armed region of the tubule (scale bar = 1μ).

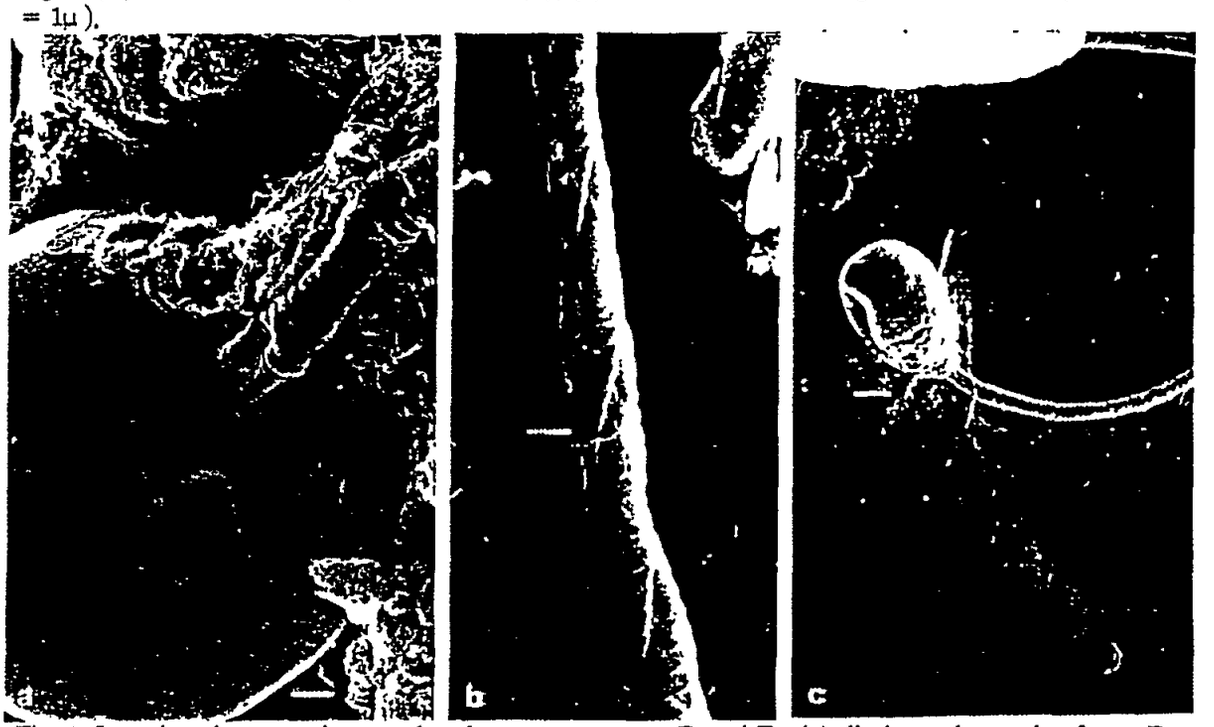

Fig. 4. Scanning electron micrographs of nematocysts type D and E. (a) discharged capsule of type D (scale bar = 1μ); (b) detail of discharged tubule type D, showing the absence of spines and the presence of V-shaped notches (scale bar = 1μ); (c) discharged capsule of type E showing the smooth tubule (scale bar = 1μ).

Tubule. The discharged cnidocyst exhibits a characteristic structure: there is a smooth, not helicoidal proximal part, shaped like a cave cylinder 12.43μ long, with a constant diameter of 1.1-1.3 μ (Table II; Figs. 5b, c, d), which contains a filament of unknown length. This filament goes out of the rigid cylinder. It shows a very sharpened tip, two lateral flattened series of spines (5-5.5 μ), flexible, "V"-shaped, hollow at the capsule side (Fig. 5d). The shape is that of a harpoon tip.

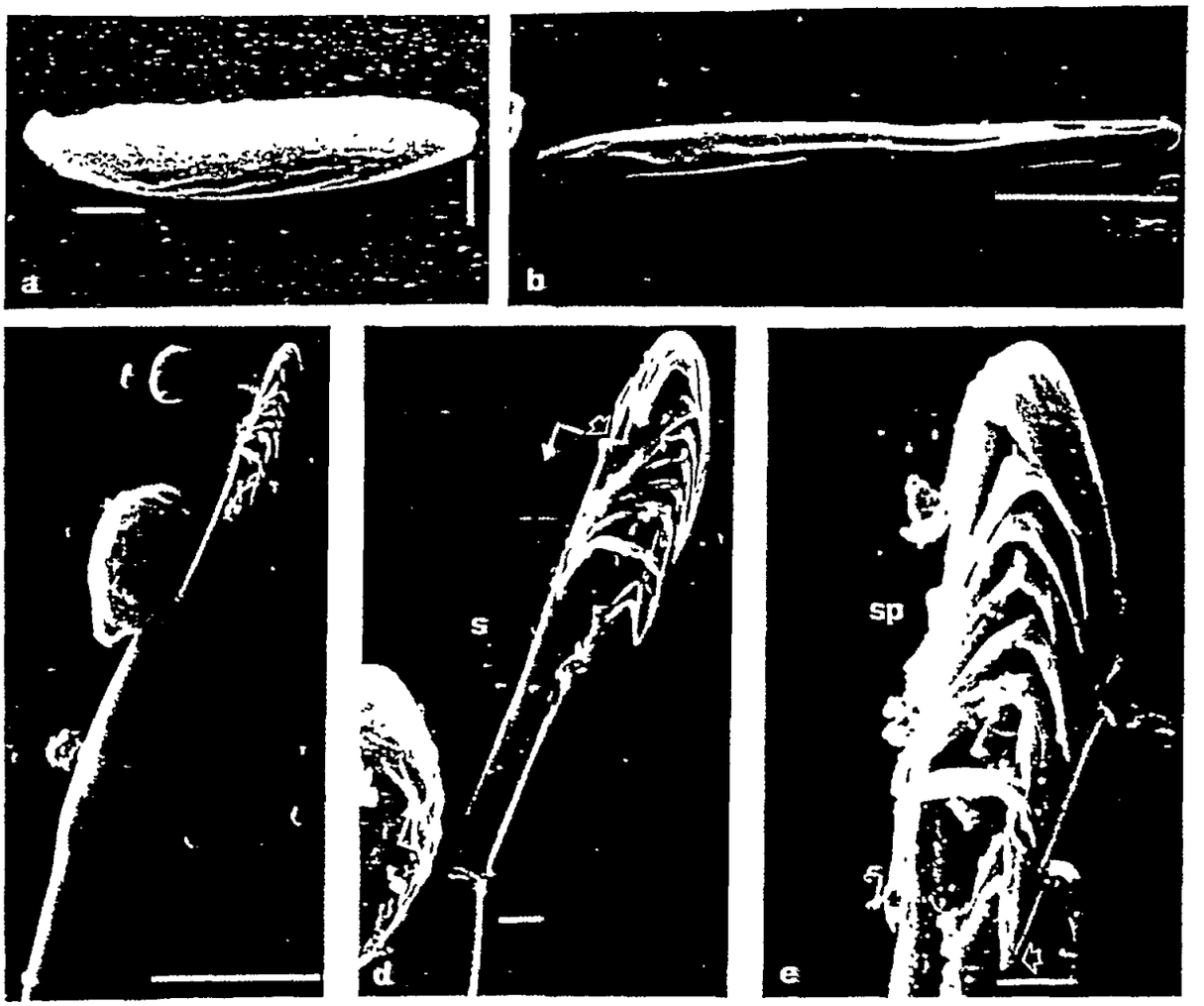

Fig. 5. Scanning electron micrographs of nematocyst type F. (a) larger side view of the undischarged capsule (scale bar = 1 μ), (b) smaller side view of the undischarged capsule (scale bar = 10 μ); (c) discharged capsule (scale bar = 10 μ); (d) detail of the discharged tubule, showing the proximal cylindrical and spineless "shaft" (s) and the distal tubule protruding from the tip of the shaft (arrow) (scale bar = 1 μ); (e) detail of the distal tubule, showing the lateral series of spines (sp) and the closed, sharpened tip (arrow) (scale bar 1 μ)

4. DISCUSSION AND CONCLUSIONS

Three types of cnidocysts in *P. noctiluca* were described in previous studies, one of them in two size populations (Wagner, 1841; Toppe, 1910; Krasinska, 1914; Alvarado, 1923; Weill, 1934; Russell, 1970). Following Mariscal's classification (1974), they are identified as:
-Heterotrichous Microbasic Eurytele, 20 x 14 ;
-Holotrichous Isorhiza, 30 x 29 ;
-Atrichous Isorhiza, in two sizes, 12 x 12 and 7 x 3 .
The nematocysts found in *P. noctiluca* are six:
Type A-Heterotrichous Microbasic Eurytele
Type B-Heterotrichous Isorhiza (new classification of the larger Atrichous Isorhiza)
Type C-Holotrichous Isorhiza
Type D-Large Atrichous Isorhiza (not previously described)
Type D-Little Atrichous Isorhiza
Type F -(never described before)

There is also a great size variability, related both to the size of the jellyfish and to the age of the tissue sampled. The distal part of a marginal tentacle for example, which develops throughout the life of *P. noctiluca*, contains fully developed cnidocysts smaller than the ones in the proximal part (the older one) of the same tentacle.

These observations *in toto* demonstrate that there is a larger differentiation of cnidocysts than previously believed, even if in only one species. It would be of great interest to re-examine the cnidocysts in other species of Scyphomedusae. Unfortunately, few data are available for Scyphozoa nematocysts, unlike Hydrozoa and Anthozoa; such a re-examination would allow us to determine whether this variability is a common phenomenon or not and whether cnidocysts like those of type F, with their particular discharge mechanism, are a common type equally distributed in the taxa, or a species-specific type.

Type A

Under the light microscope the shaft seems to be distally enlarged (Krasinska, 1914; Johnstone Papenfuss, 1936; Russell, 1970), while under the scanning electron microscope this enlargement is very small. There is an increment of the diameter of 0.08-0.09 μ, with a maximum of 0.4-0.5 μ The enlargement observed with light microscopy may be caused by refraction due to the three series of spines. Thus there is an enlargement even if small, so the previous classification is correct.

Type B

There is a difference in the structure of the spines; we distinguish two types, one proximal and one distal, even if there is not a shaft. We thus propose a new classification: Heterotrichous Isorhiza instead of the old Atrichous isorhiza.

Type C

The structure observed is similar to that described previously.

Type D

The frequency of this type in our samples is low, so initially we considered the possibility of an artifact due to a loss of spines. Nevertheless its presence is constant in all our samples, all the tubules are completely spineless and the shape of the notches is not similar to the basis of the spines of the Holotrichous Isorhiza. It may therefore be classified as Large Atrichous Isorhiza.

Type E

Our observations confirm the previous classification. This type is very frequent in the jellyfish but the techniques of purification used caused a quantitative decrease in our samples. As a consequence, frequency was underestimated.

Type F

First time observed. The undischarged capsule shape recalls the Microbasic - P Mastigophore present in the Cubozoa, but the characteristics of the tubule are completely different.

The discharge mechanism in this case is different from the common one observed in the other types (Krasinska, 1914; Weill, 1930, 1934; Carlgren, 1940; Picken and Skaer, 1966; Russell, 1970; Mariscal 1974; Carré, 1980; Carré and Carré, 1980; Tardent and Holstein, 1982; Holstein and Tardent, 1984; Salleo, 1984; Tardent *et al*, 1985); the discharge of the cylindrical shaft is normal (by evagination). On the other hand, the tubule does not evaginate like a glove finger, but protrudes from the shaft. Thus, the first part of the tubule which can be observed during discharge is the distal end and not the proximal part as in all other cnidocysts described. This discharge mechanism recalls a telescopic antenna, not an evaginating process. The closed tip of the tubule ascribes it to the Astomocnidae, but it differs greatly from all the types in this group. In this preliminary phase of our analysis nothing more can be added. We cannot even give a name to this particular cnidocyst; we simple call it "type F". Further studies on this type have already been launched.

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JELLYFISH ENVENOMATION SYNDROMES WORLDWIDE

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ABSTRACT

Jellyfish venoms are toxic and/or antigenic polypeptides and enzymes pathogenic to human beings. An accurate diagnosis of the type of reaction the patient experiences and of the offending species will be necessary to treat the various reactions to stings caused by these animals. Fatal reactions may be caused either by anaphylaxis or by the action of toxins in the venom on the heart, respiratory centre or kidneys. Cutaneous eruptions after envenomation may be local, generalized, exaggerated, recurrent, delayed, persistent, or occur at sites distant from the primary sting. Fat atrophy, pigmentary changes, vasospasm and contractures with gangrene can occur after jellyfish stings. Identification of the envenomating animal can be made by actual visualization, examination for nematocysts on skin scrappings, or serologically. It may be predicted based on knowledge of location, time and environmental circumstances of the encounter. First-aid measures designed to prevent additional nematocyst rupture are species-specific. Topical analgesic measures are currently ineffective. Anaphylaxis should be prevented by appropriate life saving measures. Other syndromes, caused by the toxins of the venom or mediated by humoural or cellular immune mechanisms, should be treated specifically.

1. INTRODUCTION

Jellyfish venoms are toxic and/or antigenic polypeptides and enzymes pathogenic to human beings. Human reactions to these compounds may result in fatal, systemic or local syndromes. Envenomation occurs when the victim's skin contacts the jellyfish tentacle to trigger the release of a venom-coated tubule from an epithelial intracytoplasmic organelle. These structures, called nematocysts, eject their threads with an approximate speed of 40,000g to enter the skin at two to five pounds per square inch (Poehler, unpublished observations, July 1984; Holstein and Tardent, 1984). This energy forces the projectile into the upper dermis, where the viscous venom, adherent to the thread, is released into the circulation to produce its effects.

2. LOCAL REACTIONS

The most common envenomation syndrome is the local sting with a linear, urticarial, painful eruption at areas of tentacular contact. The pain produced by the sting may be due to the action of exogenous or endogenous chemical mediators on cutaneous sensory nerves (Burnett and Calton 1977). One particular mediator found in these venoms that may be responsible for much of the pain is the "kinin-like" factor. The eruption may begin as blanched papules or urticaria but soon becomes erythematous. The lesions are of variable duration, usually minutes to hours, and may be vesicular, hemorrhagic, necrotizing or ulcerative (Ioannides and Davis, 1965). Localized hyperhidrosis, lymphadenopathy, subsequent fat atrophy, vasospasm, limb necrosis, gangrene and contracture can occur (Maratec and Russel, 1963; Gunn

1947; Drury *et al.*, 1980). Persistent rubbing can produce lichenification (Maratec and russel, 1963). In cases of eye contact, conjunctivitis, chemosis, corneal ulcerations and lid edema may result. Because the pain appears instantly and occurs with the patient's initial contact with the jellyfish, and because no clinical immunity has been reported, it is believed that these stinging reactions are a toxic rather than an allergic event.

A case of an exaggerated local response to jellyfish envenomation has also been reported. One individual, initially exposed to *Chrysaora quinquecirrha* and *Pelagia noctiluca*, developed a large local edematous response lasting 10-14 days after being stung by either jellyfish. Repeated investigations of his serum revealed a high antigen-specific IgE level to sea nettle and man-of-war antigen, which has persisted for many years (Hartman et al., 1980; Burnett et al., 1983a). Additionally, his basophils were found to release histamine in abundance when exposed to sea nettle antigen in the laboratory (L. Lichtenstein, J.W. Burnett, A.G. Tobias, *et al.*: unpublished observations, December 1983). Studies also were undertaken to determine whether this patient had abnormal lymphokines released by his white cells after exposure to jellyfish venom (Burnett *et al.*, 1986a). The results were suggestive but not conclusive. It is our thesis that this eruption was analogous to large local reactions produced by arthropods (Mauriello *et al.*, 1984).

Studies on the patient's peripheral blood leukocytes, collected two years after the last envenomation and exposed to these jellyfish venoms, showed that lymphocyte migration inhibition was at high normal levels but increased when indomethacin was added to the cell culture medium (Burnett et al., 1986a). It is thought from these observations that IgE was an important component in the reaction to his envenomation; the role of the suppressor T cells was uncertain. It is suspected but not proved that patients exhibiting large angioedematous reactions to a venom might later develop anaphylaxis to that agent. In the case cited in the fourth paragraph of the fatal reaction section, a female patient with anaphylaxis following a *Pelagia* sting had noticed large local reactions with some prior envenomations (Togias *et al.*, 1985).

At least 24 patients with recurrent, linear and cutaneous eruptions appearing at varying intervals after a sole, primary envenomation are known to us (Burnett *et al*, 1983;Manson *et al.*, 1985; Burnett and Calton 1985; Reed *et al.*, 1984; Williamson 1985; Ohtaki *et al.*, 1986; Burnett *et al.* 1987; M.J.A. Walker, personal communication, August 1985). Interestingly enough, there is a 20:4 female:male prediction. The interval between the primary envenomation reaction and the recurrent eruption was five to 30 days. The interval between eruptions increases and the duration of the cutaneous lesions decreases with each recurrent episode. The recurrent episodes may be either more or less severe than the initial one. In two patients' tests, only a superficial dermal lymphocytic infiltrate was present in a biopsy specimen of the eruption at the time of the recurrence. One patient, approximately one month after her original sting by *Physalia*, had antigen-specific IgG and IgE antibodies in her sera to both sea nettle and man-of-war antigens (Burnett *et al.*, 1983a). Four years after her sting, her peripheral blood leukocytes did not exhibit lymphokine activity when exposed to *Physalia* venom (Burnett *et al.*, 1986a). These cutaneous eruptions were thought to recur by an immunologic mechanism triggered either by a sequestered antigen residing intracutaneously or by exposure to a cross-reacting venom.

Another case, recently seen by us, occurred after contact with *Stomolophus meleagris* in a 32-year old woman (Burnett and Calton, 1985). Examination of a biopsy specimen taken from her ankle at the time of recurrence showed a significant lymphocytic perivascular infiltrate with eosinophils in the dermis. No nematocysts were identified in the biopsy. Direct immunofluorescence of this lesion was negative for IgG, IgM and C3 (Burnett and Calton, 1985). Peripheral blood leukocytes, drawn both at the time of recurrence and a month later, did not show any increased lymphokine activity after exposure to *Stomolophus, Pelagia, Physalia* and *Chrysaora* venom (Burnett *et al.*, 1986a), even though she had elevated serum IgG antibodies against *Stomolophus, Physalia and Pelagia* antigens, as well as normal IgE antibody levels against *Stomolophus* antigen (Burnett and Calton, 1985). In one of the cases of recurrent jellyfish eruptions, oral prednisone delayed the original cutaneous lesions (Burnett *et al.*, 1987).

It appears that certain jellyfish species (probably oceanic *Physalia*) were more likely to induce these recurrent reactions. It is also our clinical impression that persons experiencing recurrent eruptions were not envenomed frequently prior to the triggering sting.

Persistent, delayed granulomatous nodules subsequent to jellyfish envenomation also have occurred (Reed et al, 1984). One patient had moderate pain with the initial transient sting. Four to seven days later, a delayed chronic eruption began at the site of tentacular contact. This healthy young woman, presumably envenomated by *Pelagia noctiluca* in the Mediterranean Sea, developed a refractory facial lesion that persisted for seven months. This patient had normal serum levels (equal to control sera) of

antigen-specific IgG and IgE antibodies (anti-*Chrysaora*, anti-*Physalia* and anti-*Pelagia*) in her sera three years after the envenomation, as shown in tests performed by our laboratory. At the same time, however, peripheral blood mononuclear leukocytes from this patient, exposed to *Chrysaora* antigen, had slight increase in their lymphokine activity, which could be reversed by the addition of indomethacin to the culture medium, suggesting that prostaglandins played a role in the lymphokine response (Burnett *et al*, 1986). The cutaneous eruption on her cheek was an erythematous and indurated nodule, 3 to 4 cm in diameter. Examination of a biopsy specimen of this lesion showed a dermal cellular infiltrate similar in morphologic features to that of a delayed hypersensitivity reaction in human beings (Burnett *et al*, 1986; Reed *et al.*, 1984). This pathologic picture differed markedly from the scant dermal perivascular mononuclear cell infiltrate usually present in simple coelenterate envenomations (Ioannides and Davis, 1965). Because of this fact and the chronicity of the eruption, the patient's reaction to envenomation was thought to be an example of delayed cell-mediated immunity.

Other persistent eruptions lasting several weeks also have been reported after envenomation by other coelenterates (Reed *et al.*, 1984; Burnett *et al*, 198; Peters, 1967). The lesions in these patients, however, were much smaller than the lesion of the patient described in this paragraph and, in addition, were multiple rather than singular.

A case of an erythematous, inflammatory eruption appearing at a site distant to the envenomated area, was reported after a *Physalia* sting (Matusow, 1980). This patient, who experienced envenomation on her right ankle and foot, developed an exudative and erythematous inflammatory response on the right ear, gingiva and cheek a few hours later. This distant eruption progressed for two days, stabilized, then subsided after ten additional days. Seven years after envenomation, no antigen-specific IgE or IgG was detected in our laboratory against *Physalia* antigen in her serum.

An unusual contact dermatitis caused by the tentacles of *Physalia* and other jellyfish was reported recently by a Japanese group (Ohtaki *et al.*, 1986). Although no T-cell studies were performed, repeated topical patch test challenges on clinically normal skin were conducted and the results were positive.

A popular urticarial eruption was reported in the case of a pregnant 29-year old atopic Japanese housewife who contacted a powdered jellyfish that she was preparing to use as a delicacy for a meal (Yaffee, 1968). Fifteen minutes after soaking the animal in hot and cold water, her hands began to "burn". This reaction was quickly followed by generalized pruritus and giant elevated urticaria. On the following morning, the patient had multiple small scattered urticarial lesions that were 1 to 2 cm in diameter and persisted for 30 days. This patient's urticarial lesions could be controlled with low doses of chlorpheniramine and topical drying agents. Because this patient's dermatitis was caused by a dried, yellow purchased jellyfish, adequate species identification was not possible (it was presumably *Rhopalonema*). It is assumed that these lesions were a hypersensitivity reaction analogous to papular urticaria.

In another example of papular urticarial lesions, severe *Chironex fleckeri* stings resulted in tiny, pruritic, papular, erythematous, punctate lesions in non-envenomated skin a few days after a significant sting was experienced nearby (Williamson et al., 1984). In one of the recurrent eruption cases, papular urticarial lesions away from the original envenomation site accompanied an exacerbation (Burnett *et al.*, 1987).

3. CHRONIC OR LONG-TERM REACTIONS

Long-term local sequelae of jellyfish envenomation include the appearance of keloids, hyperpigmentation, fat atrophy, gangrene, contraction and scarring (Gunn, 194; Drury *et al.*, 1980; Williamson *et al.*, 1984). Subcutaneous fat atrophy has appeared at the site of envenomation from an Indian Ocean jellyfish starting six weeks after the sting and persisting for more than six months (Drury *et al.*, 1980). Four cases of vascular spasm of the upper extremity are currently known (Adiga, 1984; Filling-Katz, 1984; J.A. Williamson, personal communication, September 1986; D. Mebs, personal communication, January 1987). All of these cases occurred in the Indo-Pacific region. A self-resolving mononeuritis multiplex, on the extremity occurred after a suspected man-of-war sting off the coast of North Carolina (Filling-Katz, 1984). Temporary paralysis of multiple autonomic nerves in a swimmer followed an envenomation in Malaysian waters (Chand and Selliah 1984). This patient had a distended abdomen and urinary bladder, an inability to have an erection, urinate or lachymate. The R-R interval on his ECG did not change with breathing or carotid sinus massage. A similar case reported to us, a victim exhibiting 48 hours of low grade fever, bladder atony, diplopia and ataxia resulted after a *Physalia* sting.

Post-Envenomation Dermatitis

In one patient an episode of herpes labialis appeared a day after a severely painful sting on a New Jersey beach. In another instance in Hawaii, granuloma annulare lesions appeared on the leg a few days after a sting (R.M. Mandojana, personal communication, February 1986).

4. JELLYFISH INGESTION

Human reactions to jellyfish ingestion include toxin-induced local cramping and abdominal pain (Halstead, 1965). One case of generalized cutaneous eruption following jellyfish ingestion has been cited (Marr, 1967). The nature of the after reaction is unknown. No case of serum sickness after jellyfish envenomation, either by ingestion or natural tentacle contact, has been reported to date.

5. SYSTEMIC REACTIONS

In addition to the cutaneous eruption, some stings are accompanied by such systemic symptoms as malaise, weakness, ataxia, dizziness, local cramping, muscle spasms, paresthesias, low-grade fever, nausea and vomiting, all of which are thought to represent constitutional toxic reactions to the venom (Ioannides and Davis, 1965; Halstead 1965; Maguire 1968). In some of these cases it appears that movement of the envenomated limb leads to increased mobilization of the venom from the inoculation site as a "muscle pump" is activated.

An "Irukandji" syndrome was described several years ago after envenomation by a small jellyfish, *Carukí barnesi* (Halsted, 1965). The name of this syndrome is derived from an aboriginal Australian tribe living on northeast Queensland where the *Carukia* is endemic. A small transient sting, frequently invisible and comparable to a minor insect bite, initiates this reaction. Cutaneous pain may be delayed five to 40 minutes, after which it starts at the sacral or abdomen area as a severe boring pain which spreads to the thigh and chest where the sensation is crampy. Severe excruciating waves of generalized myalgias occurs for hours. The Irukandji syndrome persists over the next 24 to 48 hours. The other signs and symptoms may include tumour, increased "sighing" respiratory, anxiety, local or general pilorerection, headache, nausea, vomiting, sweating, restlessness, pyrexia, tachycardia, coughing, blood streaked sputum, prostration and palor, cyanosis and oliguria (P. Fenner: personal communication, May 1987). Spontaneous recovery gradually follows (Halstead, 1965). Neither histologic nor immunologic studies of these victims have been reported. In one case a lumbar puncture was done and the cerebrospinal fluid tested and found normal (JA Williamson: personal communication, October 1984). In another case left ventricular failure requiring intubation was detected (J.A. Williamson: personal communication, January 1987). Anecdotally, administration of phentolamine appears to reverse the significant hypertension seen in these cases (Fenner *et al.*, 1986). Recent experiments have demonstrated elevated serum catecholamines in rats infused with *Carukia* crude venom.

6. FATAL REACTIONS

Human fatalities may occur as a result of anaphylaxis or toxic mechanisms. Although no human beings have been intensively studied at the time of a fatal envenomation, it appears most likely that various toxins within the venom may be lethal by any of three methods. The most potent marine venom known is that of the southeast Pacific box jellyfish (*C. fleckeri* and *Chiropsalmus quadrigatus*) which kill experimental animals by inducing cardiac or respiratory arrest (Endean et al., 1969). These deaths may occur within a few seconds with concentrated venom or may be delayed for several hours. Those animals dying instantly appear to die from cardiac arrest (Hartman *et al.*, 1980). Coronary vasospasm may play a role in the lethal action (Lee *et al.* 1986). Respiratory arrest can occur rapidly and will also appear in animals receiving treatment to counteract the cardiotoxin of these jellyfish (Burnett and calton 1983). One patient developed respiratory acidosis after a *Physalia* sting (Kizer *et al.*, 1982). This state of hypoxia may have been a forerunner of the fatal respiratory arrest seen in more severely envenomated patients. Some cases

of jellyfish venom-induced delayed death in experimental animals are thought to occur because of hyperkalemia resulting from a "shocked" kidney syndrom (Burnett and Calton, 1976).

It has been estimated that at least 50 feet of box jellyfish tentacles must touch the skin of an adult in order to deliver a fatal dose (Endean 1981). Recently, however, a five-year old boy died of *Chironex* sting in which contact with only four metres of tentacles was observed (Lumley *et al.*, in press). Each tentacle imprint marks the site of additional intradermal venom injection. Perfusion of the injured skin and mobilization of the venom are increased as the stricken patient writhes or struggles because of the pain. Jellyfish deaths in humans can occur as a result of central respiratory failure appearing many minutes after envenomation. The instant death found in animals injected intravenously with jellyfish venoms has not yet been seen in human beings, probably because the blood has not achieved a sufficient threshold to injure fatally the heart before respiration ceases. However, the recent death of a five-year old child in Australia from *Chironex* envenomation mentioned above may have been due to cardiac causes (Lumley et al., in press). In order for jellyfish other than *Chironex* to kill by a toxin reaction we must assume that the victim is a small child wrapped up massively in tentacles so that it can get the venom per kilogramme at high levels.

A human case of acute renal failure associated with intravascular hemolysis and hemoglobinuria in a four year old girl stung on three extremities by the Portuguese man-of-war *Physalia physalis* has been reported (Spelman *et al.*, 1982; Guess *et al.*, 1982). A six hour latent period elapsed before she became acutely ill and her renal output was suppressed for at least two weeks. Recovery required a two-week hospitalization period. Although this case was not fatal, it is our hypothesis that it is analogous to cases resulting in delayed death of experimental animals (Burnett and Calton, 1976).

Jellyfish envenomation may also kill human beings by anaphylaxis (Maratec and Russel, 1963). Some of the initial studies on anaphylaxis were performed in dogs with the use of coelenterate (sea anemone) protein as antigen (Portier and Richet, 1902). A recent case report illustrates anaphylaxis after jellyfish envenomation. The serum of a healthy 59-year old woman, found hypotensive and pulseless 15 minutes after being stung on the knee, presumably by *P. noctiluca* contained elevated levels of IgE directed against the venom of a related jellyfish species (*Chrysaora quinquecirrha*) nine months later. At that time her basophils were capable of releasing increased levels of histamine when contacting this antigen, and a heat-labile factor in her serum could transfer the jellyfish venom sensitivity to normal human basophils (Togias *et al.*, 1985).

7. DIAGNOSIS AND THERAPY

The correct therapy for jellyfish envenomation syndromes requires both an adequate diagnosis of the disorder and accurate identification of the offending species. This fact will become apparent as technology yields better pharmaceutical and immunologic therapeutic agents (Hartman *et al.*, 1980), as well as improved protein-separating procedures to isolate venoms and delineate the pathogenesis of envenomation. The treatment of anaphylaxis consists of maintenance of the vital signs and the prompt parenteral administration of oxygen and epinephrine. Therapy for a potentially fatal toxic reaction from *Chironex fleckeri* includes the maintenance of ventilation and cardiac function; intravenous verapamil drug therapy may prove to be useful (Burnett and Calton, 1983; Burnett *et al.*, 1985). Although this agent has not been used in human beings, experimental evidence in rats and mice suggests that it may be of value in human Chironex envenomation.

In cases of *Chironex* envenomation, species-specific hyperimmune sera or antivenin are available from the Commonwealth Serum Laboratory in Melbourne, Australia. Immunotherapy should be considered to counteract the systemic symptoms and the pain in severely stung patients (Williamson *et al.*, 1984). Reassurance of the patient and immobilization of the envenomated part are essential. First aid therapy should include methods to suppress additional nematocyst rupture and may be species-specific. The patient's skin should be sprayed with vinegar if the offending animal is thought to be *C. fleckeri* or *P. physalis*; a slurry mixture of baking soda should be used for stings by *C. quinquecirrha* (Hartwick *et al.*, 1980; Turnur *et al.*, 1980; Burnett *et al.*, 1983b). Once the nematocysts are counteracted by these measures, manual removal of adherent tentacular strips follows. The use of systemic corticosteroids will be ineffective in cases of envenomation produced by toxic reactions. There is no effective form of local analgesic therapy, therefore pain relief has to be achieved by systemic medication. The application of local heat or cold is not beneficial and the former may be detrimental since it increases local absorption of the venom.

Therapy with indomethacin, ibuprofen or nonsteroidal analgesics should be entertained in cases of prolonged, persistent reactions (Burnett and Calton 1986). Refractory hyperpigmentation may be controlled by hydroquinone bleaches and keloids can be treated in the standard manner with injectable corticosteroids to alleviate the cutaneous elevation and local tenderness. Some animal experimental evidence exists that methysergide and indomethacin may reduce the cutaneous vasopermeability induced by *Physalia* and *Chironex* venoms, respectively (Burnett and Calton 1986). The therapy recommended here will probably change as research in the field continues to advance (Burnett *et al.*, 1986b), and for this reason we have recently founded the International Coalition for Jellyfish Stings to better collect and review envenomation cases.

Classification of jellyfish envenomation syndromes

Local Reactions

Toxin induced

Exaggerated local reaction (angioedema)
Recurrent reactions up to four episodes
Delayed persistent reactions up to several months
Distant site reactions
Contact dermatitis
Papular urticaria up to one month

Long-Term Reactions

Keloids
Pigmentation
Fat atrophy
Contractions
Gangrene
Vascular spasm
Mononeuritis
Autonomic nerve paralysis

Post Episode Dermatitis

Herpes simplex
Granuloma annulare

Reactions from Jellyfish Ingestion

Gastrointestinal symptoms
Urticaria

Systemic Reactions

Toxin-induced
Irukandji reaction
Respiratory acidosis

Fatal Reactions

Toxin-induced
Immediate cardiac arrest
Rapid respiratory arrest
Delayed renal failure
Anaphylaxis

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LIPID AND PROTEIN CONTENT OF JELLYFISH FROM THE LIGURIAN SEA. FIRST RESULTS

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ABSTRACT

Results of the research about macroplanktonic jellyfish *Rhizostoma pulmo* and *Cotylorhiza tuberculata*, collected in the Ligurian Sea, are reported. The composition in lipids, proteins and water of the various jellyfish structures (bell, oral arms, gonads) has been evaluated. This research aims to study the implications that these substances may have for the natural state of the jellyfish and the trophic relationsips with other plankton organisms. The lipid component has been examined in its fatty acids composition to determine the qualitative and quantitative content. There is evidence that there are some differences in the content of substances between the two jellyfish.

1. INTRODUCTION

Studies about protein and lipid content in the various zooplankton groups are important for the implications that these substances may have for the ecological, physiological, reproductive and energy aspects of the marine ecosystem; numerous studies about these subjects have already been carried out. Concerning gelatinous macroplankton and particularly Scyphomedusae, the studies about organic matter content have only recently been intensified, while the water content of many species has been examined for some time (Vinogradov, 1953; Ceccaldi and Doumas,1965; Ceccaldi *et al.*, 1976; Malej and Vucovic, 1984; Malej, 1985 1985; Shenker, 1985; Larson, 1986; Papathanassiou *et al.*, 1987).

We have been studying these biological aspects of the zooplankton in the Ligurian Sea for some years, in relation to the environmental and seasonal parameters (Carli *et al.*, 1981, 1984). In this connection (Carli *et al.*, 1985), we also launched a study about the lipid and protein content of the Scyphomedusae, and particularly the species *Rhizostoma pulmo* Macri and *Cotylorhiza tuberculata* Agassiz (Rhizostomeae).

Our quantitative studies showed that these jellyfish contain important gelatinous macroplankton components. It was of interest to effect dosages on the different jellyfish structures, rather than on the whole specimen in order to evaluate some possible differences among examined components.

2. MATERIALS AND METHODS

Jellyfish were sampled in Spotorno Bay (Fig. 1): *Rhizostoma pulmo* (umbrella diameter 32 cm., fresh weight 1.9 kg.) in October 1986 near the shore, *Cotylorhiza tuberculata* (umbrella diameter 26 cm., fresh weight 1.5 kg.) approximately two miles offshore in April 1987. The specimens were put in large containers with marine water and carried to the laboratory, where they were rapidly rinsed with distilled water and sectioned into the various structures (bell, marginal bell, oral arms, gonads) which were kept at a low temperature (-20°C) until analysis. On different portions of the structures mentioned, the fresh weight

and the dry weight, after heating at 60°C for 24 hours and exsiccating on silica gel for 24 hours, were determined. Weighings were carried out with an analytical balance Mettler mod. H_2O (precision 0.01 mg).

A portion of the dried material was homogenized with distilled water. On three portions of every homogenate the dosage of the protein contentwas determined (Lowry, 1951) against a standard of lyophilized bovine albumin (Merck) by using a Pye Unicam Mod. PU 8620 spectrophotometer.

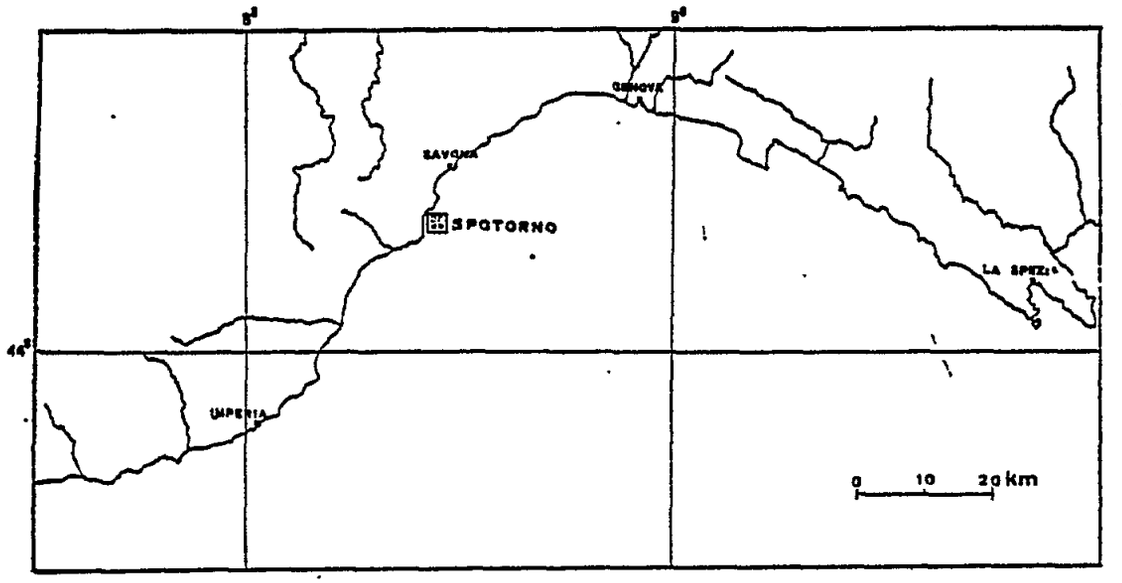

Fig. 1. Sighting localities of *Rhizostoma pulmo* (in shore) and *Cotylorhiza tuberculata* (two miles off shore)

Other portions of the dried material were subjected to lipid extraction according to Folch *et al.* (1957) method, partly modified. Samples were placed in containers with a chloroform/methanol mixture (2:1 v/v), homogenized and placed in ultra-sound bath for 5 min., left at ambient temperature for 2.5 hours and filtered with paper previously washed with chloroform. Filtrates were placed in a separatory funnel with KCl 0.05 M, in a volume equal to 20% of the extraction mixture, shaken and maintained at 4°C for one night to separate the two phases.

Chloroformic phases were placed in a vacuum test-tube and concentrated to dryness. Extracts were dissolved with benzene and put in a reaction test-tube (Supelco) which had previously been weighed. After vacuum evaporation, test-tubes were weighed until a constant weight was obtained, to determine the extract quantitatively.

Fatty acids were analyzed, after previous methylation with BF_3 -methanol (Supelco) through a gas cromatograph Hewlett Packard Mod. 5830 with a double column with FID, according to the method we had used for the zooplankton (Metcalfe and Schimitz, 1961).

3. RESULTS

Table 1 presents the dosage results. The dry weight in *R. pulmo* is globally about 5% of the fresh weight: the value of dry weight is similar in the oral arms and in the gonads while in the bell it is lower in comparison with the other structures.

In *C. tuberculata* dry weight appears more variable than in *R. pulmo* and still widely superior to 5% of fresh weight. Gonads have the highest value of dry weight of all structures examined (approximately 8%).

Table 1. Dry weight (% fresh weight), proteins (% dry weight), lipids (% chloroformic extract, respect to dry weight), * fatty acids (% dry weight), ** fatty acids (% extract) in various *Rhizostoma* and *Cotylorhiza* structures

SPECIES	STRUCTURE	DRY WEIGHT %	PROTEINS %	LIPIDS %	FATTY * ACIDS %	FATTY ** ACIDS %
Rhizostoma pulmo	BELL	3.80	8.70	0.70	0.12	16.30
	MARGINAL BELL	4.53	13.73	0.96	0.24	25.40
	ORAL ARMS	5.13	27.00	0.80	0.22	25.90
	GONADS	5.19	18.00	1.24	0.42	33.40
Cotylorhiza tuberculata	BELL	6.70	11.98	0.70	0.21	29.40
	MARGINAL BELL	5.94	7.56	0.47	0.09	20.30
	ORAL ARMS	5.67	20.00	6.40	3.60	55.30
	GONADS	8.10	36.84	5.97	3.04	51.00

In *R. pulmo*, oral arms have a high protein content in percentage which is superior to both gonads (around 2/3) and bell (around 1/3). In *C. tuberculata* the protein content is very high and clearly superior to that of oral arms and still more to that of the bell.

The chloroformic extract results were sufficiently constant for the dry weight of different structures in *R. pulmo*, while the results of fatty acids gas chromatographic analysis show a greater variety in the different structures compared to the dry weight. In fact, the bell has a low content in fatty acids, while of the examined structures the gonads have a higher fatty acid content.

In *C. tuberculata* the bell chlorophormic extract and fatty acids are present in low concentrations compared to the dry weight (inferior to 1%), while extract is around 6% in the other structures; marginal bell presents, as is also the case for proteins, an inferior extract and fatty acids content.

The gas chromatographic analysis shows a high lipid concentration in the oral arms and gonads: in these two parts the weight of fatty acids is superior to 50% of the chloroformic extract.

It should be pointed out that in the oral arms of *C. tuberculata* we have found a considerable presence of chlorophyll in the chloroformic extract. Regarding fatty acids, the gas chromatographic analysis has

shown the presence of fatty acids already emphasized by other authors for *R. pulmo* and other species (Nakel and Mastronicolis, 1983; Sipos and Ackman, 1968). In particular, the saturated acids with 14, 16 and 18 carbon atoms, the monounsaturated acids with 16 and 18 carbon atoms and some polyunsaturated acids with 18, 20 and 22 carbon atoms were identified. Substantial differences in single fatty acid percentages, in comparison to the total fatty acids in the various structures of every jellyfish, were not shown. *R. pulmo* shows a higher percentage of polyunsaturated fatty acids (40.8-51.8%) than *C. tuberculata* (26.6.-33.4%).

In *C. tuberculata* the monounsaturated fatty acids always exceed 15%, unlike *R. pulmo*, which presents a content inferior to 10% in all its structures. In the *C. tuberculata* bell, we found remarkable concentrations of saturated fatty acids, particularly palmitic acid (31.0-33.7%).

4. DISCUSSION

The data reported are preliminary and consequently do not permit definitive evaluations of biochemical composition of the species examined. Nevertheless, with respect to the data available in literature, some considerations about the examined substance variations in the single species, and particularly in the structures considered, are possible.

In *R. pulmo* we noted that the water content of the single structures is variable in a very restricted interval (94.8-27.0% of the dry weight), while Ceccaldi *et al.* (1976) reports for the whole specimen a value of 8.6%. Ceccaldi and Doumas (1965) states that the protein content varies quantitatively and qualitatively during organism development.

The chloroformic extract is about 1% of the dry weight while Ceccaldi (1978) reports a lipid content of approximately 3.5%. Values obtained show that the fatty acids content in gonads is significantly higher than in other structures.

For *C. tuberculata* our results reveal a water content varying between 91.9 and 94.3%; these values could mean for this species a lower water content than for other species. The organic matter content appears higher than in other species. Proteins vary from 7.6% to 36.8% in the different structures and chloroformic extracts vary from 0.5% to 6.4%. The organic matter content of gonads is remarkable in comparison to other structures. Such a high content can suggest an active reproductive state of this jellyfish at the moment of capture. Similar considerations were expressed by Shenker (1985) on the basis of his studies on *Chrysaora fuscescens.*

Besides, it is important to point out that the organic matter content of gelatinous macroplankton is influenced by trophic conditions (Larson, 1986). We believe therefore that the observed differences between the two species examined can appear significant; however more extensive research is required, especially with regard to the developmental and reproductive states, the physiological conditions and the trophic relationships in the marine environment.

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METHODS FOR ISOLATING THE TENTACULAR NEMATOCYSTS OF THE LION'S MANE JELLYFISH, Cyanea capillata

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ABSTRACT

A multistep procedure was devised for isolating undischarged nematocysts from the Lion's Mane Jellyfish, *Cyanea capillata*. Sieved nematocysts were separated from insoluble tissue debris by low-speed centrifugation in a Percoll medium. The four major types of tentacular nematocyst were then resolved by isopycnic sodium diatrizoate density gradient centrifugation in a preparative ultracentrifuge. The isolated nematocysts were resistant to most chemicals but could be disrupted with a French Press, Braun homogenizer, or low clearance Potter-Elvejhem homogenizer. For the first time, the influence of various density gradient media on nematocyst aggregation was analyzed.

1. INTRODUCTION

Jellyfish stings are a medical problem throughout the coastal areas of the world, although the severity of human pathological reactions varies considerably according to the envenomating species. Most stings only cause localized inflammation, itching, pain, and possibly superficial dermonecrosis (Burnett *et al.*, 1986). The most extreme reactions occur from contact with Indopacific cubomedusae such as *Chironex fleckeri*, which can cause death within a few minutes. Development of a rational therapeutic approach to these local and systemic responses has been hindered by the relatively slow progress that has been made in the past two decades in elucidating the biochemical and pharmacological properties of the active constituents of jellyfish venoms. Although several laboratories have investigated various jellyfish venoms, none has yet completely purified the toxic factors to the point that the biochemical and pharmacological properties of a single toxin could be determined, as has been done for some other cnidarian toxins (Kem, 1988a). One reason is that jellyfish (and hydrozoan) toxins are amongst the largest protein toxins produced by any living organism (Kem, 1988b). Their reported molecular sizes vary from 20,000 to 600,000, with most toxins exceeding 150,000 (Burnett and Calton, 1987). Although in most instances the protein toxins were obtained from mixed isolated nematocyst suspensions, sometimes the toxins were obtained from tentacular homogenates. In the latter situation, one cannot be sure that the toxin(s) originate(s) in nematocysts. Using venom obtained from *Chironex* nematocysts purified by density gradient centrifugation, Endean (1987) failed to detect a hemolytic protein previously reported in tentacular homogenates of this species by Crone and Keen (1969). Since jellyfish stings are assumed to result entirely from discharged nematocysts and their contents, tissue-derived constituents are unlikely to be of medical significance.

Cyanea capillata, the largest known scyphozoan, is found in all of the major oceans of the world and causes numerous stings, some of which require medical treatment. Rice and Powell (1972) investigated *Cyanea* nematocysts and venom, primarily from a morphological viewpoint. They obtained a toxic fraction with an intraperitoneal LD_{50} of 6 microgrammes per gramme mouse weight. Walker (1977) carried

out the most extensive analysis of the nematocyst venom of this species to date. He reported the presence of a single active protein fraction with an apparent molecular size of about 70,000 daltons on a Sephadex column. This fraction irreversibly contracted all types of vertebrate muscles (smooth, cardiac and striated), increased skin capillary permeability and caused dermonecrosis. In contrast to many scyphozoan toxins, it failed to lyse human erythrocytes.

Recently, we initiated an investigation of *Cyanea* nematocyst venoms. Our ultimate goals are to: (a) identify the toxic constituents of the different nematocyst types; (b) purify the toxins; (c) determine their molecular structures; (d) investigate their mechanisms of action upon cell membranes and (e) develop a better pharmacological rationale for jellyfish sting therapy. In this paper, we describe simple, efficient procedures for harvesting tissue-free, undischarged *Cyanea* nematocysts and subsequently obtaining highly enriched suspensions of each of the four major nematocyst types by density gradient centrifugation. A more complete account of this investigation, including pharmacological evaluations of venoms released from different purified nematocyst fractions, will be reported in the future.

2. MATERIALS AND METHODS

Animals. Large numbers of *C. capillata* were collected from the Gullmar Fjord at Kristineberg Marine Station, Fiskebäckskil, Sweden, during July 1987. In addition, some *C. capillata* were netted at the Whitney Marine Laboratory, University of Florida, during April 1987. Crabs (*Carcinus maenas*) used in paralysis bioassays and codfish (*Gadus morhua*) used in hemolysis assays were provided by the Kristineberg Marine Station staff.

Supplies. Percoll was purchased from Pharmacia (Uppsala, Sweden); caesium chloride and sodium ditrizoate from Sigma (St. Louis, USA); nylon (10 and 52 micron) and polyethylene (230 micron) sieves were purchased from Spectrum Medical Industries, Inc. (Los Angeles, USA); remaining chemicals were obtained from Labasco (Stockholm, Sweden).

Bioassays. 20-30g *Carcinus* were injected at the base of the third walking leg with 0.1 ml extract (dissolved in 0.5 M NaCL, 0.01 M Tris, pH 7.4) per 10g crab. Paralysis was measured by righting ability 15 min after injection, as previously described (Kem, 1976). Lethality was assessed after 12 hr. Hemolytic activity was evaluated as previously described (Kem and Blumenthal, 1978) except that codfish erythrocytes were used at room temperature.

Nematocyst evaluation. Small pieces of live fishing tentacles were exposed to a test solution in a small beaker or on the surface of a microscope slide for at least 30 min before adding the cover slip and observing the percentage discharged with an interference microscope. In most cases, the samples were periodically observed for discharge over a period of 4-6 hr. *Cyanea* nematocysts were classified according to Ostman (this volume), except that the birhopaloids were not separated from the euryteles.

Nematocyst aggregation. Clumping measurements upon Percoll-purified whole nematocyst suspensions (containing all nematocyst types) were carried out with a hemacytometer using a phase-contrast microscope. All test suspensions contained the same nematocyst concentration (8×10^7 ml^{-1}) and were held at 5°C overnight to simulate the density gradient ultracentrifugation conditions.

Density gradient centrifugation. Percoll gradients were generated in a fixed angle centrifuge rotor at 25,000g for 2 hr (5°C). After removing the aqueous meniscus solution, the nematocyst suspension was then layered on top and the tube spun at 8,100g for 2 hr.

Caesium chloride and sodium diatrizoate linear gradients containing 5 mM sodium phosphate (pH 6.8) were prepared with a plastic gradient maker. About 1.0 ml nematocyst suspension, prepared in a 1:5 dilution of the initial gradient medium, was added to the top of each tube, which was then spun for at least 8 hr at 112,000g in a Beckman L-265 preparative ultracentrifuge. The tube contents were collected from the tube bottom in 0.5-1.0 ml fractions with a peristaltic pump. After measuring the densities of these fractions, the gradient media were removed from the nematocysts by washing with 1 M glycerol; each time the nematocysts were sedimented by centrifuging at 2,500g for 10 min.

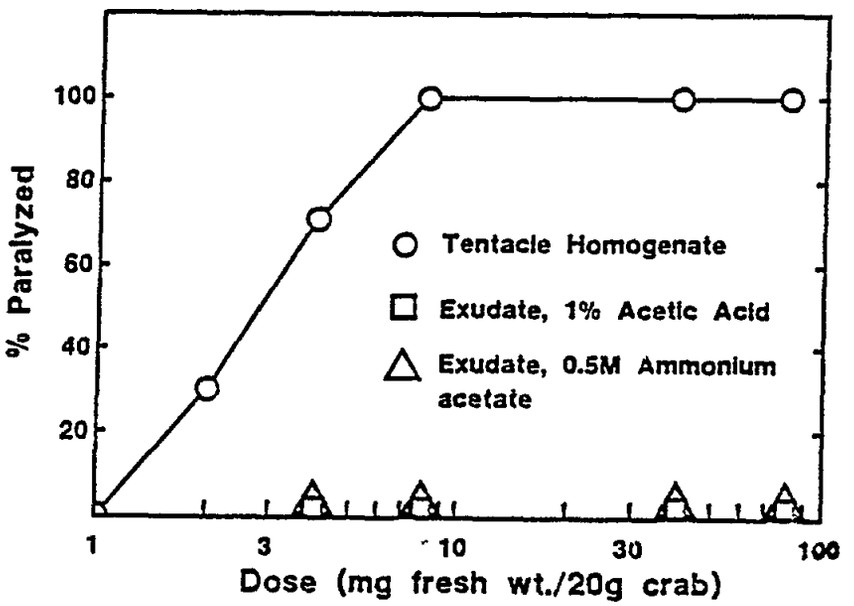
3. RESULTS

Initial attempts at harvesting venom from intact tentacles. We initially tried to obtain venom directly from live *Cyanea* fishing tentacles using two types of chemical stimuli. Acetic acid is known to discharge anthozoan (Pantin, 1942) and hydrozoan (Ostman, 1982) tentacular nematocysts. Also, 1% acetic acid

efficiently releases the integumentary protein toxins of a nemertine worm (Kem, 1976). When *Cyanea* tentacles were exposed to 1% acetic acid, a milky (turbid) suspension resulted over 2-4 min. However, when the neutralized (with NaOH) fluid was injected in *Carcinus* it was found to lack paralytic activity. Either no toxins were released or they were rapidly inactivated in the acetic (pH3) acid solution (Fig. 1). We then attempted to release venom from fishing tentacles with 0.5 M ammonium acetate, a salt concentration which is approximately isotonic with sea water. Since ammonium ions are very similar to potassium ions and thus depolarize cell membranes, we thought this might stimulate venom release. The resulting fluid displayed only marginal toxicity, so we needed to remove the ammonium acetate (which is paralytic alone at this concentration) by dialysis (1,000 MW cut-off) at 5 °C overnight. When *Carcinus* was injected with the resulting retentate, no paralysis occurred. As an experimental control, we homogenized an equal weight of fishing tentacles with a Turrax mixer for 30 sec. After removing the insoluble materials by centrifugation at 5°C, various dilutions of the supernatant were injected into *Carcinus*. A dose equivalent to about 3 mg fresh weight of tentacles was sufficient to paralyze 50% of the 20g crabs injected (Fig. 1). In contrast, extracts obtained with 1% acetic acid and 0.5 M ammonium acetate were inactive, even at doses equivalent to 100 mg fresh weight tentacles. Thereafter, we focused on isolating undischarged nematocysts which could subsequently be ruptured to yield relatively uncontaminated venom.

Isolation of undischarged nematocysts. In order to remove tissues, we initially tried tentacle autolysis (Lane and Dodge, 1958) in sea water at 5°C for two days and subsequent vacuum filtration through progressively finer sieves (230, 52, then 10 microns). The nematocyst fraction was concentrated by unit gravity sedimentation in large graduate cylinders, as sieving through the plastic screens was quite slow. Much soluble material, probably including proteolytic enzymes, was thus removed. This method yielded adequate quantities of nematocysts, but required 3 days and furthermore it was unpleasant to work with large quantities of deteriorating tissues! In addition, the resulting nematocyst suspensions contained bacteria, were gray to black in colouration, and failed to paralyze *Carcinus*.

Therefore, we utilized a more rapid and pleasant procedure which involved the soaking of live tentacles in 4 vol of 1 M glycerol (previously shown by Yanagita (1959) to stimulate the extrusion of undischarged sea anemone nematocysts) for 1 hr followed by 30 sec homogenization in a Turrax mixer. The nematocysts



Effectiveness of different methods for releasing Cyanea venom

Fig. 1. Crab (*Carcinus*) paralytic activity of *Cyanea* fishing tentacles exudates released by acetic acid or ammonium acetate solutions relative to a whole tentacle homogenate

were concentrated by unit gravity sedimentation at 5°C, sieved, and finally centrifuged at 2,500g for 10 min. The resulting gray-white pellet was still contaminated with tissue debris.

Removal of tissue debris from nematocysts by centrifugation in Percoll. McKay and Anderson (1988) utilized this osmotically inactive high density medium to isolate nematocytes and nematocysts from tentacles of a variety of cnidarian species. Nematocysts sediment to the bottom of a centrifuge tube containing a mixture of 3 volumes Percoll per volume of crude nematocysts suspension, whereas tissue debris remains near the meniscus. The final conditions we adopted for *Cyanea* nematocyst isolation are summarized in Fig. 2. Although most scyphozoan (and apparently hydrozoan) nematocysts seem unaffected by hypotonic media (in contrast with anthozoan nematocysts), the glycerol concentration in the Percoll medium was made approximately isosmotic in order to minimize nematocyst discharge. Using this procedure, we obtained nematocyst suspensions which were remarkably free of tissue debris in most instances. Immediately after decanting the Percoll supernatant, the nematocysts were washed twice with 1 M glycerol-20 mM Tris HCL (pH 7.4)-1 mM $CaCl_2$ medium to remove residual Percoll. Weber *et al.* (1988) have reported that Hydra nematocysts often discharge if exposed to the Percoll medium for a long period of time. Also, it should be noted that pure Percoll is alkaline and must be adjusted to neutral pH before use.

Figure 3 shows several nematocyst suspensions obtained by Percoll centrifugation. The mixed nematocyst population obtained by Percoll centrifugation of a Florida *Cyanea* sample contained 50% a-isorhizas, 35% euryteles, 10% O-isorhizas and 5% A-isorhizas.

Density gradient centrifugation of Cyanea nematocysts

Burnett and Calton (1973) reported the resolution of *Chrysaora* isorhizas and euryteles on caesium chloride gradients, while Endean and Rifkin (1975) separated two types of *Chironex* nematocysts in a Urografffin gradient. Thus, we attempted to resolve the different *Cyanea* nematocyst types by similar procedures. Percoll gradients seemed advantageous since they do not produce a significant osmotic pressure and linear gradients can be generated by centrifugation at relatively low speeds. In this way, we were able to obtain a practically homogeneous suspension of the large A-isorhizas at 1.10 g ml^{-1} density (Fig. 4). The more dense Percoll fractions unfortunately contained a mixture of different nematocysts, often in clumps. Aggregation probably prevented satisfactory separation of these nematocyst types.

The relative "clumping" effect of different centrifugation media upon Percoll-isolated nematocyst suspensions was then investigated (Fig. 5). Aggregation strongly depended upon the medium. Calcium chloride (20 mM) enhanced clumping. On the other hand, calcium removal by the calcium-chelator EDTA caused some nematocyst discharge (particularly the a-isorhizas) which also probably enhanced aggregation. Sucrose and diatrizoate density gradient media produced only small amounts of nematocyst aggregation; this indicated that they might be particularly suitable density gradient media. In the absence of salts, 60% sucrose produced little nematocyst aggregation. Unfortunately, a saturated sucrose solution was insufficiently dense to prevent the complete sedimentation of *Cyanea* nematocysts.

Although *Cyanea* nematocysts showed considerable aggregation (Fig. 5) in high concentrations of caesium chloride, we nevertheless tested the ability of a shallow gradient of this salt to separate the nematocyst types. We only obtained two overlapping absorbance peaks, each containing two nematocyst types. The lighter peak (1.30 gml^{-1}) actually contained two partially resolved populations of O-isorhizas and euryteles, while the denser (1.32g ml^{-1}) peak contained A- and a-isorhizas.

Sodium diatrizoate was then tested. With this gradient medium, we were able to obtain highly enriched suspensions of each nematocyst type (96% a-isorhizas, 75% euryteles, 56% O-isorhizas, and 50% A-isorhizas) in a single centrifuge run (Fig. 6). The isopycnic densities (measured at room temperature) of the four nematocyst types in this medium were (g ml^{-1}): A-isorhiza, 1.26; O-isorhiza, 1.28; eurytele, 1.29; and a-isorhiza, 1.32. It is interesting that the relative densities of the four nematocyst types in the diatrizoate gradient varied inversely with their size. This suggests that nematocyst density may be largely determined by the relative contribution of the capsule wall to the nematocyst mass. The least dense A-isorhiza fractions (12-15 in Fig. 6) were still contaminated by the other three major nematocyst types. This was probably due to the aggregation or clumping of different nematocyst types. In the presence of high concentrations of the A-isorhizas, such clumps would have a density similar to these nematocysts. It is possible that some of these nematocysts possessed fragments of adhering lipid bilayer membrane, which would make them less dense.

SCHEME FOR ISOLATING *CYANEA CAPILLATA* NEMATOCYSTS AND NEMATOCYST VENOMS
(All steps done at 5°C)

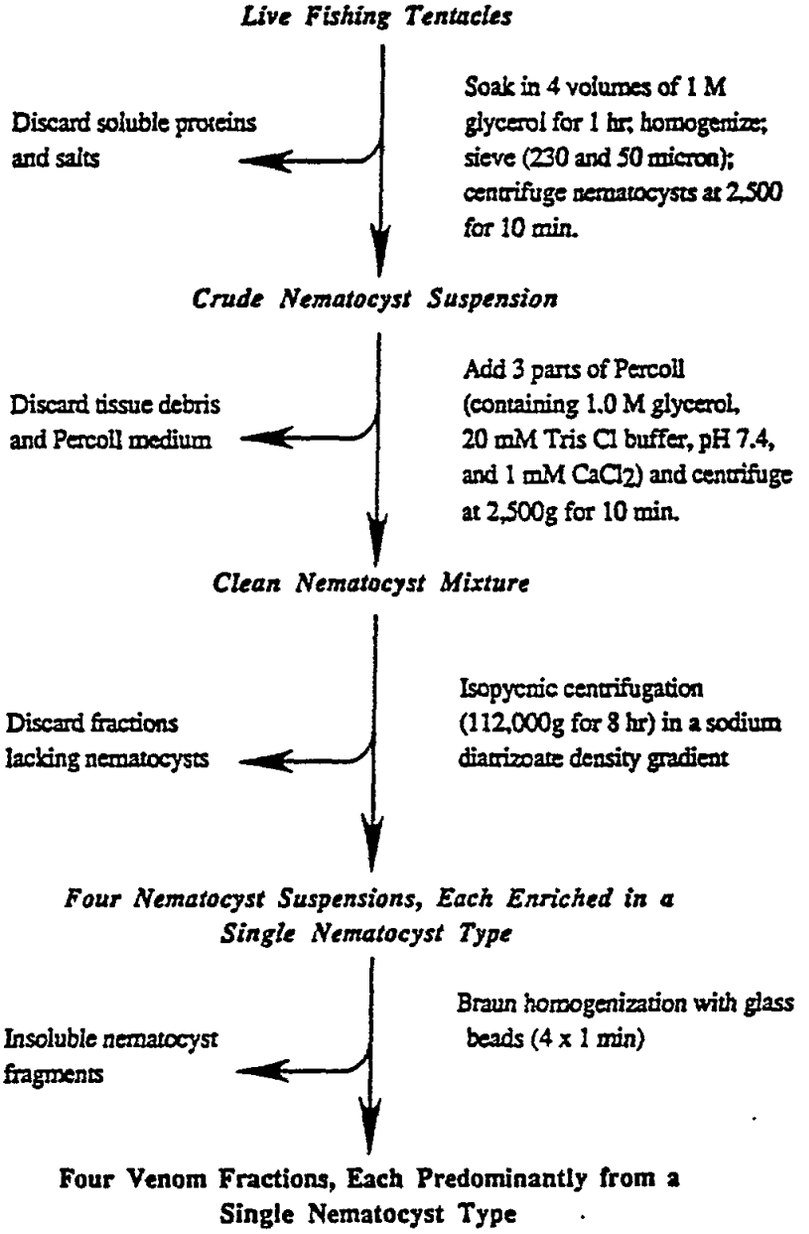


Fig. 2. Flow diagramme of procedure adopted for isolating the four major types of *Cyanea* nematocysts

It is interesting that the A-isorhiza density differed considerably in the two density gradient media, whereas the other nematocyst types displayed little dependence upon the medium.

Venom release from nematocysts. Isolated nematocysts could not be stimulated to discharge by a variety of chemical agents, in contrast with their ability to discharge in situ (Table 1). High (0.5 M) concentrations of the disulfide reducing agent dithiothreitol eventually dissolved capsules and released their contents. Fig. 3.4 shows the dissolution of several A-isorhizas, which were most sensitive to dithiothreitol. Although not yet tested, it is anticipated that this treatment would also inactivate nematocyst protein toxins.

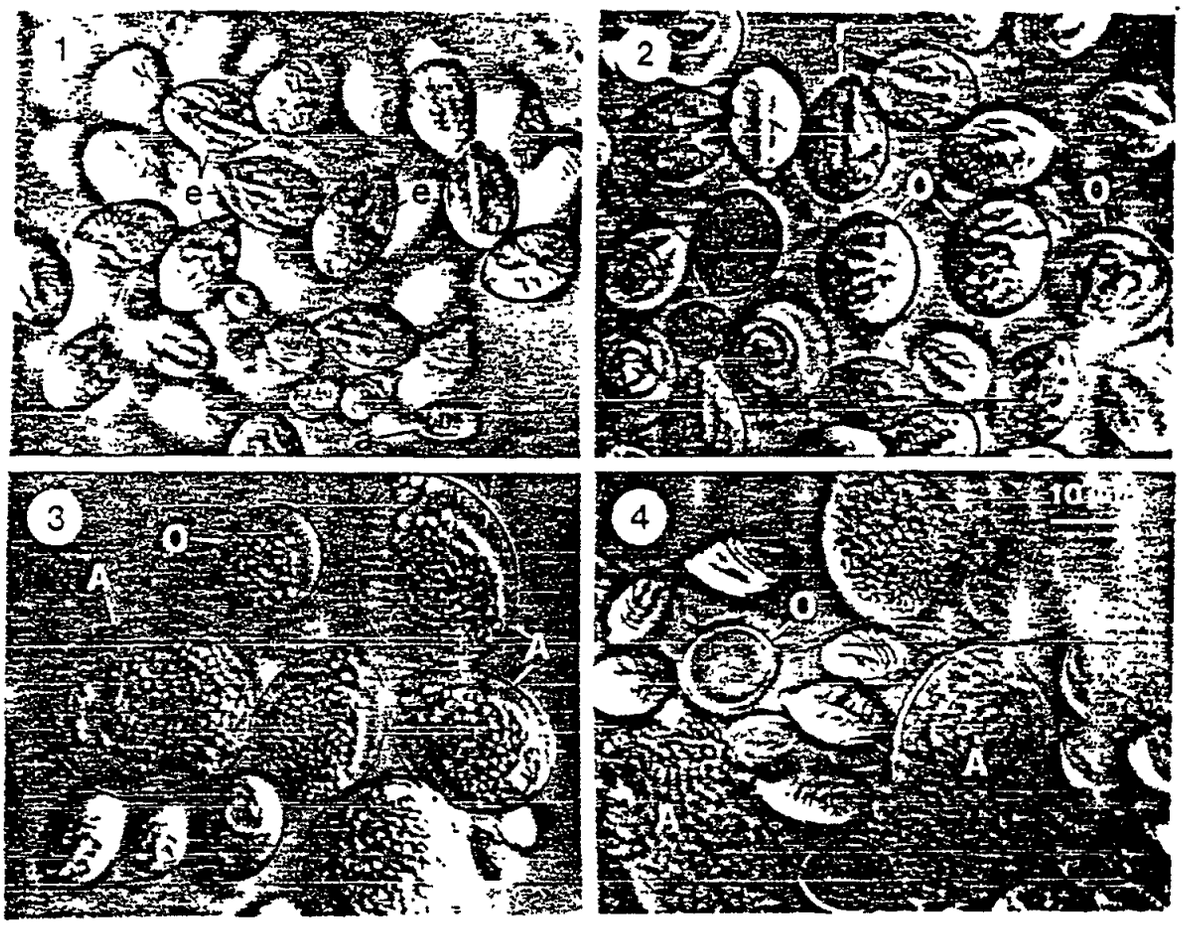


Fig. 3.Fig. 3 Interference microscope photographs of tissue-free *Cyanea* nematocyst suspensions obtained by centrifugation in Percoll. Abbreviations: a,a-isorhiza; A,A-isorhiza; b, birhopaloid; e,eurytele; O,O-isorhiza. Part 4 is a photograph showing A-isorhiza dissolution by 10^{-2} M dithiothreitol (Magnification 1,000X)

The neutral detergents digitonin, emulgen and Triton-X-100 failed to significantly discharge tentacular nematocysts, even though they dissolved the tentacular tissues. In the future, they may be useful for selectively dissolving tissue debris in nematocyst suspensions. The calcium ion sequestering agents sodium citrate and sodium EDTA provoked considerable nematocyst discharge from intact tentacles. They may be a useful means of collecting *Cyanea* venom.

The relative effects of several other irritating substances were also tested upon individual types of *Cyanea* nematocysts (Table 2). Although the nematocyst capsule wall is thought to be composed of a collagen-like protein, collagenase alone failed to disrupt the capsule wall. Potassium iodide was tested because Salleo *et al.* (1984) found it to be very effective in discharging isolated *Pelagia noctiluca* nematocysts. However, *Cyanea* nematocysts were unaffected by this chaotropic salt.

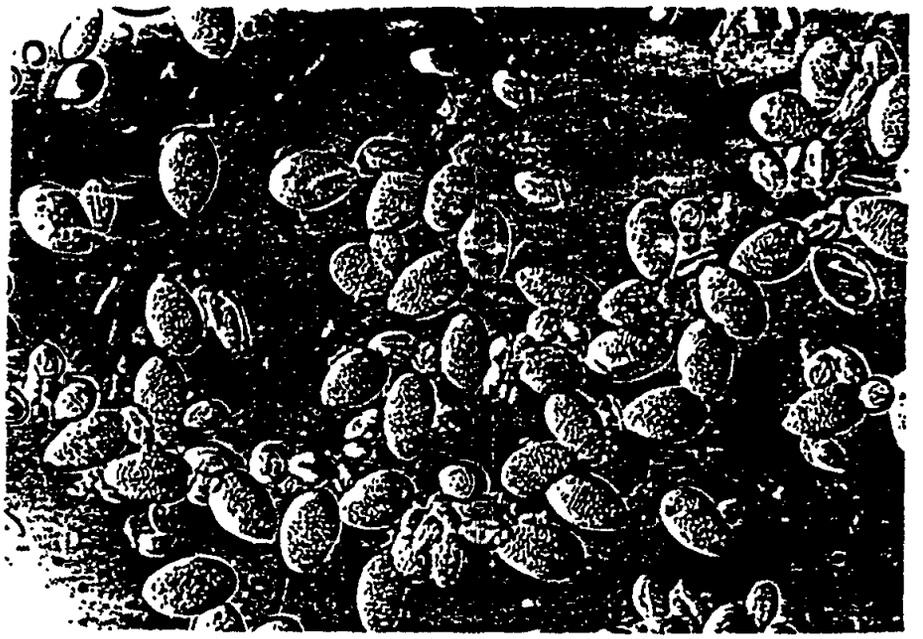


Fig. 4. Nomarski microscope photograph of a *Cyanea* nematocyst Percoll density gradient fraction (d = 1.09 g ml^{-1} enriched in A-isorhizas (Magnification 400X).

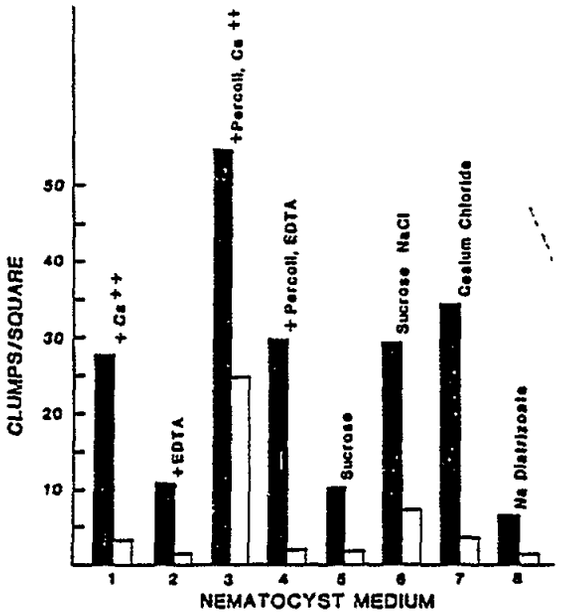


Fig. 5. Influence of density gradient medium composition upon *Cyanea* nematocyst aggregation. Dark bars indicate the frequence of clumps containing at least 3 nematocysts, while the light bars indicate frequence of clumps containing 10 or more nematocysts. The clumping estimates are based upon a density of 500 nematocysts per hemacytometer square (volume 6.25 x 10^{-6} cm^3). Conditions: (1) 1 M glycerol-0.020 M $CaCl_2$; (2) 1 M glycerol - 0.020 M Ba_2 EDTA; (3) 1 M glycerol - 0.020 M $CaCl_2$ in 3 parts Percoll - 1 part H_2O; (4) 1 M glycerol - 0.020 M Na_2 EDTA in 3:1 Percoll-H_2O; (5) 60% sucrose; (6) 60% sucrose - 0.10 M NaCl; (7) Caesium chloride (d = 1.3 g ml^{-1}); (8) Sodium diatrizoate (d = 1.3 g ml-1).

We then turned to physical methods of nematocyst disruption (Table 2). Potter-Elvehjem homogenization, sonication at 400 watts and extrusion through a French Press at 18,000 pounds per square inch (psi), only partially succeeded in rupturing the larger nematocysts (A-isorhizas and O-isorhizas). Braun homogenization (shaking the suspension with glass beads) and French Press extrusion at 26,000 psi were the only means of disrupting practically all nematocysts. Unfortunately, these two instruments were unavailable for our use at the two marine laboratories where most of these experiments were carried out. Recently, we did however succeed in disrupting most *Cyanea* nematocysts using two simpler methods: (1) grinding with a low clearance Potter-Elvehjen homogenizer and (2) homogenization by shaking the nematocysts with glass beads (Table 2). These seem to be the most practical methods for obtaining *Cyanea* nematocyst venoms.

4. CONCLUDING REMARKS

Isolation of undischarged nematocysts is essential for obtaining pure venom uncontaminated by tissue constituents, including pharmacologically active substances that might be otherwise mistaken as nematocysts toxins. Since the nematocysts of different jellyfish species differ in their ability to discharge (or rupture), the isolation procedure must be empirically adapted to the species under consideration. Microscopic observation of nematocyst condition is the best way in which to monitor the isolation. Since jellyfish nematocyst toxins are large, labile proteins, it is important that the entire nematocyst isolation and rupture procedure be carried out quickly and at low temperature in order to minimize toxin inactiva-

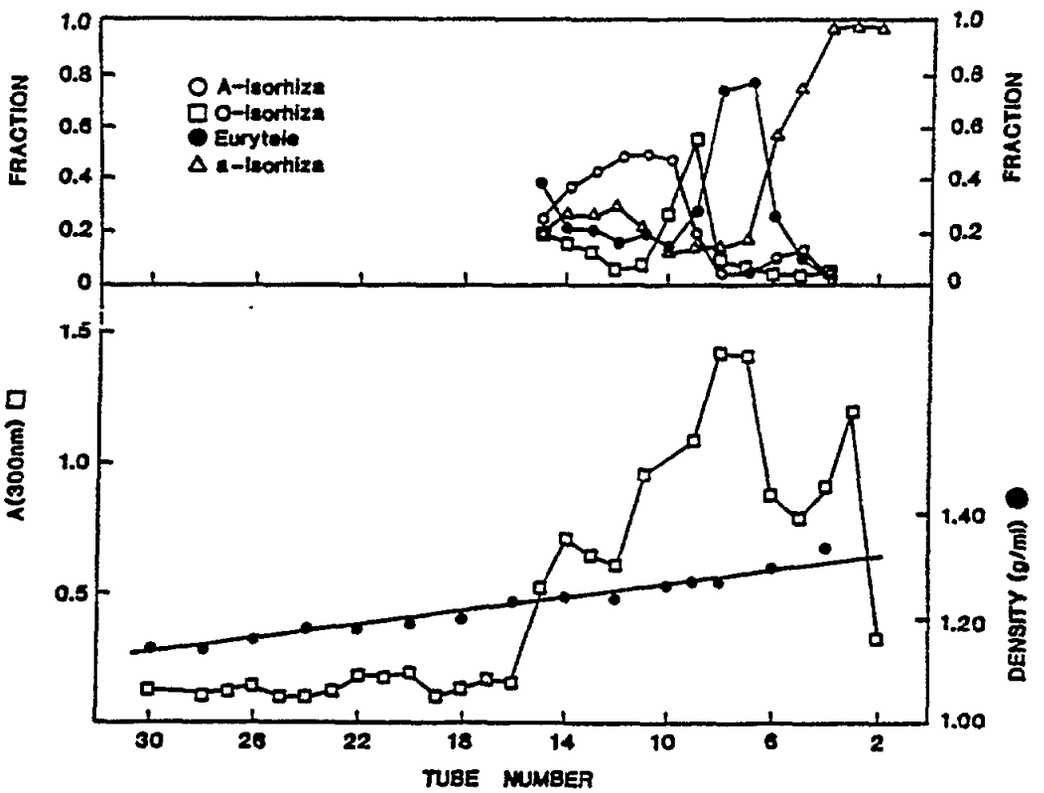


Fig. 6 Separation of the four major types of Cyanea fishing tentacle nematocysts on a linear density gradient composed of sodium diatrizoate (0.6 - 1.0 X saturation) and 0.005 M sodium phosphate, pH 6.8. Tube volume was 38 ml; fractions are numbered from the bottom to the top of the gradient, in order of recovery (max. centrifugal force, 112,000g, 8 hr, 5°C). The nematocysts were detected by measuring their absorbance at 300nm. The fraction of each type of nematocyst is indicated at the top

Table 1. Relative Effectiveness of various Chemical Treatments in causing venom release from Cyanea nematocysts (fresh fishing tentacles and percoll-isolated fishing tentacle mixed nematocysts were used)

Chemical	Nematocyst Preparation	
	Tentacular	Isolated
Detergents		
Cetyltrimethylammonium (1%)	0[1]	0
Digitonin (1%)	+	0
Emulgen (1%)	0	0
Sodium Deoxycholate (1%)	++	0
Sodium Dodecylsulfate (1%)	++	0
Triton-X-100 (1%)	0	0
Isotonic Media		
Glycerol (1 M)	0	0
Potassium Iodide (1 M)	0	0
Sodium Citrate (1 M)	++	0
Sucrose (1 M)	0	0
Sucrose (1 M) + EDTA (0.02 M)	++	0
Disulfide-Reducing Agents		
Dithiothreitol (10^{-2} M)	++	+
Dithiothreitol (10^{-1} M)	+++	+++
Mercaptoethanol (10^{-2} M)	0	0
Other		
Acetic Acid (1%)	++	0
Acetic Acid (10%)	+++	0
Collagenase (10 mg/ml, 5 hr)	0	0

1. Relative measures of venom release: 0, 0-10% (discharged, broken, or solubilized): +, 10-40%, ++, 40-70%, +++, 70-100%.

Table 2. Effects of certain chemical and mechanical treatments upon individual types of *Cyanea* fishing tentacle nematocysts.

Treatment	Percentage Discharged or Ruptured			
	a-Isorhiza	A-Isorhiza	O-Isorhiza	Eurytele
Control	2	4	7	6
Chemicals				
Acetic Acid (10%)	0	10	4	14
Collagenase (10 mg/ml)	4	2	8	4
Digitonin (1%)	4	4	6	4
Emulgen (1%)	2	6	2	9
Potassium Iodide (1 M)	3	8	2	11
Sodium Deoxycholate (1%)	3	9	8	10
Sodium Dodecylsulfate (1%)	3	1	9	6
Mechanical				
Bead-Beater (4 min)	90	98	95	90
Braun Homogenization (4 min)	78	96	96	83
French Press Extrusion (18,000 psi)	31	85	64	51
Potter-Elvehjem Grinding (20X)	45[3]	70	69	51
Sonication (400 W)	15	36	30	25

1. In all cases the total number of nematocysts inspected per sample exceeded 100.
2. A BioSpec (Bartlesville, Oklahoma, USA) Mini-Beadbeater with 0.5 mm glass beads was used.
3. A Kontes (Vineland, New Jersey, USA; K-885450) all glass P-E grinder, custom-made for minimal clearance, was used.

tion. The addition of protease inhibitors may improve the yield and stability of the jellyfish toxins so obtained.

The ability to obtain nearly homogeneous samples of the major types of nematocysts in *Cyanea* provides an excellent opportunity to investigate the biochemical and pharmacological differences among the nematocysts and their venoms.

5. ACNOWLEDGMENTS

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RATES OF METABOLISM OF JELLYFISH AS RELATED TO BODY WEIGHT, CHEMICAL COMPOSITION AND TEMPERATURE

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1. INTRODUCTION

Interest in the ecological importance of gelatinous marine zooplankton has been increasing in recent years since they are widespread and often abundant members of marine planktonic communities. Some recent studies suggest that jellyfish can be important consumers in both neritic and open ocean communities and may have a significant impact as nutrient recyclers (Alldredge, 1984). Some species, namely *Aurelia aurita* and *Cyanea capillata* are even considered to have a regulating effect in pelagic ecosystems during summer (Lindahl and Hernroth, 1983). *Pelagia noctiluca* (Forskal) has been abundant at times in the Mediterranean Sea, especially in summer (Mayer, 1910). Its exceptional density in various areas - coastal and offshore - of the Mediterranean since 1977 has attracted special interest and concern, as it may have an impact on different human activities in this region.

The main aim of our study was to determine the metabolic rates of *P. noctiluca* as related to temperature, body size and condition, and to examine the relative chemical composition of bodies as a base for estimates of the energetic budgets. Furthermore, some features of *P. noctiluca* distribution and the ecological significance of this species in the Northern ADriatic were studied.

2. MATERIALS AND METHODS

Field observations and sample collection

The distribution pattern of *P. noctiluca* was studied by observations of free-swimming, undisturbed animals which were made from the shore, boats and by scuba divers.

To minimize damage to experimental animals, we collected them in jars by hand. On several occasions we sampled *P. noctiluca* by random sweeping with a net to determine size composition.

Zooplankton was sampled vertically from the bottom to the surface with a 200 μ mesh net (mouth opening 0.5 m^2, length 2.6 m) and samples were size fractionated by means of a 500 μ mesh screen to give size groups 500 μ and 200-500 μ.

Excretion and respiration rates of *P. noctiluca* were measured for a variety of sizes over a temperature range from 12 to 25°C. All experiments were performed on individual organisms within less than one hour after capture.

The animals were carefully transferred to 2 l glass containers filled with filtered (Whatman GFC) seawater, sealed and incubated in the dark at a constant temperature. The oxygen uptake, ammonium and phosphate release rates were estimated by differences between jars with animals and controls. The experimental temperatures approximated the ambient values and varied from 12°C to 25°C. At the end of the incubation period, subsamples for oxygen and excretory products were taken and analyzed immediately according to standard methods (Grasshoff, 1976).

Various measures of body size have been determined: bell diameter (at the interredialia), wet weight (after blotting), dry weight (after drying at 60°C to constant weight) and their relationship calculated using the equation $W = a\,D^b$ (W = wet weight, dry weight; D = diameter). The "condition" of animals at different temperatures was estimated using the equation:

$CF = DW(g)x10^2 / D\ (cm)^3$ (Fulton's condition factor)

Animals for chemical analyses were pooled according to their bell diameter, packed in small plastic bags, deep frozen and stored at -20°C. The samples were later freeze-dried and kept in a desiccator with silica gel until they were analyzed. Dried material was homogenized; total lipids were determined in chloroform: methanol extract following the recommendations of Barnes and Blackstock (1973); total proteins were extracted in NaOH and estimated by the Comassi blue method (Bradford, 1976) with kazein as standard and the carbohydrates by the Dubois *et al.* method (1956).

The carbon and nitrogen content of dried pulverized organisms were determined using a Coleman C and N analyzer at combustion temperatures of 720°C and 870°C respectively. The determination of phosphorus was made by digestion with a mixture of perchloric and nitric acid and followed by colorimetric estimation of the phosphate produced (Murphy and Riley, 1962).

3. RESULTS AND DISCUSSION

Respiration and excretion rates

Measurements of the metabolic rates relative to experimental temperature showed a considerable increase with higher temperatures. At 12°C the oxygen uptake rate gave a mean value of 62.2 ±25.0 µol g dry weight^{-1} day^{-1} (n = 6, dry weight range 0.06-1.17 g); at 16°C 108.5 ±54.2 (n = 12, dry weight range 0.17 - 1.65 g); at 19° C 181.0 ± 71.9 (n = 7, dry weight range 0.6 - 1.46g); at 23° C 490.5 ± 284.0 (n = 14, dry weight range 0.35 - 1.19 g); and 25°C 1729.0 ± 33.0 (n = 3, dry weight 0.28 - 0.51).

At 12°C we found higher ammonium (29.7 ±10.3 µol g dw^{-1}d^{-1}) and phosphate (3.6 ± 2.3 µol g dw^{-1}d^{-1}) excretion rates than at either 16°C (13.9 ± 4.0 for ammonium, 1.8 ± 0.7 for phosphate excretion) or 19°C (28.8 ± 6.6 and 2.7 ± 0.7, ammonium and phosphate excretion, respectively). The excretion rates increased to 32.4 ± 13.6 for ammonium and 3.6 ± 0.6 for phosphate at 23°C. However, *Pelagia* sampled at 12°C were not in good condition as seen also from the condition factor (Table 3).

The correlations for respiration and excretion rate vs. temperature (values at 12°C were omitted in the calculations) were highly significant ($p < 0.01$) yielding Q_{10} values of 2.62 to 3.35 in the temperature range from 16° to 23°C.

The relationship between metabolic rate and size is usually expressed by the power function $M = a\,w^b$ (Table 1). Estimates of coefficients b for for some gelatinous zooplankton varied from values close to unity, giving indication that metabolic rate was directly dependent on W (Kremer, 1976; Kremer *et al.*, 1986), to intermediate values (Gyllenberg and Greve, 1979), and values indicative of surface-dependant metabolism (Kremer *et al.*, 1986). A generalized relationship between metabolic rate and body mass for *Pelagia* could not be drawn from our study. The reasons probably lie in the relatively small number of measurements in the lower and upper range of body mass, and in the choice of dry weight as a body mass unit. Ikeda (1985) considers carbon or nitrogen as a superior unit to dry weight when one aims to establish a generalized metabolic rate-body mass relationship. This is especially true for gelatinous animals which have a high ash content.

Some decrease of metabolic rate was observed when the incubation period (animals held without food) was extended from 4 to 16 hours (Table 2); the reduction was more pronounced for the respiration than the excretion rate.

Metabolic quotients O:N (oxygen uptake: ammonium release), O:P (oxygen uptake: phosphate excretion), N:P (ammonium: phosphate excretion) were not statistically different at various temperatures and were pooled to give average values: O:N 9.0 ± 5.4; O:P 91.5 ± 60.2 and N:P 9.5 ± 3.1 These ratios were also largely independent of body mass (r^2 0.4 to 6%).

Table 1. *Pelagia noctiluca*. Regression coefficients (b) and correlation coefficients at four temperatures, estimated by linear regression: $\log y = a + b \log x$ where y = ammonium excretion (µgat day^{-1}), phosphate excretion (µgat day^{-1}), oxygen uptake (µgat day^{-1}) and x = body dry weight (mg).

	Temperature (°C)			
	12	16	19	23
Ammonium excretion				
regr. coeff. (b)	1.058	0.647	0.428	0.687
corr. coeff. (r)	0.904**	0.936**	0.725*	0.552*
Phosphate excretion				
regr. coeff. (b)	0.978	0.558	0.328	0.789
corr. coeff. (r)	0.862*	0.884**	0.754*	0.902**
Oxygen uptake				
regr. coeff. (b)	0.941	0.449	0.206	0.1
corr.coeff. (r)	0.802*	0.359^{NS}	0.229^{NS}	0.252^{NS}

NS = $p > 0.05$
* = $p < 0.05$
** = $p < 0.01$

Table 2. Respiration and excretion rates of individual *Pelagia noctiluca* at 19°C in 4 and 16 hour starvation period (Means ± standard deviations).

Ammonium excretion ($\mu mol\ an^{-1}.\ d^{-1}$)	4^h	48.4 ± 6.7
	16^h	32.1 ± 6.3
Phosphate excretion ($\mu mol\ an^{-1}.\ d^{-1}$)	4^h	6.4 ± 0.9
	16^h	3.0 ± 0.4
Oxygen uptake ($\mu mol\ an^{-1}.\ d^{-1}$)	4^h	696.6 ± 172.1
	16^h	198.1 ± 67.3

The O:N ratio provides some information about the diet of the animal. Our mean ratio of 9.0 suggests that *Pelagia* primarily metabolize protein. The indication of protein-oriented metabolism was supported by the results of biochemical analyses which gave a consistently low lipid content (average 2.2% of dry weight). Low lipid reserves probably explain the decrease of O:N ratio in starving *Pelagia*.

Distribution and ecological significance

Our observations of *P. noctiluca* revealed that this species displays two types of groupings: the first, which we call passive aggregation, was composed of shallow aggregations of lethargic organisms with their umbrellas touching or even superimposed on each other. Passive aggregations often occurred in the form of windrows or slicks offshore and as accumulations in the heads of bays and sheltered parts along the coastline. Actively swimming animals formed subsurface groupings (active aggregations) which had variable shapes, most frequently ovoidal or stretched longitudinally. Spacing between individuals ranged from few dm to few m without any discernable pattern. Passive aggregations were either short-term events or persisted up to a few days; jellyfish were later washed ashore or sank to the bottom. From our observations of active aggregations at the same site for several consecutive days we speculate that a particular group might keep its integrity up to 10 days. When disturbed the passive aggregation reacted only slightly with some individuals increasing pulsation rate for a short time, while medusae in the active aggregation swam away from the source of disturbance but in an uncoordinated fashion. Conventional sampling with the plankton net suggests that ephyrae also aggregate.

Passive aggregations of *P. noctiluca* appear to develop from active ones as a result of reduced activity, for whatever reasons. The cessation of activity may be caused by different factors of which food deprivation and completion of the normal life cycle are probably the most important. The function of active aggregation may be to increase the concentration of gametes and thus maximize reproductive success; grouping is also supposed to afford protection against predation.

Jellyfish have been shown to exert a significant influence on the pelagic ecosystem directly by predatory activity and by release of dissolved materials. In addition, jellyfish can stimulate phytoplankton growth by reducing grazing pressure while feeding upon herbivores and by producing positive feedback on phytoplankton through bacterial regeneration. By combining the *in situ* abundances of *P. noctiluca* and the average respiration data at relevant temperatures, we calculated that the population of this jellyfish respired 3.99 mg C m^{-2} daily during summer and 0.98 mg C m^{-2} daily during winter. Using these data and zooplankton production data from our previous studies we can conclude that during the summer there was not enough zooplankton to satisfy even the respiratory needs of the *Pelagia* population; in other seasons, respiratory food demand varied from less than 10% to about 50% of the zooplankton production. If we make an average over the year, this jellyfish population respired about 22% of the annual zooplankton production of the area.

The impact of the *Pelagia* population on the turnover of nitrogen and phosphorus in the water column was assessed by ammonium and phosphate excretion rates and *Pelagia* numbers. Nitrogen regeneration was substantial in summer due to elevated excretion rates and presence in great numbers: 49 μM m^{-2} d^{-1}; it was much lower in the colder part of the year, with only about 2 μM m^{-2} d^{-1}. Similarly, phosphate regeneration rate was high in summer (5.4 μM m^{-2} d^{-1}) and diminished at lower temperatures. A quantitative comparison of the relative importance of *P. noctiluca* nitrogen and phosphorus excretion and zooplankton regeneration suggests that *Pelagia* may provide a nutrient source similar to that of other zooplankton from May to October. If phytoplankton nitrogen and phosphorus demands in this area are roughly 400 mM m-2 year-1 and 25 mM m-2 year-1, zooplankton excretion, integrated annually, contributes about 11% and 24%, while *Pelagia* fluxes contribute 7% and 9% of the nitrogen and phosphorus required.

Since the appearance of *P. noctiluca* in the Gulf of Trieste, modifications of zooplankton community have been observed. Although these changes may be due to the natural variability of plankton or some other factors, we speculate that mass presence of *P. noctiluca* contributed to the observed alternations. We studied the dynamics of net zooplankton in two size groupings (200-500μm) and (>500 μm) over three one-year cycles: 1973-74, the period before the appearance of *P. noctiluca*; 1978-79, the onset of the "bloom" period; and 1984-85 when the phenomenon reached its maximal intensity. The trend of changes which have occurred during the period of our study may be summarized as follows: the average total zooplankton stock increased from 15.1 mg dry weight m^{-3} (8.9 mg ash free dry weight m^{-3}) in 1973-74 to 25.4 mg SW m^{-3} (12.8 mg AFDW m^{-3}) in 1978-79, and decreased to 12.8 mg DW m^{-3}

(7.7 mg AFDW m^{-3}) in 1984-85. In addition, there has been an apparent tendency of a relative increase of the >500 μm size fraction, which represented 65.5% of total DW (67.4% AFDW) in 1973-74; 77.9% of total SW (75.0% AFDW) in 1978-79, and 86.7% (84.0%) in 1984-85. A similar trend is also apparent when abundances are considered: the 200-500 μm size fraction dropped from 58.2% of the total abundance in 1973-74 to 41.5% and 32.8% in 1978-79 and 1984-85, respectively. The modification in the relative proportion of the two size fractions observed in the three periods (1973-74, 1978-79, 1984-85) in the Gulf of Trieste may be explained in a rather straightforward way as a result of changes in the community structure. These changes could be described as a shift of the zooplankton community towards gelatinous zooplankton (Siphonophora, medusae, Ctenophora, Thaliacea) together with a decrease of the relative proportion of copepod stock and some meroplanktonic groups and an increase of Cladocera.

Body dimensions and chemical composition

In total, 1638 individuals were analyzed for body dimensions. The measurements revealed that the relationships between bell diameter, wet weight and dry weight can be described by the following equations:

$$WW = 0.91 \cdot D^{3.02} \quad (r = 0.92)$$
$$DW = 0.34 \cdot D^{2.19} \quad (r = 0.86)$$
$$DW = 2.40 \cdot WW^{0.67} \quad (r = 0.86)$$

(D - umbrella diameter, WW - wet weight, DW - dry weight).

At umbrella diameter between 3.4 and 6.1 cm, the length of manubrium varied from 3.5 to 10.4 cm. The ratio diameter:manubrium was in 76% of the measurements between 0.5 to 0.7. The average umbrella wet weight represented 62% of the medusa's total weight, while the ratio of umbrella to manubrium dry weight ranged from 1.22 to 2.15.

Based on weight determination of *P. noctiluca* of various sizes, dry weight amounted from 4.6 to 9.8% of wet weight with an average of 6.6% ± 1.3%, which is slightly higher from values obtained by other investigations for a variety of species of other gelatinous zooplankton. These organisms have also high ash weights: our measurements of *P. noctiluca* gave an average ash content of 71.1 ± 2.4% of DW.

With the aim of differentiating the "health" of individual animals, we also determined the condition factor (CF) which relates the weight and bell diameter: the heavier a jellyfish is at a given diameter, the higher the value of CF and the better the "condition" of the animal.

This CF has been chosen because of its simplicity, the nearly isometric growth of *Pelagia*, and because the bell diameter was the last easily measurable biometric characteristic that changed following prolonged starvation. During the starvation period, *Pelagia* passed through a series of morphological changes from a "healthy" individual having a dome shaped umbrella and expanded oral arms, to an individual with a flattened umbrella, depressed on both sides and contracted oral arms. This static condition index was related to metabolic rates and a positive correlation was established with respiration and a negative one with excretion rates, even though neither was significant at the 95% level. A significant correlation was found only between the condition factor and the O:N ratio. This result is further supported by measurements of respiration and excretion rates over 4 and 16 hour incubation periods (Table 2) when animals held without food reduced their metabolic rates. This reduction was more pronounced for respiration than excretion, giving a lower O:N ratio in starving animals.

A major biochemical constituent of *P. noctiluca* is protein ranging from 10.9 to 19.8% od dry weight (35.2 - 62.5% of ash free dry weight) which showed a trend of relative decrease in bigger animals. The lipid content expressed as % of DW ranged from 1.3-2.9% (4.1 to 10.0% AFDW). The carbon and nitrogen content varied from 7.8 to 9.6% and 2.3 to 2.8% DW, respectively. Only 0.2 to 0.3% of the body dry weight consisted of phosphorus. All these values were quite similar to the results for other gelatinous animals but substantially lower than for crustacean zooplankton.

Table 3. Condition factor (CF) of *Pelagia noctiluca* collected at different temperatures and zooplankton organic carbon as available food.

Temperature °C	Condition factor (CF) X ± SD	N	Zoopl.org.C mg m^{-3}
12	0.53 ± 0.03	98	2.3
16	0.87 ± 0.21	122	2.5
19	0.87 ± 0.21	238	9.5
23	0.68 ± 0.07	56	1.5

4. CONCLUSIONS

The respiration and excretion rates for *P. noctiluca* found in our study are comparable to the data reported for other gelatinous plankters like *Aurelia aurita* and various Ctenophora species, but considerably lower (when calculated on a dry weight basis) than those reported for other marine zooplankton.

The weight specific metabolic rates of *P. noctiluca* evidently increased in the temperature range from 16°C to 23°C, with a Q_{10} coefficient of 2.62 to 3.35, indicating sensitivity to temperature.

A generalized relationship between metabolic rates and body mass (as expressed by the power function $M = aW^b$) in *P. noctiluca* could not be drawn from our study. The reasons probably lie in the relatively small number of measurements in the lower and upper range of body mass and in the choice of dry weight as a body mass unit, since this gelatinous animal has a high ash content.

Extended starvation periods caused the reduction of metabolic rates of *P. noctiluca*. This reduction was more pronounced for respiration than excretion, giving a lower O:N ratio in starving animals.

A total of 1,638 individuals were analyzed for body dimensions and the relationships between bell diameter, and wet and dry weight were described by the allometric equation $W = a \cdot D^b$ (W - weight, D - diameter).

Chemical analyses (water and ash content, protein, lipid, carbohydrate, carbon, nitrogen, phosphorus) demonstrated that *P. noctiluca* contained, on average, 93.4% of water and had a high ash content (71.1% of dry weight). Protein was the main constituent of jellyfish ash free dry weight, while lipids and carbohydrates were less important. The carbon, nitrogen and phosphorus contents are similar or slightly higher than the literature values for the few other gelatinous zooplankton taxa that have been studied.

The observations of *P. noctiluca* revealed that this species formed dense monospecific aggregations which were either passive, i.e. composed of shallow aggregations of lethargic organisms, or active, subsurface aggregations formed of actively swimming animals.

Using our respiration and excretion data at relevant temperatures and *in situ* and abundances and zooplankton production data, we may conclude that during the warmest months there was not enough zooplankton to satisfy even the respiratory needs of the *Pelagia* population; in other seasons respiratory food demand varied from less than 10% to about 50% of the zooplankton production. The significance of *Pelagia* excretion to phytoplankton nutrient demand is also more important during the warmer part of a year, when seasonal stratification is well developed. On a yearly basis, *Pelagia* fluxes contribute only about 7% and 9% respectively of the phytoplankton nitrogen and phosphorus demands.

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THE BLOOM OF THE JELLYFISH Pelagia noctiluca IN THE MEDITERRANEAN AND ADRIATIC AND ITS IMPACT ON HUMAN HEALTH

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ABSTRACT

In 1977 huge swarms of *Pelagia noctiluca* appeared in the Adriatic. This phenomenon interfered with all human activities at the sea, as recreations, tourism, fisheries, and also had an important impact on human health. The causes of this jellyfish bloom are still not satisfactory explained.

The authors studied this phenomenon since 1977, and since 1983 in collaboration with UNEP's Mediterranean Action Plan and WHO EURO Project. The types of stinging cells found in *P. noctiluca* were the atrichous izorhiza and the holotrichous izorhiza (according Weill's classification). By electrophoresis (SDS-PAGE Method) 8 fractions were obtained. Epidemiologically pelagism (the clinical picture due to sting of *P. noctiluca*) is not only a problem for bathers but may represent also a professional disease for fishermen. The clinical picture is mostly not severe consisting of erythema, swelling, vesicles, crusts but, in sensitive individuals, and/or in multiple stings, it may also produce general symptoms. In addition, due to its localization, as in eyes, genitals and lips, it may have a severe course. IgG antibodies for *P. noctiluca* toxin were found in (sera) of patients in a significant percentage by Micro-ELISA Method. In laboratory experiments, guinea pigs showed themselves surprisingly resistant to contact with jellyfish, or even to their ingestion. As first aid, measures, washing of lesions with sea water and fixing the eventually remaining nematocysts with aluminum subacetate or weak ammonia are recommended, as well as local treatments with analgesic antihistamine-corticosteroid (balms). A special emphasis was put as prevention to pelagism on health education. Although a decrease of jellyfish bloom was noted in 1986, further investigations are necessary.

1. INTRODUCTION

One of the authors (Z.M.) working since 1947 in the Adriatic around Pula on epidemiology and clinics of stings due to venomous marine animals had only a few opportunities to observe stings of jellyfishes until 1977. For this reason until 1975 it was believed that sea anemones, especially *Anemonia sulcata*, had a much greater impact on human health than medusae (Maretic, 1975). However, in less than two years the situation changed thoroughly: in early summer 1977 a small brownish yellowish jellyfish with an umbrella of 2 cm diameter, similar to a small mushroom, which we identified as a juvenile form of *Pelagia noctiluca* appeared in Adriatic, also in waters around Pula, in large numbers. Even in that form it showed to inflict painful stings; that year we had our first patients.

In the course of the summer of 1977 we observed the development of these jellyfish, how the diameter of their umbrellas increased till 8 cm, how the umbrellas wrinkled and furrowed and how through the gelatinous surface the drawing of internal organels was reflected. The oral tentacles became still longer, thicker, full of various excrescences and knots and the originally ochre yellow color changed in a pallid violet with a brownish tone. These Scyphomedusae are the dominant sexual freely swimming stages of the class Scyphozoa. Their umbrella is of round shape and on the basal part wears four thick oral tentacles placed around the manubrium with the oral aperture. The oral opening continues into the gastrovascular cavity from which radially extends channels till the border of the umbrella where they are connected with a circular channel. The nervous system is distributed diffusely. On the border of the umbrella they are

the sensitive border organs. From there 8 thinny tentacles are extended which can prolong more than 1 meter, with which the jellyfish catches its prey. The jellyfish moves by pulsation of its umbrella. It is a carnivorous organism feeding on zooplankton or micronecton.

The jellyfish do not disappear during the winter; in 1978 their number, and thus the number of their stings, increased (Maretic, 1978; Maretic, 1979). With eventual oscillations in the course of years after their number was constantly high or even increased. It was suggested that the cold winters of 1981/1982 and particularly the winters of 1984/1985 would destroy them, but this was not true. There was a huge number of them in summer and autumn of 1985. At the same time also very large number of the plankton *Noctiluca miliaris* appeared, so that sometimes in the night due to joint lumiciscence of *P. noctiluca* and the plankton the sea appeared as an enormous gleaming mass. In the summer 1986 the number of *Pelagia* rapidly decreased, being also infrequent during the fall and winter, similarly as in other parts of the Mediterranean and the Adriatic.

Not even the eldest "people from the sea" remembered such episodes with jellyfish. It is true that perhaps at the beginning of the century when tourism and recreation activities on the sea were not developed on such a scale as today, a bloom of jellyfish would not have such an impact on human health as nowadays; however, we believe it would have been certainly noticed. There were surely phenomena of appearance of *P. noctiluca* also previously, but not many reliable notes remained. In 1910 A.G. Mayer and in 1953 F.S. Russell described mass appearance of *P. noctiluca* but not only in Mediterranean (Mayer, 1910; Russell, 1953). The first notes on *P. noctiluca* in Adriatic date as far as 1910 at the island Vis and 1913 at the islands Brioni (Babic, 1913), so as 1922 around Trieste (Neppi, 1922). From then till nowadays nothing can be found on its presence in Adriatic.

What is indeed the cause of this biological explosion ? It is known that among some animals and their predators perturbances in a natural equilibrium, e.g. increased sources of food, favourable bioclimatic, meteorological and other ecological conditions, as well as other unexplained reasons, an excessive reproduction may occur, (protozoa such as dinoflagellates, arthropods such as spiders (*Latrodectus* sp.), lepidoptera, hymenoptera - till higher animals, as fish, frogs, snakes, rodents).

As to jellyfish, a lot of hypotheses were made to explain the phenomenon. Among them are the decrease in number of jellyfish predictors, the increased temperature of the sea (which would help the survival of ephyres), the cyclic entering of warmer and saltier water masses from the Mediterranean into Adriatic. Even pollution has been elaborated to explain the phenomenon in the sencre of the enrichment of water by introducing of various substances which would favour if not the development of medusae themselves, the growth of plankton which they use for food (Maretic, 1984, Maretic *et al*, in press, Vücetic, 1985). It was also observed that blooms of other jellyfish, i.e. *Aurelia aurita*, would occur around the power plants in Baltic sea (Verner, 1984). However, all these are only hypotheses.

What we experience with jellyfish in the coastal sea is only the consequence of separated and dispersed parts of huge masses, mile-long streams of medusae, so called zoocurrents, which flow on the deep open sea. Jellyfish are poor swimmers. They are carried by streams, waves and winds; sometimes they agglomerate in great multitude along some coasts or in some coves. However, they have also their own movements, horizontal and vertical.

In addition to *P. noctiluca* other jellyfish are also found in the Adriatic; *Rhisostoma pulmo*, *Chrysaora hysoscella*, *Nausithoë punctata* and the large jellyfish with vivid colors and not very toxic: *Cotylorhiza tuberculata*. Among *Hydrozoa*, *Lyriope tetraphylla*, *Aequorea aequorea* and *Phialidium haemisphericum* are found in the Adriatic. *Physalia physalis* strays only exceptionally into the Mediterranean (Halstead, 1965; Maretic, 1975; Riedl, 1963).

According to the clinical picture, which is diagnostically different, other coelenterates are also considered, i.e. sea anemones (Anthozoa). The most important in the Adriatic are *Anemonia sulcata* and *Actinia equina*, eventually *Actinia cari* and *Sagartia rhododactylos* which causes the "spong disease".

2. AIMS, MATERIALS AND METHODS

- The venom apparatus was studies by embedding parts of tentacles and umbrella into paraffin, staining them with hematoxilin and eosin and examining microscopically the sections.

- Electrophoresis (SDS - PAGE method) of homogenates of *P. noctiluca* bodies with cnidocysts was performed.

- Epidemiology of pelagism (= intoxication due to stings of *P. noctiluca* (Maretic, in press) was studied through observations and by questionnaires.

- The clinical picture was observed and followed up in many patients

- IgG antibodies on *P. noctiluca* venom were established by enzymatic method (Micro-ELISA Method) according the proceeding of Ruitenberg *et al.* (1975).

- Experiments were performed on guinea pigs to study their skin reactions. The resistance of guinea pig was tested also by forced feeding with fresh specimens of *P. noctiluca*. The immune response on 4 rats which were immunized with the pure homogenate of specimens of *P. noctiluca* was examined. Their serum was tested by the method of immunodiffusion in gel. As control group, 3 rats immunized with human IgG were used.

- First aid measures and treatment of stings were elaborated.

- Possibilities of prevention of pelagism were examined and health education on all levels was performed.

3. RESULTS

Venom apparatus

According to Weill's classification (Weill, 1934) there were two types of cnidocysts in *P. noctiluca*, the atrichous izorhiza and the holotrichous izorhiza. The former is round shaped, about 15 of diameter and have threads of equal diameter throughout the whole length without lateral spines. It is also called "glutinant" since it releases a sticky substance which adhere to the body of the victim and inflict the sting. The latter is of slightly larger size and more oval shape. It has also the thread of uniform diameter, but it is armed with lateral spines.

The venom

The venom of *P. noctiluca* is of protein nature, it contains peptides, it is antigenic, it acts dermonecrotically and hemolytically. By the electrophoretical analysis we established 8 fractions whose molecular masses amounted from 14.500 to 330.000. In order to establish the molecular masses, the normal serum of the rat was used as standard. The fifth fraction of the homogenate was completely congruent with the transferring fraction of the rat serum.

Epidemiology

In 1977, when *Pelagia* first appeared in the Adriatic, all specimens were of the same generation; in the next years, in any season, all evolutional forms could be found, from the very young to the oldest ones. The victims of *Pelagia* are mostly the bathers. According to one of our inquiries, in 1978 52% of 214 randomly chosen bathers in Pula were stung by *Pelagia* during the season, once or several times (Maretic, 1979; Maretic *et al.*, 1979). The author was stung by *P. noctiluca* till now at least 30 times and only in 1978 seven times, which illustrates the great possibilities of exposition to the sting of this jellyfish. On the bases of these observation, one could make an approximate count that the total number of bathers stung every year along the Adriatic coasts amounts not to hundreds but to millions.

Pelagism may assume also the character of a professional disease among fishermen. In fact it occurred in Pula that fishermen caught in their nets tons of jellyfish drifted by streams and waves. While collecting the fish, they were repeatedly stung on hands and arms.

Clinics

The sting itself is felt by the victim as a sharp pain which many patients compared with an electric stroke. Many of them reported that before the sting itself they firstly felt above the wrist the winding tentacles and immediately after a vivid pain. This localization, however, is pathognomonic for breast-stroke swimming,

since moving with Palms the water aside, the swimmer pushes apart also the jellyfish which will then wind their tentacles above him/her. Since the breast-stroke swimming is most common in women, the lesions by tentacles above the wrist are most frequent in them.

The site of sting blanches immediately due to ischemia. Infiltration occurs and it arises like an urtica on a reddened basis. However, already within a few hours the infiltration becomes dark red/brown usually showing the marks of tentacles, sometimes also of umbrella or of entire jellyfish. Vesicles also appear which later pass over into crusts. These lesions are on the beginning painful and later the itch is especially marked. Not seldom, an increase of lymphatic nodes may be found. The scratching is contra-indicated since this way even after 10 days and more the lesions may be again activated. After recovery, traces of the jellyfish in form of hyperpignmented or not so frequently hypopignmented marks may be still seen. However, the site of sting may eccematize, necrotize or leave scares, or keloids may develop.

General signs and symptoms do not occur frequently. It may happen only in sensitive individuals, ectopics; eventually in sensitized persons or in events such as a swimmer dropping in a swarm of *Pelagia* and suffer multiple stings. In this case, dizziness, nausea, vomiting and collapse might occur.

The intensity and severity of pelagism depends also on the localization of the sting, e.g. the eyes, genitals, lips, and if there is an ingestion of a jellyfish or part of it. The stings of jellyfish, but also of anemones, into the genitals represent a specific pathology - severe due to delicate structure of these organs - in a specific population, i.e. in nudists. Therefore it was called "Cnidarismus nudorum" (Maretic, 1986). The quantity of venom injected and the magnitude of lesions does not depend only upon the number of stinging specimens, but also of the mode of contact of the jellyfish with the man, i.e. if the jellyfish slightly touched him, or if it largely clingged to him firing a lot of many batteries of nematocysts.

Since the clinical picture in most of cases is not severe, most of patients treat themselves with various antihistamines and other creams, so that they do not come to see a doctor. Due to this fact, generally speaking, the clinical problem of pelagism has not been thoroughly elaborated.

In the out door clinic of our hospital ward in the last 10 years only 97 patients were treated, 59 males and 38 females, 43 of them being foreign tourists. Their age varied from 4 till 60 years, but mostly they were young people. Admitted to the hospital were only 2, one due to severe edems following repeated stings and the other because of stings into genitals.

In 1984 we started sending to health centers in Istria questionnaires related to stings of *P. noctiluca*. Untill now we collected 138 completed questionnaires from which we gathered the following information: Most of patients were in a good general condition. Only 14 of them were registered as middle serious, 10 among them as serious on the basis of following criteria: headache, dizziness, shivering, fever or severe local edema with marked lesions. In one case, a fairly extensive necrosis of the skin was observed. The duration of illness was 1-10 days, averagely 3,4 days.

Immunology

Untill now 56 sera of patients stung by *P. noctiluca* were examined on IgG antibodies by Micro-ELISA test. Nine of them were paired sera, i.e. the first was taken at the first control and the second 3-4 weeks later. The others were sera of patients who visited our out door clinic some time following the sting or who were admitted to our ward because of other diseases, but following their anamnesis they had suffered *P. noctiluca* stings during 1985 and 1986. The following results were obtained with paired sera: Four sera showed a clear turning from negativity to positivity, 4 were both times positive and 1 both times negative. The last year we had all together a total of 65,1% of positive sera. Now this percentage decreased to 57,1%, probably due to the fact that many of the persons that tested in, long time had passed from the moment of the sting to the moment that the serum was taken for testing. 103 persons who believed they never did come into contact with *P. noctulica* were taken as control group. Among them, 95 (92,3%) were negative, 5 (4,8%) undetermined and 3 (2,9%) positive.

Experiments on animals

We tried to study changes on the skin provoked by *P. noctiluca* stings on guinea pigs since they are very sensitive animals. But surprisingly they showed themselves very resistant. Following a long contact (2 and 4 hours) of their depilated skin with vital specimens of *P. noctiluca* they showed only a papule. Histologically only elements of a mild epidermolysis were determined, i.e. separation of the corneous layer with the

presence of fresh erythrocytes (Epidermolysis circumscripta gradus levioris. Oedema et haemorrhagia regionis papillaris dermis).

One guinea pig fed forcedly with two alive specimens of *P. noctiluca* did not show any signs of intoxication; it died, however, 20 days later, probably due to taking of blood and extensive excisions of skin. However, its organs did not show any significant histopathological change. In its serum (Micro-ELISA method test) no IgG antibodies to pelagia homogenate could be proven.

Out of 4 rats immunized with *P. noctiluca* homogenates, two were positive and two negative. The three control rats immunized with human IgG were all positive in tests with immunodiffusion in gel.

First aid and treatments

The following measures were practiced:

As first aid measure, the adherent parts of tentacles are removed. The site of the sting is always well washed with sea water, by no means with fresh water. Due to difference in osmotic pressure of between the nematocyst and the fresh water, the still intact nematocysts could be activated for stinging and injecting additional quantities of venom into the skin of the victim. Farther on, aluminum subacetate (Burow's solution), weak ammonia or alcohol should be applied on the site of the sting in order to fix the remaining cnidocysts. The popular medicine uses vinegar or the milk of the fig tree. The large metal surface of a meat tenderizer posed on the site of the sting could bring some relief. Subsequently, an analgesic-antihistamine-corticosteroid cream should be applied on the stung site such as Russell's Balm ("Land & Sea", Marinetech, USA) which contains hydrocortisone 1,5%, tetracaine 2%, benadryl 1,5%. This balm showed very good effects in our patients. Pains may be combated with means as aspirin or codeine (Maretic *et al*, 1980).

If general signs and symptoms appear, a symptomatic treatment has to be applied to maintain the vital functions, i.e. to combat the allergic or even anaphylactic reactions, to maintain the respiration and the circulation.

Prevention

Best results in preventing pelagism were obtained individually, e.g. swimming with a diving mask, which enables the bather to avoid contact with jellyfish.

The main and most efficient approach to the prevention of pelagism represents the health education.

4. DISCUSSION

The problem of *P. noctulica* and pelagism represents from one side a biological phenomenon, not satisfactory explained, and anthropomorphistically, from the medical point, a true epidemic of a disease.

The venom apparatus of the jellyfish consists of a keratine capsule filled with the venom in which a sharp, sometimes barbed, hollow thread is coiled. When a sensory organel, the cnidocyl, is instigated due to contact or chemical excitation, the capsule "explodes", the operculum opens, the thread rectifies and stings introducing the venom into the body of the victim. These cnidocysts or nematocysts are found often in batteries of hundreds of thousand and millions, mostly on tentacles, but they are present, though in a lesser number, also on the umbrella. The cnidocysts in medusae and coelenterates in general are of course not equal. They differ in size, form and function. According to Weill's classification, there are 17 types of nematocysts (Weill, 1934). The size of the cnidocysts varies from 5 microns to more than 1 millimeter in *Hydra*. The capsules may be round shaped, elongated, even spindle formed, as in *Anemonia sulcata*. According to their function they are divided into a small group of non injectors (*Astomocnides*), without terminal opening on the thread, and injectors (*Stomocnides*). They are further divided according to the shape and function of the thread which may be sometimes armed with lateral spines, which may be of same diameter throughout the whole length or have a thicker part (Weill, 1934).

In addition to the atrichous izorhiza and holotrichous izorhiza types which we found in *P. noctiluca*, according to Halstead (1965) there should be also a third type: heterotrichous microbasic euryteles, with a short butt with unequal size of spines.

Previous authors found in the venom of coelenterates biological compounds-mixtures with deleterious effects, which they named thalassin (Richet, 1903), congestin (Riedl, 1963), originating from *Anemonia sulcata*, and hypnotoxin (Portier and Richet,1902) from *Physalia physalis*. Thalassin acts releasing his-

tamine and could correspond to 5-hydroxytryptamine. Congestin may provoke vomiting, splanchnic vasodilation, fall of blood pressure and bloody diarrhoeas. Hypnotoxin acts anesthetically provoking a central nervous depression and coma. Among the most important components of coelenterates venom we find 5-hydroxytryptamine, which provokes the pain, tetramin with its paralysing action, proteins of low molecular weight acting upon cholinergic neurons, homarin, cholin, N-methylpyridine, trigonelline, zooanemonin and hyaluronidase (Halstead, 1965; Russell, 1984).

The epidemiological and clinical characteristic of pelagism could be experienced as follows: Pelagism is rather a nuisance than a real danger for human health; however, owing to the epidemic of stings, pelagism becomes without doubt an important epidemiological problem. In addition to these quite classical epidemiological implications, pelagism, as mentioned previously, interferes with all human activities on the sea, from recreation, tourism, fisheries to politics and others (Cruzado, 1984).

The invasion of *Pelagia* has been going on for 10 years and our impression is that in the years 1985-1986 we noticed a few cases of people who were stung more severely than usual. According to experiences of Russell (Maretic and Russel, 1983) along the coasts of Southern California, a tendency towards immunity in persons previously stung was noted. Conversely, with the advent of board certain American coasts an increasing number of persons seems to have become sensitive to jellyfish stings. Russell did register more than 20 cases of anaphylactic shock in California with, perhaps, two facilities - following jellyfish stings. One must also consider the possibility that jellyfish could, in sensitive individuals or in those receiving numerous stings, eventually cause the death, directly or indirectly by secondary drawing. With regard to the sensitivity, the testing of sera on IgE antibodies by Micro-ELISA method would be very desirable. With regard to the percentage of positive IgG antibodies, one can comment that the figures are satisfactory, especially if one takes into consideration only the first batch of taken sera in which 65,1% were positive, compared with the control group.

With regard to resistance of guinea pigs not only to contact with living *Pelagia* but also on ingestion of them, it is a surprising fact. However, it shows only again the great differences in sensitivity or resistance of various species towards different toxins. Experiments also with other animal species exposed to *P. noctiluca* toxin would be of interest.

Discussing the first aid and treatment it is common opinion that alcohol should be avoided for fixing the remaining cnidocysts in the skin since it could eventually have an opposite effect, i.e. activating these cnidocysts (Benovic, personal communication).

In spite of the proven good therapeutic effects of "Land & Sea Balm" it is necessary to mention that the local application of antihistamines and anesthetics could have as a consequence an allergic sensibilisation of the skin.

Prevention could be in principle performed on three levels: at the level of the *Pelagia* environment itself, at the level of preventing and avoiding the stings and at the level of the patient himself.

Combating the medusae population either by changing their living conditions into unfavourable ones or even by some destroying means for the time being is not considered.

The possibilities to avoid their stings are very limited. Protective nets for bathing resorts did not prove successful. Better, but not satisfactory, results were obtained by creating a kind of functional curtain with air bubbles, as experimented in power plants in the Baltic Sea (Verner, 1984). Often one can see bathers with a net for butterflies catching jellyfish and so for a short time making safe for swim a cove or some other protected place !

Certainly a protective tricot suit for swimmers -even if unpractical- could be in some way effective. As mentioned, for the second level of protection, i.e. hindering of stings, the best is to avoid jellyfish with help of a diving mask.

Thirdly, possibilities of immunotherapy or desensibilisation of sensitive individuals, or of vaccination, should be examined.

The decrease of the number of stings in the population could be attained also by health education. Since the very beginning of the *P. noctiluca* bloom and the epidemics of its stings we often wrote on this problematics in the daily and popular press, so as in popular journals. Lectures were held and papers presented at various meetings, popular as well as professional and scientific, on the radio and in the television. Health education was performed at all levels: tourists, sportsmen, health workers e.t.c. (Benovic and Maretic 1978; Lebez *et al.* 1979, Maretic 1975; 1978; 1979; 1984a; 1986; (in press); Maretic *et al,* in press, Maretic *et al,* 1980).

The tourist organisations in Pula edit a journal especially for tourists under the name "Willkommen". The journal appears in several European languages and has a wide distribution among tourists. In this

journal many papers on the jellyfish problem appeared trying not only to advise tourists on *Pelagia* first aid measures and treatment, but also to avoid the panic which sometimes arises (Maretic, 1984b).

5. CONCLUSIONS

The explosive bloom of *P. noctiluca* is a phenomenon which deserves attention from many standpoints, including medical point of view. Surprisingly, our health workers in general did not pay enough attention to this phenomenon, so that the necessary observations and work which would have enriched the knowledge on this problem important for our regional pathology and touristic medicine, were not carried out.

At present the blooms of *P. noctiluca* are decreasing in intensity. However, one cannot still say, whether it represents a definite end of the cycle, or if after this stagnation the blooms will continue with the same or a similar intensity.

In our opinion, in both cases it is worthwhile to continue the work on *Pelagia* to try to solve some important practical questions or simply to give the entire and rounded off picture on this exceptional phenomenon.

6. ACKNOWLEDGMENTS

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BIOCHEMICAL AND ECOLOGICAL RESEARCH ON JELLY FISH AND OTHER ORGANISMS IN THE MEDITERRANEAN SEA

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ABSTRACT

Total lipids were extracted from the whole alive *Aurelia aurita* (0,02% of fresh tissue). The Nl were isolated (62.5%) and were found to contain sterol esters, triglycerides, fatty alcohols, free fatty acids and sterols. Also the PL were found to contain Car 7%, PE 17%, Pnl 18.9%, PC 46.8%, lyso and uncharacterized compound 8%.

The TL of *Pelagia noctiluca* (0.19% of the fresh tissue) were found to contain NL 73.8% and PL 26.2%. The NL fraction consisted mainly of sterol esters (11.3%), triglycerides (20.7%), free fatty acids (56.6%) and sterols (7.6%). PC (36%), PE (24%) and SPnl (24.3%) were recognized as the major lipids of the PL fraction. Remarkably high was the content of the free fatty acids (41.7%) of TL of *P. noctiluca*, as well as the content of a C_{15}-isoprenoid acid due to the fact that the biosynthetic route for isoprenoid formation is absent in medusae.

The results suggested that the phospholipid fraction of *Boops boops* contain small amounts of Pnl.

1. INTRODUCTION

In a long-term research programme on the chemistry and biological significance of lipids, we have studied the neutral, phospho and phosphonolipids of the scyphomedusae *Pelagia noctiluca* and *Aurelia aurita* as well as the Teleostean Sparid *Boops boops*, which is known to feed on medusae, molluscs, etc., (predator-prey relationship).

The study of the lipids of the above organisms is of special interest since it has not been investigated until now and because the occurrence of phosphonolipids in such organisms has not been reported before. Possible functional roles (Hilderbrand and Henderson, 1983) of phosphonolipids includes the ability to provide cationic buffering capacity or facilitated transport of essential ions, the ability to provide resistance to hydrolytic enzymes and the ability to provide inter- or intra- species communication or recognition processes.

The knowledge of the fatty acid composition is very helpful in the investigation of the complex trophic interrelationship which exist in the aquatic environment and for the recognition of the importance of polyunsaturated fatty acids from the course in human nutrition (Jeanne, 1979).

Note: Abbreviations

PE, Phosphatidylethanolamine; PC, phosphatidylcholine; SPM, sphingomyeline; Car, cardiolipin; AEPn, 2-aminoethylphosphonic acid; Pnl, phosphonolipids; SPnl, sphingophosphonolipids; T.L.C., thin layer chromatography; NL, neutral lipids; TL, total lipids; PL, phospholipids; A, acetone; P, phosphorus; G.L.C., gas liquid chromatography; T.M.L., trimethyllauric acids; C, chloroform; ME, methanol; W, water; A.A, acetic acid; Pn-P, phosphonate phosphorus; P S, phospatidylserine; Et. A, ethyl acetate; MAS, mild alkaline stable.

Once ingested by higher predators, the medusae cannot be recognized in any detailed examination of stomach contents. It is thus difficult to assess the entente to which the numerous and varied smaller jellyfish act as intermediates between smaller carnivorous and filter feeders or between the larger pelagic fish and aquatic animals which may pray upon them. The accessibility of the *A. aurita* and *P. noctiluca* facilitated a study of their lipids.

2. MATERIALS AND METHODS

Reagents

Silica gel G type 60 was purchased from MERCK; silica gel, 100 mesh, for column chromatography from MALLINCKRODT; Car, SPM, PE, PC, lyso-PE, Lyso-PC, sphingosine, ceramide, tripalmitin, oteyl alcohol, oleic acid, cholesterol, and methyl ester fatty acid from SERVA; AEPn from SIGMA.

Samples

Specimens of *P. noctiluca*, sample A (20 individual approx. 10-17mm diam. and weight of fresh tissue 220 gr.), were collected at Saronic bay, in late September 1983.

Specimens of *A. aurita*, samples B (4 individuals, 500 gr. weight of fresh tissue) and C (9 individuals, approx. 90-130mm diam., and 912 gr. weight of fresh tissue), were collected at Salamis island during September 1983 and Elefsis bay during June 1986. The medusae were brought to the laboratory alive in sea water. The individual specimens were examined, drained as thoroughly as possible and transferred to an OMNI MIXER homogenizer.

B. boops, sample D (five fishes with body length 26-32 cm), were collected at Euboea island during October 1983.

The experimental animals were kept at -20 °C and were analyzed 24 hours later. Their head and main body were dissected and immediately homogenized in an OMNI MIXER for 2-10 min. at 7.000-10.000 rpm. and kept in an ice bath.

Extraction of lipids

Samples A, B and C.

The lipids were extracted using the Bligh and Dyer (1959) method (modified). The organisms were homogenized separately with a 3 fold volume of C/Me (1:2, v/v) in an OMNI MIXER (0 °C, 5' at medium speed). One volume C was added to the homogenate and the solvent was removed by centrifugation (0 °C, 10', 3000 rpm). One volume C/Me (1:1, v/v) was added to the residual material and it was rehomogenized and centrifuged as above. One volume of water and one volume C were added to the combined extracts and, after mild mixing, it was left quiet (12h) for phase separation. The lower chloroform phase (including the fluffy layer) was evaporated to dryness in the rotary evaporator and redissolved in C/Me (9:1, v/v) "total lipids".

Sample D.

The lipids of each tissue homogenate were extracted as follows: 1) the main bodies weighed 370 gr. were extracted with 3.3 lt C/Me/W, (1.5:2:0.8, v/v/v) mixture which had separated into a "Chloroform phase" (680ml) and a "Water-methanol" phase (2 400ml); 2) the heads weighing 40 gr. were extracted with 1.2 lt C/Me/W (15:2:0.8, v/v/v) mixture, which had separated into a "chloroform phase" (250ml) and a "water methanol phase" (900ml).

Fractionation of lipids

Sample A.

A portion of "total lipids" was evaporated to dryness, redissolved in a minimal amount of C/Me (98:2, v/v) and applied to a column (1.1x10cm) packed with 2g of celite. Stepwise elution was performed with

solvent mixtures of increasing polarity as indicated in Table 2. The elution was monitored by TLC developed with C/Me/W (65:25:4, v/v/v).

Sample B.

A portion of "total lipids" was fractioned by preparative T.L.C. (solvent system C/Me/A.A/W, 50:25:6:2). The lipid zones were extracted from silica gel and their lipid-P was determined by the Long-Staples (1961) method.

Sample C.

"Total lipids" were fractioned by the following procedures:

(1) A portion of "total lipids" (1099 P) was subjected to mild alkaline hydrolysis by the method of Kapoulas *et al* (1969). A portion of mild alkaline stable lipids (469 P) was separated on a 1.5g silicic acid and 1.5g celite column (100 mesh, activated at 120 °C overnight). Elution was carried out successively as shown in Table 5.
(2) A portion of "total lipids" (405 P) were fractioned by counter-current distribution (Galanos and Kapoulas, 1962) in "polar" and "neutral" lipid fractions. The "polar" lipids were then fractioned on preparative T.L.C. (Solvent system, Petroleum Ether/Ether/A.A., 70:30:1, v/v/v).

Sample D.

The yield total P in the "chloroform phase" of main bodies was 99.8mg. A portion (4mg P) of this "chloroform phase" was fractioned into 6 fractions on a silicic acid column (1.2x27 cm) packed with 6g of silicic acid activated at 120C overnight, mixed with 3g Celite. Stepwise elution was performed with solvent mixtures of increasing polarity as indicated in Table 7.

The "chloroform phase" and "water-methanol phase" of heads contained 5.1mg and 13.5mg lipid-P respectively. A portion (4mg P) of the "water-methanol phase" was fractioned into 5 fractions on a silicic acid column (1x27 cm) packed with 6g of silicic acid activated at 120 °C overnight mixed with 5g Celite. Stepwise elution was performed with solvent mixtures of increasing polarity as indicated in Table 8.

Thin layer chromatography

T.L.C. was carried out on layers of silica gel G 0.25 mm thick, activated at 110 for 1h. The neutral lipids were separated using C/Me (95:5, v/v) or petroleum ether/ether/A.A.(90:10:1, v/v/v). The spots were detected by exposure to iodine vapors and by charring after spraying with 50% sulfuric acid. For phospholipid detection the chromatograms were developed with C/Me/W (65:25:4, v/v/v) or C/Me/A.A./W (50:25:6:2, v/v/v) and the spots were visualized by spraying with molybdenum blue reagent (Dittmer and Lester, 1964; Stillway and Harmon, 1980).

The individual neutral lipid components were isolated by preparative T.L.C. using petroleum ether/ether/A.A. (70:30:1, v/v/v) as developing solvent system.

Degradations

a. Mild alkaline hydrolysis of phospholipids. According to Kapoulas *et al* (1969).
b. Dry acid methanolysis: According to Vance and Sweeley (1967) method.
c. Saponification of neutral lipids: According to Kates (1964).

Analytical methods

a. Phosphorus was determined by the Long-Staples (1961) method.
b. Phosphonolipids were determined by the method of Kapoulas *et al* (1984).
c. Nitrogen was determined according to Haohmi and Umar (1962).
d. Long-chain bases were determined according to Lauter and Trams (1962).

Gas Liquid Chromatography

Analysis of fatty acids methyl esters: The free fatty acids and the fatty acids of ceramide aminoethylphosphonate and triglycerides were converted to fatty acid methyl esters by dry acid methanolysis (see above). The fatty acid methyl esters were purified by preparative T.L.C. developed with dichloromethane; G.L.C. was performed on a GOW MAC 750-P gas chromatograph equipped with flame ionization detector and connected with Honeywell recorder. The studies were carried out on a 2m.steel column packed with 2% diethyl glycol succinate on chromosorb WAW (80-100 mesh) at 190C and the carrier gas (N_2) pressure was 10 psi.

Scanning

The quantitative analysis of neutral lipids was measured with a photodensitometer type Quish Scanner T.L.C. HELENA LABORATORIES.

The free fatty acids, the fatty acids of triglycerides as well as of the major phosphonolipid were converted in to methyl esters which were studied by G.L.C. The results are shown in Table 4.

3. RESULTS

The general analytical data of the total lipid extract of *P. noctiluca* (sample A) and *A. aurita* (sample C) are given in Table 1.

Table 1. General analytical data of total lipids of the medusae

Sample	Species	Weight of wet tissue gr.	Weight of TL mg	% TL of wet tissue	% PL of TL	% NL of TL
A	P. noctiluca	220	418	0,19	26,2	73.8
C	A. aurita	912	208,5	0,02	37,5	62,5

The total lipids of *P. noctiluca* were fractioned into 7 fractions (Table 2). The first fraction A consisted of the neutral lipids (73.8%) while the remaining 6 fractions (B through H) consisted of phospholipids 26.2% (Nakhel and Mastronicolis, 1983; Nakhel *et al.*, 1987; Mastronicolis *et al.*, 1984).

The quantitative composition of neutral lipids was investigated by T.L.C. before and after saponification. The quantitative composition was determined by scanning and the results are given in Table 3. Remarkable is the high content of free F.A. (41.7% of the total lipids).

Table 2. Separation of Total Lipids of *Pelagia noctiluca* on Silicic Acid Column

Fractions	Solvent systems C:M(v/v)	Bed Volumes	P% of total PL	Lipids	Pl% of Tl
A	98:2 90:10	8 1	-	NL	73.8
B	90:10	1	8.5	Car	2.2
C	90:10 85:15	3 1	24.7	PE	6.5
D	85:15 80:20	3 1	21.0	SPnL I	6.4
E	80:20	3	3.3	SPnL (II,III)	
F	80:20 60:40	1 4	36.0	PC	9.5
G	20:80	4	4.5	Lyso PE and Lyso PC	1.2

Table 3. Composition of the Neutral Lipids of *P. noctiluca*

Lipid	% of NL	% of TL
Sterol esters	11.3	8.34
Triglycerides	20.7	15.3
Unknown	3.77	2.78
Free fatty acids	56.6	41.7
Free fatty alcohols	0.88	0.59
Sterols	7.54	5.56

As shown in Table 2, the 24.3% of PL belongs to the SPnL class. These SPnL (II, III) with different R_f values due to the different molecular species of the same type (Nakhel and Mastronicolis, 1983; Nakhel *et al.*, 1987; Mastronicolis *et al.*, 1984).

Table 4. Contents % of fatty acids of *Pelagia noctiluca* lipids

Fatty Acid	R.R.T.	Free fatty acids	Triglycerides	Sphingophosphonate
T.M.L.	0.41	38.4	10.0	32.8
$C_{14:0}$	0.51	0.66	1.33	4.47
$C_{15:0}$	0.71	0.56	1.66	11.0
$C_{15:1}$	0.78	tr	tr	0.55
$C_{16:0}$	(7.95)	19.4	26.9	44.4
$C_{16:0}$(b)	1.09	0.16	-	-
$C_{16:1}$	1.24	0.20	tr	1.17
$C_{17:0}$	1.40	0.88	2.93	0.83
$C_{17:0}$(b)	1.57	tr	-	-
$C_{17:1}$	1.66	-	tr	-
$C_{18:0}$	1.96	27.9	24.7	1.77
$C_{18:1}$	2.18	0.62	14.7	0.39
$C_{18:2}$	2.71	2.1	7.5	0.48
$C_{18:3}$	3.46	tr	-	tr
$C_{20:0}$	3.91	1.47	0.70	0.60
$C_{20:1}$	4.09	0.37	-	-
$C_{20:2}$	5.19	-	-	-
$C_{20:3}$	6.55	-	-	-
$C_{20:4}$	6.72	1.63	2.66	1.19
$C_{20:5}$	8.62	1.53	2.83	-
$C_{22:0}$	7.67	1.21	tr	-
$C_{22:5}$	9.68	-	-	-
$C_{22:6}$	10.3	-	-	-
Unknown	12.4	-	-	-
% Unsaturated		6.45	27.7	3.78

tr: trace, b: branched chain, R.R.T. : relative retension time

The neutral lipids of *A. aurita* (sample C, procedure 2) consisted of cholesterol esters, fatty acids, triglycerides, sterols and fatty alcohols as indicated qualitatively against authentic standards by T.L.C. The free fatty acids and triglyceride zones were extracted separately from the silica gel of the preparative T.L.C. The free fatty acids of triglycerides as well as the fatty acids of the "polar lipids" fraction were converted into methylesters for G L C analysis.

Table 5. Separation of milde alkaline lipids of *A. aurita* (Sample C) on a silicic acid column

Fractions	Solvent systems C:M(v/v)	Bed Volumes	P% of total PL	Major Lipids
A	98:2	3	-	
B	98:2	4	0.8	
C	90:10	2	10.4	
D	85:15	2	13.3	SPnL I
E	80:20	2	12.6	
F	80:20	4	11.3	SPnL I, LysoPE
G	60:40	2	22.6	SpnL (II, III) Lyso PE, Lyso PC
H	20:80	8	29.0	

The MAS components of total lipids of the above organism were fractionated by column chromatography and, as shown in Table V, the SPnl of *A. aurita* were constituted of a major SPnL(I) component and two minor SPnL(II,III) with different Rf values.

Table 6 indicates the composition of the phospholipids of *A. aurita* (Sample B). The total lipid-P of this sample was determined before and after mild alkaline hydrolysis. The MAS layer is the 25% of total lipid-P and the SPnL molecules represent 36.4% of total alkali stable lipid-P.

The remaining 63% is consisted of deacylated ether lipids.

The column fractions which were obtained after the fractionation of the "chloroform phase" of the main bodies (*B. boops*), were studied by T.L.C. with the quantitative analysis of total P (00.8mg or 26.7% of fresh tissue) as well as of the Pn-P and the data shown in Table 7.

In the fraction D eluted with C:M (4/1), after determination of Phosphonate phosphorus, about 7% of the lipid-P was phosphonate-P.

The "chloroform phase" and the "water-methanol phase" of the head's extract contained 5.1mg and 13.5mg lipid-P, respectively. The column fractions of the above "water methanol phase" were studied by T.L.C. accompanied by quantitative analysis of total-P as well as of phosphonate-P. The data are shown in Table 8.

Table 6. Composition of the polar lipids of *Aurelia aurita* (Sample B).

Lipid	% of pL
Car	7
PE	17
SPnl	18.9
PC	46.8
uncharacterized compound	8

As it is shown in Table 8, in the fractions A and D eluted with C / Me (19:1) and EtA/Me (3:2), after determination of Phosphonate-P, about 7% of both lipid-P was Pn-P.

4. DISCUSSION

Scyphozoan medusae are mostly fragile animals of very high water content. It is noteworthy that the total lipid content of 0.19% (v/v) of *P. noctiluca* is comparable to that reported for *C. quinguecirrha* while

Table 7. Separation of the lipids* of the main bodies (*Boops boops*) on a silicic acid column

Fractions	Solvent systems v/v)		Bed Volumes	Lipids	P% of Total PL	% Pn-P of column fraction
A	C/Me	98:2	5	NL		
B	C/Me	9:1	1	Car	1.5	
C	C/Me	9:1	3	PE	22.0	
	C/Me	4:1	1			
D	C/:e	4:1	2	PS and PnL	5.0	7
E	C/Me	4:1	3	PC	49.0	
	EtA/Me	3:2	1			
F	C/Me	1:1	2	Lyso PE &	22,5	
	Me		5	Lyso PC		

* The lipids of the "chloroform phase" as described in "Materials and Methods"

Table 8. Separation of the lipids* of the heads (*Boops boops*) on a silicic acid column

Fractions	Solvent systems v/v)	Bed Volumes	Lipids	P% of Total PL	% Pn-P of column fraction lipid P
A	C/Me 19:1	3.5	NL and PnL		7
B	C/Me 9:1	2.5	PE	14	
	C/Me 4:1	2			
C	C/:e 4:1	3			
	A/Me 4:1	3	PC	57	
	EtA/Me 3:2	2.5			
D	EtA/Me 3:2	2	Lyso PC and PnL	4	7
E	C/Me 1:9	5	Lyso PE &	25	
	Me	5	Lyso PC		

* The lipids of the "water-methanol phase" as descibed in "Materials and Methods"

in the non stinging scyphozoan species *A. aurita* with fully developed gonads the respective figure is only 0.027% or 0.02 (Table 1). Thus it seems that there is a correlation between the lipid armature of tentacles and the intensity of some of their specific bioactions.

An attractive field of study has developed in recent years about the widespread distribution and unpredicted variety of unique phosphonolipids occurring in marine organisms (Hilderbrand and Henderson, 1983). However, to our knowledge this is the first report of the composition of the phosphonolipids occurring in scyphomedusa species. The results of the present investigation reveal that *P. noctiluca* and *A. aurita* contain a significant amount of SPnL (Table 2, 5 and 6) which belong to the ceramide-AEPn type regardless of their chromatographic resolution into one major (SPnL I) and two minor (SPnL II and III) components.

Extraction of lipids of *P. noctiluca* and *A. aurita* showed that non polar lipids comprised 73.8% and 62.5% of the total lipid present, values different from that obtained for the lipids of *C. qinquecirrha* (neutral lipids 31.1%) and to that obtained by Stillway (1976) in his study of *P. physalis* lipids (neutral lipids 50%) Table 9.

The percentage of sterols observed in *P. noctiluca* is not as high as that found by Goldner *et al.* (1969) in *C. quinquecirrha* (2.09% of the dry body weight).

Van Aarem *et al.* (1964) reported that the jellyfish *Rhizostroma* does not incorporate the 1-^{14}C-acetate into sterols. Furthermore, Ferezou *et al.* (1972) failed to show sterol and squalene synthesis in the sea anemone *Calliactis parasitica.* From these investigations, it is suggested that the sterols of coelenterates are of dietary origin (Yasuda, 1974).

It is probable that the high levels of fatty acids were due in the occurrence of the hydrolytic enzymes, despite that, as described in material and methods, the extraction was carried immediately after the capturing alive medusae.

The results of G.L.C. analysis of *P. noctiluca* medusae fatty acids are shown in Table 4. A comparison of this pattern with that of *C. capillata* from Terence bay, Novascotia (Sipos and Ackman, 1968), portuguese man-of-war *P. physalis* *(Stillway, 1974) and *S. meleagris* as *C. quinquecirrha* from Chesapeake bay, Maryland, shows that they have not many features in common (Table 10). The Mediterranean *P. noc-*

tiluca contains significantly more saturated fatty acids. The absence of polyunsaturated fatty acids is noteworthy and quite unusual for marine animals. It is possible that environmental conditions may be an important factor in regulating fatty acid synthesis in this medusae.

Table 9. Neutral lipid composition of temperate waters medusae.

Species References	Portugese P. Physalis (19)	C. quinquecirrha (2)
Lipid class	Percent	Composition
Hydrocarbons	n.r*.	1.7
Sterol esters	5	4.5
Wax esters	n.r*.	
Triglycerrides	13	14.0
Free fatty acids	11	7.3
Cholesterol	21	47.8
Mono and diacyl glycerol	1	13.9
Uncharacterized	-	10.8
Total N.L.	50	31.1

* nr: not reported

Fatty acids, commonly accepted as essential to higher animals, such as $C_{18:2}$ and $C_{18:3}$, are present in amounts similar to most marine animal lipids (Sipos and Ackman, 1968). *P. noctiluca* contains considerably more $C_{18:2}$ in triglycerides which raises the total content of $C_{18:2}$, to what may be a result of nutrition. Arachidonic acid ($C_{20:4}$, is typical of terrestrial mammal polar lipids. This acid is a prominent component of both medusae lipids, triglycerides and phospolipids (Jeanne, 1979). In *P. noctiluca* unlike in other medusae this is a minor polyunsaturate. The species *C. capillata* and *P. physalis** of temperature waters contain less $C_{20:4}$ (Sipos and Ackman, 1968) but still much higher than *P. noctiluca.* This acid is not very obvious in most mollusc analyses (Gruger, 1967). In phospolipids of higher aquatic animals the $C_{20:2}$ acid is usually present in a ratio of about 1 part to 4 of $C_{20:5}$. The proportion in *C. capillata* is about 1:2 (Table 10) which permits an interesting comparison with the depot fatof the Atlantic leatherback turtle. This animal is now known to feed almost exclusively of jellyfish of one form or another (Sipos and Ackman, 1968). Analyses of lipids form *Caretta caretta* lipids are not available for comparison.

In *P. noctiluca's* lipids, the C_{182}, $C_{20:4}$ are the principal long-chained polyunsaturated fatty acids whereas in the other medusae's lipids the primary polyunsaturates are $C_{22:1}$, $C_{20:5}$ and less $C_{20:4}$.

In the fatty acid composition of the 5 species, there are two notable differences. The cold water medusae *C. capillata* and *A. aurita* have significantly more momoenoic acids $C_{20:1}$, $C_{22:1}$ and less $C_{20:4}$. The difference in percentage of monoenes might well be attributed to differences in the diets of the medusae. The C_{20} and C_{22} monoenes are characteristic triglyceride fatty acids of a number of north east Atlantic Ocean fish: herring (*Clupea harengus)*, capelin (*Mallotus villosus*) and sand launce (*Ammodytes americanus*) (Eaton *et al* . 1975; Pascal and Ackman, 1976). In contrast, although published data are somewhat more limited, lipids of fish and pelagic crustaceans of temperature and tropical waters appear to contain relatively minor amounts of $C_{20:1}$ and $C_{22:2}$ acids (Jeffries, 1970; Lee *et al.*, 1971a; Lee *et al.*, 1971b).

P. physalis is a collony of polypods rather than a single organism

Table 10. Comparison of the fatty acid composition of the lipids from representative species of jellyfish, Atlantic leather back turtle, Atlantic herring and Mediterranean boque.

	Aegean Sea *P. Noctiluca*		Portugese *P. Physalis*			Chesapeake bay (Maryland)		Canadian Water			Mediter-ranean	Atlantic (North)	
						S.Mele-agris	*C.quin-cirrha*	*C.capillata*		*A.aurita*	Bogue (*B.Boops*)	Herring	Leather Back turtle
References			(19)			(2)	(2)	(17)		(42,43)	(44)	(40)	(42)
Fatty Acid	Free F.A.	T.G.	TL	Polar Lipid	T.G.	TL	TL	Polar Lipid	T.G.	TL	TL	TG	TG
12:0			–	–	–	1.7	0.7	–	0.2	3.3	0,2	–	10.2
TML	38 4	10	–	–	–	–	–	–	–	–	–	–	–
14:0	0.66	1.33	3.5	6,2	6.6	–	–	0.9	1.9	–	3.5	5.1	14.2
15:0	0.56	1.6	–	–	–	–	–	–	–	–	1.2	–	–
16:0	19.4	26.9	22.6	20.7	36.2	12.1	10.0	6.9	13.3	16.0	20.4	10.9	11.8
17:0	0.88	2.93	–	–	–	–	–	–	–	–	3.3	–	–
18:0	27.9	24.7	9.1	11.6	7.6	8.7	10.9	4.4	4.6	6.4	8.0	1.2	3.1
20:0	1.47	0.7	0.4	0.7	0.8	0.5	1.9	2.4	1.4	1.2	–	–	0.2
Σ	39.27	68.2	35.6	39.2	51.2	23.0	23.5	14.6	21.4	26.9	36.6	17.2	39.5
16:1	0.2	–	3.9	–	–	2.9	3.2	–	1.3	4.7	10.5	12.0	8.6
18:1	0.62	14.7	6.7	5.2	10.0	3.4	3.9	2.1	7.3	11.8	24.5	12.6	29.2
20:1	0.37	–	0.8	0.9	1.2	0.4	0.7	7.2	6.5	13.7	1.9	16.1	4.2
22:1		–	0.1	0.5	0.5	0.1	0.4	0.9	3.0	4.5	2.9	19.8	1.8
Σ	1.19	14.7	11.5	6.6	11.7	6.8	8.2	10.2	18.1	34.7	39.8	60.5	43.8
18:2	2.1	7.5	1.4	1.0	1.6	0.9	0.5	0.2	0.8	0.8	1.0	0.2	0.9
18:3	tr	–	0.9	0.5	1.0	0.5	0.4	0.1	0.5	0.4	0.5	0.4	–
20:3	–	–	–	–	–	–	–	–	–	–	0.1	–	–
20:4	1.63	2.65	9.1	8.7	1.5	15.5	22.4	11.1	3.3	6.7	0.2	0.8	1.6
20:5	1.53	2.85	7.7	6.1	4.3	19.1	7.6	24.5	12.4	8.5	7.6	7.4	3.4
22:5	–	–	1.1	1.1	0.8	3.1	3.6	5.5	4.0	1.6	3.4	1.5	1.6
22:6	–	–	15.6	15.0	10.3	15.9	11.9	17.6	21.1	7.0	6.0	3.9	2.2
Σ	5.26	13	35.8	32.4	19.5	56.2	52.9	59	42.1	25	18.8	14.2	9.7

The carnivorous nature of even the small jellyfish of temperate waters was attested by the observation of a small fish about 2.5 cm long entrapped and killed by a jellyfish of 10 cm diam. (Sipos and Ackman, 1968).

P. noctiluca and *P. physalis* fatty acid of triglycerides contain considerably more $C_{16:0}$. For fish, triglycerides saturates 60% $C_{16:0}$ is a usual figure, but in *P. noctiluca* $C_{16:0}$ is 39,4% of the total triglyceride saturates.

Table 10 compares features of a typical marine depot fat (herring oil) with cold water *C. capillata* triglycerides. Appreciable differences are apparent, suggesting a non depot role in the latter (Sipos and Ackman, 1968). The jelly fish has a little solid material, a large surface area, no obvious depot fat reserves and much of the lipid must be involved in cell membranes. In Table 10 medusae polar lipids are compared with the phospholipids of the squid, a predatory mollusc. Reliable polar lipid analyses do not seem to be presently available for any animal lower on the evolutionary scale. In phospholipids of higher aquatic animals the characteristic polyunsaturated $C_{22:6}$ almost exceeds $C_{20:5}$ but this is not as obvious in the shell fish lipids (Gruger, 1967). Probably the jellyfish results reflect a heavy intake of $C_{20:5}$, the characteristic fatty acid of phytoplankters, which is not necessarily chain extended to $C_{22:6}$ (Brocherhoff *et al.*, 1963).

The observed low ratio of $C_{16:1}$ relative to $C_{16:0}$ is a characteristic of lipids of many marine shell fish (Gruger, 1967). This may be due to their lower place on the evolutionary scale but is more likely to be also due to a food intake primarily of phytoplankton. Pasby (1965) has also shown the high ratio of $C_{18:0}$ relative to $C_{19:1}$ occurring in the jellyfish lipids.

The fatty acids of the SPnL from *P. noctiluca* were found to consist mainly of four saturated fatty acids (96.7%). To our knowledge, there is no other report in the literature concerning the fatty acid components of SPnL molecules from related organisms.

However, a combination of the present data with information referring to other genera leads to a tentative conclusion that most natural SPnL's follow a common trend with other sphingolipids, i.e. they seem to contain almost exclusively saturated fatty acids (including straight or branched-chain and hydroxy-fatty acids).

Thus, three SPnL's isolated from *T. pyriformis* WH-14 (Nozawa, 1984) were found to contain exclusively saturated fatty acids of the n- and isoseries (4 to 6 major components), accompanied by 2-24% of 2-hydroxy-acids with 16-18 carbon atoms (mainly of the iso-series) (Ferguson *et al.*, 1972). Interestingly, the above studies (Ferguson *et al.*, 1972) revealed that the content of 2-hydroxy acids was markedly altered in response to changed environmental and nutritional conditions. When grown in a chemically defined medium, *Tetraphymena* failed to synthesize hydroxy fatty acids while growth in a proteose-peptone medium restored this biosynthesic ability.

Similar features are found in the fatty acid composition of PNnL's from the sea anemones *M. senile* and *A. elegntissima* (Simon and Rouger, 1966) and from several species of sea molluscs (Hori *et al.*, 1984). A rare exception is a SPnL fraction isolated from a mycete, Pythium prolatum, that was found to contain large amounts of mono-and polyunsaturated fatty acids (Wassef and Hendrix, 1977).

The high content of a C_{15}-isoprenoid acid (trimethyl-lauric, TML) found in *P. noctiluca* deserves some particular comments. TML was tentatively identified according to its equivalent chain length (ECL), that was found almost identical to the ECL of 3, 7, 11- trimethyl-dodecanoate, although it was also very close to the ECL calculated for the isomyristic acid (iso-$C_{14:0}$). The following data supported the acceptation of the TML structure: The jellyfish C. capillata was found to contain no more than negligible amounts of $C_{14:0}$ and no $C_{14:1}$ (Jeanne, 1979; Sipos and Ackman, 1968) while the isoprenoid acid 2,6, 10, 14-tetramethyl-$C_{15:0}$ (pristanic) and 3, 7, 11, 15-tetramethyl-$C_{16:0}$ (Phytanic) were significantly present; although the biosynthetic route for isoprenoid formation is absent in medusae, the occurrence of isoprenoid acids and sterols in these organism was interpreted as coming from nutritional sources (Yasuda, 1974).

Well known facts such as that *P. noctiluca* is a phytoplankton feeder too, and that isoprenoid chains are major components of the lipids of haliphilic bacteria (Snyder, 1972), are in support of the TML structure for the above component of the *Pelagia*'s fatty acids. A possible further implication of this is that fluctuations of the T.M.L. content of *P. noctiluca*'s lipids may reflect respective qualitative and/or quantitative changes of phytoplankton (as a result of changing degree of pollution), reflecting also concomitant alterations in the pelagic food web.

The next step of our work is the GLC analysis of the fatty acids of *A. aurita* of the Aegean Sea, which will help in the interpretation of the above results.

The presence Pn-P organisms like fish (e.g. *B. boops*) are very interesting and their origin must be elucidated (nutrition or biosynthesis).

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SCANNING ELECTRON MICROSCOPIC OBSERVATIONS ON SCANDINAVIAN SCYPHOZOANS WITH SPECIAL REFERENCE TO THEIR NEMATOCYSTS

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ABSTRACT

Developmental stages and medusae of *Aurelia aurita* and *Cyanea* spp. from the Swedish west coast were examined by scanning electron microscopy. Of particular interest were the nematocysts, cnidocil apparatus and cilia. The nematocyst terminology within Scyphozoa will be discussed. One nematocyst type not previously described from *Cyanea* medusae was identified. The nematocysts increased in size with the increasing size of the medusae. Size differences between morphologically identical nematocysts of the reddish *Cyanea capillata* and blue pigmented *Cyanea* medusae of the same size were observed.

1. INTRODUCTION

Aurelia aurita (Linnaeus, 1758) and two, maybe three, species of the genus *Cyanea* Péron and Lesueur, 1810 are common jellyfish on the Swedish west coast. The reddish *Cyanea capillata* (Linnaeus 1758) can be a large medusa, and because of its painful stings it is sometimes a significant pest. The blue pigmented medusae might either be specimens of *Cyanea lamarcki* Péron and Lesueur, 1810 or *Cyanea palmstruchi* Swarts, 1809. These two species can only be separated from each other by differences in their developmental stages (Widersten, 1973). In the present investigation no attempt has been made to separate the blue pigmented medusae from each other.

Within Scyphozoa the complement of nematocysts seems remarkably similar from one species to another. Nevertheless, scyphozoan nematocysts can be used as taxonomic characteristics due to variations in their occurrence, anatomical distribution and size. The scyphopolyps and ephyrae of different species have been successfully identified from each other by their nematocysts (Calder 1971; 1977).

Weill (1934), Papenfuss (1936), Russell (1970) and Widersten (1973) reported three categories of nematocysts within the genus *Cyanea*, namely: atrichous isorhizas, heterotrichous anisorhizas and heterotrichous microbasic euryteles. In adult *Cyanea* medusae Weill (1934) further distinguished two varieties of atrichs, the a-atrichs and the A-atrichs.

Burnett (1971) Burnett and Calton, (1987) and Rice and Powell (1972) reported only two different categories but three different nematocyst types within the *Cyanea*, namely atrichous isorhizas, holotrichous isorhizas and heterotrichous microbasic euryteles. The holotrichous isorhizas might be identical to the heterotrichous anisorhizas of Weill (1934).

Calder (1974), using light microscopy, concluded that the scyphozoan nematocysts, previously characterized as atrichous isorhizas, bear spines on their tubules. Consequently, he changed the terminology of the "a-trichs and A-trichs" of Weill to "a-isorhizas and A-isorhizas". However, Calder noticed that the tubules of these nematocysts gradually became more slender towards the distal end rather than being of uniform diameter throughout. Furthermore, the proximal spines seemed to be more developed than the distal spines. These nematocysts should therefore be classified as heterotrichous anisorhizas (Calder, 1974).

Slight differences in the tube diameter and in spine size are not always obvious with a light microscope. Thus, scanning electron microscopic (SEM) analysis of scyphozoan nematocysts was desirable in order to verify the observations made by Calder (1974). A survey based on SEM observations of nematocysts present in *Cyanea* medusae from the Swedish west coast is presented here. One nematocyst type, previously not described from the *Cyanea* medusae, has been identified. The nematocyst terminology proposed

by Calder (1974) is discussed and some modifications suggested. A more complete description of the different nematocysts will be given in a separate publication.

The autecology of *A. aurita* and *C. capillata* from the Swedish west coast has recently been studied (Hernroth & Gröndahl, 1983, 1985; Gröndahl & Hernroth, 1987). SEM observations on cilie structures from developmental stages of *Cyanea* and *Aurelia* are also presented here.

2. MATERIALS AND METHODS

Aurelia aurita and red and blue pigmented *Cyanea* medusae were collected from the Gullmar Fjord on the Swedish west coast (58° 18.6' N, 11° 32.4' E) from June to September during 1986-1987. Scyphopolyps and planulae were cultured or liberated in the laboratory. Ephyrae were collected from plankton. Tentacles of the *Cyanea* and *Aurelia* medusae and different developmental stages were studied under SEM. Nematocyst investigations were made from the fishing tentacles and from the manubrial lappets of the *Cyanea* medusae.

Squash preparations for nematocyst studies were made as previously described (Ostman, 1987). Fresh nematocysts were examined and photographed with an interference microscope. Measurements of undischarged nematocyst capsules were made with an accuracy of about 0.5 m. Nematocysts were identified by type according to Weill's (1934) classification as modified by Calder (1974). Preparations for SEM were made as described in Ostman (1987). Some preparations were, however, fixed directly in 2% OsO_4 in filtered sea water. Glutaraldehyde was omitted since this fixative preserved the mucus (Cormier & Hessinger, 1980). Moreover, an almost immediate fixation directly in OsO_4 preserved the cilia pattern better than prefixation in glutaraldehyde (Chia, personal communication). The OsO_4- fixed preparations were washed in filtered sea water and in distilled water before dehydration.

3. RESULTS

A total of five different types of nematocysts were identified in the *Cyanea* medusae examined (Figs. 1-14). The various nematocysts differed in size, capsule shape, pattern of the inverted coiled tubule and structure of the everted tubule. In the present investigation *Cyanea* nematocysts are classified as follows:

1. Small homotrichous a-isorhiza with ovate to pear-shaped capsule (Figs. 1, 11, 13).

2. Large homotrichous A-isorhiza with pear-shaped, ovate to sub-sphaerical capsule (Figs. 2, 3, 11-13). In *C. capillata* two size classes were found.

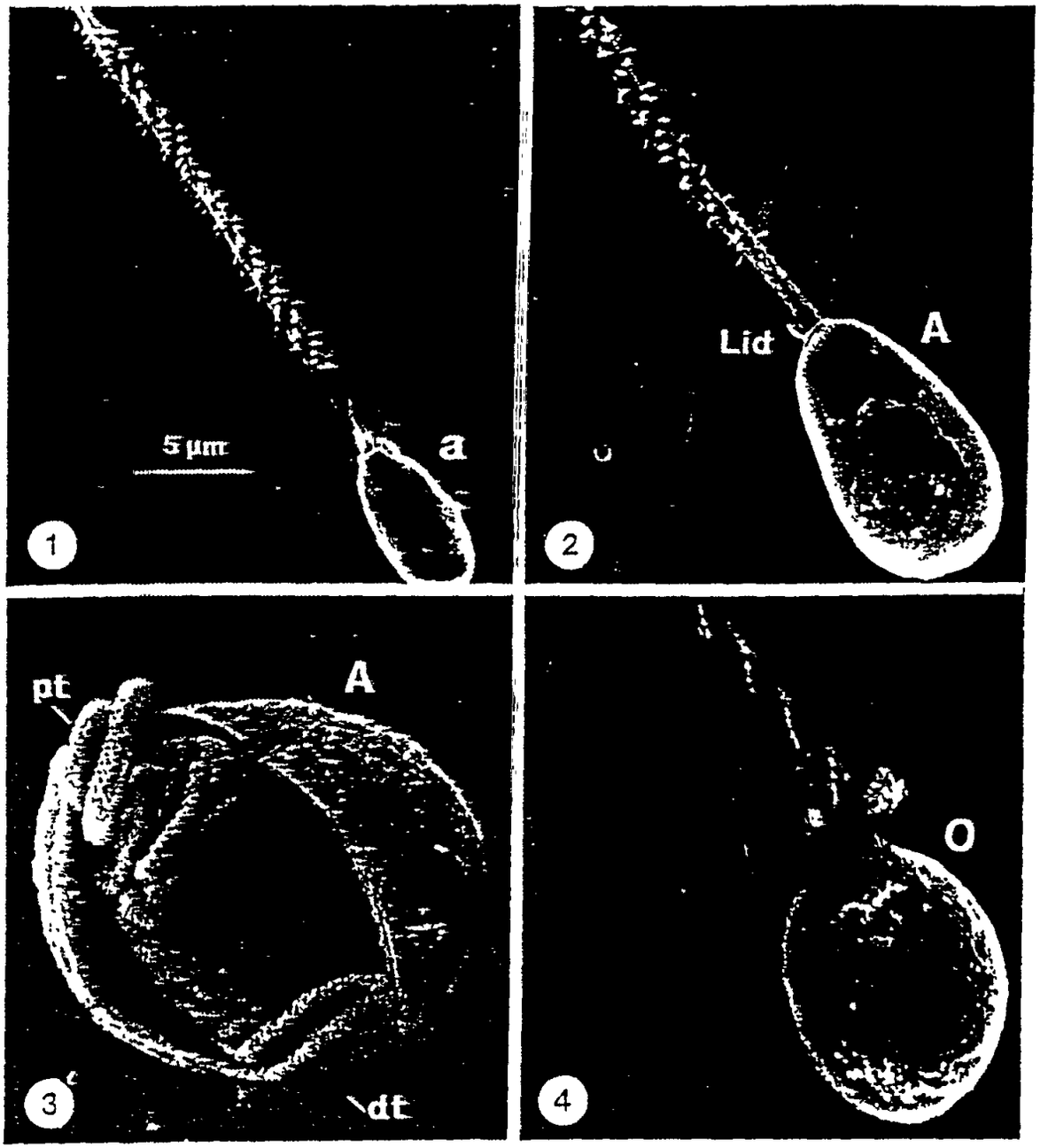
3. Large O-isorhiza with sub-sphaerical capsule (Figs. 4, 11).

4. Large mircobasic heterotrichous eurytele with ovate capsule (Figs. 5, 6, 11).

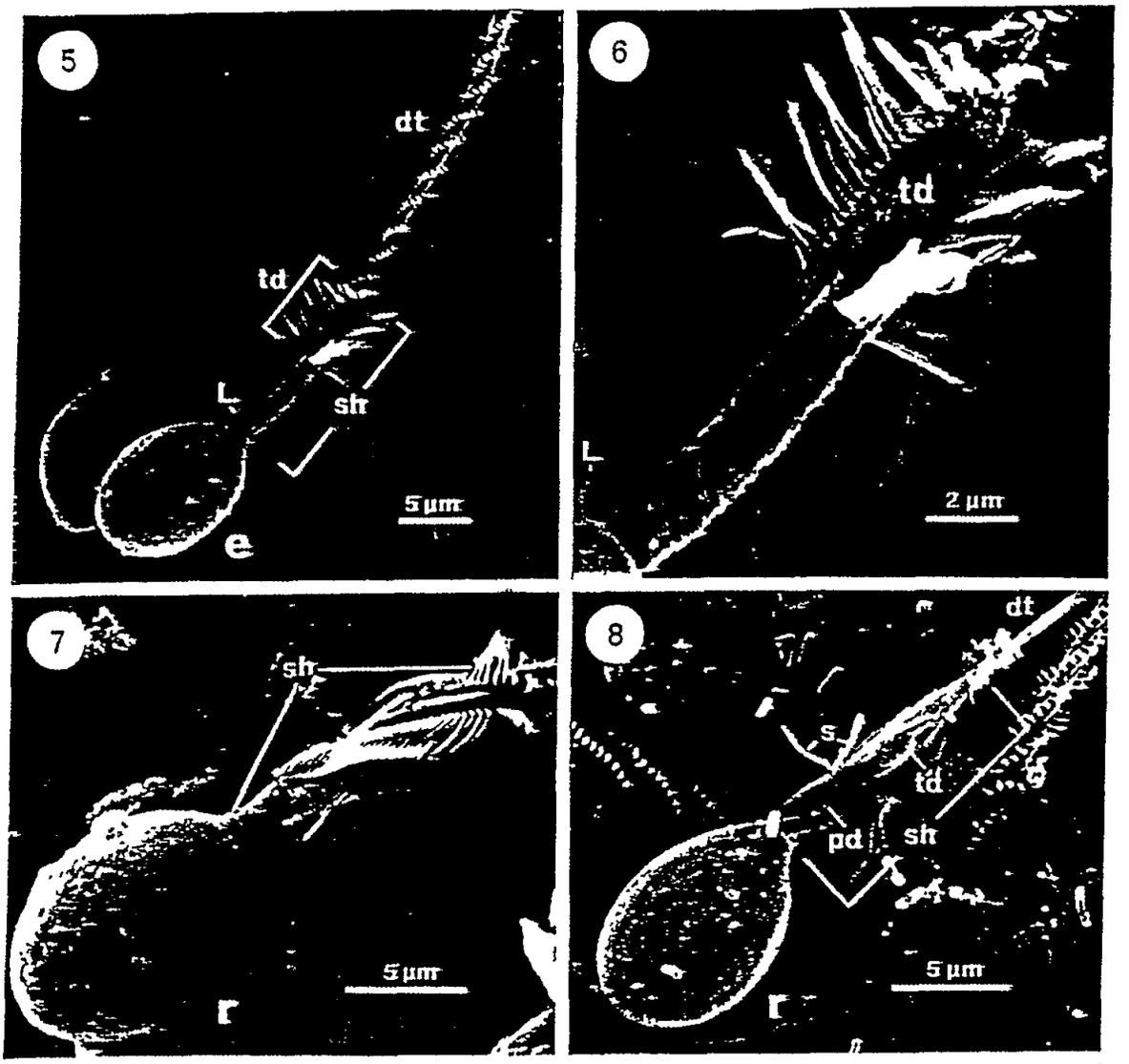
5. Large and small microbasic heterotrichous birhopaloids with ovate to sub-sphaerical capsule (Figs. 7, 8, 13, 14).

The pattern as well as the abundance of the nematocysts varied between fishing tentacles and manubrial lappets. All types were found on the fishing tentacles as well as on the manubrial lappets. The nematocysts were most abundant on the fishing tentacles. Here they occurrred in clusters or batteries along the whole length of the tentacles (Figs. 9-11). The number of nematocysts in a battery varied from five to over 80. Rarely were all the different nematocyst types present in a single battery. The small a-isorhiza, the most abundant type, was present in nearly every battery. The frequency of the other nematocyst types varied and no special pattern was observed. The nematocysts increased in size with increasing size of the medusae. This was most obvious for the A-isorhizas. On the manubrial lappets nematocysts were diffusely distributed (Fig. 13). Only on a narrow region close to the manubrial rim were the nematocysts dense.

SEM observations of the tentacles of *Cyanea* medusae showed batteries of nematocysts (Figs. 15, 16). The observed cnidocils were short, upright and rigid. A ring of sterocilia surrounded their bases (Fig. 17). The areas between the nematocyst batteries were lightly ciliated. Some cilia were also seen between the cnidocil apparatus (Figs. 16, 17).



Figs 1-4. Scanning electron photomicrographs of homotrichous isorhizas of *Cyanea* medusae. All ×3 200. -1. a-isorhiza (a). -2. A-isorhiza (A) of the small size class. -3. Broken capsule of an A-isorhiza (A) of the large size class of *C. capillata*. Note the difference in diameter between the proximal (pt) and distal (dt) tubule regions. -4. O-isorhiza (O).



Figs 5-8. Scanning electron photomicrographs of rhopaloid nematocysts of *Cyanea* medusae. 5,6 Heterotrichous microbasic eurytheles (e). Note the terminal dilation of the slender shaft (sh). 5. ×1,800. 6. ×6,000. 7,8. Heterotrichous microbasic birhopaloids. Note the proximal (pd) and terminal (td) dilations of the broad shaft. 7,8. ×3,200. dt, distal tube; L, lid; s, remaining proximal spines; sh, shaft.

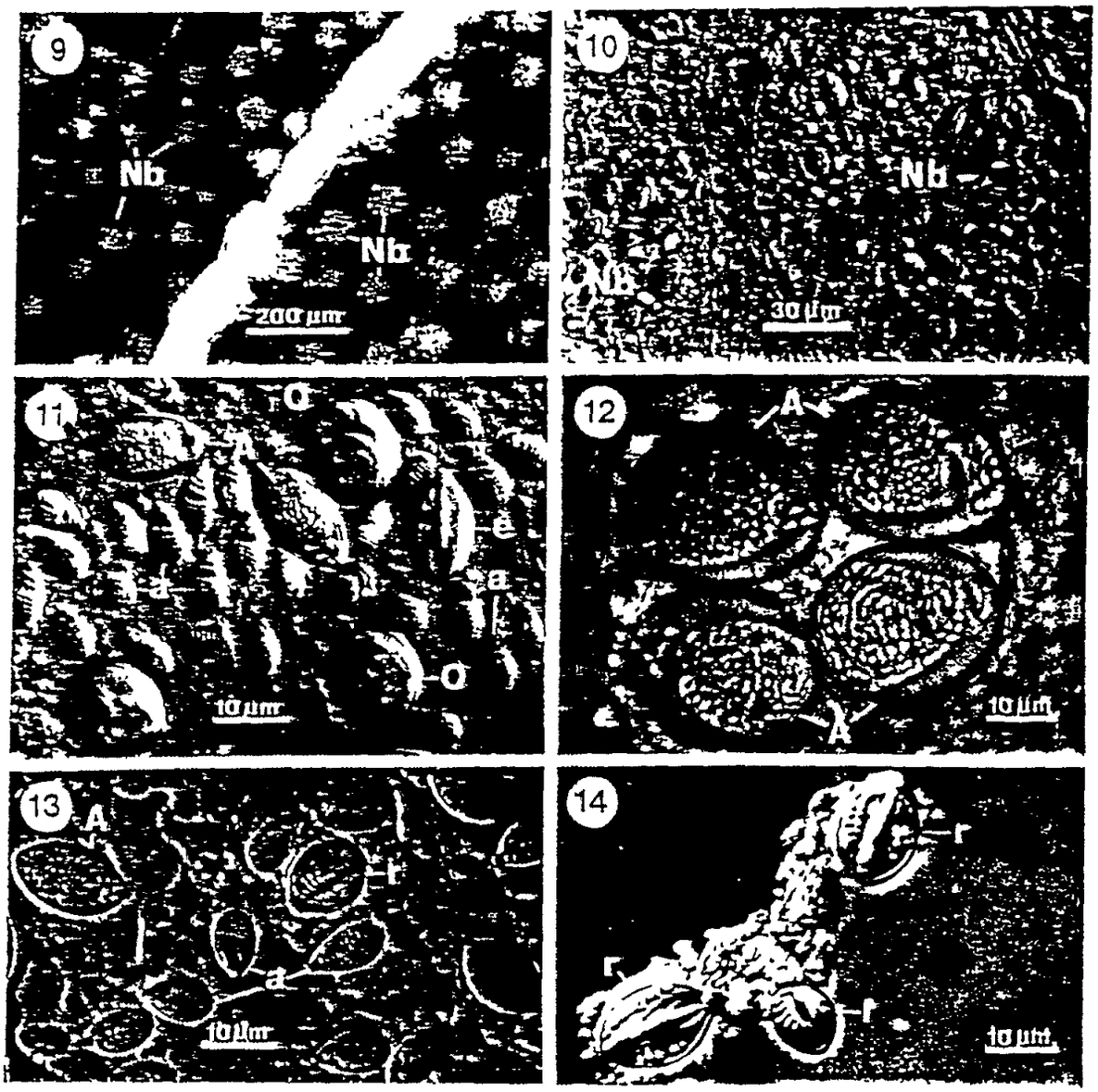
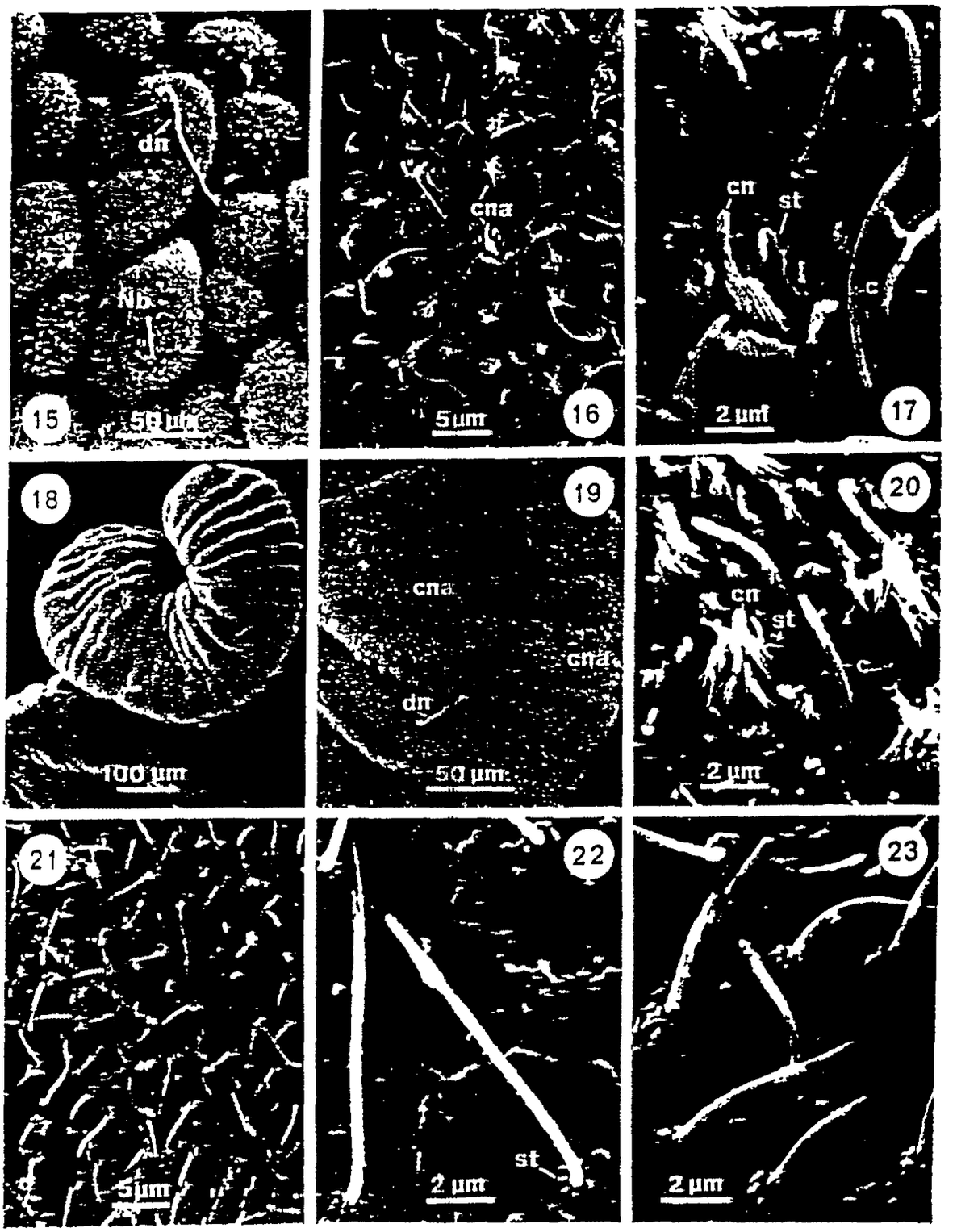


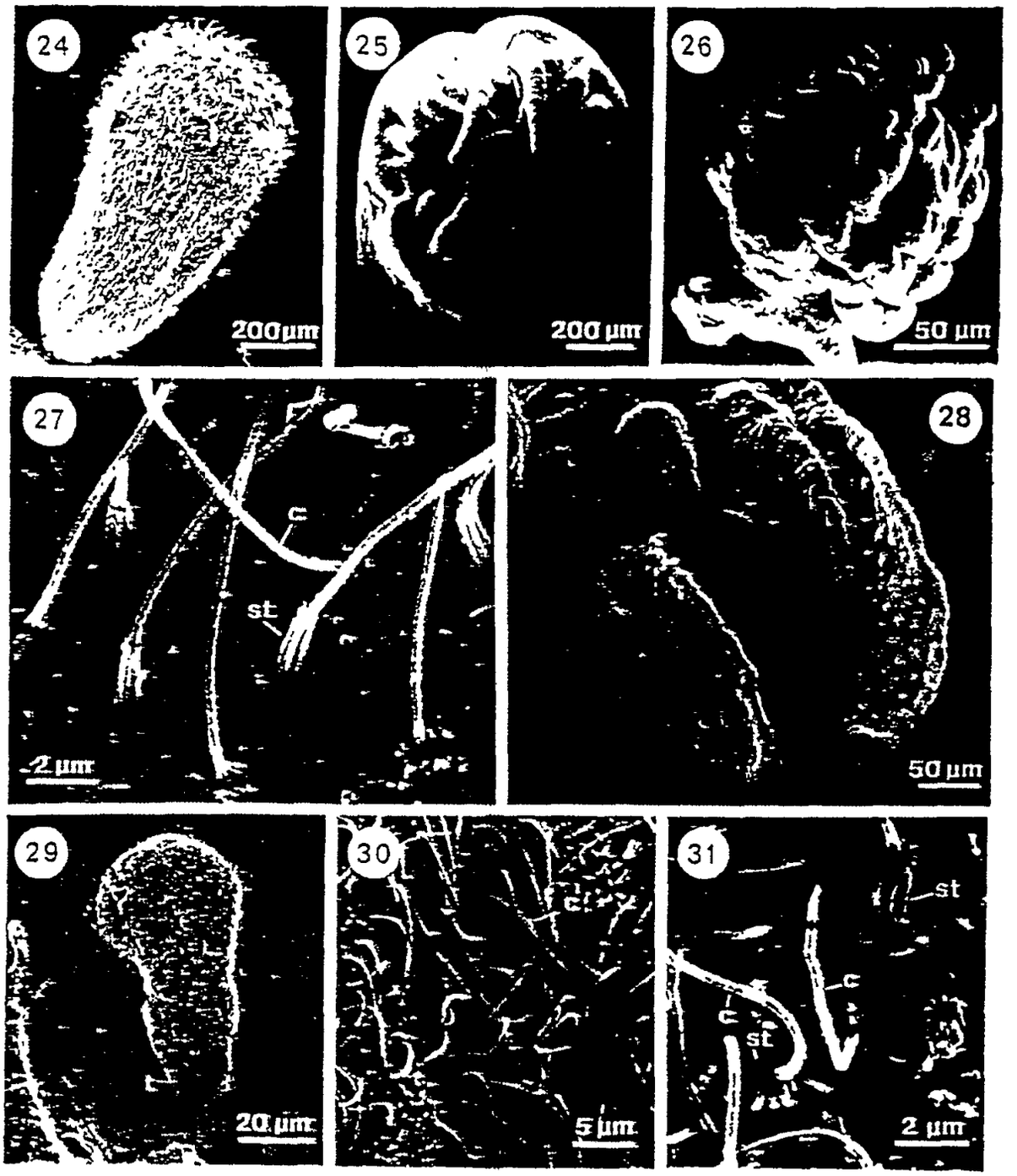
Fig. 9-14 Stereo photomicrograph of a fishing tentacle with nematocystbatteries (Nb) of a*Cyanea medusa* (x7) Figs 10-14 Interference photomicrographs of *Cyanea* nematocysts. 10 (x°C 11-14 x[illegible] 0 -10,11. Nematocyst batteries from a fishing tentacle showing different nematocyst types -12 A-isorhizas of the large size class of *C. capillata*. -13,14 Marginal nematocysts

a, a-isorhizas; A, A-isorhizas; e microbasic heterotrichous eurviteles, Nb, nematocyst batteries O I-isorhizas; r, microbasic heterotrichous rhopaloids



Figs. 15-23. Scanning electron photomicrographs of medusa tentacles. -15-17.*Cyanea capillata*. Part of contracted tentacles ×300. -16,17 Part of a nematocyst battery showing cnidocil apparatus (cna) and cilia (c) 16 ×2,000, 17. ×6 000 -18-23. *Aurelia aurita* -18. A marginal tentacle ×50 -19. Cnidocil appa- as (cna) surrounded by sterocilia (st) ×6,000 21-23. Cilia from base of a tentacle Note the ariation in length and the surrounding sterocilia (st). 21. ×2,000; 22,23 ×6,000

Bn, bands of nematocysts, c, cilia on cnidocils, dn; discharged nematocyst; st, sterocilia; Nb, nematocyst batteries



Figs 24-31 Scanning electron photomicrographs of developmental stages of *Aurelia aurita*. -24 Planula. ×360 -25. Scyphistoma ×48 -26 Strobila. ×54. -27. Cilia (c) from a scyphistoma. Note the surrounding ridged long stereocilia (st) ×6,000 -28 Part of an ephyra showing the rhopalium ×200 -29 A rhopalium. Note the nonciliated tip ×660 -30,31 Cilia (c) from a rhopalium. Note the long stereocilia (st) 30. ×2,000 31 ×5,300

The nematocysts of the *Aurelia* medusae were arranged in transverse bands across the tentacles (Figs. 18, 19). The cnidocils were short and surrounded by stereocilia (Fig. 20). Some cilia were found between the cnidocils and in the areas between the bands of nematocysts. At the base of the *Aurelia* tentacles the cilia were short, more dense and evenly distributed (Figs. 21-23).

The surface of the planulae, scyphopolyps and ephyrae were ciliated (Figs. 24-31). Some of the cilia of the *Cyanea* polyps were surrounded by long, rigid sterocilia at their bases (Fig. 27). The rhopalium of the ephyrae was heavily ciliated except on its tip (Figs. 28-30). Many of the cilia were surrounded by sterocilia (Fig. 31).

4. DISCUSSION

The present study has shown that nematocysts earlier classified as atrichous isorhizas (Weill, 1934) are actually armed with spines along the entire tubule (Figs. 1, 2, 4). The tubule of these nematocysts gradually becomes more slender towards the distal end, rather than being of uniform diameter. Broken capsules of the large A-isorhiza, investigated under SEM, clearly show the difference in diameter between the proximal and distal inverted tubule regions (Fig. 3). Furthermore, the proximal spines of these nematocysts are more developed than spines towards the tip of the tubule (Ostman, in prep.). In agreement with Calder (1974) these nematocysts could therefore be classified as heterotrichous anisorhizas.

SEM analyses of isorhizas within Hydrozoa and Scyphozoa showed that adjacent to the capsule and further distally over a large region the tubules were nearly isodiametric and the spines of the same size (Figs. 1, 2, 4). However, distal to the mid-regions and toward the tips the diameters of the tubules were markedly narrower and the spines less developed (Ostman, 1982; 1983; Ostman, in prep.). Thus, it seems more convenient to retain the old classification and regard these nematocysts as homotrichous isorhizas in order to distinguish them from the more conspicuous heterotrichs and anisorhizas. The heterotrichous anisorhiza of Weill (1934) and Papenfuss (1936) has in the present investigation beeen classified as a homotrichous isorhiza (Burnett, 1971; Burnett and Calton, 1987). This nematocyst has been named here O-isorhiza. The "O" refers to the shape of the capsule.

A nematocyst type not previously reported in *Cynaea* medusae has been found. This nematocyst has a short shaft armed with large spines. The shaft has one proximal and one terminal dilation (Figs. 7, 8). Nematocysts with shafts of unequal diameter belong to the main group rhopaloids according to the classification system of Calder (1974) and Mariscal (1974). The morphology of this *Cyanea* nematocyst, however, does not really fit any of the described nematocyst types within the rhopaloids. In the present investigation this new type is referred to as a "microbasic heterotrichous birhopaloid" until further consultations with other scientists working with nematocysts. The term birhophaloids refers to the two swellings on the shaft. This birhopaloid was very common on the manubrial lappets. However, it also occurred rarely on the fishing tentacles. The capsule shape and the pattern of the inverted tubule were rather similar to the eurytele type, from which it had probably not been distinguished earlier. But when discharged the two nematocyst types can clearly be separated from each other (Figs. 5-8).

Differences in the nematocyst complement between *C. capillata* and the blue *Cyanea* medusae were also found. This provides further evidence that *C. lamarcki* is a valid species distinct from *C. capillata*. The larger A-isorhiza with sphaerical capsule (Fig. 12) has so far not been observed in the blue pigmented *Cyanea* medusae. The largest nematocysts were found in *C. capillata*. This was also the case if size comparisons of the nematocysts were made between red and blue pigmented medusae of the same size.

SEM analyses on tentacles of the *Cyanea* and *Aurelia* medusae showed upright, rigid cnidocils surrounded by sterocilia (Figs. 17-20). Similar cnidocil structure was expected on the surface of the developmental stages. So far only cilia were found. Some of the cilia, however, were surrounded by prominent sterocilia (Fig. 27). The following questions are thus raised, which may be answered by further electron microscopic observations: Do all scyphozoan nematocysts have cnidocils? Are the cilia surrounded by long, rigid sterocilia cnidocils, or do they have other sensory functions? The cilia surrounded by shorter sterocilia,

observed on the rhopalium of the ephyrae, undoubtedly have sensory function (Fig. 31: cf. Hundgen and Biela, 1982).

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EVENTS ASSOCIATED WITH THE DISCHARGE IN NEMATOCISTS OF Pelagia noctiluca

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ABSTRACT

In order to identify the mechanism of discharge of the holotrichous isorhiza nematocysts of *Pelagia noctiluca*, the following factors were investigated: (i) the discharging effectiveness of the -S-S- reducing agent thioglycolate, (ii) the changes in capsule volume associated with the discharge, and (iii) the kinetics of the release of free calcium from discharging capsules following the treatment with either SCN^- or thioglycolate. The latter was revealed by the light emission of aequorin which was present in the reaction medium.

The results show that 25 mM thioglycolate is as effective in inducing the discharge as 500 mM SCN^-. Following treatment with both discharging agents, the nematocysts were observed to swell before the discharge and to shrink after the eversion of the tubule. The discharge is also preceded by morphological changes of the inverted tubule that appears swollen and partially uncoiled. Finally, the release of free calcium occurs in two distinct phases, both taking place before the eversion of the tubule.

These results support the primary role played by capsule wall and tubule in the mechanism of discharge of the nematocysts of *P. noctiluca*.

1. INTRODUCTION

A relevant aspect of the discharge mechanism of the nematocysts of Cnidaria is the source of energy that causes the eversion of the tubule. The osmotic theory is based on the observation of a high concentration of solutes in the capsule fluid. When the permeability of the wall increases, an inflow of water enhances the inner pressure, thus causing the eversion of the tubule. More recently, it was stated that the capsule wall is freely permeable to water, even at rest (Lubbock and Amos, 1981). Consequently, the osmotic theory was modified (Lubbock and Amos, 1981; Lubbock *et al.*, 1981; Gupta and Hall, 1984). It was taken into account that the capsule fluid contains (i) a protein molecule unusually rich ($\simeq$80%) in glutamate (Blanquet, 1970; Phelan and Blanquet, 1985) and (ii) a very high amount of calcium, that could aggregate the above protein molecules (Lubbock and Amos, 1981; Lubbock *et al.*, 1981). Therefore it was suggested that before the discharge calcium is unbound, so that the dissociated protein molecules osmotically recall water into the capsule fluid.

The constant pressure theory suggested that the capsule fluid of resting nematocysts exerts hydrostatic pressure against the wall. Thus, when the "stopper" (i.e. the operculum or apical flaps) is weakened (Yanagita and Wada, 1954) this pressure pulls the tubule outward. The constant pressure theory should be revised too. In fact, since the capsule is permeable to water, constant pressure could not be maintained, except with all water in a bound condition. It has been suggested by Blanquet (1970) and by Salleo *et al.* (1984a; 1984b; 1986) that conformational changes of protein molecules could be associated with the process of discharge. Conformational changes could be involved in the discharge either through a swelling of the protein matrix of the capsule fluid, or by producing a change in the mechanical characteristics of the capsule wall such as for instance the release of an elastic tension stored in the latter. In both theories, calcium could stabilize the resting condition. For instance, calcium binding sites have been described by Watson and Mariscal (1984; 1985) either in the tip seams or on both sides of the inverted tubule. Thus, calcium could act by maintaining the "stopper" closed and the tubule pleated.

In order to identify the mechanism of discharge, the following controversial aspects should be clarified:

(i) The volume change of capsules before and after the discharge. In fact, in the modified osmotic theory, a swelling is expected before the discharge, without any shrinkage after the ejection of the capsule fluid with respect to the resting volume. On the other hand, the release of elastic tension from the wall is expected to be associated with a reduction in volume after the discharge.

(ii) Since a main component of the capsule wall is a disulphide-linked collagen (Blanquet and Lenhoff, 1966), a discharging effect of -S-S- reducing molecules is expected if the discharge depends on a mechanism located in the wall.

(iii) The stabilizing effect of calcium is a main aspect of the overall problem. In particular, the kinetics of the release of Ca^{2+} associated with the discharge is expected to provide useful information about the discharge mechanism. In fact, the osmotic theory proposes that calcium is unbound from protein molecules present in the capsule fluid. Thus, most calcium is expected to reach the medium as the capsule fluid is ejected. On the other hand, if calcium is unbound from the sites located in the sealing structures (Watson and Mariscal, 1985), free Ca^{2+} should be released as soon as the discharging agent is applied, namely before the eversion of the tubule.

The above questions were proposed as the main aim of the research project.

2. MATERIALS AND METHODS

All experiments were performed on holotrichous isorhiza nematocysts of *P. noctiluca*, isolated as described elsewhere (Salleo *et al.*, 1983). The discharging agents were either 500mM NaSCN (Salleo *et al.*, 1984a) or Na Thioglycolate at the following concentrations: 12.5, 25, 50, 75, 125 mM, buffered at pH 9.6 with 0.1M Tris-HC1 (Salleo *et al.*, 1986). The discharge rate was measured with a dissection microscope at 2.5, 5, 10, 15 min after treatment with the discharging agent.

The diameters of resting, discharging and discharged capsules were measured with an interference contrast microscope (Zeiss, Photomicroscope III).

The release of free calcium from the discharging nematocysts was revealed by measuring the light emission of Aequorin (Shimomura, *et al.*, 1963; Blinks *et al.*, 1976), which was present in the reaction medium. 0.2 ml of a dense suspension of nematocysts, the concentration of which had been previously determined by a Burker cell, were added to the reaction medium which was contained in the cell of a Luminometer (L.K.B. mod. 1250) equipped with a recorder. The reaction medium (0.3 ml) contained 833mM NaSCN,333 M $MgCl_2$, 20 mM Tris-Hc at pH 7.4 (Azzi and Chance, 1969). 0.1 ml of Aequorin (SIGMA, III) solution were added immediately before each light emission test. When the 25 or 50mM thioglycolate were used as a discharging agent in place of SCN-, the reaction medium was buffered at pH 8.2. The light emission of Aequorin was continuously recorded for 15 min after having injected the nematocysts into the reaction medium (Salleo *et al.*, 1987).

3. RESULTS

The treatment with thioglycolate induced the discharge of capsules. Its effectiveness was found to depend on concentration. At concentrations of 125 and 75mM the discharge of capsules was almost complete within 5 min. A more gradual response was obtained with 50 and 25 mM. In particular, with the latter concentration a discharge rate was obtained which was similar to that induced by 500 mM SCN^- (Fig. 1). At 12.5 mM only 10% of capsules was discharged in 15 min.

The average capsule volume of resting capsules was 11,133 ($\pm$ 235) μm^3. When this volume is compared with that of discharged capsules, which was 6,338 ($\pm$165) m^3, a 43% reduction results. It should be stressed that no wrinkling was observed in the discharged capsules. Following the treatment with either SCN^- or thioglycolate the volume increased significantly before the discharge, so that a swelling of 16.9% could be observed. Moreover, some changes in the shape of the inverted tubule could be observed following the treatment with both discharging agents. The tubule appeared to be enlarged and less strictly coiled than before the treatment. These morphological changes were observed only in capsules that subsequently discharged, while the unresponsive capsules were unmodified.

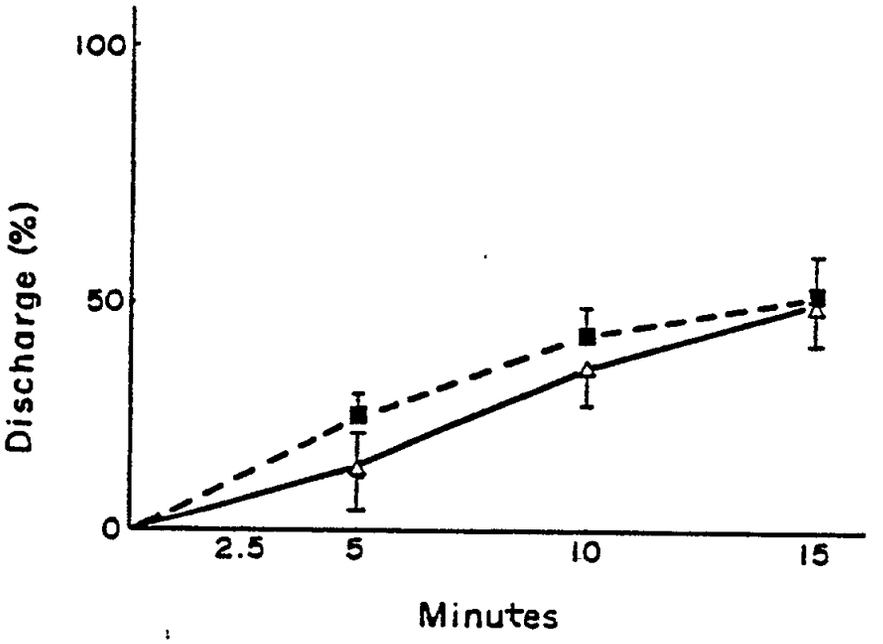

Fig. 1 Discharge rate induced by 500 mM SCN^- (dotted line) and by 25 mM Thioglycolate (solid line)

The experiments performed with Aequorin to test the release of free calcium from the discharging nematocysts revealed that calcium is actually released following the treatment with both discharging agents.

The light emission from Aequorin had two distinct phases: (i) a rapid, spike-shaped one that followed within 1 sec the immission of the resting capsules into the reaction medium, and (ii) a subsequent slower

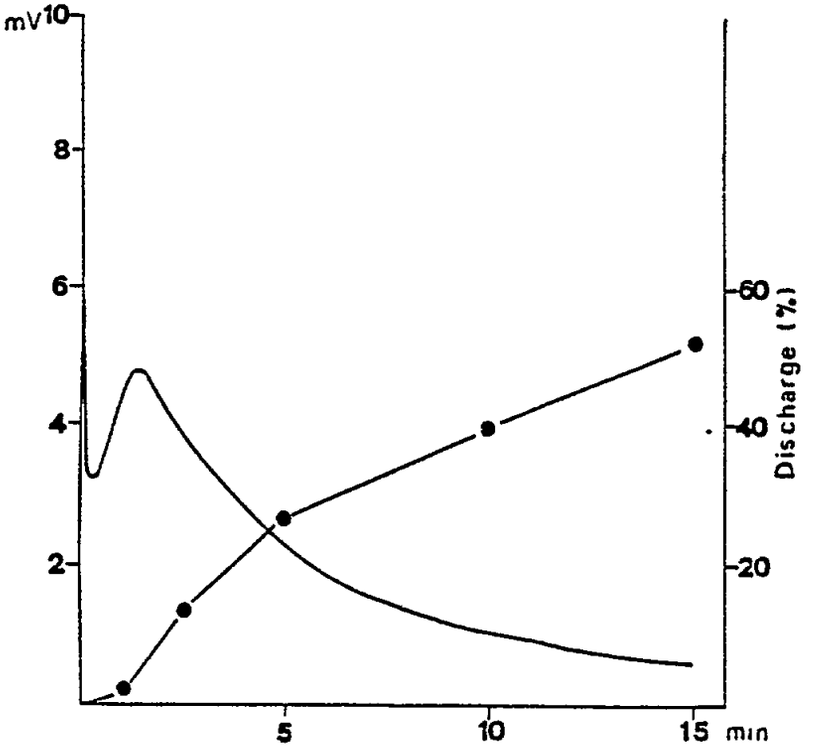

Fig. 2. Light emission signal (solid line) and discharge rate following treatment with SCN^-

one that reached its peak amplitude at 102 sec (± 19.9) and then decayed exponentially (Fig. 2). No significant differences were observed between SCN^- and thioglycolate as regards the light emission signals. When the kinetics of calcium release was compared with the discharge rate, it could be observed that both phases of Ca^{2+} evolved completely while only 5% of capsules discharged.

4. DISCUSSION

The results of the present investigation support the hypothesis that a conformational change in proteicules is a crucial event in the mechanism of discharge of the nematocysts of *P. noctiluca*. In fact, either thioglycolate, which acts by reducing -S-S- bonds, or SCN^-, which is expected to act on hydrogen bonds as well as on hydrophobic interactions between protein molecules, induces the discharge.

As regards volume changes, it has been observed that the volume of chemically stimulated nematocysts increases before the discharge and decreases following it. This is in agreement with the observations of Tardent and Holstein (1982), Holstein and Tardent (1984) and Phelan and Blanquet (1985). The swelling has been interpreted as the result of an osmotically-induced water inflow (Lubbock *et al.*, 1981; Holstein and Tardent, 1984). On the other hand, the hydration of protein structures caused by conformational changes could also be responsible for this effect. Moreover, the swelling and partial uncoiling of the inverted tubule could produce an increase in volume. The latter is in agreement with the observation that calcium binding sites are placed either on tip seams or on both sides of the inverted tubule (Watson and Mariscal, 1985) which, as it has been suggested, maintain the tip closed and the tubule pleated.

Finally, the release of free calcium, revealed by the light emission of Aequorin, occurs before the discharge. In fact, both phases of the light emission signal evolve while a percentage as small as 5% of capsules have discharged. Free calcium could derive either from the capsule fluid, as proposed by Lubbock *et al.* (1981) or from the capsule wall and tubule (Watson and Mariscal, 1985; Salleo *et al.*, 1987). In the former case, although the outward diffusion of some calcium unbound from dissociating protein molecules could generate a light signal before the discharge, a further amount of free calcium is expected to reach the medium as the capsule fluid is ejected during the discharge. In the latter, regardless of whether the released free calcium derives from the tip seams or the tubule, it is expected to appear in the medium as soon as the discharging agent is applied, namely before the discharge. Then, the hydration of capsule structures proceeds, and induces the eversion of the tubule. Therefore, although the osmotic hypothesis cannot be excluded, the role of the capsule wall and of the tubule in the mechanism of discharge is strongly supported by the above results.

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THE STIMULATION OF REPRODUCTION IN COELENTERATES BY LOW LEVELS OF TOXIC STRESS

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ABSTRACT

Experimental work with the colonial hydroid *Laomedea flexuosa* has demonstrated two mechanisms by which sexual and asexual reproduction may be increased in response to low levels of stress induced by toxic and other agents. The relevance of these findings is considered in relation to jellyfish swarms and their causes in the Adriatic.

1. INTRODUCTION

The purpose of this paper is to indicate two kinds of mechanism that have been identified in colonial hydroids which might explain the abnormal proliferation of scyphomedusae in the Adriatic in recent years. Our work on the responses of colonies of the hydroid *Laomedea flexuosa* to toxicologically-induced stress suggests two mechanisms by which low concentrations of environmental contaminants may increase the reproduction of coelenterates. Here the two mechanisms will be briefly described first in relation to asexual and then sexual reproduction. The relevance of such mechanisms to the occurrence of scyphomedusan swarms will then be discussed.

2. HORMESIS

The asexual reproduction of members of hydrozoan colonies such as *L. flexuosa* is increased by low levels of a variety of toxic agents, to give a characteristic dose-response relationship (Stebbing, 1981). Such examples, involving the stimulation of growth processes by low concentrations of toxic agents, are now known from many experiments with plants and animals and in response to a wide variety of toxic agents (Stebbing, 1982). Hormesis, as this phenomenon is termed, has now been known for a century, but there is no generally accepted hypothesis to account for it. Our work on the kinetics of perturbed growth of *L. flexuosa* and a marine yeast indicates that it may be a consequence of the action of control mechanisms responsible for regulating growth (Stebbing, 1987). Specific growth rate ratios (R%) indicated the output of a control mechanism which, in overcorrecting too low levels of inhibitory challenge, cumulatively results in increased colony growth. Experiments with a range of stressors, including cadmium, copper, tributyl tin, fluoride and reduced salinity have all been shown to cause hormesis. As an example data are given here for the effect of copper on colony growth in *L. flexuosa* in an experiment lasting 16 days (Fig. 1a). At each concentration, fluctuations in R% indicate the behaviour of the control mechanism during the course of the experiment.

3. GONOZOOID PRODUCTION

A similarly biphasic response occurs in the frequency of gonozooids in colonies of *L. flexuosa* exposed to low concentrations of toxic agents (Stebbing, 1980). This response results not from an increase in the rate of biosynthesis, as appears to be the case with hormesis, but from a switch in the allocation of growth to the formation of different types of colony members. Thus with increasing subinhibitory levels of stress, as the numbers of new hydranths formed decreases, there is a proportionate increase in the number of gonozooids. The relationship is shown in results from an 11-day experiment with copper, the response requiring at least 9 days to become maximal (Fig. 1b). Like hormesis, this is a non-specific response to

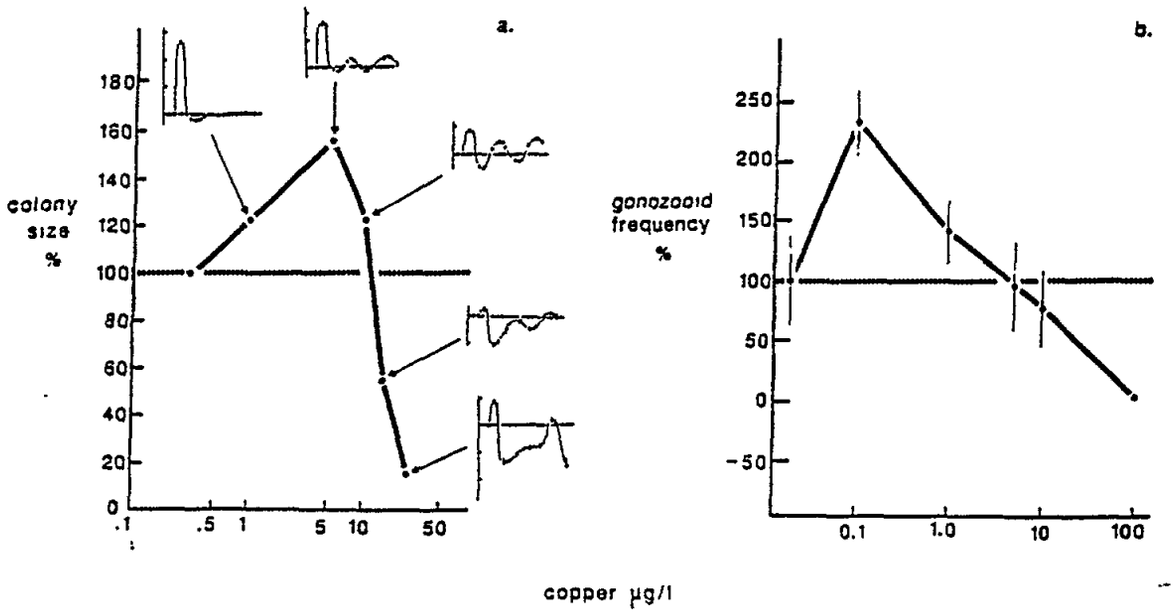

Fig. 1. Examples of stimulation of asexual reproduction a) and sexual reproduction b) in *Laomedea flexuosa* in response to low levels of copper

stress and has been shown to occur following exposure to a wide range of toxic agents. The generality of the response has made it possible to use gonozooid frequency as a measure of biological water quality in pollution studies (Stebbing *et al.*, 1983). The response is adaptive in that it provides a sessile organism with a means of increasing investment in the dispersal phase, and has survival value when conditions are locally unfavourable on the bottom. Greater investment in the production of gonozooids must increase genetic heterogeneity, which is also likely to be advantageous in changing environmental conditions.

These two processes occur independently and have separate explanations: hormesis is apparently a by-product of the action of control mechanisms that overcorrect in responding to levels of inhibition well within their capacity to counteract. Enhanced gonozooid production is an adaptive response to stress that results from the transfer of growth effort from the formation of new hydranths to an equivalent biomass of gonozooids. These data show not only that coelenterates can respond to toxic stress by increasing investment in growth or reproductive processes, but also indicate two explanations for increased reproduction of scyphomedusae that might be explored.

4. RELEVANCE OF HYDROID DATA TO SCYPHOMEDUSAN REPRODUCTION

It is well known that there are marked natural fluctuations in the abundance of scyphomedusae (Rottini-Sandrini and Stravisi, 1981). However, in areas such as the Northern Adriatic, particularly from 1977 to 1980, their abundance from April-May to October-November has been so great as to require additional explanation. The experimental work outlined here suggests that the unusual abundances of scyphomedusae may be due to responses of their parents to stress, so a relationship must be sought between the spatial and temporal occurrence of such swarms and stressful conditions that may have stimulated reproductive processes in their parents. However, such correlations are not straightforward, as the conditions that could elicit the response may be expected to precede the occurrence of increased numbers of scyphomedusae by some months, at a considerable distance from the swarms themselves. In order to identify potential causal stimuli retrospectively, it is necessary to interpret the hydrography of the system in relation to the distribution of scyphomedusae as Vucetic (1983) and Legovic and Benovic (1984)

have done. However, if *Pelagia* swarms result from the effects of stress on the parent, then it is necessary to back-calculate from data on the size distribution and growth rates of medusae together with data on the direction and velocities of currents to predict where such effects might be occurring and thus try to identify the agents responsible.

Vucetic (1983) first suggested that swarms of *Pelagia* might be a result of hormesis, in that sublethal concentrations of toxic contaminants may increase reproduction in the way that colonial growth in hydroids is stimulated. However, it should be made clear that in *L. flexuosa* hormesis occurs as increased asexual growth of colonies, while in *Pelagia* reproduction is typically by sexual production of planulae (Rottini-Sandrini and Avian, 1983). However, it has recently been demonstrated that corals can produce planulae asexually and Shuker (1986) has shown that 'planuloids' may be produced asexually by the scyphistomae of *Cassiopea*. Clearly, any such capability that might be switched to adapt and further stimulated by low concentrations of toxic agents must increase significantly the potential rate of reproduction of scyphistomae.

In the Northern Adriatic the most likely causes of poor water quality that could elicit such responses are the nutrient and effluent inputs which enter the sea by the Po and other smaller rivers. While they carry significant quantities of toxic materials, the most widespread effects are likely to relate to reductions in salinity in surface waters in recent years (Degobbis *et al.*, 1979), which have been shown to induce increases in gonozooid frequency in *L. flexuosa*. More significant for scyphomedusan species with a benthic scyphistoma is the depression of oxygen levels on the bottom in the summer months (Degobbis *et al.*, 1979; Smodlaka, 1986), which may be expected to elicit the same kind of escape reponse for the sessile phase by increased investment in the planktonic dispersal phase.

Benovic and Bender (1987) have established a clear relationship betwen oxygen depletion near the bottom and the disappearence of hydromedusan species from the fauna of the Northern Adriatic.

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EPIDEMIOLOGY AND THERAPEUTIC METHODS OF "JELLYFISH" POISONING IN GREECE

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ABSTRACT

In the present study we have analyzed the epidemiological data of jellyfish stings referred to our Poison Control Center in the years 1981-1984. We have also comparatively evaluated the therapeutic value of medications applied for local symptoms. Our findings are as follows: the adults cover 75% of the whole number of stings. Monthly distribution has its pick in July and August. The symptoms noticed are mainly local (93%) as: redness, pain, burning and itching. Severe systemic reactions are very rare. From the comparative study of therapeutic methods we have noticed the following: Local application of corticosteroids or antihistamines relieves the pain, burning and redness faster than placebo (statistically significant difference) following double blind test.

1. INTRODUCTION

With the exception of the effects on tourism and fishery, jellyfish mainly affect the swimmers after occasional contact (Halstead 1965, Burnett *et al* 1968b).

Many swimmers however, are negatively affected not only by the contact, but also by the unpleasant feeling arising from their presence in the sea and by the possibility of being stung.

EFFECT OF JELLYFISH ON THE MAN

After an occasional contact of a jellyfish with a swimmer, the nematocysts of the medusa stick on the skin of the victim and the cnidocyst brakes, producing the penetration of the toxins in the skin. The next step is the reaction caused by the toxins. Mainly we have local reactions while systematic symptoms rarely occur (Burnett *et al* 1968, Burnett and Calton 1977). Rarely severe intoxication may occur in very sensitive individuals. It has to be noted that the appearance of symptoms does not depend only on the jellyfish but also on the individual, either because of local factors (hair, sensitive area of the body, thickness of the skin etc.), or because of the sensitivity and state of the victim. Is it therefore possible to predict which individuals are likely to suffer severe reactions ? The answer to this question is not so easy; however, there are many cases where we can predict that specific individuals may react severely after a contact. Such individuals are those known as having an allergic predisposition, and mainly those who have in the past reacted severely after contacts with animals or insects. On the other hand, severe reaction can also appear in individuals who never had an apparent allergic predisposition before.

SCOPE OF THE STUDY

The scope of the present study is to evaluate the epidemiological aspects of jellyfish poisoning in Greece and the evaluation and comparison of the therapeutic accuracy of the most important means of treatment of the local symptoms (Maretic 1983).

2. MATERIALS AND METHODS

A) Epidemiological data

The cases of medusa stings referred to the Poisons Control Center for the years 1981-1984 are analyzed in relation to sex, age, time of the year, areas, symptoms occurred and therapeutic methods.

B) Collection of information from doctors

Contacts with physicians working at coastal areas gave us the chance to obtain information on the medusa stings. The information did not concern statistical results, but mainly doctors' personal experience. The contacts were made either through telephone, with special letter delivery with questionnaire, or by visiting coastal areas. More specifically, doctors were asked for an approximate number of cases, the kind of problems occurred, if the cases were medically severe, which was the therapeutic method applied and which was the outcome of the case.

Answers concerning the above, or some of the above, were obtained for the following areas: Attica, Kammena Vourla, Volos, Kos, Milos, Creta, Argolis, Chalkidiki, Kalamata, Corfu.

C) Comparative study of therapeutic methods

Sixty-nine cases of medusa stings which occurred during the summers of 1985 and 1986 to individuals of 15-60 years of age were evaluated.

The cases were divided into 3 groups: A, B, C, consisting of 23 persons each. The selection as well as the division to three different groups was made independently from sex and age.

The selection of cases was made according to the following criteria:

1. Presence of local symptoms-not systematic-and mainly redness, pain and burning.

2. Evaluation of the case in the first two hours after the sting.

3. Stings near sensitive areas such as eyes, lips etc. were not evaluated.

The application of local therapeutic treatment was performed following the method of double blind test. The physician didn't know the kind of agent used in each group.

In group A the agent used was pomade betamethasone 0,1%. In group B pomade Dimethindenum Maleic 0,1% and in group C pomade without active ingredient (placebo).

In all cases a thin layer of pomade was applied in a single dose. The area of the sting was not covered.

The time needed for the relief of pain, burning and redness was evaluated for each of the three groups. The evaluation was subjective. All patients were guided on how to note down and refer of the time when symptoms were reduced after the application of the agents. Evaluation of redness was done by the physician. All cases were examined periodically (every 30'). The results were given according to the findings and in combination to the information reported by the patients. At the end of the study code numbers were shown and groups were compared according to the results.

3. RESULTS

A. Epidemiological data

The total number of medusa sting cases cannot be defined because not all of them are referred to the Poison Control Center. On the other hand, the total number depends on the number of the medusa which exists in the coastal areas where swimming is performed.

The following numbers therefore are purely representative. We have noticed that during the years 1981-1983 the total number of cases does not show great differences, while their number in 1984 is quite

different. This is probably due to the fact that year jellyfish where not so many and especially in the Attica coastal area.

1981: (200))
1982: (230)) *Total number of stings (n) by year.*
1983: (280))
1984: (52))

In the following evaluation (Table 1-8) the cases related to the year 1984 are not included because they are very few. Therefore the years 1981-1983 are only evaluated.

Jellyfish stings occur during the swimming period which begins in May and extends up to September. As its seen on Table 3 the frequency is higher in August and lower in May. There is however a difference from year to year and that probably depends on the quantity of the jellyfish existing every year.

Symptoms can be divided to local which cover the 92,3% and general which cover a very low percentage, as its seen on Table 4. The most interesting local symptoms are presented on Table 5 and general symptoms on Table 6.

The most frequent symptoms occurring after the medusa poisoning are redness and pain. Pain is described as severe and penetrating like electric current but it is of short duration.

The local symptoms last for 1-2 days and sometimes for a week.

Table 1. Sex distribution of jellyfish cases

	1981	1982	1983	Total
Male	103(51,5%)	113(49,1%)	146(52,1%)	362(51%)
Female	97(48,5%)	117(50,9%)	134(47,9%)	348(49%)

Table 2. Age of the patients

	1981	1982	1983	Total
Adults	152(76%)	180(78,3%)	215(76,8%)	547(77%)
Children	48(24%)	50(21,7%)	65(23,2%)	163(23%)

Table 3. Montly distribution of 710 cases

	1981	1982	1983	Total
May	10(5%)	12(5,2%)	17(6,1%)	39(5,50%
June	31(15,5%)	18(7,8%)	31(11,1%)	80(11,2%
July	58(29%)	92(40%)	76(27,1%)	226(31,8%
August	72(36%0	81(35,2%)	120(42,9%)	273(38,5%
September	29(14,5%)	27(11,8%)	36(12,8%)	92(13,0%

Sometimes, on the area of the sting, persisting hyperpigmentation of the skin can occur.
General symptoms occur fortunately very rarely and only the allergic shock is life threatening.
The 82,8% of the cases were reported in the coastal area of Attica (Saronic and South Evoic bay) and only the 17,2% in the rest of the country. This can also be explained by the fact that in other areas the contact with the Poison Control Center for jellyfish stings is less frequent. In Attica the contact with the Center is easier.

Table 4. Symptoms after jellyfish contact

	1981	1982	1983	Total
Local	183(91,5%)	212(92,2%)	260(92,8%)	655(92,3%)
General	17(8,5%)	18(7,8%)	20(7,2%)	55(7,7%)

Table 5. Local symptoms

	1981	1982	1983	Total
Redness	180(90%)	210(91,3%)	257(91,8%)	647(91,1%)
Pain	142(71%)	172(74,8%)	210(75,0%)	524(73,8%)
Itching	100(50%)	140(60,8%)	175(62,5%)	415(58,2%)
Burning	61(30,5%)	73(31,8%)	95(34.0%)	229(32,3%)
Vesicles	30(15%)	40(17,4%)	46(16,4%)	116(16,3%)

Table 6. General symptoms

	1981	1982	1983	Total
Dizziness	11(5,5%)	12(5,2%)	13(4,6%)	36(5,1%)
Vomiting	7(3,5%)	10(4,3%)	15(5,3%)	32(4,5%)
Fall of blood pressure	4(2,0%)	2(0,9%)	2(0,7%)	8(1,1%)
Diarrhea	3(1,5%)	4(1,8%)	6(2,1%)	13(1,8%)
Shock	1(0,5%)	-	-	1(0,14%

The treatment applied is presented on Table 7. As it can be seen, antihistamines, corticosteroid ointment and other medicaments such as liquid ammonia, cold dressings etc. are used. The highest percentage of drugs used are antihistamines and corticosteroids.

Table 7. Geographic distribution

	1981	1982	1983	Total
Attica	170(85%)	191(83%)	227(81%)	588(82,8%)
Rest of country	30(15%)	39(17%)	53(19%)	122(17,2%)

B. Information from doctors

With regards to the answers received from doctors concerning the medusa stings the following can be summarized.

The number is variable every year depending on the existence or not of jellyfish in the seas.

The stings mainly cause local symptoms and doctors have to face general or systematic symptoms, not of great severity.

Table 8. Treatment of local symptoms

	1981	1982	1983	Total
Antihistamine ointment	75(37,5%)	95(41,3%)	110(39,3%)	280(39,4%)
Corticosteroid	55(27,5%)	62(27,0%)	80(28,6%)	197(27,8%)
Other medicaments	37(18,5%)	40(17,4%)	55(19,6%)	132(18,6%)
No therapy	18(8,0%)	15(6,5%)	15(5,3%)	46(6,5%)

The therapeutic methods include the use of local means (ointments, liquids, etc.) and mainly antihistamines and corticosteroids. Some of the local symptoms (itching, and specially hyperpigmentation of skin) persist for a little or longer period but they always have a good prognosis and outcome.

C. Comparative study of therapeutic methods

Pain and burning

In group A the recovery from pain or burning corticosteroids, occurs 30-50 in minutes (average 39, 59±,92) after the application of the agent.

In group B (antihistamines), in 33-59 minutes (average 44,47±7,55) following the application.

In group C (placebo), in 63-105 minutes (average 82,04±12,16) after the application.

The time is calculated from the moment that the agent is applied on the victim's skin.

Redness

Recovery from redness occurs in 2,25-4,50 hours (average 3,22±0,71) after the application of agent to patients of group A.

In group B (antihistamines), 2,50-5,25 hours (average 3,61±0,89) are needed for recovery.

In group C recovery occurs in 4,50-8,75 hours (average 6,42±1,38) after the application.

The time is calculated in the same way as for pain and burning.

4. DISCUSSION

From the above epidemiological data we the following can be concluded.

The total number of jellyfish poisoning cases cannot be evaluated, and this because only a small number of patients contact the Poison Control Center or other doctors.

There are no great differences in the results among patients of different sex, but there is a considerable difference if the age is considered. The adults represent in fact the 75% of the whole number of patients.

The monthly distribution has its pick in July and August which are considered as the swimming months.

The symptoms caused are mainly local (94%) and in some cases systematic. The local symptoms have a short duration. Most of the systematic symptoms are simple and do not cause medical problems except shock, which is very rare.

For the management of general symptoms, corticosteroids parenterally were used as well as antihistamines peros. In two cases calcium gluconate was used and in one of them (shock) norepinephrine. There is not a generally accepted therapeutic method for local symptoms.

The therapeutic process includes the use of ointments (corticosteroids and antihistamines); use of ammonia is recommended by the physician, and in many cases it is applied without any medical advice.

From the comparative study of the therapeutic methods we can notice that the local application of corticosteroid agent (betamethazone 0,1%) or antihistamine (Dimethindenum maleic 0,1%) relieves from pain and burning faster than group C which had no treatment (placebo) (statistically significant, $p < 0.001$).

It seems that corticosteroids give a faster relief than antihistamines but not to a statistically significant degree.

The same as above can be applied even to the symptoms of redness. Relief from the symptom was noted in three hours with application of corticosteroids or antihistamines and 6 hours in persons with no treatment (placebo) (statistically significant difference, $p < 0.001$). Corticosteroids seem to act better compared to antihistamines but not to a statistically significant degree.

It has also to be noted that after the relief of symptoms due to the first application of agents, possible recurrency can occur. This has not been examined.

The doctors who were contacted had to come to the same conclusion concerning the appearance and severity of symptoms and the evaluation of therapeutic methods.

The prevention of the swimmers from medusa stings is a matter related to the management of jellyfish problem. Medically, it seems to be no way of prevention.

The problem of the therapeutic method and management still remains unsolved, as there is not a generally accepted therapeutic method.

However, we think that in all cases of medusa stings with local symptoms (pain, burning or redness), the application of corticosteroidal or antihistaminic agents is recommended for a faster relief.

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