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Mesozooplankton dynamics in the northern Adriatic Sea and the influence of eutrophication by the River Po

von

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Kurze Zusammenfassung (Abstract)

Die Dynamik des Mesozooplanktons in der nördlichen Adria und der Einfluß der Eutrophierung durch den Fluß Po

Die räumliche und jahreszeitliche Verteilung des Mesozooplanktons in der nördlichen Adria wurde unter der speziellen Fragestellung nach dem Eutrophierungseinfluß durch den Ausstrom des nährstoffreichen Po-Wassers untersucht. Das Forschungsprojekt stand in engem thematischen Zusammenhang mit dem von dem EU finanzierten MARE (Microalgae of the Adriatic Region) - Projekt zur Aufklärung des 'Mucilagine' Phänomens. Im Zeitraum zwischen 1993 und 1996 wurde das Probenmaterial auf verschiedenen Ausfahrten gewonnen, die von mesoskaligen Übersichtsaufnahmen bis zu feinskaligen Frontenuntersuchungen reichten. Als sehr hilfreich erwies sich die Satellitenozeanographie. So konnten aktuelle Temperatur- und abgeleitete Pigmentverteilungsübersichten direkt für die Auswahl der Stationen im Mündungsgebiet des Po verwendet werden. Das Po-Wasser war generell durch seinen hohen Nährstoffgehalt mit einem deutlichen Stickstoffüberschuß charakterisiert. Das N/P-Verhältnis erreichte Werte bis zu 70. Das Frontengebiet zwischen dem eutrophierten Flußwasser und dem oligotrophen Adria-Wasser war durch eine starke hydrographische Dynamik gekennzeichnet. Wie zu erwarten, herrschte im oligotrophen Wasser das Picophytoplankton (< 2 µm) und im eutrophierten Bereich das Mikrophytoplankton (> 20 µm) vor.

Die Zooplanktonverteilung zeigte ebenfalls deutliche Unterschiede. Die Larvalstadien der Copepoden, Nauplien und Copepodite waren besonders zahlreich im eutrophierten Küstenwasser anzutreffen, während im Adria-

Wasser mehr Adulte vorherrschten. Die häufigsten im Mai angetroffenen Copepodenarten im Küstenwasser waren *Acartia clausi*, *Oithona similis*, *Centropages* spp.,*Temora stylifera* und unter den Cladoceren *Podon* spp. Copepodit-Stadien von *A. clausi* dominierten. Die Frontenzonen stellten keine scharfe Grenze für die Zooplanktonverteilung dar. Die jahreszeitliche Verteilung zeigte einen bimodalen Verlauf mit einem Frühjahrsmaximum von 20 000 Ind. m^{-3} im Mai und einem Herbstmaximum von 12 300 Ind. m^{-3} im November. Cladoceren mit den Arten *Podon* spp., *Evadne* spp. und *Penilia avirostis* folgten aufeinander in den Sommermonaten von Mai bis Juli.

In einer zusammenfassenden Darstellung werden die unterschiedlichen Trophiestufen und jahreszeitlichen Variationen der abiotischen und biotischen Umweltfaktoren im Mündungsgebiet des Po und in der offenen Adria im Hinblick auf die Zooplanktonverteilung diskutiert.

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CONTENTS

1. INTRODUCTION

Zooplankton population dynamics in natural environments depend on a variety of factors including hydrographical parameters, predation and food source. In eutrophic environments of an estuary which is strongly influenced by anthropogenic nutrient inputs, zooplankton populations are expected to react to eutrophication, respectively on mass development of microalgae. An estuary like that of the River Po exhibits strong heterogeneity and variability of abiotic and biotic factors. It is not well known how zooplankton reacts to these strong environmental changes (LAPRISE & DODSON 1994).

Due to the large amount of nutrients carried by the Po River, the northern Adriatic Sea can be considered as the most eutrophied region in the Mediterranean (MARCHETTI *et al* 1989). Man-made eutrophication in the northern Adriatic Sea has increased rapidly during the last 50 years (DEGOBBIS 1989).

The River Po catchment area with its 75 000 km^2 (CATI 1981) includes large cities like Milan (> 3 million inhabitants) with insufficient, or no sewage treatment. The Po valley is also an area of intensive agricultural activities and animal production with consequent nutrient losses to the river system running into the northern Adriatic Sea. A considerable part of the pollution load originates from industry.

DEGOBBIS & GILMARTIN (1990) reported that approximately 75 % of total P and N loads transported into the northern Adriatic Sea is due to the effluents from the River Po.

The Adriatic Sea with a surface area of 138 000 km^2 (1/20th of the entire Mediterranean) has been recognized as a region of high fish production. The annual fish catches from the Adriatic Sea are 250 000 tons which is 1/4th of the fish production of the whole Mediterranean (BOMBACE 1991). The process of eutrophication obviously affects all links in the food web, and permits high levels of productivity of fish and shellfish. The Italian Fishery Statistics (OLIVETTI 1989) reported that 55 % of total Italian fish catches come from the Adriatic Sea (or Adria) and the northern and central Adriatic Sea contribute 57 % of the "small pelagic" fish biomass. Since 1987 the contribution of fish catch from the northern Adriatic Sea has decreased by 10 %, which may be due to an indirect impact of overfishing

(BOMBACE 1991). Thus, the overfishing in this area might have led to the reduction of catches per unit fishing effort.

The most important link between eutrophication and fish production is the zooplankton. GAMULIN & HURE (1983) stated that important pelagic fishes like sardine and anchovy spawn intensively in the more eutrophic coastal and offshore water of almost the entire Northern and Middle Adriatic Sea. The investigation indicates a significant zooplankton production in almost all the sardine and anchovy spawning grounds.

The change in fish biomass due to both overfishing and eutrophication may alter zoooplankton abundance and community structure. Hence the response of zooplankton to eutrophication has been investigated in the present study.

First investigations on the zooplankton and especially the copepods of the Adriatic Sea are known from CLAUS (1881); CAR (1890) and GRAEFFE (1900). Copepods of the Adriatic Sea were early described by STEUER (1910) from the first large expedition into the northern Adriatic Sea.

During 1911-1914 seasonal cruises were conducted covering the entire Adriatic Sea. Some of the results including also zooplankton data were described by FRÜCHTL (1924), however the material was never fully elaborated due to the first World War. A preliminary description of the distribution of phytoplankton and zooplankton in the Adria was made by LEDER (1914). Further work on the production cycle as well as horizontal and vertical distribution of zooplankton in the Adriatic Sea was conducted by several authors: e.g. GAMULIN (1979); HURE (1965); HURE & SCOTTO DI CARLO (1968, 1974); VUCETIC (1961) and REGNER (1973). However, these studies were restricted to certain areas of the Yugoslavian waters and the southern Adriatic Sea.

The correlation between zooplankton distribution and water circulation pattern in the Adriatic Sea was first described by VUCETIC (1973). HURE *et al* (1980) reported on the general copepod distribution in the Adriatic Sea and found 3 different Adriatic zooplankton communities : estuarine, coastal and oceanic. HURE *et al* (1980), GAMULIN & HURE (1983) and BENOVIC *et al* (1984) stated that the maximum copepod abundance was found in the northern Adria and along the Italian coast up to Bari, south Italy. FONDA UMANI (1982) and FONDA UMANI *et al* (1989) investigated the influence of eutrophication in the northern Adriatic Sea on the zooplankton biomass, and found a positive correlation between eutrophication and zooplankton. The Po River eutrophication, however, was not really taken into account.

The Po River discharge into the northern Adriatic Sea can be considered as a good example for an eutrophication process in a relatively enclosed basin in which nutrient-rich waters mix with the oligothrophic waters of the northern Mediterranean. Our specific interest, when planing this work, was to get more information on how zooplankton and their larval stages react to this strong eutrophication process and to determine relations between lower and higher trophic levels in this dynamic ecosystem.

The first part of work focussed on the distribution of mesozooplankton in the northern Adriatic Sea, the analysis of the zooplankton species composition and detection of their heterogenity in the whole Adriatic basin in relation to particular water masses.

The second part of work aimed at obtaining a more detailed information on the horizontal and vertical mesozooplankton distribution within the Po Estuary and ambient waters. Special emphasis was paid to the reaction of zooplankton to river plume fronts and the habitat preference of zooplankton in relation to salinity gradients and eutrophication level.

The third part of work was to analyse the seasonal effects on the succession of mesozooplankton and their larval stages, including variation of hydrography and seasonal changes of eutrophication levels in the northern Adriatic Sea.

2. MATERIAL AND METHODS

2.1 Topography and hydrography

The Adriatic Sea extends 800 km from north to south and 200 km from east to west. It can be devided into three sub-basins. The southern sub-basin is separated by a deep Palagruza Sill (170 m) from the middle sub-basin, which consist of three pits located along tranversal line off Pescara. The northern sub-basin (northern Adriatic) is rather shalow with the bottom sloping gently southwards and reaching at most 100 m. The northern Adriatic Sea has an average depth of 40 m in its northwestern part and 40-80 m in the southeastern part.

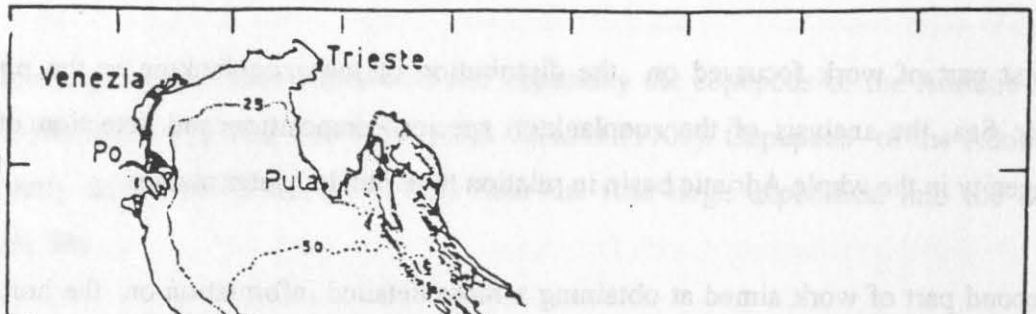


Figure 2.1.1 Bathymetric map of the Adriatic Sea.

During spring the total heat budget is positive. The heat flux into the surface layer generates a seasonal thermocline. The vertical stability of the surface layer is also enhanced due to the fresh water inflow of Po River, which reaches its maximum during this season. The riverine input and the successive heating generates a highly stratified water colum in summer (FRANCO 1986). The cooling process of the surface layer in late autumn breaks up the thermocline. However, a vertical discontinuity front separating the less saline water masses along the western coast of the Adriatic Sea from offshore waters is persistent throughout the year (FRANCO 1983; 1986).

The circulation of the northern Adriatic Sea is influenced by the tophography and also by meteorological changes during the seasons (BULJAN & ZORE-ARMANDA 1976; FRANCO1972; FRANCO *et al* 1982). During winter, when the total heat budget is negative (HENDERSHOTT & RIZZOLI 1976), the newly formed less saline water diluted by the River Po flows southward along the Italian coast and is separated from the offshore waters by frontal systems. The high saline waters (38 to 38.5 psu) are found in the central Adriatic Sea and along the Yugoslavian coast, being advected from the southern basins to the northern Adriatic Sea (NELSON 1970; FRANCO 1983). Both water masses are mixed by wind-driven stirring and by frontal mixing processes. The sills control the circulation of the dense waters in the deeper parts of the central and southern basin. ARTEGIANI & SALUSTI (1987) observed that the dense bottom water masses ($\sigma_t = 29.6$) were flowing southeastward, following the 75 m isobath in the central Adriatic Sea. The position of the thermocline in the southern basin is strongly influenced by the exchange with Ionian Sea waters.

The northern Adriatic Sea is dominated by freshwater inflow from the Italian Rivers. High discharge rates from the River Po, Tagliamento, Piave, Adige, and the low rates from the Rivers Reno, Fiumi Uniti, Savio are characteristic for the northwestern part of the Adriatic Sea. The yearly average of the Po River inflow is 1585 m^3s^{-1} (CATI 1981); the mean of Riverine input is 3111 $m^3s^{-1}a^{-1}$. The complex circulation of water masses in the Adriatic Sea is the result of a counterclockwise flow from the eastern Mediterranean, large differences in the density of water masses, and seasonal change in wind direction, from northeast in winter to southwest in summer (BULJA & ZORE-ARMANDA 1976). Fig. 2.1.1 presents a schematic picture of the seasonal variability of the general circulation within the Adriatic Sea. A prominent feature of the circulation is the northern Adriatic Current (NAd current) situated in front of the Po River mouth. During winter the NAd extends ~ 100 km to the south. During spring the current broadens and is well defined along the Italian coast. The current in the middle Adriatic Sea is called the Western-Middle Adriatic Current (W-MAd), since in summer it appears separated from the NAd. The NAd and W-MAd appear broad and meanders occur. In autumn both currents join again to form an extended boundary current along the Italian coast (Artegiani *et al* 1996 in press).

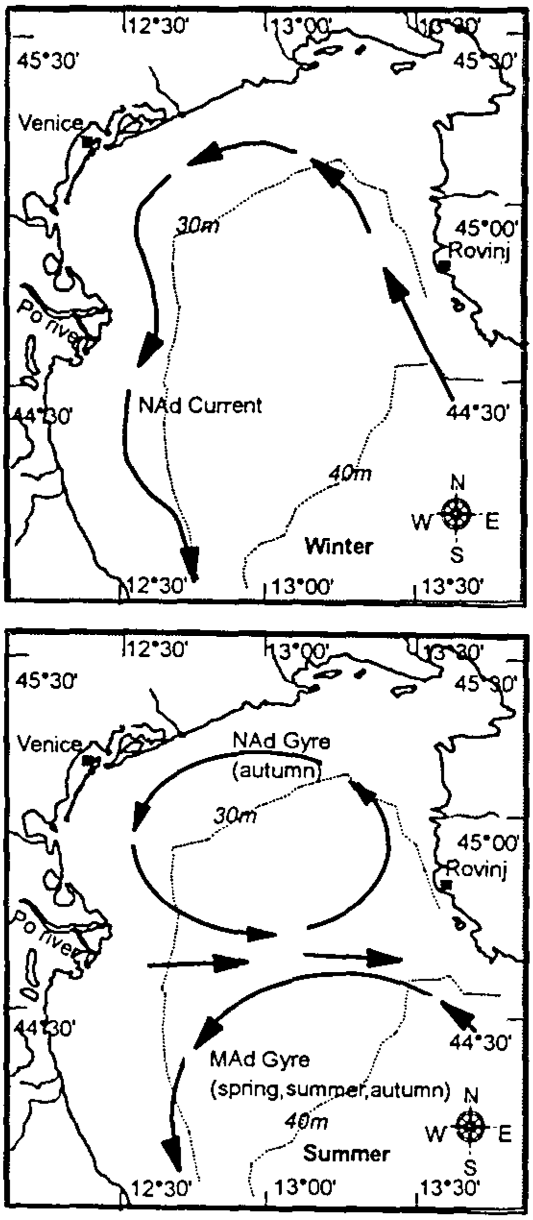


Figure 2.1.2. Schematic diagrams of surface water circulation in the northern Adriatic Sea.

The River Po is the longest Italian River (652 km) with its source at Monte Viso (2000 m) in the Alps. The Po watershed is very large (75 000 km^2; CATI 1981), and is a highly populated industrial and agricultural region with 15 million inhabitants (ANONYMOUS 1977). The Po valley is intensively cultivated and natural and artificial fertilizers are excessively used. Large cities like Milan with a population of over 3 million and without sewage treatment drain into the River. Therefore nutrient-rich discharges from the River Po markedly increase the rate of primary production in the northern Adriatic Sea (GILMARTIN & RELEVANTE, 1983) due to eutrophication (MARCHETTI *et al.* 1985). The down stream of the Po Delta consist of 9 branches : Po di Levante in the northest, Tramontana, Dritta, Scirocco, Bonifazi, Bastimento, Po di Tolle, Po di Gnocca and Po di Goro in the south. DEGOBBIS (1989) stated that more than 50 % of the nutrient load from the rivers in the northern Adriatic is anthropogenic, namely 331 000 t a^{-1} nitrogen and 28 200 t a^{-1} phosphorus.

The Po River discharge into the northern Adriatic Sea results in a river plume, its extension depends on river discharge. At the beginning of the warm season the excess Po waters are completely utilized to flood rice fields. Therefore the maximum discharge of the Po River occurs in July - August (BARALE *et al*, 1984). An analysis based on monthly averaged CZCS images shows that a positive correlation seems to exist between the amount of freshwater entering the Adriatic Sea and the spatial extent of pigment concentrations (> 1.0 $mg.m^{-3}$) in the Gulf of Venice (BARALE *et al* 1986). On a monthly basis, the plume is well established in the southeastern direction, while easterly and northeasterly extensions of the plume occur during periods of continued high river runoff. The plume scale reaches about 40 - 50 km at an average discharge rate of 1500 $m^3.s^{-1}$ (BARALE *et al.* 1987). During late autumn and winter the Po River discharge is confined to a narrow belt along the Italian coastline and the strong salinity front prevents an exchange of water masses with the interior basin. In late spring and summer startification is noticeable, and the River Po outflow, which is warmer than the interior water mass, remains in the surface layer and spreads radially symmetrically towards the interior of the northern Adriatic Sea, while the bottom layer consists of salty water of southern origin (MALONETTE-RIZOLI & BERGAMASCO 1983; DIPPNER 1991).

2.2 Sampling methods and sampling strategies

2.2.1 Mesoscale investigation

Within the framework of an EU-Environment Project (MARE), 25 stations covering the area 43°00' - 44° 30' N / 12°30' - 14°00' E in the northern Adriatic Sea were sampled. A cruise with the research vessel 'Poseidon' (length 60 m) was conducted from 16. to 23.05.1993 (*Figure 2.1.3*).

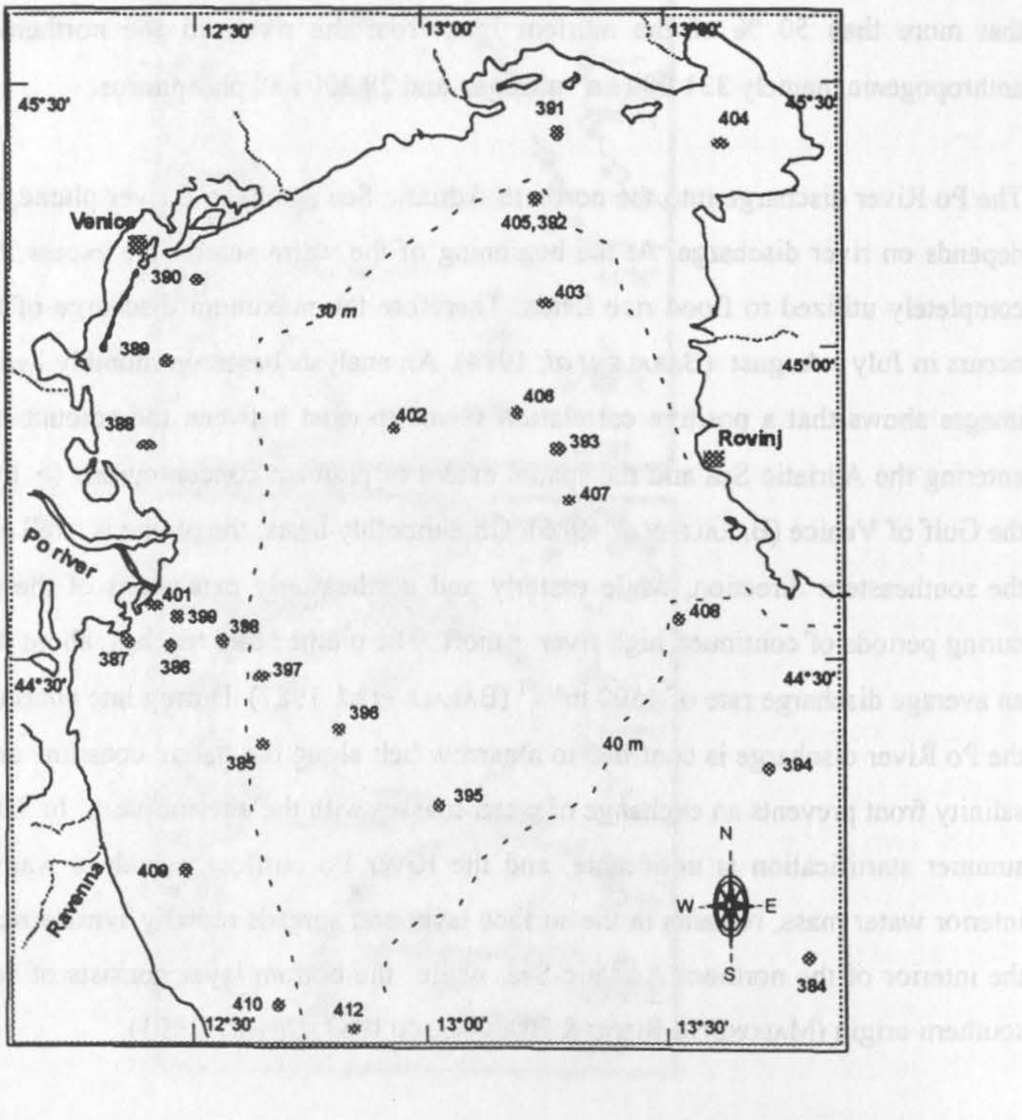


Figure 2.1.3. Map showing the station positions of the cruise from 16. to 23.5.1993 in the northern Adriatic Sea.

2.2.2 Estuary processes in the vicinity of the Po Delta

In order to study the distribution of mesozooplankton and their development stages in the Po Estuary, measurements have been conducted from the different Po River mouths towards east and southeast, depending on the plume extension, decided from the SST-AVHRR satellite images and at some stations corrected for sampling along salinity gradients by in-situ salinity measurements. Profiles were taken along satellite derived temperature gradients using working boat (7 m length). A total of 9 stations (11-16.9.93), 40 stations (16-26.5.94), 20 stations (15-23.6.94) and 5 stations along a transect (17.11.94) were sampled in the immediate neighbourhood of the Po delta. The area of investigation covered 44°05' - 44°50' N/ 12°10' - 13° 00' E (*Fig.2.1.4* and *Fig.2.1.5*).

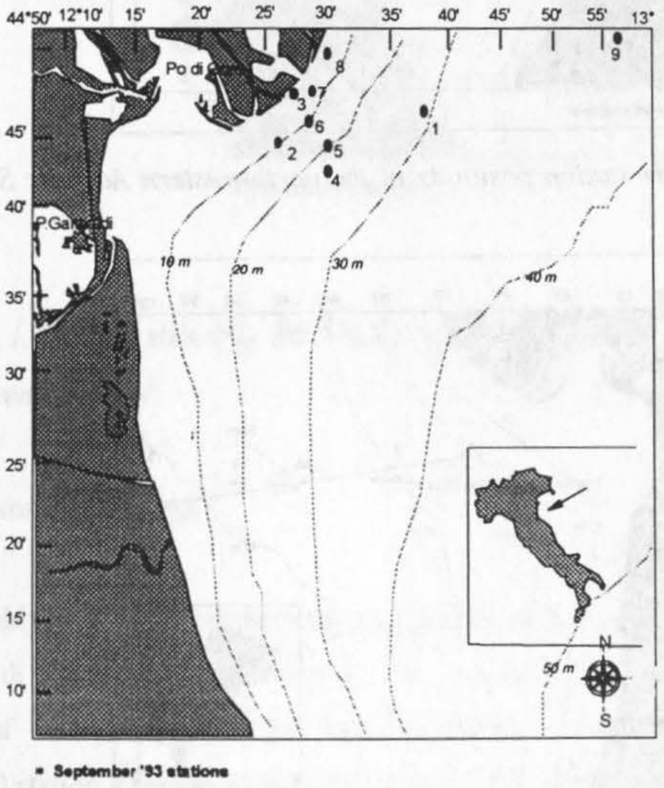


Figure 2.1.4. Map showing the station positions in the north-western Adriatic Sea in September 1993.

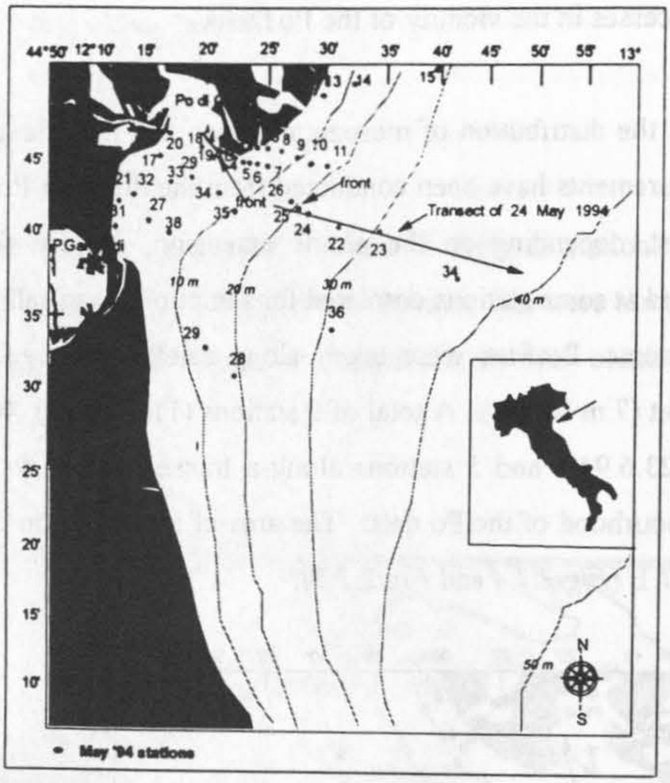


Figure 2.1.5. Map showing the station positions in the north-western Adriatic Sea in May 1994.

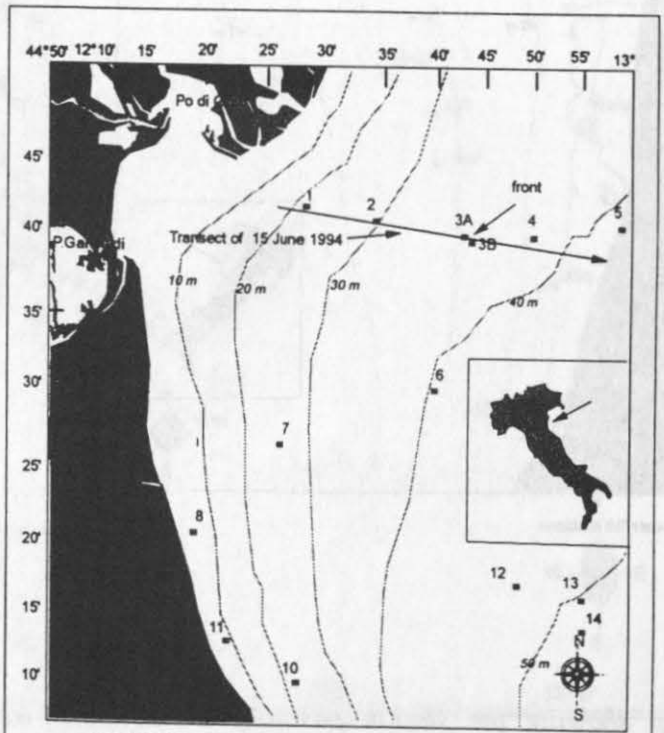


Figure 2.1.6. Map showing the station positions in the north-western Adriatic Sea in June 1994.

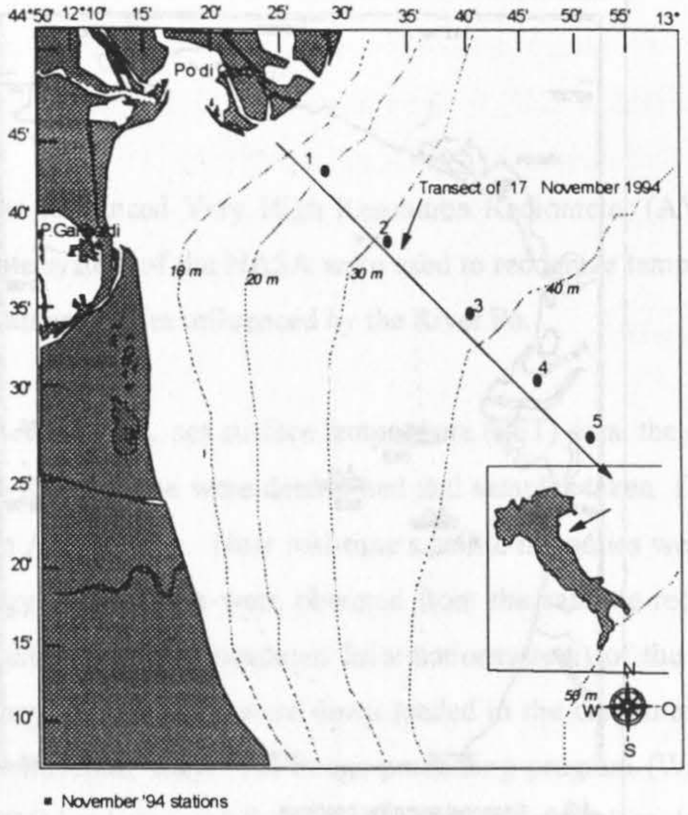


Figure 2.1.7. Map showing the station positions in the north-western Adriatic Sea in November 1994.

2.2.3 Seasonal samplings

The monthly field observations were undertaken with fast running boats (20 m) of the Italian 'Guardia di Finanza'. On one day cruises 2-6 stations were visited, representing different degrees of eutrophication in the northern Adriatic Sea. A series of cruises were conducted on a fixed station (Station 1) between 1994 - 1996. It was located 25 km south of the mouth Po di Goro (southern branch of the Po River) at 44.6°N/12.5°E. The other stations were located at different distances from the Po delta depending on satellite information, turbidity and chlorophyll content of the water, measured during the cruises.

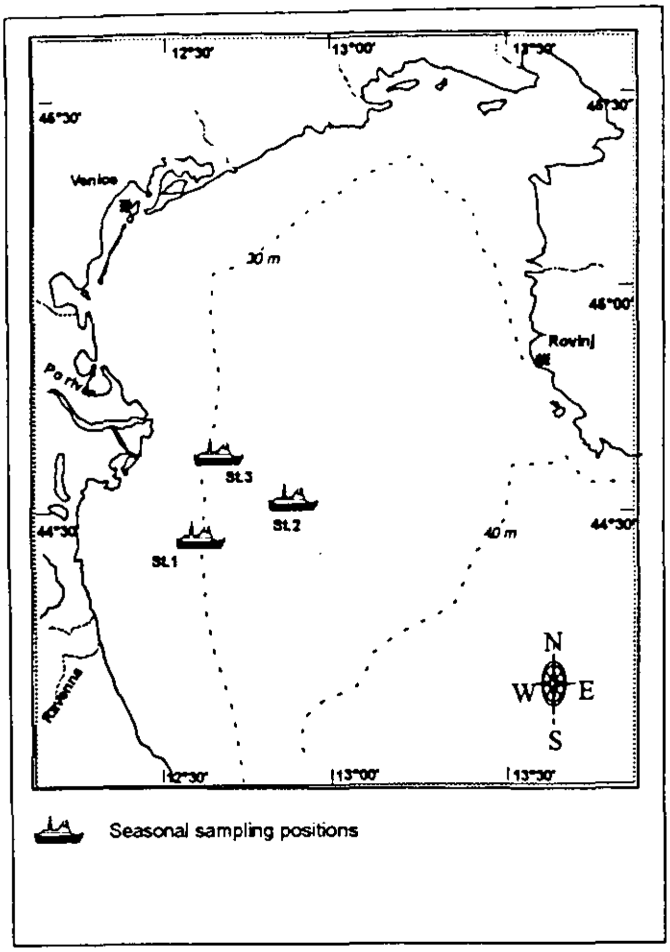


Figure 2.1.8. Map showing the station position of seasonal sampling from 1994 - 1996.

Table 2.1.1 Date of seasonal samplings from 1994 - 1996. The dates are arranged in monthly order irrespectively of the year.

Date of samplings	Station 1	Station 2	Station 3	Adjacent stations
21.01.95	*	*		
02.03.95	*	*	*	
18.04.95	*	*	*	
24.05.94	*	*	*	
19/22.06.95	*	*	*	*
13.07.95	*	*	*	*
15.09.95	*	*	*	
17.11.94	*	*	*	**
13.12.94	*	*	*	**

2.3 Measurements

2.3.1 Abiotic variables

The satellite images of the Advanced Very High Resolution Radiometer (AVHRR) of the NOAA (10 and 11) satellite system of the NASA were used to recognize temperature and to a certain extent water colour anomalies influenced by the River Po.

Based on a series of NOAA-AVHRR sea surface temperature (SST) data, the distribution of the stations within the Po River plume were determined and samples taken from the River mouth across the northern Adriatic Sea. Near real-time satellite imageries were used for an optimum sampling strategy. The images were obtained from the satellite receiving station through ISIS system (Intelligentes Satellitendaten Informationsystem) of the DFD-DLR in Oberpfaffenhofen (Germany). The images were down loaded in the computer centre of the University of Bologna in Ravenna, Italy. An image processing program (Windows Image Manager/WIM, KAHRU 1994) has been used for further processing of satellite data on a PC.

During the cruise of R/V Poseidon in May 1993, vertical profiles of salinity, temperature and fluorescence were obtained using a CTD (Meerestechnik-Elektronik). The oxygen concentration was measured in the water samples taken with a rosette system. following the method of Winkler (GRAßHOFF *et al* 1983). The secchi depth was also determined to calculate the 1 % light depth.

During the cruises with the working boat and during seasonal sampling cruises, vertical salinity, temperature and oxygen profiles were obtained using OTS-WTW probes (Type LF 196 with accuracy of +/- 0.1). The depth of light levels was determined using a light meter (LI-COR 189) equipped with a Licor Instruments Underwater Quantum sensor.

During the R/V Poseidon expedition the nutrients were sampled at 3 respectively 5 depths according to the T-S profile and the fluorescence signal. During cruises with the working boat and on the vessel of Guardia di Finanza, water samples were taken at 2 to 3 depths. Anorganic nutrients were analysed in the Laboratory of the 'Istituto Zooprofilatico' in Fano (Italy) using spectrophotometrical (Camspec M230) methods (GRAßHOFF *et al* 1983).

Samples for the determination of particulate organic matter (POM) were filtered through Whatman GF/F filters and stored afterwards at -20°C. The filters were later analysed in a CHN-Analyzer (HAEREUS) for particulate organic nitrogen (PON) and particulate organic carbon (POC) according to the method of ERHARDT (1983).

2.3.2 Biotic variables

Vertical profiles of chlorophyll fluorescence were measured by means of a Backscat Fluorometer (Haardt).

To determine the total phytoplankton biomass and different size fractions measured as chlorophyll-***a***, the following methods were applied :

(1) The whole sample was filtered through a GF/F Whatman filter for total chlorophyll-***a*** determination.

(2) The fraction < 2 µm was filtered through a 2 µm Nucleopore filter and the filtrate retained on a GF/F filter.

(3) The fraction < 5 µm was filtered through a 5 µm Nucleopore filter and the filtrate retained on a GF/F filter.

(4) The fraction < 20 µm, was passed through 20 µm Nitex gaze and the filtrate retained on a GF/F filter.

Microplankton was determined by substraction of < 20 µm fraction from total, and nanoplankton by subtracting the < 2 µm from the < 20 µm fraction. Nanoplankton was further divided into the 2-5 µm and 5-20 µm fractions. Filters retaining chlorophyll-***a*** were frozen at -20°C and extracted in 96 % ethanol (within one week from the sampling time) following the procedure of JESPERSEN & CHRISTOFFERSEN (1987).

Primary production was estimated by ^{14}C uptake following the method of STEEMAN NIELSEN (1957). Radioactivity was determined by means of a scintillation counter in the Isotope Laboratory of the Institut für Meereskunde, Kiel.

Phytoplankton samples were preserved with 2% buffered formaldehyde solution and counted using the Utermöhl method (UTERMÖHL 1958).

2.4 Data analysis

2.4.1 Estuary processes

To distinguish the influence of dilution and mixing of a conservative parameter (salinity) from that of non-conservative parameters (nutrients, chlorophyll-*a* and particulate organic matter) in the Po River plume the 'mixing curve' method was used (BOYLE *et al* 1974), which is also called 'reactant approach' (LISS 1976). The 'black-box' approach (JOUANNEAU & LATOUCHE 1982) was used to estimate net fluxes across the seaward plume boundary. Curve fitting by means of polynomial interpolation was applied to achieve an 'observed mixing line' which represents the behaviour of dissolved nutrients and particulate organic matter. The intercept areas between the theoretical linear dilution line of a conservative parameters and an observed mixing line express the 'removal' of dissolved nutrients or the 'addition' of particulate organic matter along the salinity gradient within the Po Estuary (*Fig.2.1.9*).

2.4.2 Zooplankton sampling, identification, abundance and biomass

During the cruise in May 1993, mesozooplankton was collected with a WP 2 (UNESCO 1968) zooplankton net (64cm, 100 μm). During the cruises in 1994 - 1996, mesozooplankton was caught with a smaller vertical net, a so-called Apstein net (Hydrobios-Kiel) with a closing mechanism (17 cm, 200 μm and 55μm). Net hauls were taken from the upper layer (0-10 m depth, including the halocline), mid layer (10-20 m) and lower layer (20-40m). Since the 100 μm net used before did not sample the small copepod stages quantitatively, the 55μm net was used to sample copepod nauplii. The net zooplankton samples were preserved in a 4 % buffered formaldehyde solution and then split with a rotary (for a large sampling volume) or modified Folsom splitter.

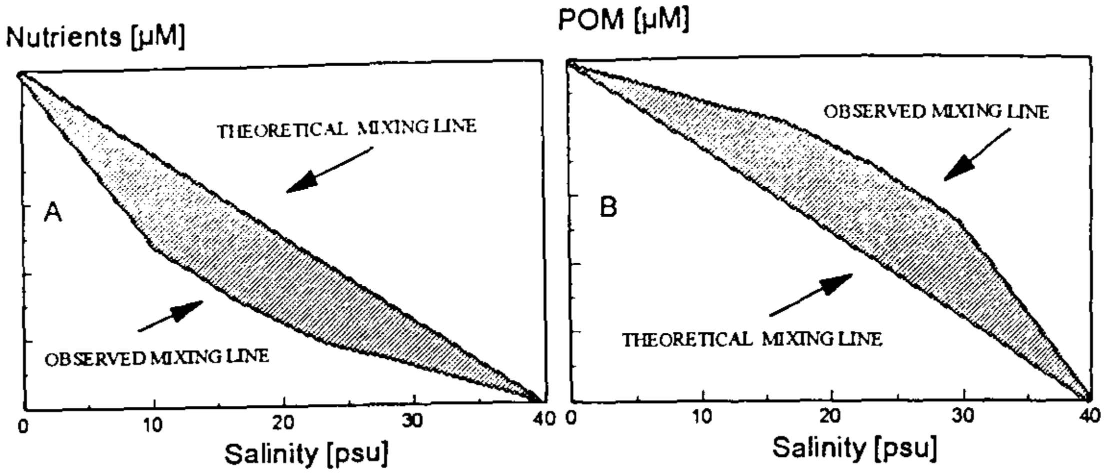


Figure 2.1.9. Schematic examples of the behaviour of A) nutrients and B) particulate organic matter during estuarine mixing. Shaded areas between the theoretical and observed mixing line represent 'removal' of nutrients or 'addition' of particulate organic matter.

Before counting, the samples were stored in a formaldehyde-free solution (prophenphenoxetol:propylenglycol:aquadest ~ 0.5:4.5:95, modified after Steedman 1976). One half of the sample was used for biomass measurements (dry weight, respectively ash-free dry weight). The other sub-sample was placed into a Bogorov chamber and counted using a 'Wild M7' binocular microscope with a 60 x zoom.

Adult copepods were identified up to the species level, except for *Clausocalanus* spp. and *Oncaea* spp. The copepodites and nauplii were determined up to the genera. The developmental stages (CI-CVI) of the most frequent species (*Acartia clausi*, *Paracalanus parvus*, *Oithona* spp., *Temora* spp., *Centropages* spp) were enumerated separately. The other frequently occurring mesozooplankton groups like Cladocera, Appendicularia and Chaetognatha were also counted. The abundance is expressed as number of individuals per cubic metre (ind m^{-3}).

For the identification of mesozooplankton species the following literature was used : Oberg 1906, Ogilvie 1953, Klein Breteler 1982, Malt 1982a,b (naupliar stages); Farran 1948a,b (*Centropages* and *Acartia*); Farran & Vervoort 1951a,b,c (*Paracalanus*, *Pseudocalanus* and

Eucalanus); Nishida 1985 (*Oithona*); Frost & Fleminger 1968 (*Clausocalanus*); Mori 1964, Rose 1933 (general Copepods); Bückmann 1969 (Appendicularia); Della Croce 1974 (Cladocera).

Biomass was determined as dry weight (DW), respectively ash-free dry weight (AFDW). Zooplankton subsamples were filtered using GF/F-Whatman filters, after rinsing with aquadest. The filters were then dried in an oven at 60 °C for 12 h. After 4 hours of acclimatization to room temperature and humidity, the samples were weighted on a Sartorius balance type 2474 (d=0.01mg). For determination of AFDW the filters were burned in an oven at 550°C for 10 hour and weight again under the same conditions. A factor of 0.5 of AFDW was applied for calculating zooplankton carbon content (Lenz 1974, Hirota 1981; Schneider 1989).

2.4.3 Zooplankton assemblages and community structures

Mesoscale distribution

In order to classify the northern Adriatic Sea into different trophic regimes, the stations were grouped on the basis of abiotic (salinity, temperature and density) and biotic (chlorophyll-***a*** content) variables into 5 different water masses. A cluster analysis (CA) was employed following the K-mean algorithms (Späth 1980; Bakus 1990) and complete linkage clustering techniques (SPSS 1993).

The cluster analysis (CA) was also used to describe the spatial distribution of mesozooplankton abundance in the northern Adriatic Sea. The distance index was used to calculate similarities between stations (Q-mode). The results from the hierarchical cluster analysis were projected onto a map of the investigation area. Thus spatial assemblages were built up by superposition of dendrogram results, enabling the establishment of different geographic areas with similar abundance (*Fig.2.1.10*)

Estuary processes and seasonal variation

It is difficult to describe zooplankton composition and distribution in terms of geographical location because of the dynamics of estuarine water masses. Therefore salinity was chosen as a descriptor of spatial distribution pattern because of its conservative properties (BARETTA & MASCHAERT 1988). The samples were taken in the vicinity of Po Estuary along the salinity gradient from 0 to 37 psu .

The structure of the zooplanktonic system in the vicinity of the Po Estuary during May and June 1994 is described using the Principal Component Analysis (PCA) applied to a linear correlation matrix with 27 zooplankton variables of 35 samples. The PCA is primarily a data analysing technique that produces linear transformations of a group of correlated variables so that optimal conditions are achieved (GAUCH 1982; BAKUS 1990). The PCA was applied using a varimax rotation in the projection axis in order to simplify the interpretation after the factor projection (STATISTICA 1994). The data (abundance of copepod nauplii, copepodites, and adults) were $\log_{10}(n+1)$ transformed prior to the analysis. The objectives of PCA in this study are to identify zooplankton assemblages and to describe the spatial and temporal variability of their structure. A correlation of the ordination in the PCA with the environmental variables was calculated to elucidate variables, influencing the zooplankton community structure (*Fig.2.1.11*). The environmental variables used to explain the spatial distribution of zooplankton applying PCA were :

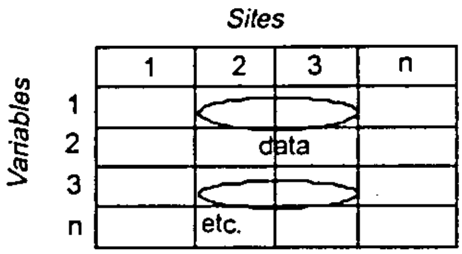
- salinity (S/dZ) and the salinity gradient (dS/dZ)
- temperature (T/dZ) and the temperature gradient (dT/dZ)
- chlorophyll-***a*** (Chl/dZ) and the chlorophyll *a* gradient (dChl/dZ)
- fluorescence (F/dZ) and the fluorescence gradient (dF/dZ)

The gradient was used to explain the different values in the upper and the lower water column as a measure for the degree of stratification.

The PCA was also used to describe and summarize the overall seasonal and spatial development of zooplankton abundance. The temporal relationship between zooplankton and phytoplankton biomass (chlorophyll-***a***) at the seasonal stations was analyzed using the product-moment (Pearson's) correlation (SOKAL & RAHLF 1981).

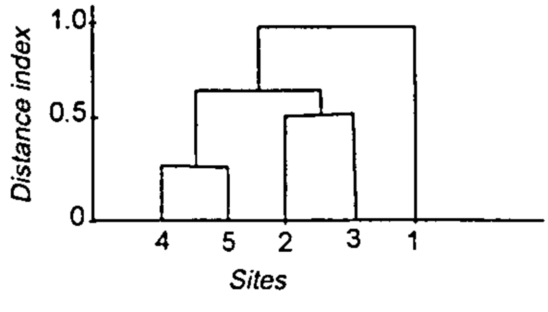
Steps of cluster analysis (CA) :

1) Input : - Environmental data (S, T and Chl-a)
- Zooplankton abundance



2) Process : - K-mean algorithms
- Complete linkage clustering technique

3) Output : - Dendrogram of sites grouping
- Geographical projection map of hydrodraphic and zooplankton cluster

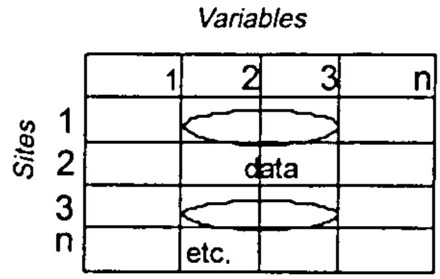


4) Information : Mesoscale zooplankton distribution in correlation to water masses

Figure 2.1.10. Schematic representation of steps in cluster analysis (CA).

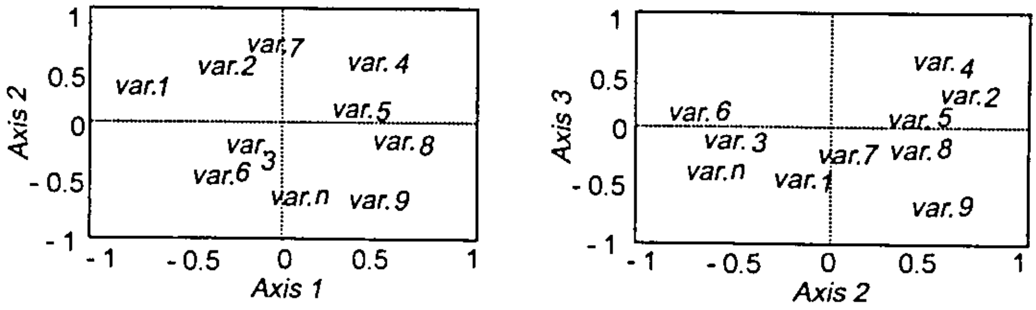
Steps of principal component analysis (PCA) :

1) Input : - environmental parameters (hydrographical data, nutrients and phytoplankton)
- biological descriptors (zooplankton species abundance)



2) Process : - Linear correlation matrix
- Varimax rotation technique

3) Output : - Principal component ordinates (axes projection)
- Component loadings (correlation coefficients of axes)



4) Information : - Characterization of zooplankton assemblages
- Variability of zooplankton community structure (spatial and seasonal) in relation to the degree of eutrophication.

Figure 2.1.11.Schematic representation of steps in principal component analysis (PCA).

3. RESULTS

3.1 Mesoscale investigation

3.1.1 Hydrography, nutrients and phytoplankton parameters

Temperature

The sea surface temperature (SST) distribution in the northern Adriatic Sea can be seen on NOAA-AVHRR infrared images. During spring the NOAA images show a distinct pattern of warmer plume waters extending from the river mouth different directions. The images of May 16, 17 and 23 show that the Po river plume extends to the north-east and another part of it to the south. The plume waters can be clearly distinguished from atmospheric signals through different pattern structure, pattern extension (clouds pass sea-land borders) and from pattern differences on consecutive days. In situ measurements indicated that the temperature signal was usually correlated with higher particle concentrations in terms of chlororophyll-***a*** and particulate organic matter *(Fig 3.1.1a,b+ c).*

In spring, the river-influenced water masses are stratified by a halocline and a thermocline. There are two ways in which temperature increase in surface water can occur :

(1) The river water induced halocline and takes care that the energy from solar radiation is maintained in the surface water layer.

(2) Particulate and dissolved matter from the river as well as increased phytoplankton standing stocks due to eutrophication may convert solar radiation into heat and form a distinct warm water layer at the surface (PLATT & SATHYENDRANATH 1988).

Most probably both phenomena lead to an increase of temperature in the Po River plume and the other river water-influenced regions in the northwestern Adriatic Sea.

Salinity

In spring, monthly flow rates of the Po River are 1800 - 2000 m^3s^{-1} on average (RAICICH 1994). During this time, plumes can be recognized on Ocean Colour satellite images to extend up to a distance of 70 km from the river mouth (BARALE *et al* 1987). In May 1993 a river discharge of 1500 $m^{-3}.s^{-1}$ was registered by the Monitoring Program of the 'Regione Emilia-Romagna' (1993). Low-saline water was found to extend from the Po River mouth up to the midle of the northern Adriatic Sea and more than 200 km toward the south. The high saline water (> 37 psu) dominated in the eastern part of the Adriatic Sea *(Fig 3.1.2)*. The vertical contours of salinity showed that a rather thin layer of low-saline water occupies the upper part (< 10 m) of the water column *(Fig. 3.1.4)*. In the northwestern Adriatic Sea, the water below 18 m did not exceed a salinity of 37 psu in spring 1993. In the eastern part, however, the salinity reached 38 psu. The bottom salinity distribution (sampling 4 m above the sea bottom) is shown in *Fig. 3.1.2b*.

Oxygen

The vertical distribution of oxygen concentration ranged from 5 - 10 $ml.l^{-1}$. The oxygen values correlated well with primary productivity and chlorophyll data. Oxygen concentration data have been converted into percent saturation values, and show that in most of the plume water the oxygen concentration exceeds 100 % saturation. Up to > 160 % O_2 were observed on a station 50 km off the Po River mouth. On this station (St.396) with the exception of silicate, all nutrients and phytoplankton biomass data were very high. The near bottom O_2 concentrations showed a saturation of 70-80 % *(Fig.3.1.3 and Fig.3.1.4)*.

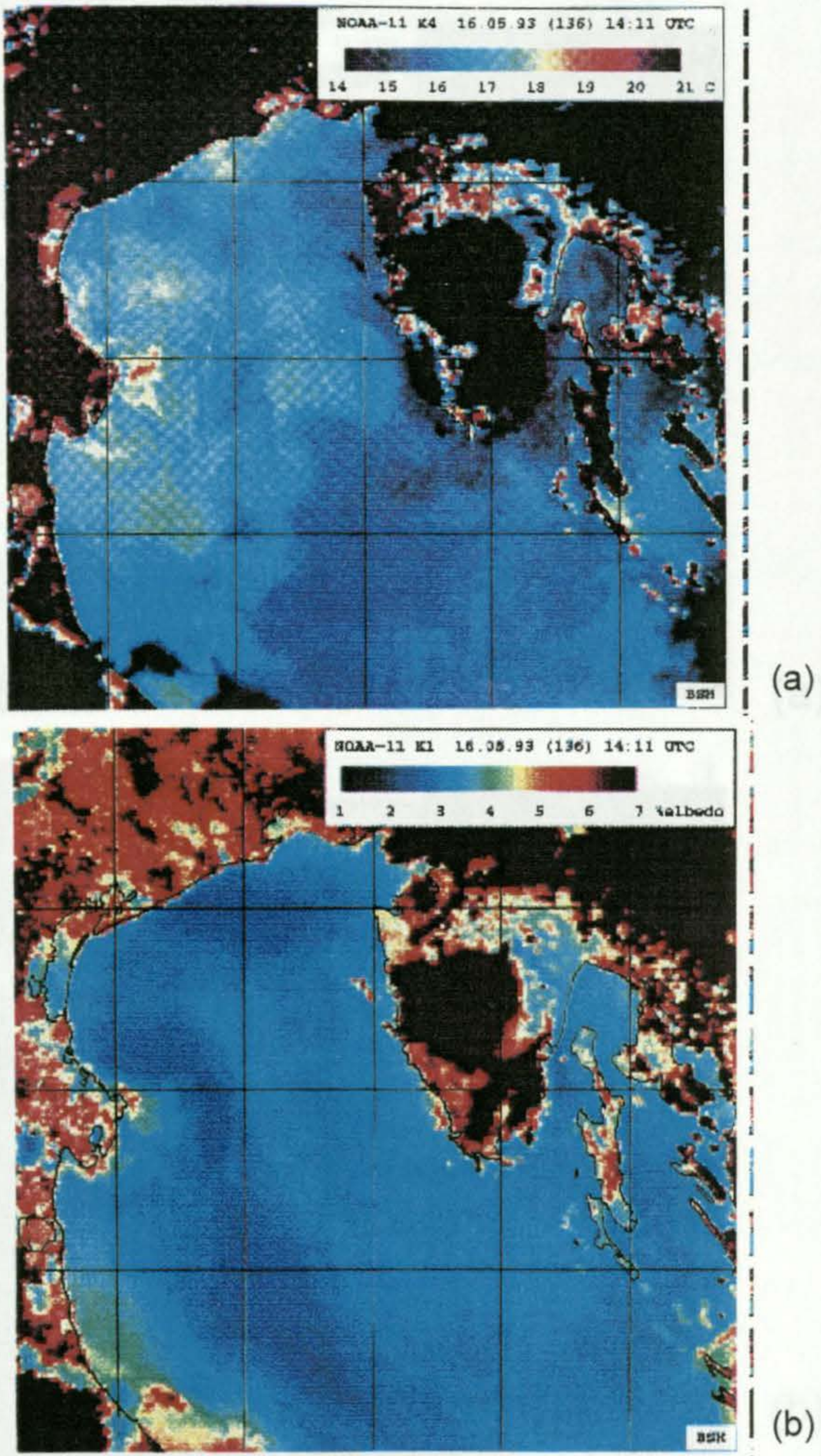


Figure 3.1.1a. Distribution of the sea surface temperature (SST) and ocean color albedo of channel 1/2 derived from NOAA-AVHRR satellite in the northern Adriatic Sea: Images of 16.5.93.

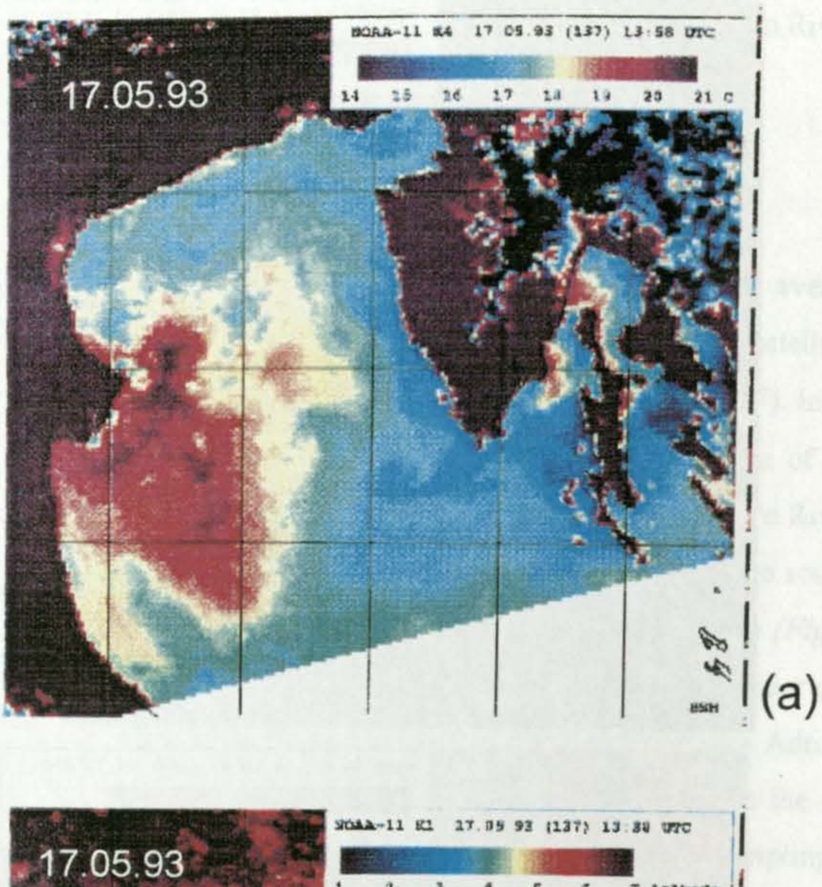


Figure 3.1.1b. Distribution of the sea surface temperature (SST) and ocean color albedo of channel 1/2 derived from NOAA-AVHRR satellite in the northern Adriatic Sea: Images of 17.5.93.

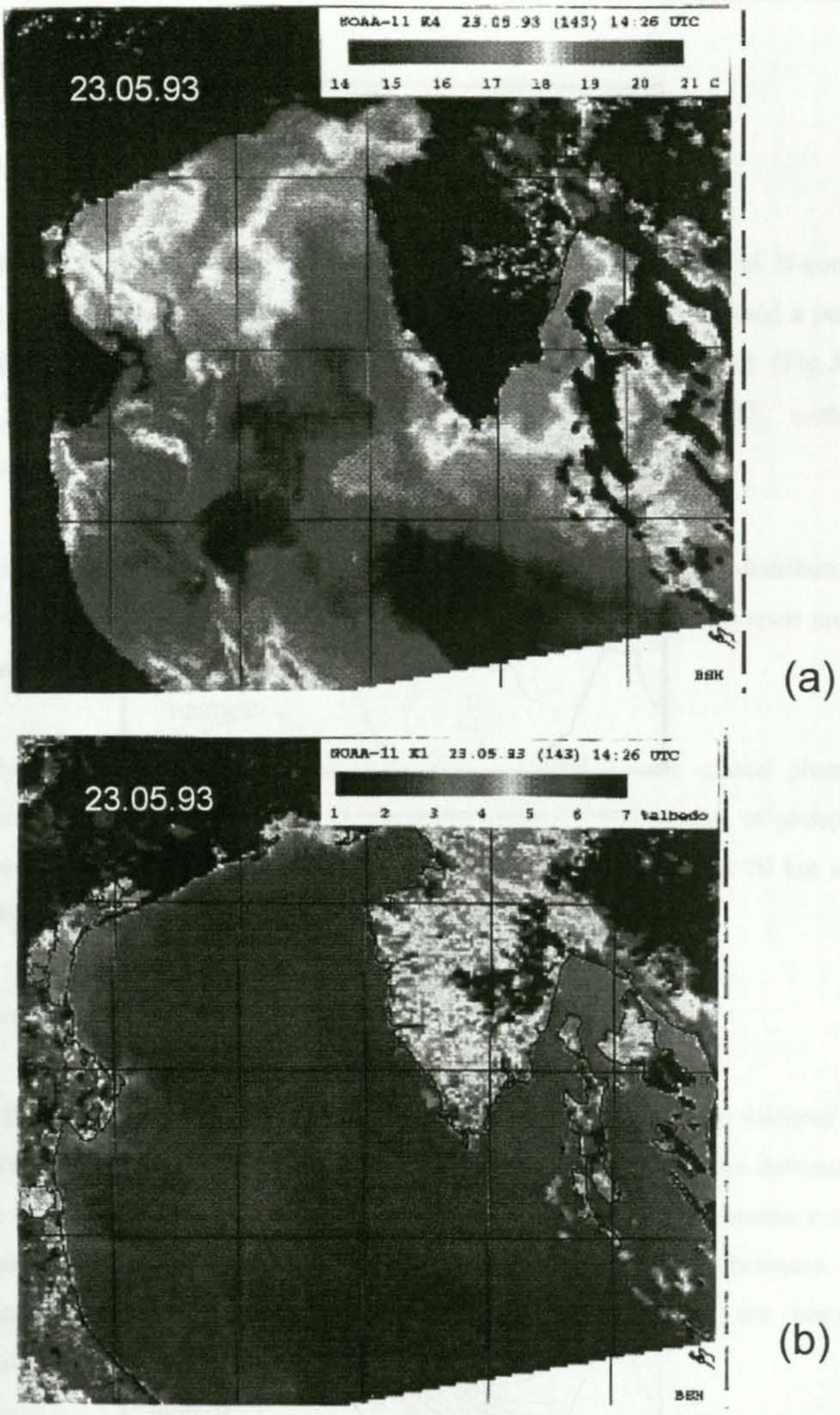


Figure 3.1.1c. Distribution of the sea surface temperature (SST) and ocean color albedo of channel 1/2 derived from NOAA-AVHRR satellite in the northern Adriatic Sea: Images of 23.5.93.

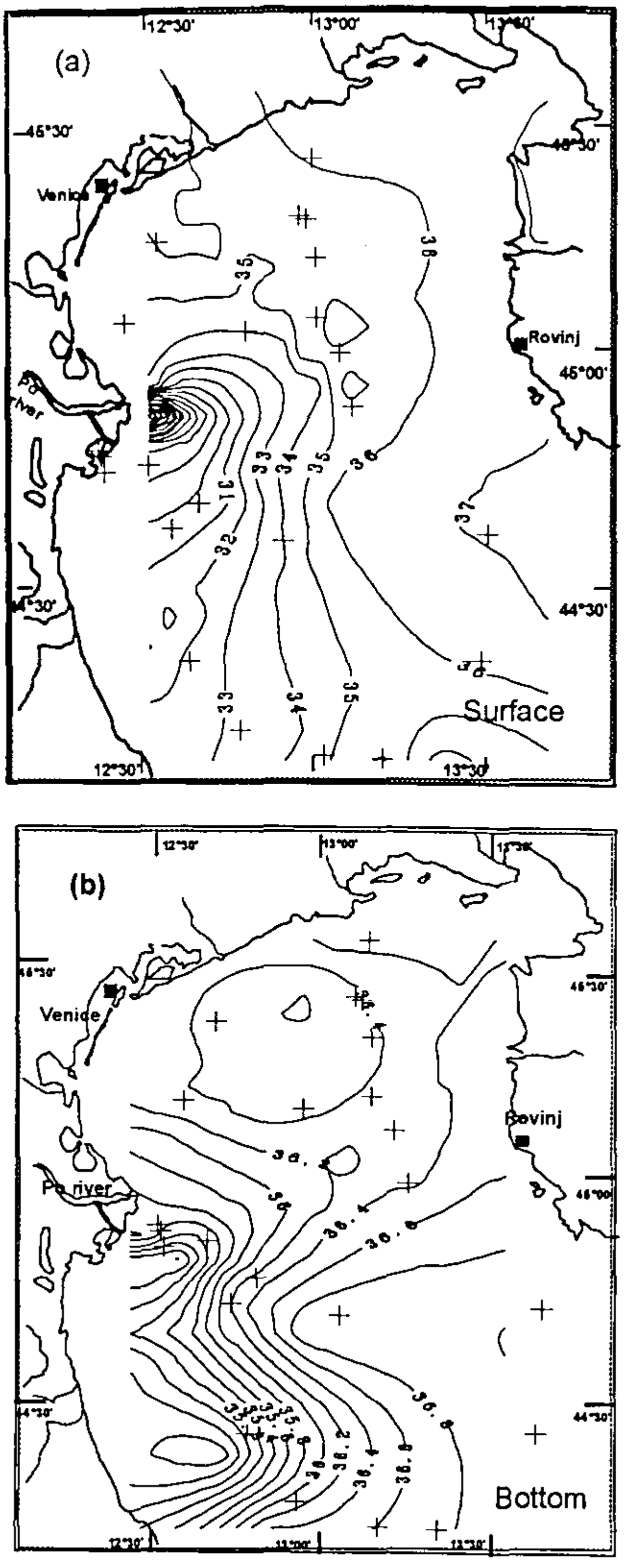


Figure 3.1.2. Surface (a) and bottom (b) salinity distribution during May 1993 in the northern Adriatic Sea. Bottom values were collected at 4 m above the sea-bed

Nutrients and phytoplankton parameters

Dissolved inorganic nitrogen (DIN)

The late spring observations showed that the River Po is a large source of N-compounds. The nitrate concentrations were high at the surface up to 30 µM and showed a peak in the bottom water near the Po River mouth and another peak 50 km east (*Fig.3.1.3* and *Fig.3.1.4*). The distribution of nitrite showed similar patterns as NO_3, with highest concentrations of 24 µM near the bottom.

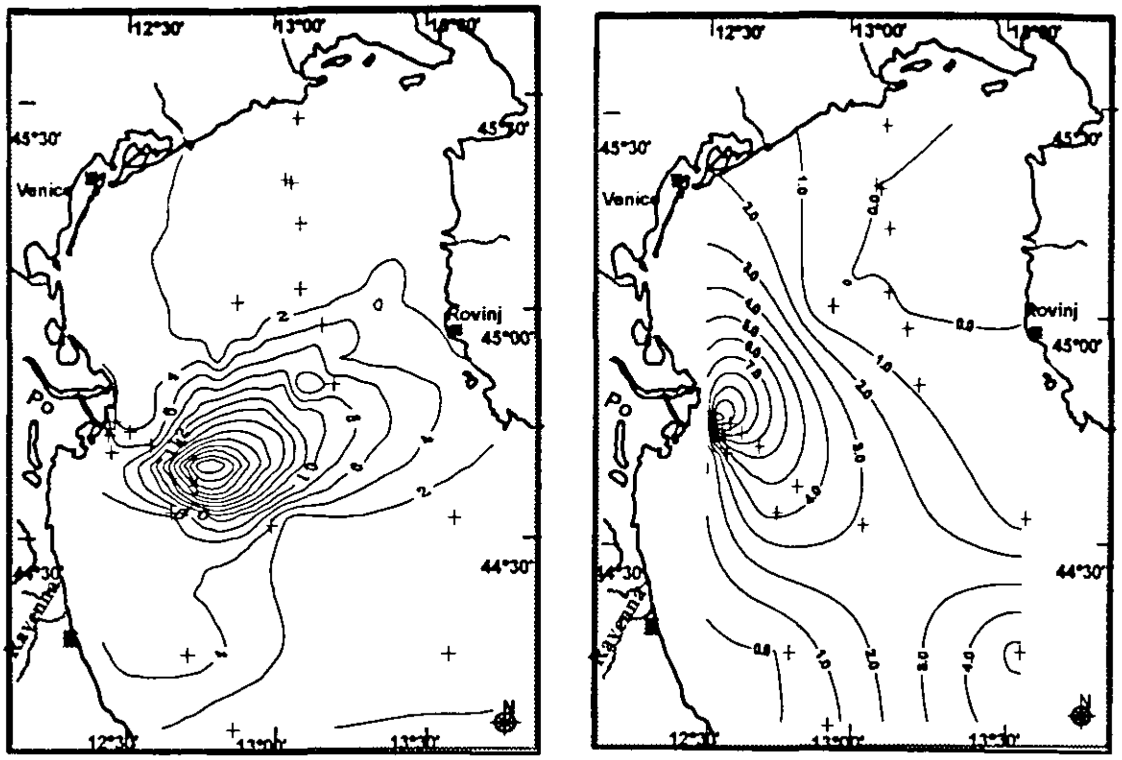
The pattern of the NH_4 distribution was different from NO_3 and NO_2 distribution. High values of > 2 µM can be found in the bottom water 30 km away from the river mouth on a NW-SE transect *(Fig. 3.1.4.)*.

A relatively low concentration of phosphate was observed in the coastal plume of the north-western Adriatic Sea in May 1993. Increased surface concentration of phosphate was measured at the open Adriatic Sea, with its maximum value of 4 µM at 70 km south-east from the Po delta.

Particulate organic matter (POC, PON and POP)

The River Po is also a major source of particulate material for the northern Adriatic Sea. The particles are associated with the pattern of low-saline water. In the northern Adriatic Sea, the particulate organic carbon (POC) near the river mouth is much more a measure of organic detritus (pollutants), but offshore it is more a measure of phytoplankton biomass. The POC surface concentrations were significantly higher (~300 µM) than the bottom POC concentrations(~150 µM)*(Fig. 3.1.4)*.

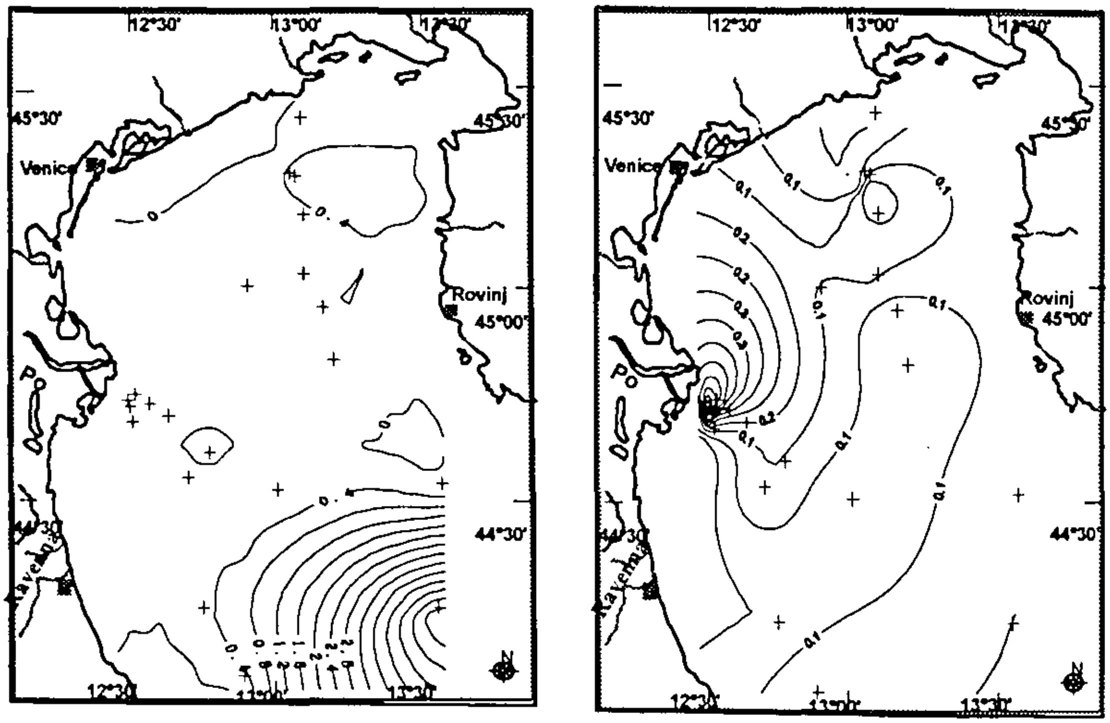
Particulate organic nitrogen (PON) showed a similar distribution pattern as POC ranging from 4-20 µM in the surface layer and ~ 2 µM near the bottom (4 metres above the sea-bed).



Surface

Bottom

Nitrate [µM]

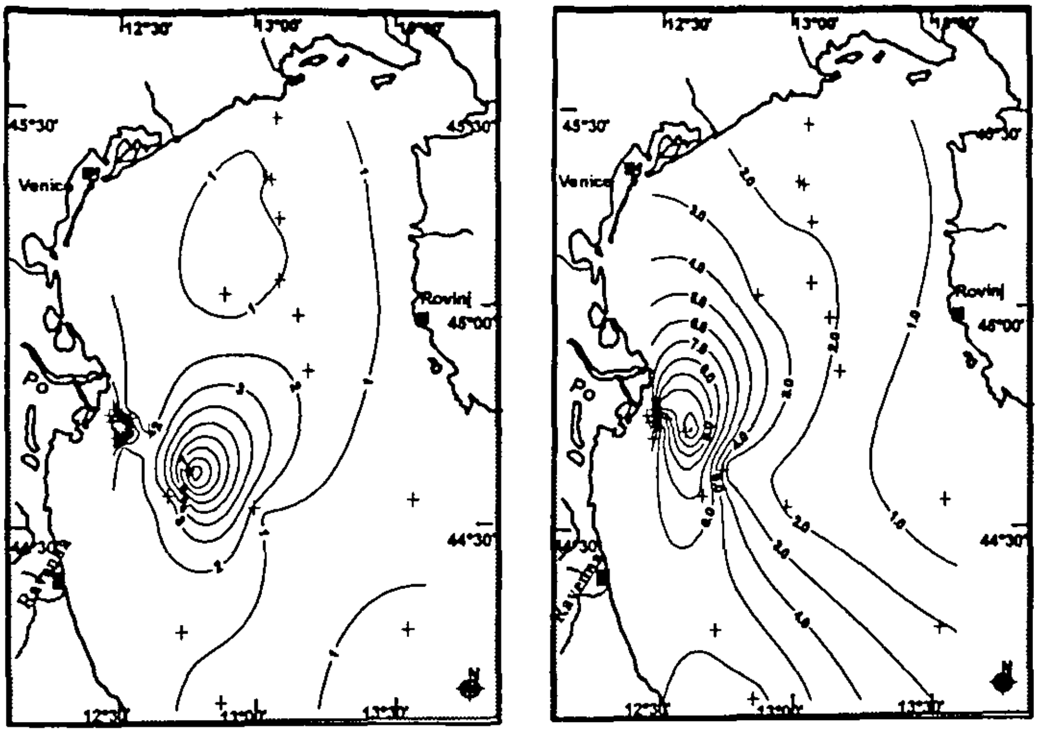


Surface

Bottom

Phosphate [µM]

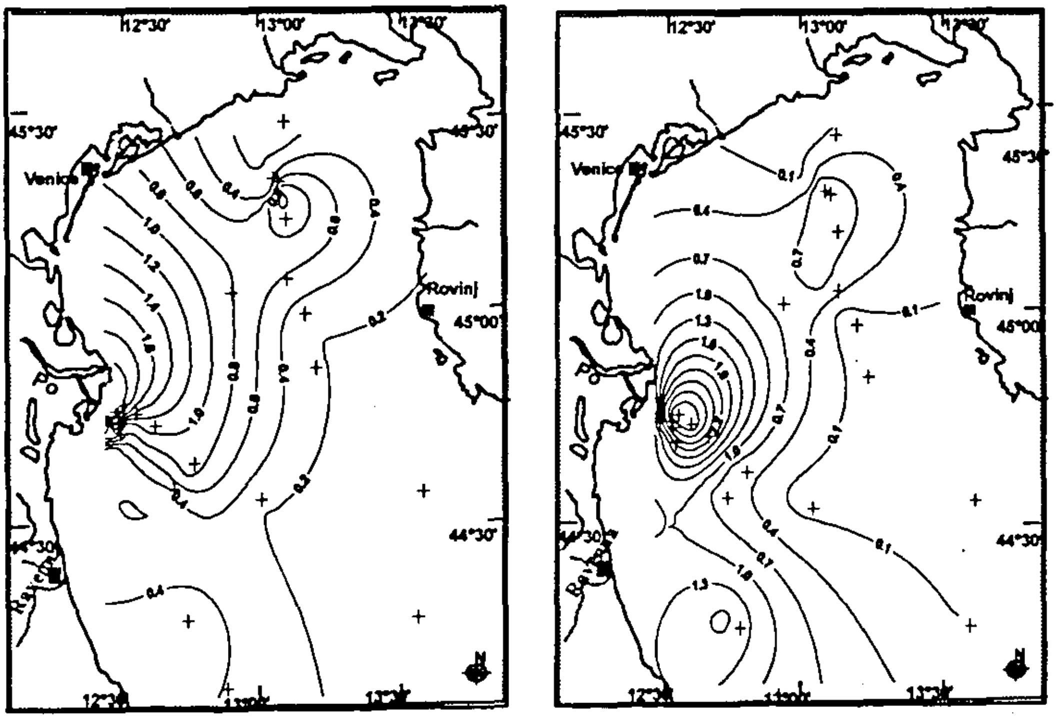
Figure 3.1.3a. Distribution of nitrate [µM] and phosphate [µM] in the northern Adriatic Sea during May 1993. Bottom values were collected at 4 m above the sea-bed.



Surface

Bottom

Silicate [µM]

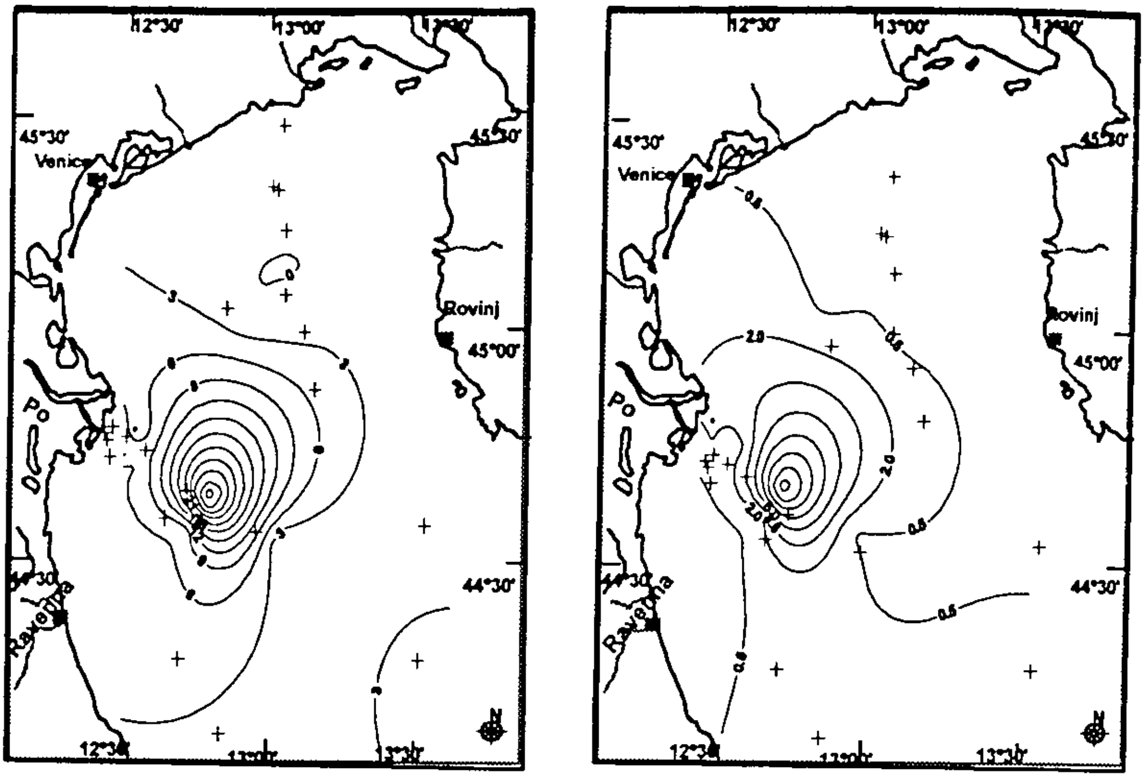


Surface

Bottom

Ammonia[µM]

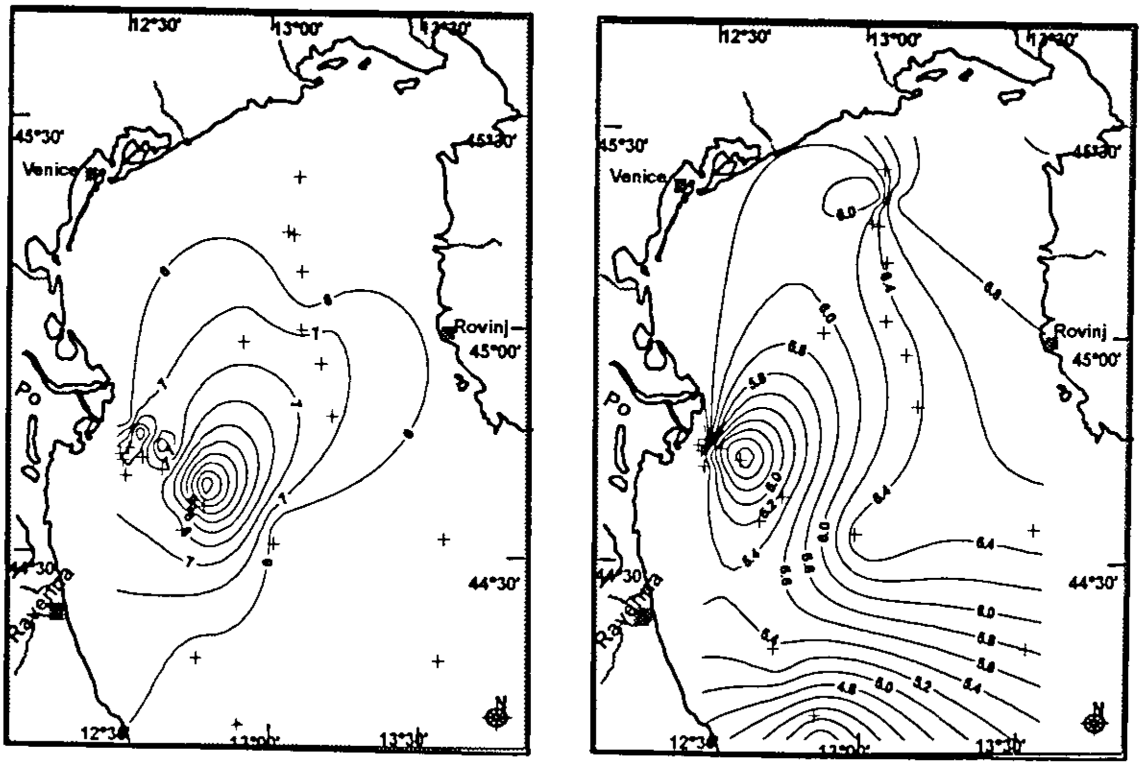
Figure 3.1.3b. Distribution of silicate[µM] and ammonia [µM] in the northern Adriatic Sea during May 1993.



Surface

Bottom

Nitrite [µM]

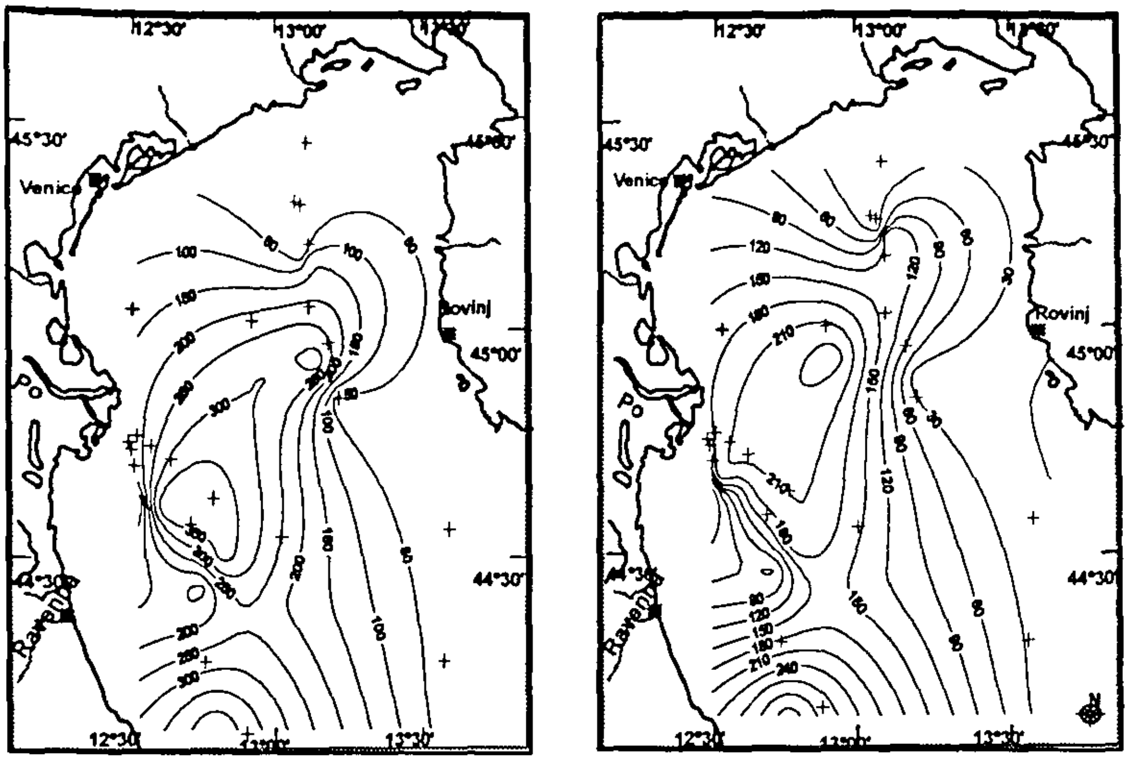


Surface

Bottom

Oxygen [ml/l]

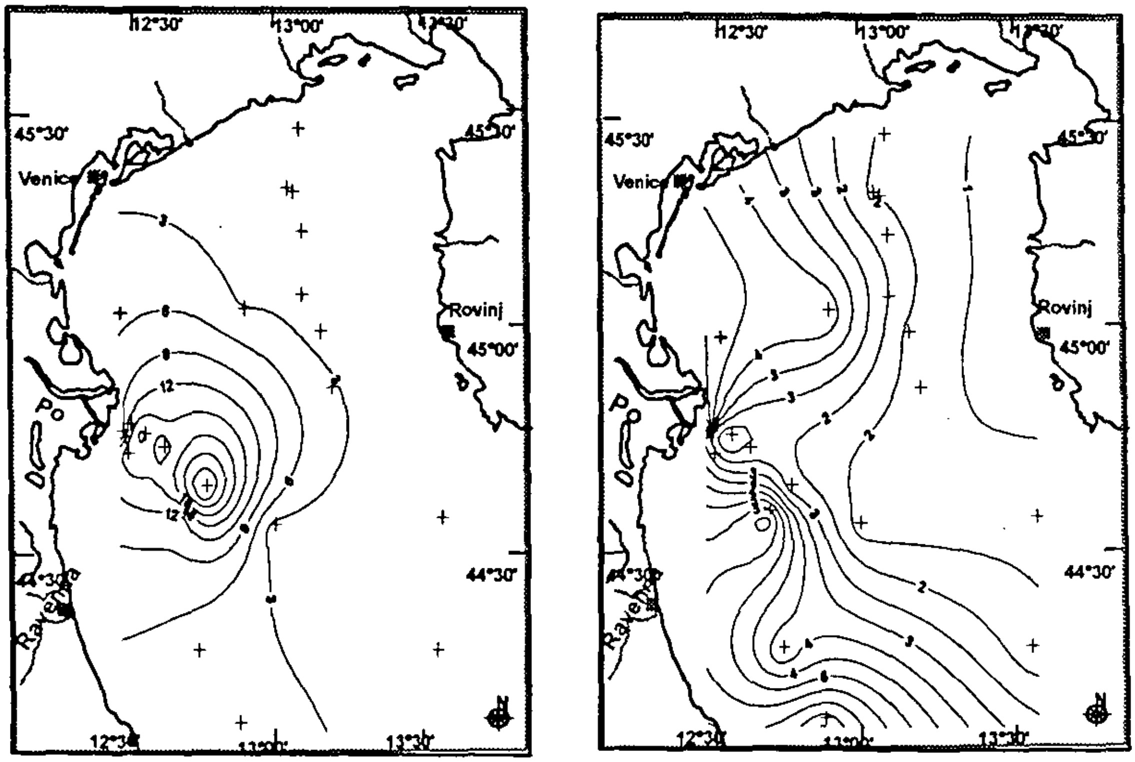
Figure 3.1.3c. Distribution of nitrite [µM] and oxygen [ml.l⁻¹] in the northern Adriatic Sea during May 1993.



Surface

Bottom

POC [μM]



Surface

Bottom

PON[μM]

Figure 3.1.3d. Distribution of particulate organic carbon [μM] and particulate organic nitrogen [μM] in the northern Adriatic Sea during May 1993.

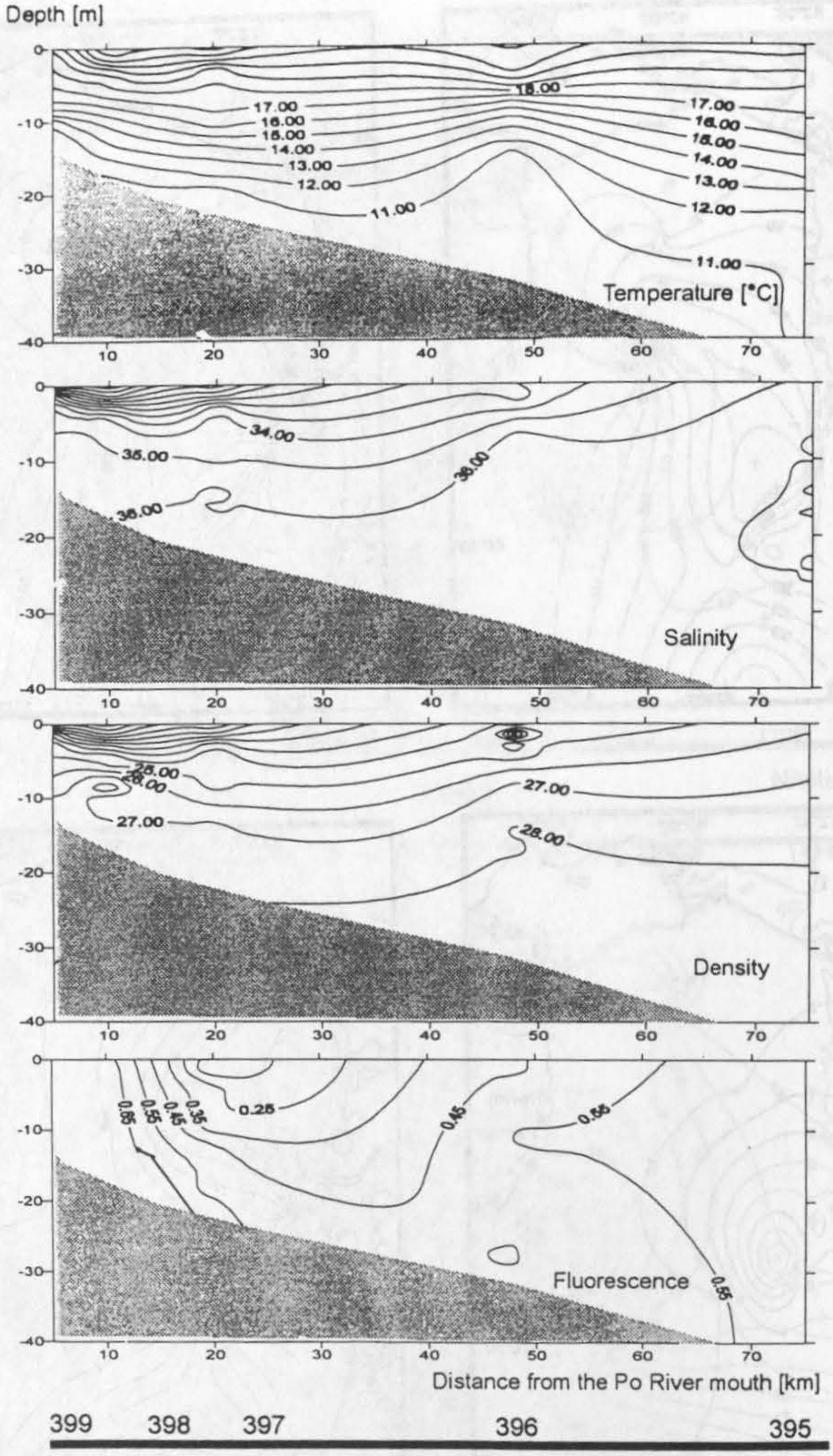


Figure 3.1.4a. Vertical distribution of physical, chemical and biological variables along a transect from the Po river mouth (St.399) to the offshore station (St.395) in the northern Adriatic Sea during May 1993: temperature [°C], salinity [psu], density and fluorescence.

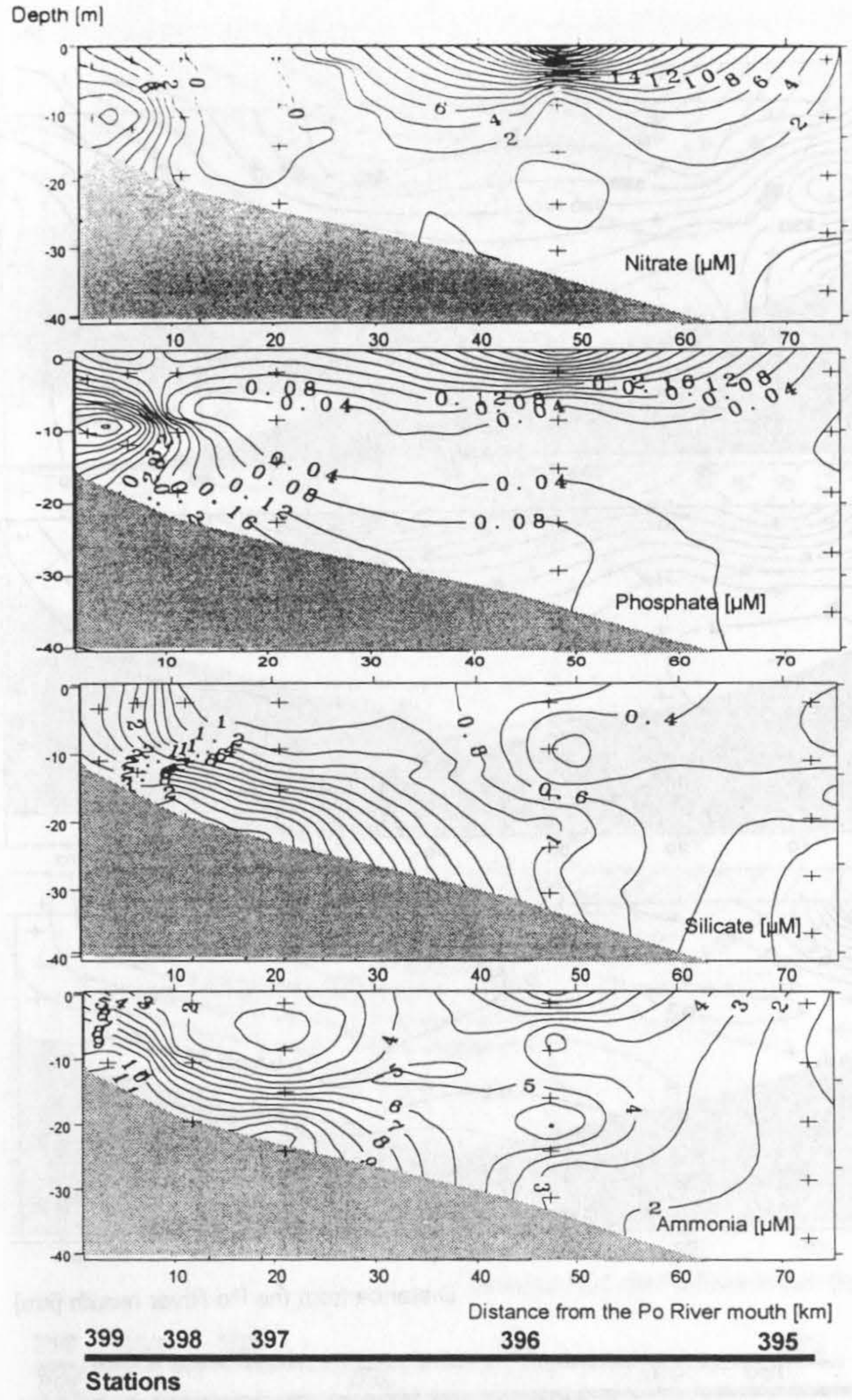


Figure 3.1.4b. Vertical distribution of physical, chemical and biological variables along a transect from the Po river mouth (St.399) to the offshore station (St.395) in the northern Adriatic Sea during May 1993: nitrate [µM], phosphate [µM], silicate [µM] and ammonia [µM].

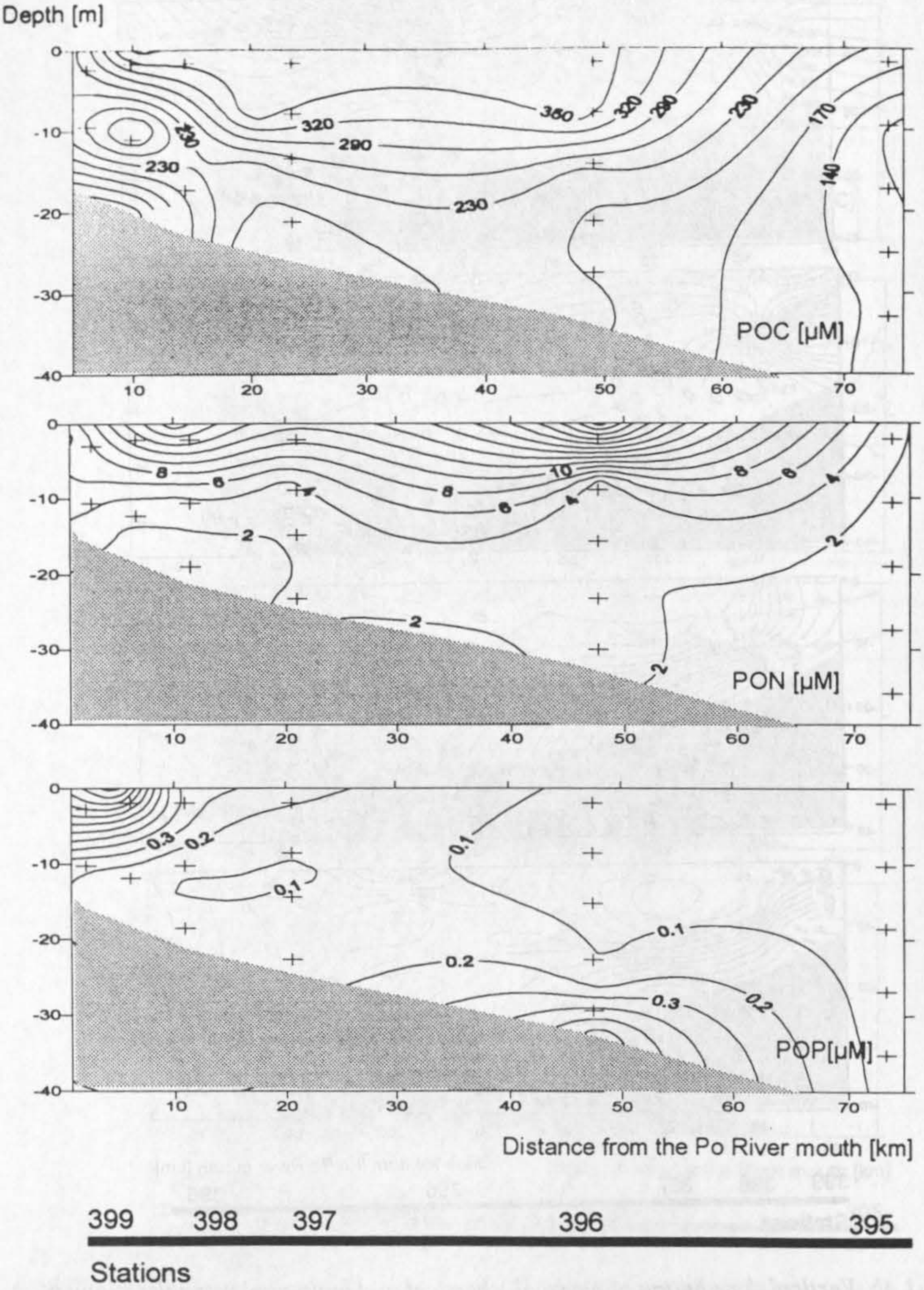


Figure 3.1.4c. Vertical distribution of physical, chemical and biological variables along a transect from the Po Rver mouth (St.399) to the offshore station (St.395) in the northern Adriatic Sea during May 1993: POC [μM], PON [μM] and POP [μM].

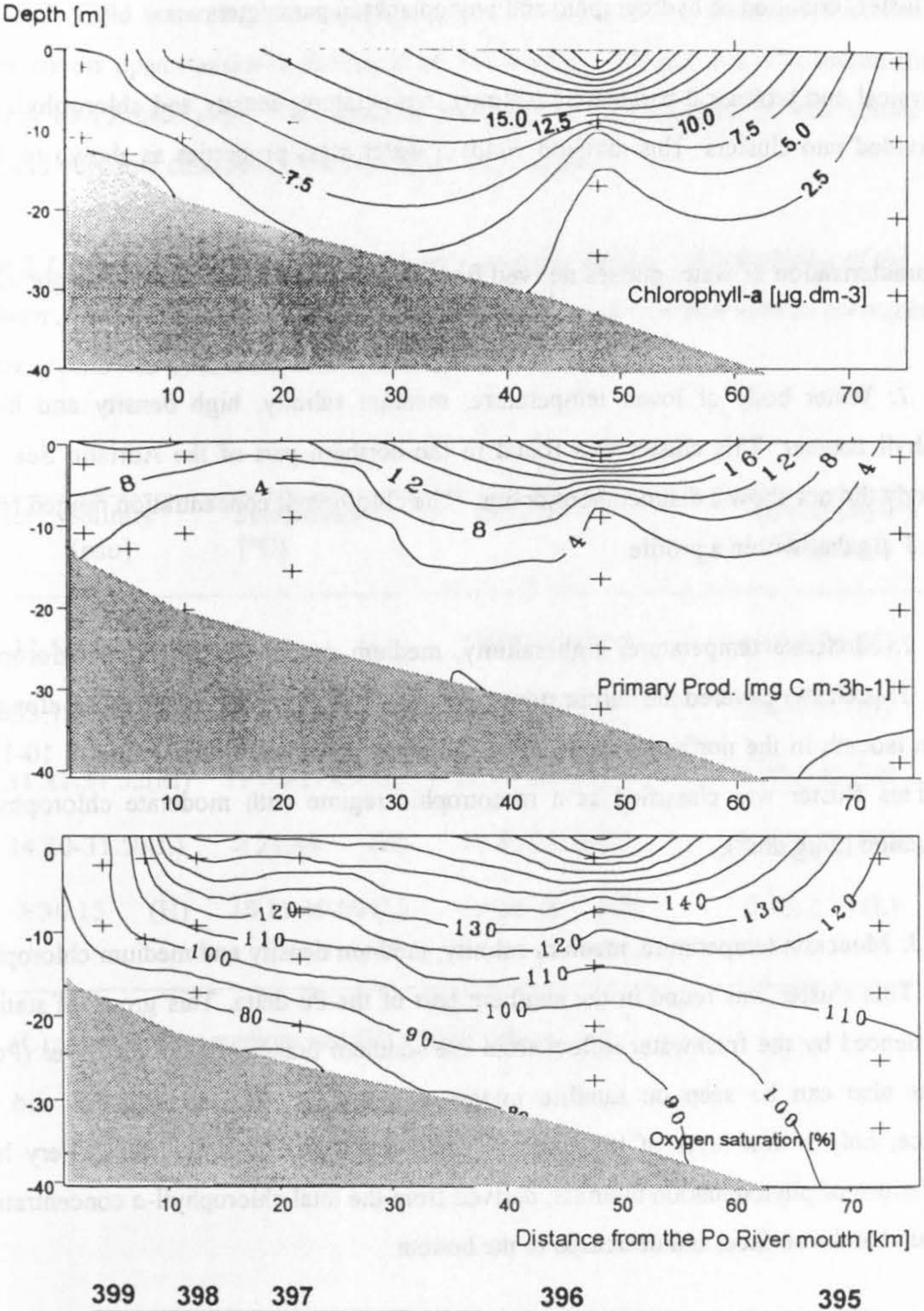


Figure 3.1.4d. Vertical distribution of physical, chemical and biological variables along a transect from the Po River mouth (St.399) to the offshore station (St.395) in the northern Adriatic Sea during May 1993: chlorophyll-a [µg.dm^{-3}], primary productivity [µgCdm^{-3}h^{-1}] and oxygen saturation [%].

3.1.2 Cluster formation of hydrographic and phytoplankton parameters.

The physical and biological parameters (salinity, temperature, density and chlorophyll-*a*) were divided into clusters. This division yields 5 water mass properties as shown in Table 3.1.1.

The characterization of water masses derived from the cluster analysis can be categorized as follows :

Cluster 1: Water body of lower temperature, medium salinity, high density and higher chlorophyll content. This cluster was found in the northern part of the Adriatic Sea. The water body did not show a distinct thermocline. The chlorophyll concentration ranged from 4.4 to 5.3 µg dm^{-3}within a profile.

Cluster 2: Moderate temperature, high salinity, medium density and medium chlorophyll content. This cluster covered the neritic stations in the southern part of the Po delta along the 30-50 m isobath in the northern Adriatic Sea. A strong thermocline was found at 10-15 m depth. This cluster was classified as a mesotrophic regime with moderate chlorophyll-*a* concentration (2 µg dm^{-3}).

Cluster 3: Moderate temperature, medium salinity, medium density and medium chlorophyll content. This cluster was found in the southern part of the Po delta. This group of stations was influenced by the freshwater inflow from the southern branch of the Po River (Po di Goro) as also can be seen on satellite images *(Fig.3.1.1)*. The stratification did not pronounce, only a thin layer of low salinity water was found at the surface. Very high accumulations of phytoplankton biomass, derived from the total chlorophyll-*a* concentration, were found at the surface, and decreased to the bottom.

Cluster 4: Warmest water body, lowest salinity and high chlorophyll content near the surface (4-8 µg dm^{-3}) and lower values near the bottom (< 1µg dm^{-3}). This cluster covered the coastal station in the vicinity of the Po delta, characterized by a shallow topography (15-20 m isobath).

Cluster 5: Cold water, highest salinity, highest density and low chlorophyll content. This cluster covers open stations in the centre of the northern Adriatic Sea. The thermocline was found at 10-15 meter depth. This group of stations showed the highest salinity values (35-38 psu), and very low chlorophyll concentration (0-1 $\mu g.dm^{-3}$).

Table 3.1.1. Cluster formation of temperature, salinity, density, chlorophyll-a of the northern Adriatic Sea (May 1993). The classification of each station with its corresponding cluster is obtained by K-means calculations.

Cluster	Salinity [psu]	Temperature [°C]	Density	Chlorophyll-a [$\mu g\ dm^{-3}$]
1.	31.53-33.77(M)	< 18.11 (L)	25.08-26.27(H)	4.40-5.28 (H)
2.	33.78-36.14(H)	18.97-19.91(M)	24.77-25.07(M)	2.4- 4.00 (M)
3.	31.21-31.52(M)	19.92-21.83(M)	21.29-24.76(M)	4.10-4.40 (M)
4.	14.50-31.50(L)	> 21.84 (H)	17.30-21.10(L)	> 5.29 (H)
5.	> 36.15 (H)	18.11-19.00 (L)	> 26.28 (H)	0.76-2.30 (L)

(L) = low, (M) = medium and (H) = high values.

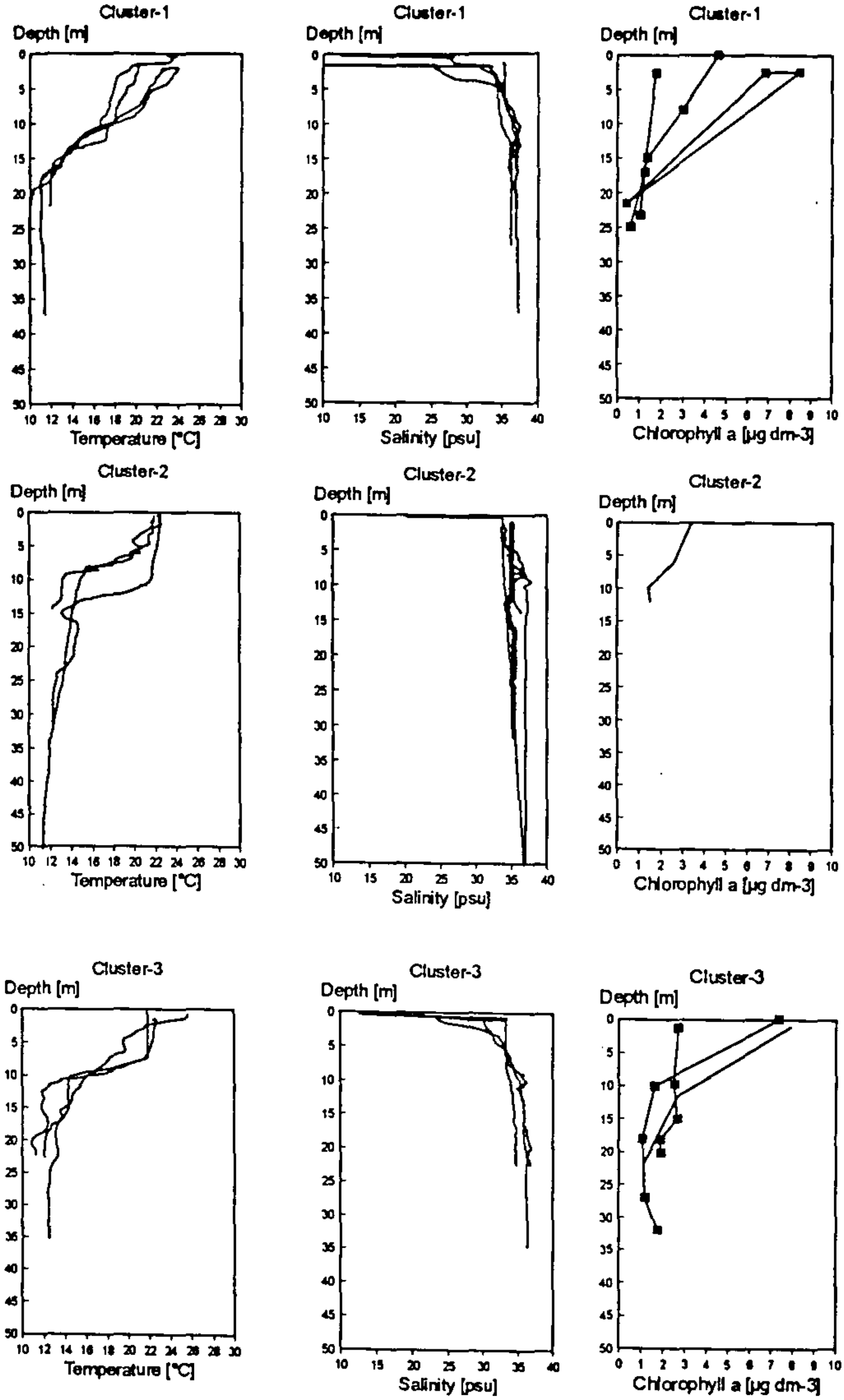


Figure 3.1.5a. Vertical profiles of temperature [°C], salinity [psu] and chlorophyll-a [µg dm^{-3}] characterized by cluster analysis for the northern Adriatic Sea in May 1993: Cluster 1, 2 and 3.

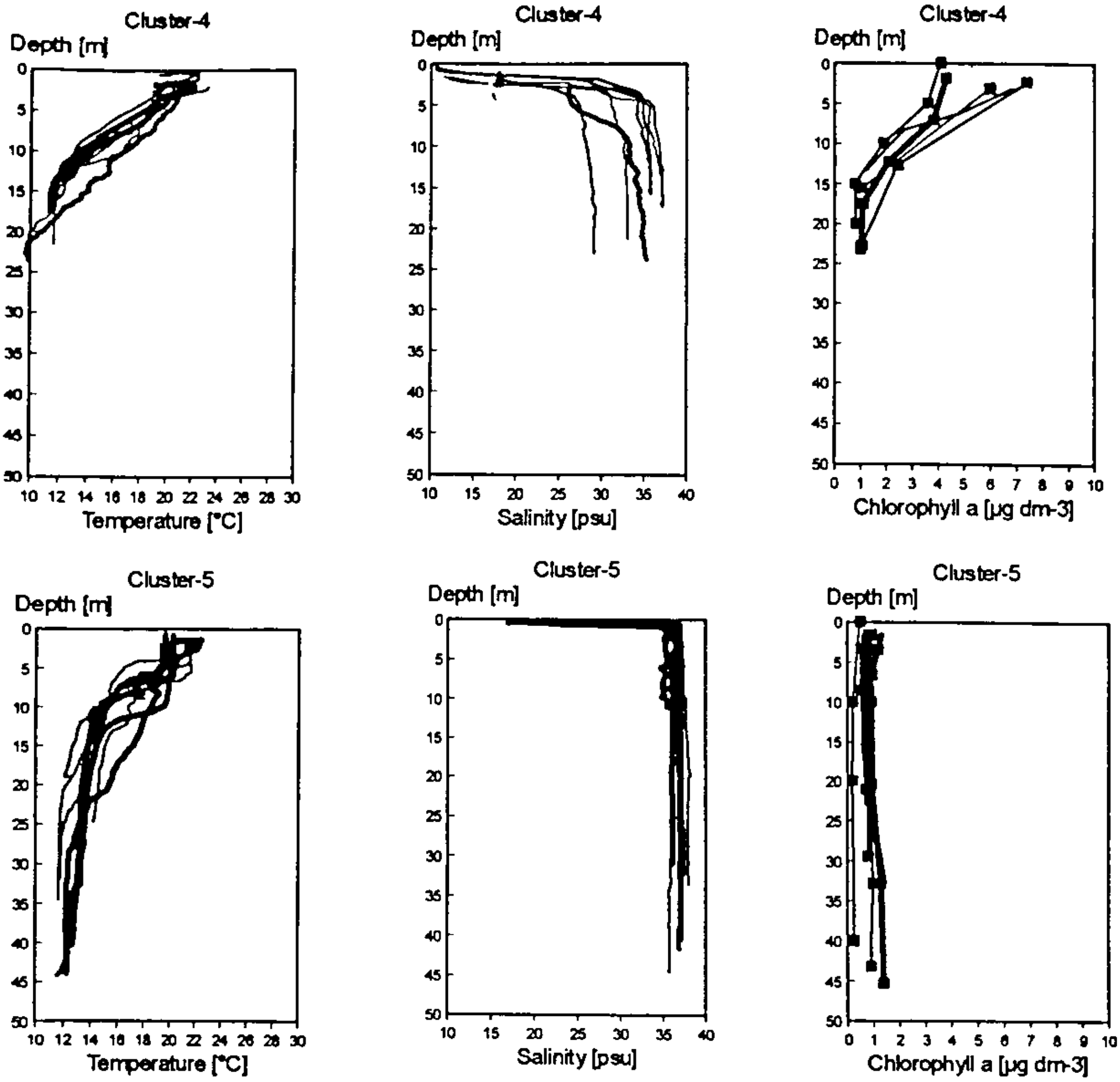


Figure 3.1.5b. Vertical profiles of temperature [°C], salinity [psu] and chlorophyll-a [µg dm^{-3}] characterized by cluster analysis for the northern Adriatic Sea in May 1993: Cluster 4-5.

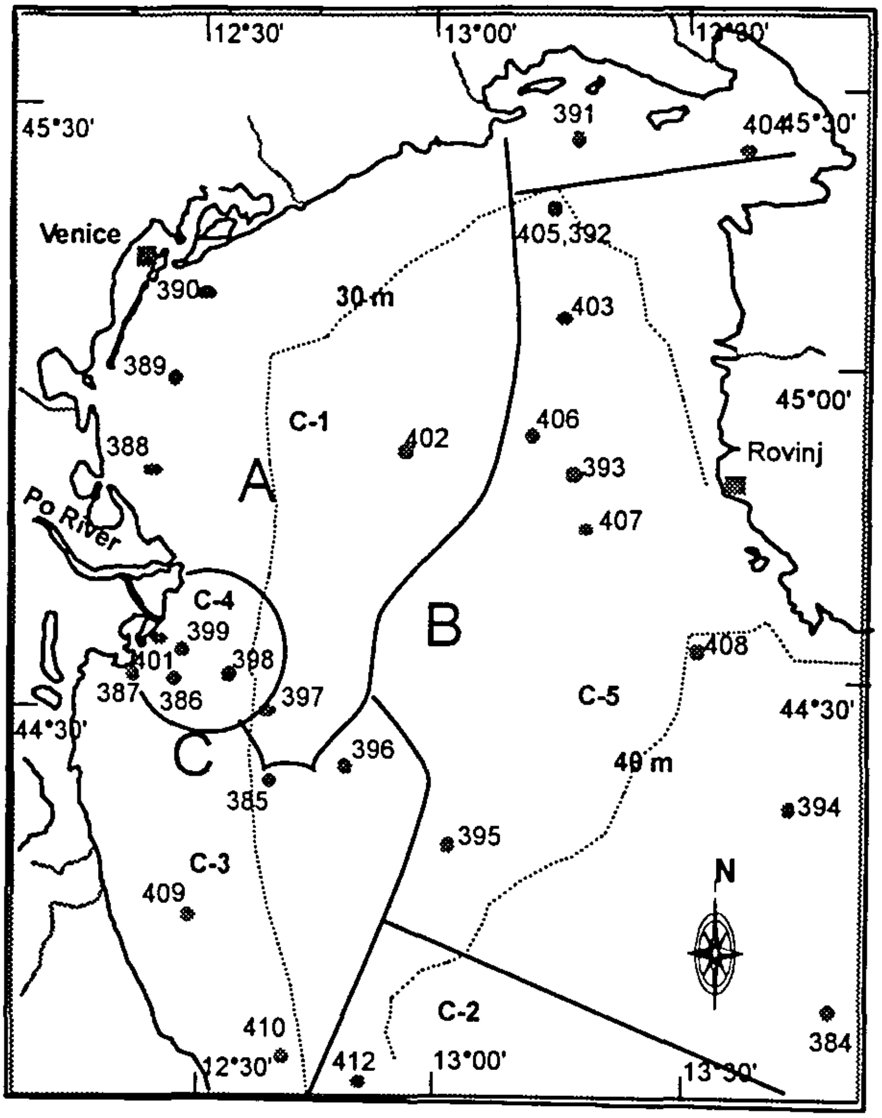


Figure 3.1.6. Horizontal projection of cluster formation of salinity, temperature, density, and chlorophyll-a derived from cluster analysis for the northern Adriatic Sea in May 1993. The clusters consist of the following stations : C-1 (388,397,390,396, 402 and 389), C-2 (411 and 412), C-3 (385,396,409 and 410), C-4 (386,387,398,399 and 400) and C-5 (384,392,393,394,395,403,405,406 and 407). Solid line is border of sub-clusters ; Dotted line is isobath. A = North-western part, B = Eastern part and C = South-western part (see Fig. 3.1.8)

3.1.3 Phytoplankton biomass and production

The spatial distribution of surface total chlorophyll-*a* was associated with the lower saline waters. Highest chlorophyll-*a* concentrations (15 µg dm^{-3}) occurred in the plume front region at the "offshore" site. In the near Po River outlet, a lower chlorophyll-*a* concentration (3-4 µg dm^{-3}) was found.

Generally, a decreasing gradient of chlorophyll-*a* from the river mouth to the south-east was found during late spring 1993. Concentrations of chlorophyll-*a* > 1 µg dm^{-3} extended up to the middle of the basin. Higher fluorescence signals, however, were detected in some stations in the open northern Adriatic Sea *(Fig. 3.1.7a)*.

The distribution pattern of the smallest fraction of chlorophyll-*a* (< 2 µm) was associated with the low saline waters, ranging from 0.1 µg dm^{-1} in the stations located in the midle of the northern Adriatic Sea to 2 µg dm^{-3} in the intermediate salinity regime. The pattern of the integrated values of this smallest chlorophyll fraction within the euphotic zone was consistent with the surface chlorophyll-*a* distribution, ranging from 4 to 20 µg dm^{-3} in the water column *(Fig. 3.1.7b)*.

The distribution of the medium fraction of chlorophyll-*a* (2-5 µm) showed a similar pattern as the other fractions, associated also with the less saline water. The integrated value of this chlorophyll fraction within the euphotic zone ranged from 4 to 30 µg dm^{-3}*(Fig.3.1.7b)*.

Primary production was also closely associated with the nutrient concentration. The surface primary production within the plume waters ranged from 4-30 µg C dm^{-3} h^{-1}. A peak value of bottom (4 metres above sea-bed) primary production (2 µg C dm^{-3} h^{-1}) was observed app. 20 km away from the Po river mouth. A relatively high primary production (7 µg C dm^{-3} h^{-1}) was obtained off Ancona. Since that value could not be correlated with any other phytoplankton parameter (chlorophyll-*a* or biomass), a methodological error might be the reason for this high value *(Fig. 3.1.7c)*.

Diatoms and dinoflagellates showed a distinct pattern within the River Po influenced waters. The diatom concentrations ranged from 200-1500 x 10^3 cells dm^{-3} and consisted of

Chaetoceros cf. sociale, *Rhizosolenia fragilissima*, *Asterionella* spp. and *Nitschia cf. delicatissima*. The maximum number of the diatoms occurred in the southern part of the Po delta. The dinoflagellates concentration ranged from 20 -100 x 10^3 cells dm^{-3}. Its maximum was found 40 km east of the river mouth. A strong association of dinoflagellates (*Prorocentrum* spp, *Ceratium* spp, *Gonyaulax* spp and *Dinophysis* spp) with the Po River influenced-water was found. Chrysophyceae and coccolithophorides showed highest concentrations near the main outflow of the River Po *(Fig.3.1.7d)*.

3.1.4 Mesozooplankton distribution

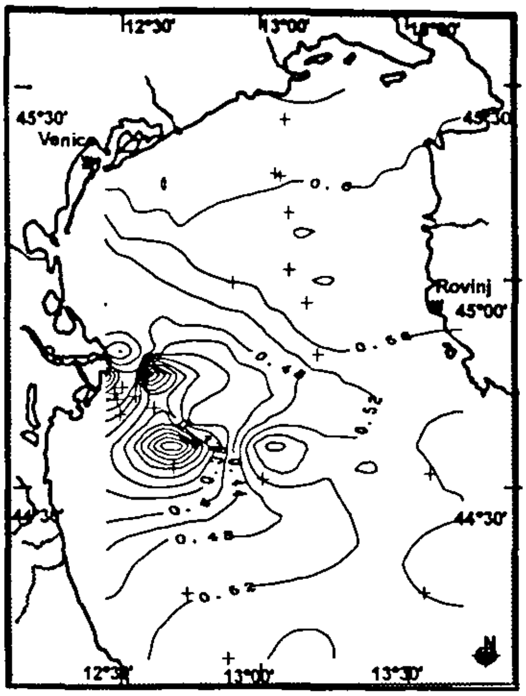
Zooplankton biomass

The horizontal distribution of biomass ranged from 2 to 7 µg C dm^{-3}. The largest biomass (> 5 mg C m^{-3}) was found off the Croatian coast and in the open Adriatic waters, where lower temperatures were measured. The minimum biomass < 3 µg C dm^{-3} was found in the north-western Adriatic Sea off the Venice lagoon up to the Gulf of Triest (*Fig. 3.1.9*).

The biomass of mesozooplankton was not significantly correlated to other biological and chemical parameters. However, a clear negative correlation between mesozooplankton biomass and the smallest fraction of chlorophyll-*a* (< 2 µm) can be observed (*Fig. 3.1.7* and *Fig. 3.1.9*).

Zooplankton abundance

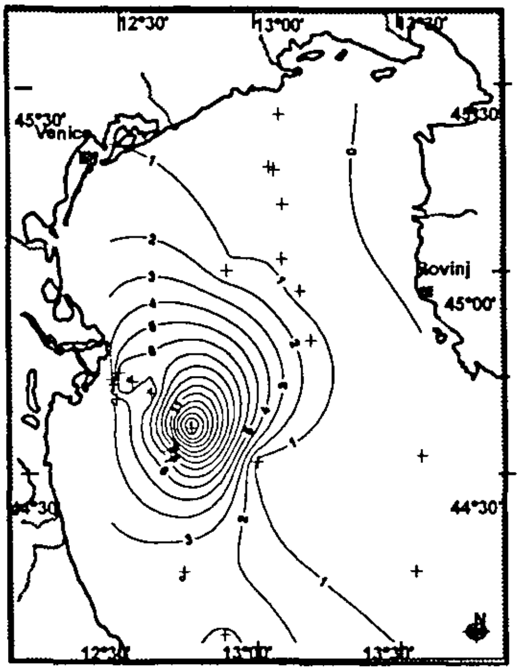
The overall zooplankton composition during May 1993 was dominated by larval stages of copepods. Among the calanoid copepods, *Acartia clausi* was the most abundant species. *Oithona similis* was the most abundant of the three species of cyclopoid copepods. Cladocerans were rare during May. Copepod nauplii, with mean and maximum densities of 3 800 ind m^{-3} and 18 000 ind m^{-3}, respectively, were the most abundant taxon, contributing 20 % to total zooplankton (*Table 3.1.2*).



Surface

Bottom

Fluorescence

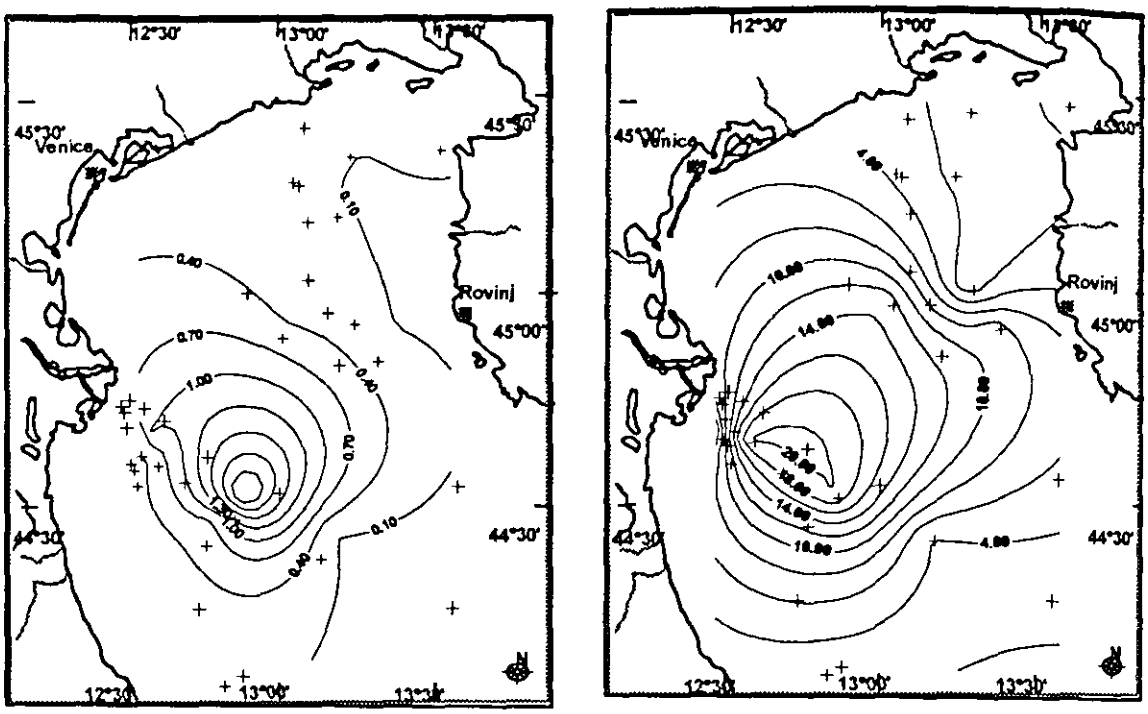


Surface

Bottom

Chl. a [μg dm^{-3}]

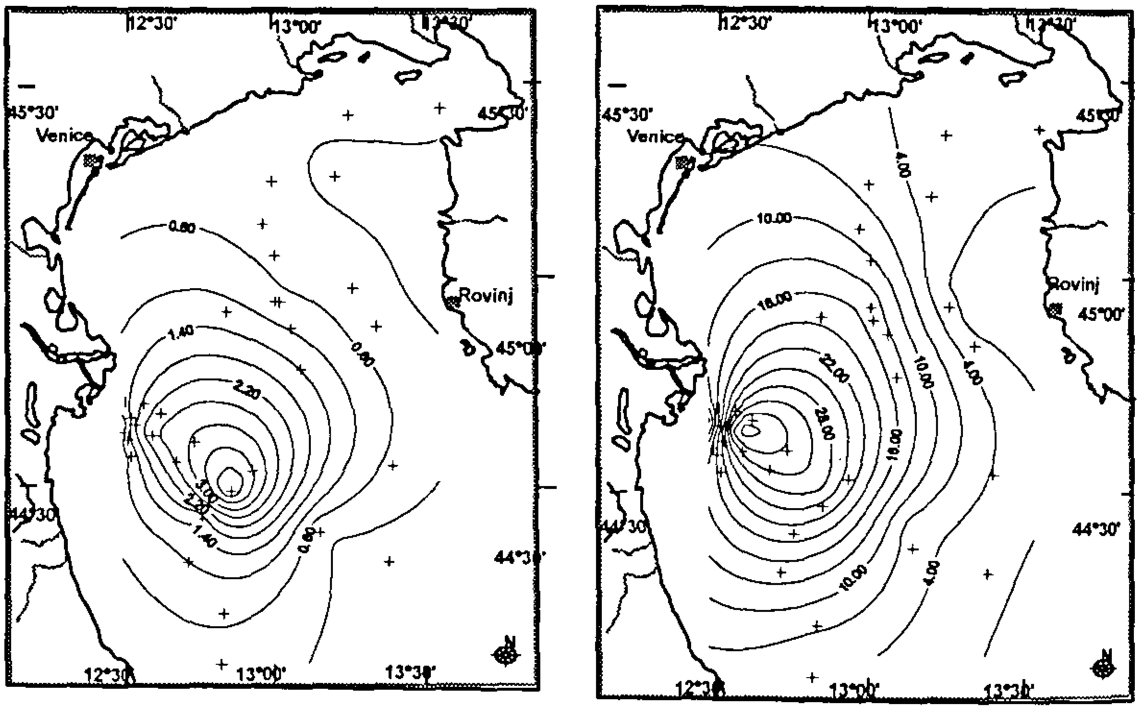
Figure 3.1.7a. Distribution of fluorescence and total chlorophyll-a [μg dm^{-3}] in the northern Adriatic Sea during May 1993. Bottom values were collected at 4 m above the sea-bed.



Surface

Water column

Chl. a <2 µm [µg dm-³]

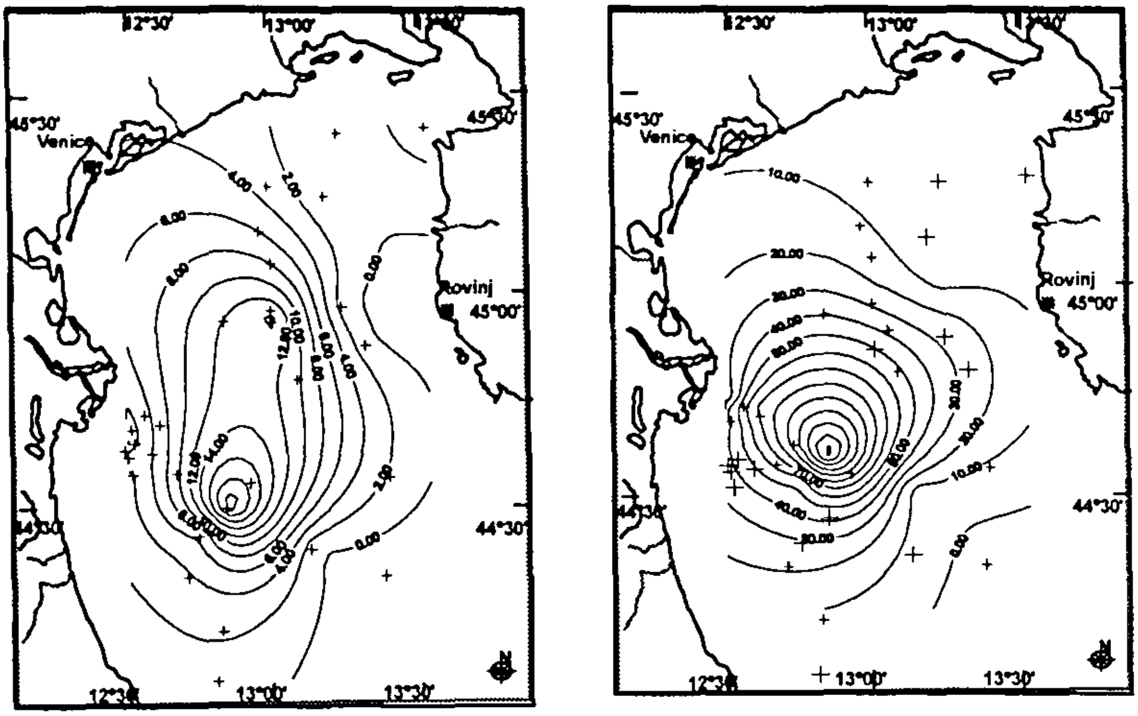


Surface

Water column

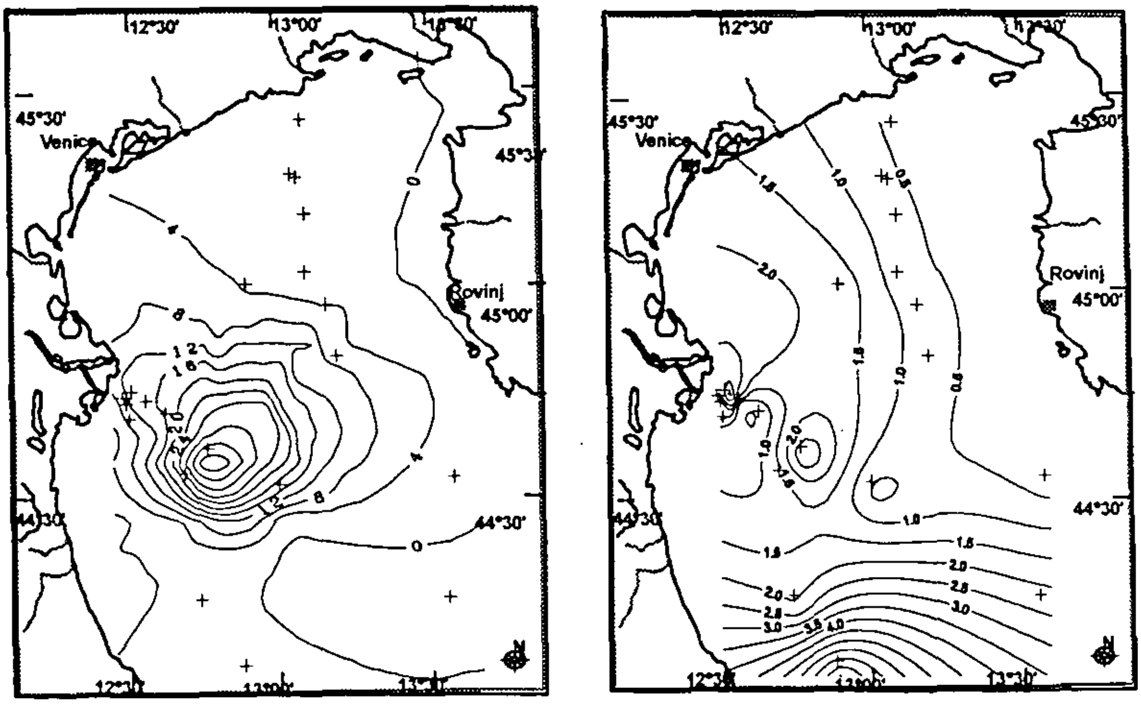
Chl. a 2-5 µm [µgdm-³]

Figure 3.1.7b. Distribution of chlorophyll-a < 2 µm [µg dm^{-3}] and chlorophyl-a 2-5 µm [µg dm^{-3}] in the northern Adriatic Sea during May 1993. Water column = integrated values within euphotic zone.



Surface

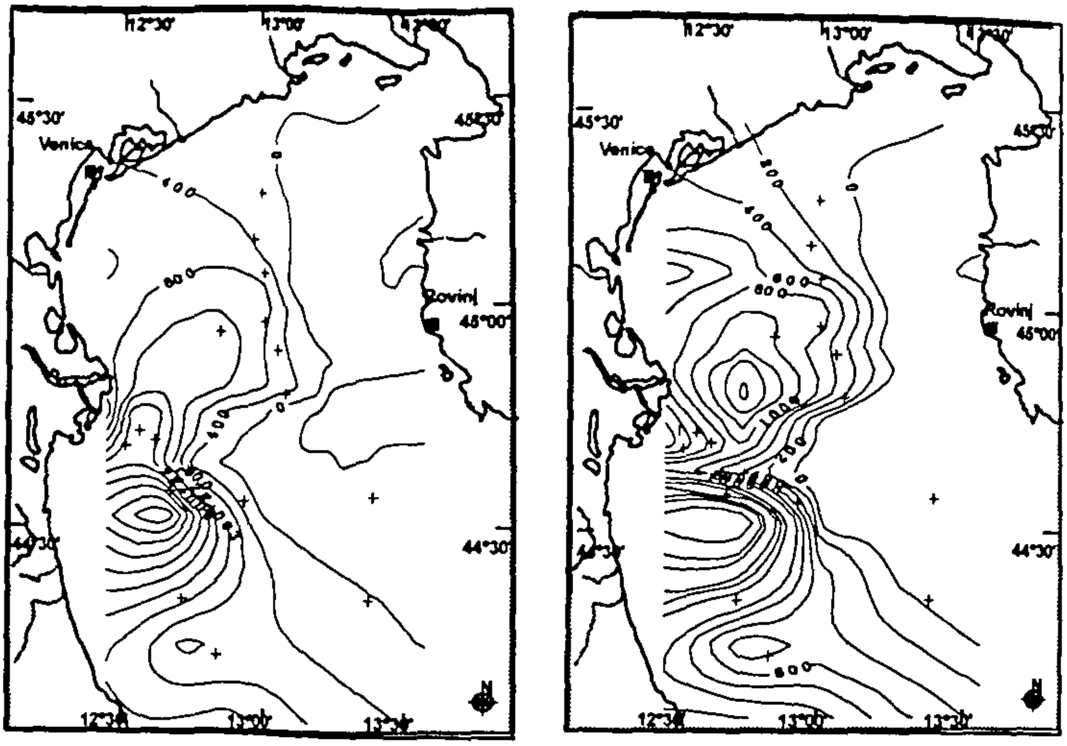
Water column Chl.a 5-20 µm [µg dm-³]



Surface

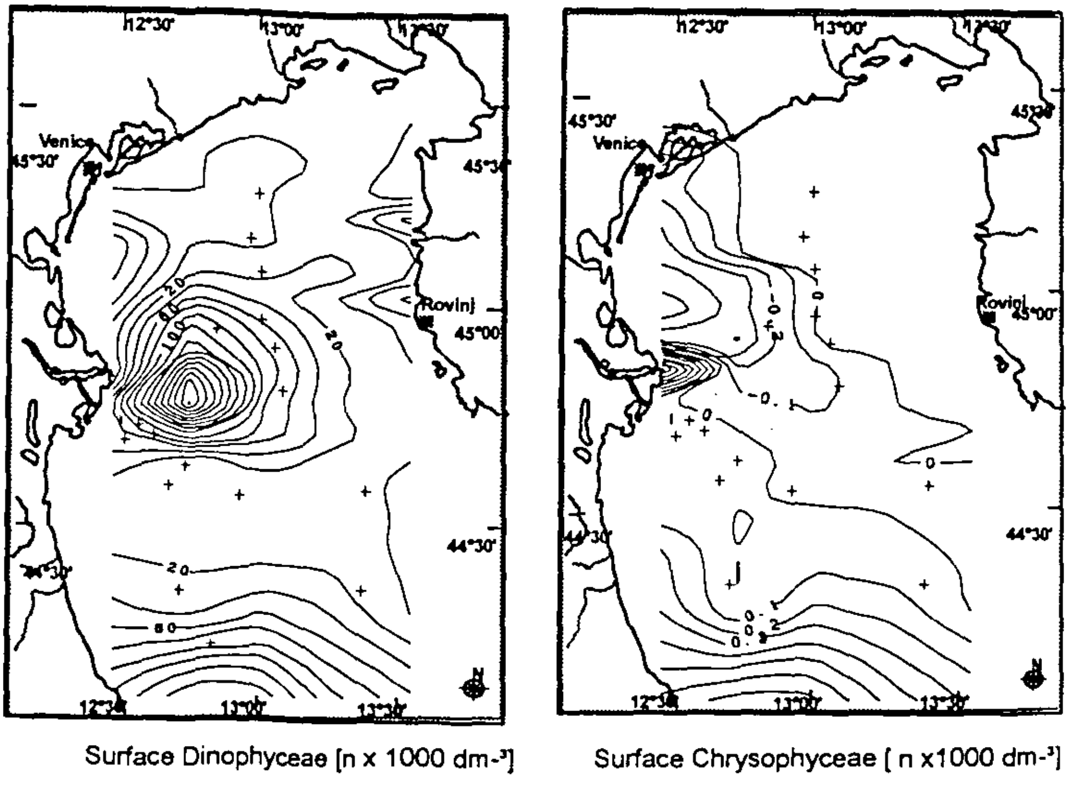
Bottom Primary production [µgCdm-³h-1]

Figure 3.1.7c. Distribution of chlorophyll-a 5-20 µm [µg dm^{-3}] and primary production [µg C dm^{-3} h^{-1}] in the northern Adriatic Sea during May 1993. Water column = integrated values within euphotic zone. Bottom values were collected at 4 m above the sea-bed.



Surface total phytoplankton [n x 1000 dm^{-3}]

Surface diatom [n x 1000 dm^{-3}]



Surface Dinophyceae [n x 1000 dm^{-3}]

Surface Chrysophyceae [n x1000 dm^{-3}]

Figure 3.1.7d. Distribution of surface total phytoplankton, diatoms [n x 1000 dm^{-3}], Dinophyceae and Chrysophyceae [n x 1000 dm^{-3}] in the northern Adriatic Sea during May 1993.

Table 3.1.2. Mean abundance, percent contribution and the rank of abundance of the zooplankton collected in the northern Adriatic Sea during May 1993.

Zooplankton taxa	Mean abundace (ind.m-3)	Percent of total (%)	Maximum abundance (ind.m-3)	Rank of top 10 taxa
Copepods (CVI):				
Acartia clausi	1148	6	6500	6
Calanus helgolandicus	4	< 0.1	51	
Calocalanus pavo	6	< 0.1	67	
Clausocalanus arcuicornis	1	< 0.1	13	
Clausocalanus paululus	16	< 0.1	125	
Centropages typicus	38	< 0.1	100	
Euterpina acutifrons	16	< 0.1	100	
Microsetella rosea	7	< 0.1	46	
Oithona similis	1612	8	7300	3
Oithona nana	1091	6	5000	8
Oithona plumifera	1137	6	5800	7
Oncaea spp.	1331	7	5700	4
Paracalanus parvus	754	4	2400	
Pseudocalanus elongatus	147	1	815	
Temora longicornis	198	1	1200	
Temora stylifera	70	< 0.1	262	
Copepodites (CI-CV):				
Acartia	4208	22	24938	1
Paracalanus	1174	6	4400	5
Oithona	979	5	2492	9
Temora	126	1	646	
Centropages	59	< 0.1	159	
Copepod nauplii:				
Acartia	2533	13	13625	2
Paracalanus	480	2	1154	
Oithona	596	3	2415	10
Temora	153	1	479	
Centropages	11	<0.1	58	

Zooplankton taxa	Mean	Percent	Maximum	Rank of top
	abundace	of total	abundance	10 taxa
Copepod nauplii:	(ind.m-3)	(%)	(ind.m-3)	
Calanus	13	<0.1	123	
Cladocera:				
Evadne nordmanni	161	1	1.099	
Evadne tergestina	62	<0.1	300	
Podon polyphemoides	108	1	563	
Podon intermedius	20	<0.1	100	
Appendicularia	512	3	1.758	
Bivalve larvae	585	3	2.646	
Gastropod larvae	56	<0.1	313	
Polychaeta larvae	24	<0.1	250	

Table 3.1.2. Continued.

From the 5 different cluster (see above), 3 differents sites, were identified :

(1) Cluster 1. - Site A

(2) Cluster 2 and 5 .- Site B

(3) Cluster 3 and 4 . - Site C, with a temperature range of 20 - 23 ° C and a salinity range of 14 - 31 psu and chlorophyll-*a* 5-12 μg dm^{-3}.

The mesozooplankton abundance estimated for these 3 areas was different (Kruskal-Wallis Anova by ranks, H=17.75 (5.99)*, N=60, $p < 0.05$). The average mesozooplankton concentration at site C (median = 4616 ind m^{-3}) was higher comparing to site A (median = 1988 ind m^{-3}) and site B (median= 808 ind m^{-3}). The multiple comparison (Non-Parametric: Nemenyi Test) showed that there was a significant difference in mesozooplankton abundance between site A versus site B (19.14/14.7*) and site B versus site C (21.30 /13.53*). In the eutrophic waters the mesozooplankton abundance was 5 times higher compared to the offshore oligotrophic areas.

The co-occurrence of different development stages of copepods was noted at all sites. Higher percentages of adult copepods (37-59 %) were found at site A and B, whereas higher percentages of copepodites stages (38-40 %) and nauplii (19-25 %) were found at site B and C. The percentages of Cladocera with respect to the total mesozooplankton population was found to be higher in site A and B (1.4 - 3.6 %). Very small abundances of Appendicularia (1 % of total abundance) were observed at stations central Adria, whereas 3.6-4.5 % could be found at sites A and B (*Fig.3.8*).

Table 3.1.3. Results of a significance test of mesozooplankton abundance at three sites (A, B and C) in the northern Adriatic Sea (Kruskal-Wallis rank, N=20).

Sites	C VI	C I-V	Nauplii	Cladocera	Appendicularia	Meroplankton
A, B and C	n.s	H=5.9 * ($p < 0.05$)	H=5.6 * ($p < 0.05$)	H=6.1 * ($p < 0.05$)	H=7.5 * ($p < 0.05$)	n.s

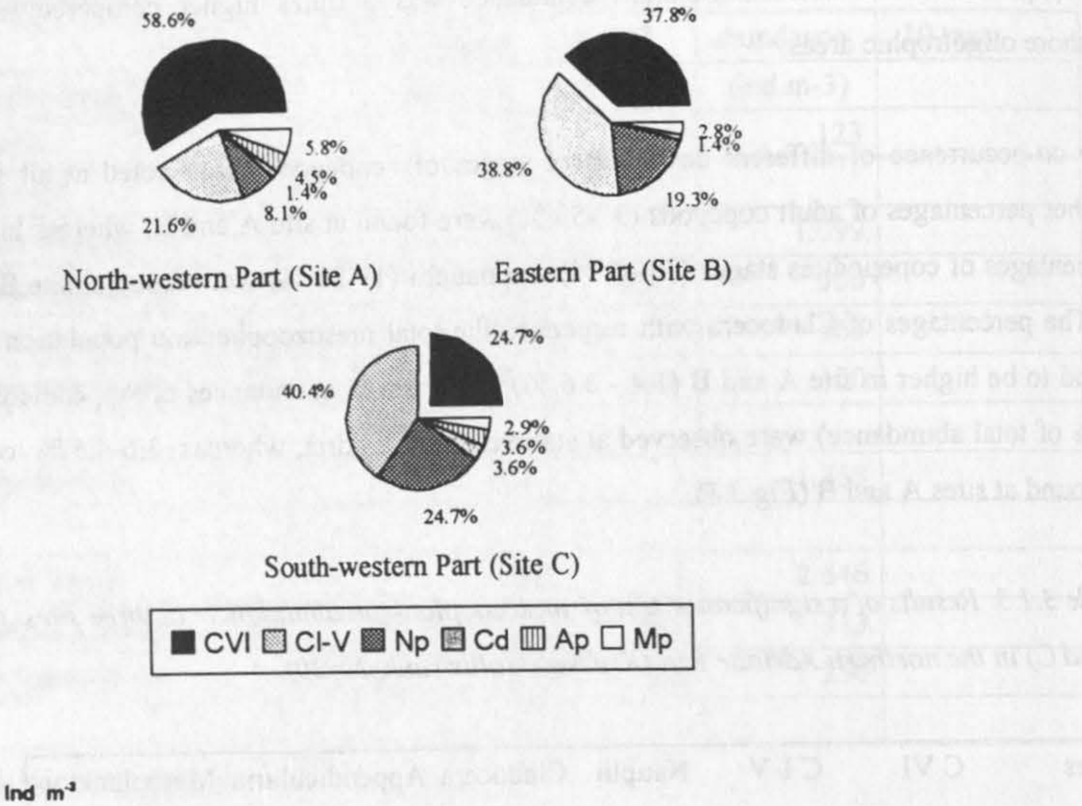
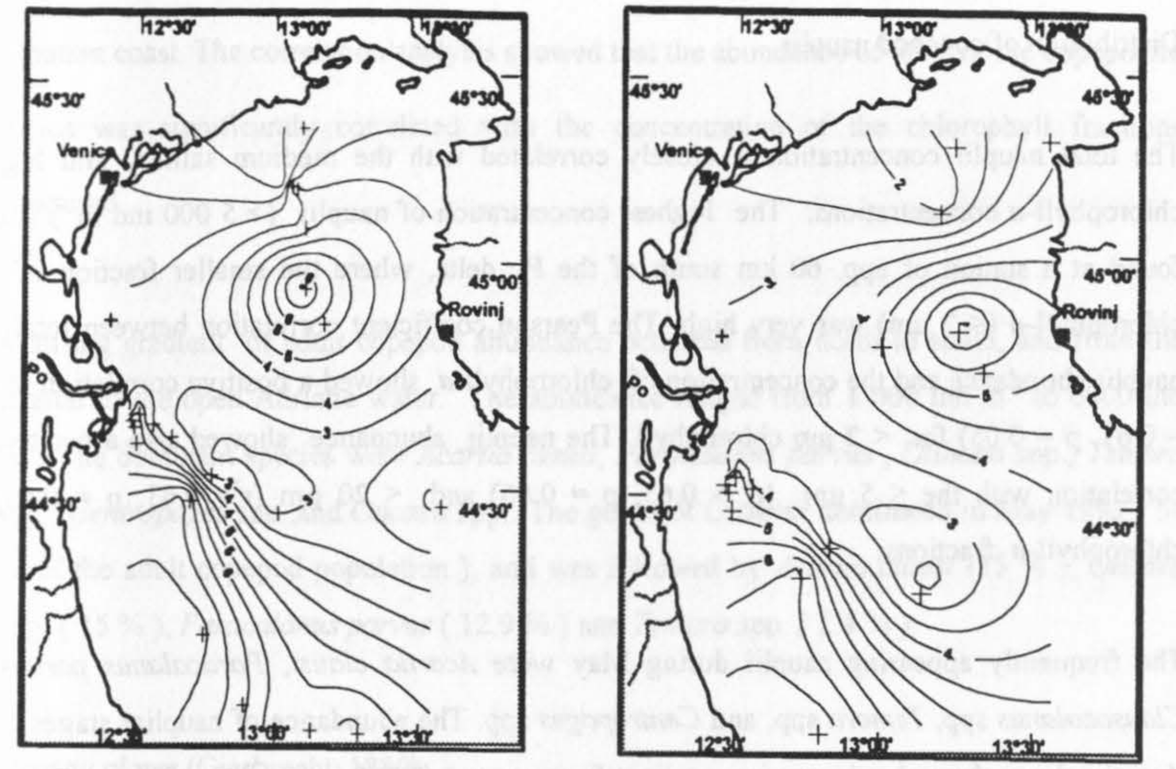
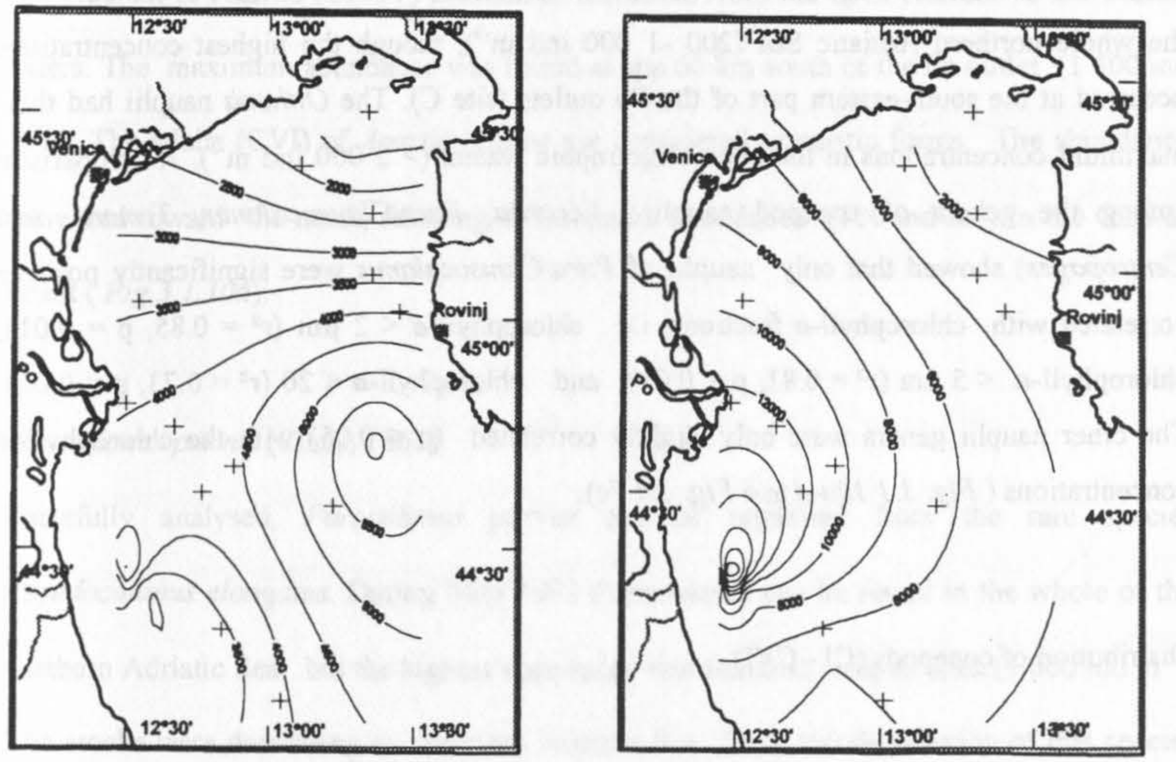


Figure 3.1.8. The abundance [ind.m^{-3}] and age structure of copepod populations as well as contribution of other groups at three different sites in the northern Adriatic Sea. CVI = adult copepods, CI-CV= copepodites, Np = copepod nauplii, Cd = Cladocera, Ap = Appendicularia, Mp = meroplankton (bivalve larvae).



Zooplankton DW [mg m-³] Zooplankton biomass [mg C m-³]



Total CVI [ind m-³] Total CI-VI [ind m-³]

Figure 3.1.9. Spatial distribution of zooplankton biomass [>100µm] in terms of zooplankton dry weight [mg m⁻³], biomass [mg C m⁻³] and total copepod abundances [ind m⁻³] in the northern Adriatic Sea during May 1993.

Distribution of copepod nauplii

The total nauplii concentration is closely correlated with the medium salinity and high chlorophyll-*a* concentrations. The highest concentration of nauplii (> 5 000 ind m^{-3}) was found at a station of app. 60 km south of the Po delta, where the smaller fraction of chlorophyll-*a* (< 2 µm) was very high. The Pearson coefficient correlation between total nauplii abundance and the concentration of chlorophyll-*a* showed a positive correlation ($r^2 = 0.67$, $p = 0.05$) for < 2 µm chlorophyll. The nauplii abundance showed also a positive correlation with the < 5 µm ($r^2 = 0.65$, $p = 0.06$) and < 20 µm ($r^2 = 0.63$, $p = 0.07$) chlorophyll-*a* fractions.

The frequently appearing nauplii during May were *Acartia clausi*, *Paracalanus parvus*, *Clausocalanus* spp, *Temora* spp. and *Centropages* spp. The abundance of naupliar stages of *Acartia clausi* showed a decreasing gradient from coastal (8 000 ind m^{-3}) to offshore waters (< 1000 ind m^{-3}). The nauplii of *Para/Clausocalanus* were almost equally distributed within the whole northern Adriatic Sea (200 -1 000 ind m^{-3}), though the highest concentrations occurred at the south-eastern part of the Po outlets (site C). The *Oithona* nauplii had their maximum concentrations in the open oligotrophic waters (> 2 000 ind m^{-3}). A comparison among the genera of copepod nauplii (*Acartia*, *Para/Clausocalanus*, *Temora*, and *Centropages*) showed that only nauplii of *Para/Clausocalanus* were significantly positive correlated with chlorophyll-*a* fractions, i.e : chlorophyll-*a* < 2 µm ($r^2 = 0.85$, $p = 0.01$), chlorophyll-*a* < 5 µm ($r^2 = 0.81$, $p = 0.01$), and chlorophyll-*a* < 20 ($r^2 = 0.73$, $p = 0.01$). The other nauplii genera were only slightly correlated ($p < 0.05$) with the chlorophyll-*a* concentrations (*Fig. 3.1 10a-d* and *Fig. 3.1.7c*).

Distribution of copepods (CI - CVI)

High concentrations of total copepodite stages from CI - CV (> 10 000 ind m^{-3}) were clearly associated with the river-influenced water south of the Po delta (*Fig. 3.1.9*). The minimum abundance of copepodite stages (< 10 m^{-3}) was found in the coldest water body off the

Croatian coast. The correlation analysis showed that the abundance of none of the copepodite stages was significantly correlated with the concentration of the chlorophyll fractions measured.

A strong gradient of adult copepod abundance occurred from north to south, and from the coastal to the open Adriatic water. The abundance ranged from 1 000 ind m^{-3} to 6000 ind m^{-3}. The dominant species were *Acartia clausi*, *Paracalanus parvus* , *Oithona* spp., *Temora* spp., *Centropages* spp.,and *Oncaea* spp.. The genus of *Oithona* dominated in May 1993 (54 % of the adult copepod population), and was followed by *Acartia clausi* (15 %), *Oncaea* spp. (15 %), *Paracalanus parvus* (12.9 %) and *Temora* spp. (2.4 %).

Acartia clausi (Giesbrecht, 1889)

The gradient of Acartia (CI-CV) abundance increased from the open Adriatic to the coastal waters. The maximum abundance was found at app.60 km south of the Po outlet (1 500 ind m^{-3}). The adults (CVI) of *Acartia clausi* are considered as neritic forms. The abundance decreased toward the north, reaching a minimum abundance (100 ind m^{-3}) in the Gulf of Triest (*Fig.3.1.10a*).

Paracalanus parvus (Claus, 1863)

Carrefully analysed, *Paracalanus parvus* can be separated from the rare species *Pseudocalanus elongatus*. During May 1993 *Paracalanus* can be found in the whole of the northern Adriatic Sea, but the highest abundance was found in coastal sites (1 000 ind m^{-3}). The stocks were decreasing in the open Adriatic Sea. Thus the distribution of this species was correlated with the eutrophic waters (*Fig.3.1.10b*).

Oithona spp.

These small cyclopoid copepods consist of *Oithona similis* (Claus, 1863), *Oithona plumifera* (Baird, 1843) and *Oithona nana* (Giesbrecht, 1892). During May 1993, a relatively high abundance of *Oithona* spp. was found in the whole of the northern Adriatic Sea. The maximum of the adult population (2 500 ind m^{-3}) was found in the open Adriatic waters. This pattern of copepodite distribution nearly coincides with the distribution patterns of *Acartia* and *Paracalanus*. The gradient of abundance increased to the southern direction from the Po delta and ranged from 100 to 1 000 ind m^{-3} (*Fig.3.1.10c*)

Temora spp.

Two species of *Temora* spp, i.e. *T. stylifera* (Dana, 1849) and *T.longicornis* (Müller,) were found. The contribution of these species to the total stocks was low in May 1993. Their copepodite stages were mostly found in the open Adriatic waters with > 1000 ind m^{-3}. Their abundance decreased in direction to the coast. Only 10 - 100 ind m^{-3} were found near of the Po delta.

The horizontal distribution pattern of the adult *Temora* spp *in* May 1993 showed its maximum (300 ind m^{-3}) in the open Adriatic waters. The adult population was rarely caught within the coastal areas. An accumulation occurred in the plume front with abundances reaching values > 100 ind m^{-3} (*Fig.3.1.10d*).

Centropages typicus (Kröyer, 1849)

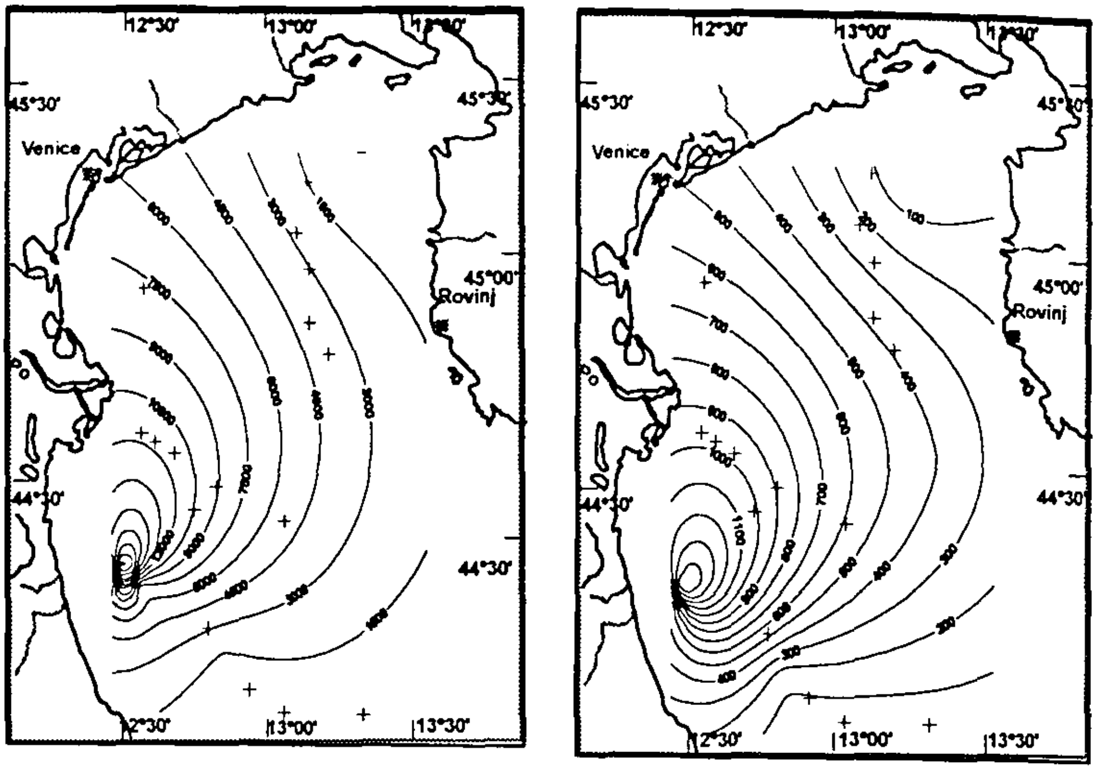
The copepodite abundance of *Centropages typicus* ranged from 10 to 100 ind m^{-3}. Their abundance decreased from coastal sites to the open Adriatic waters. The horizontal pattern of distribution of the adult *Centropages* was similar to that of *Temora*, associated with low saline waters (*Fig.3.1.10e*).

Oncaea spp. (Philippi, 1843)

The *Oncaea* spp consisted of *O.media* and *O.subtilis.* The horizontal distribution pattern was associated with the high saline waters. The maximum stock was 1000 ind m^{-3} with a salinity of 35 psu (*Fig.3.1.10f*).

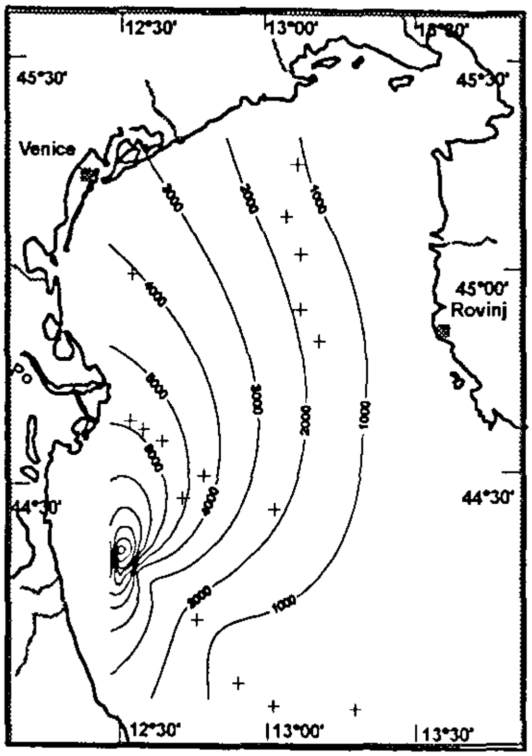
Cladocera

Cladocera were represented by *Podon* spp and *Evadne* spp. In May 1993, Cladocera were infrequently encountered ranging from 50 to 300 ind m^{-3} (*Fig.3.1.10f*).



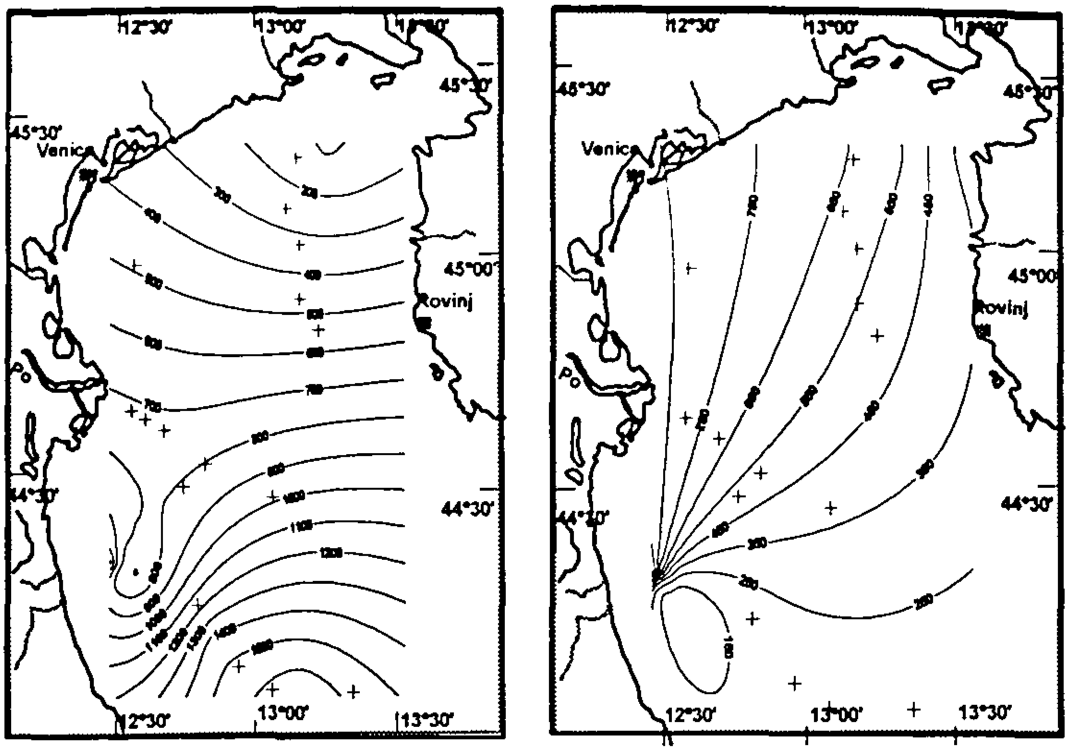
Acartia clausi (CI-VI) [ind m-^{3}]

Acartia clausi (CVI) [ind m-^{3}]

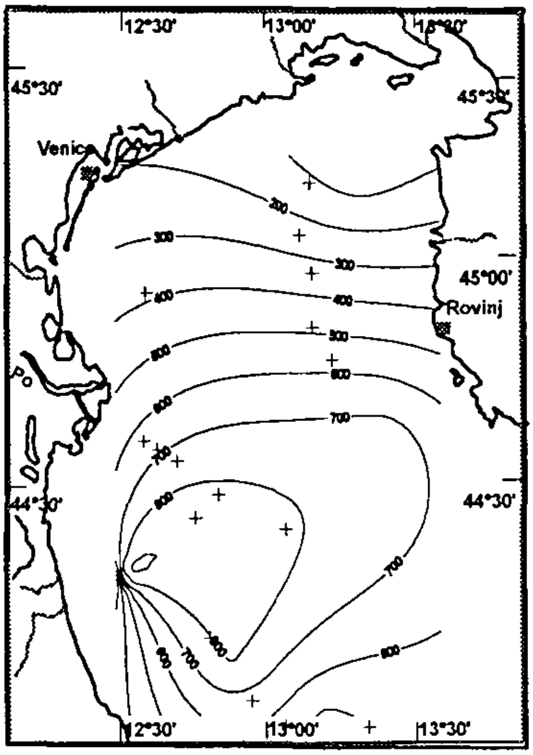


Acartia clausi (N) [ind m-^{3}]

Figure 3.1.10a. Spatial distribution of the most common copepods in the northern Adriatic Sea during May 1993 : ***Acartia clausi*** *.*

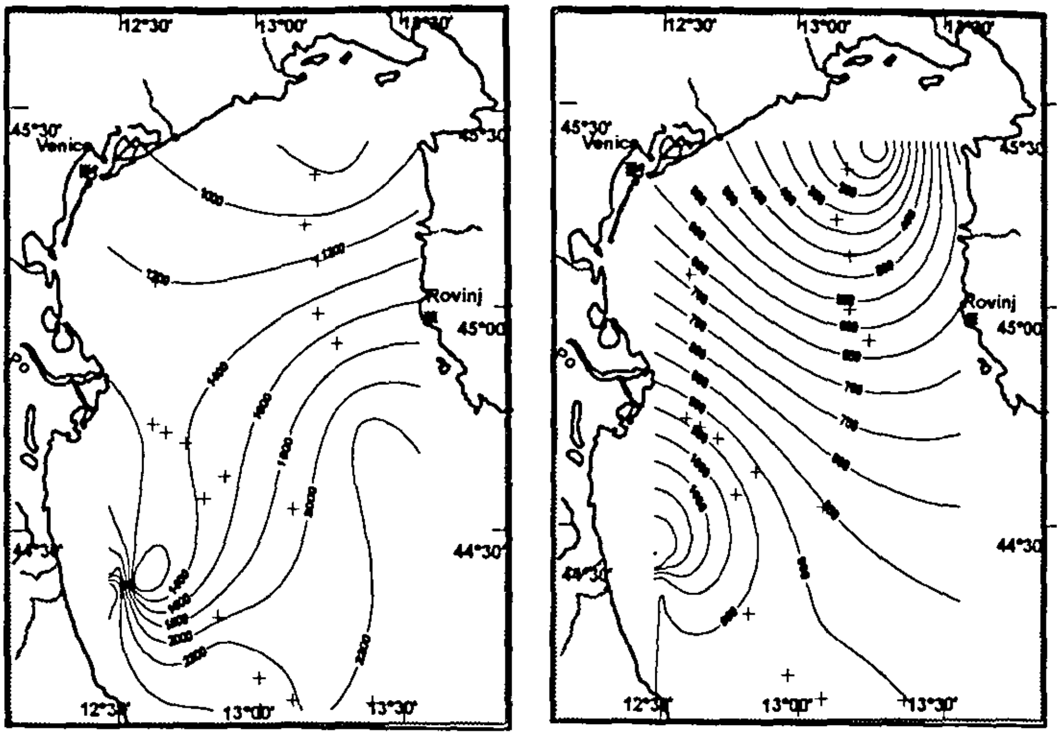


Paracalanus parvus (CI-VI) [ind m-³]   *Paracalanus parvus* (CVI) [ind m-³]



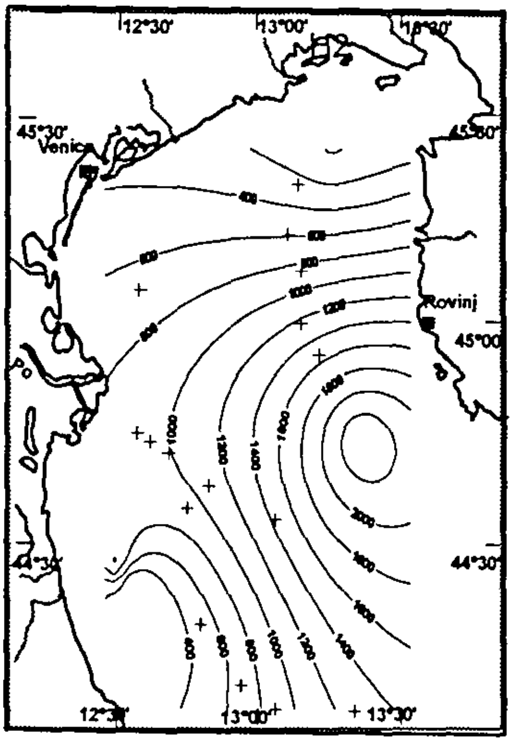
Para/Clausocalanus. (N) [ind m-³]

Figure 3.1.10b. Spatial distribution of the most common copepods in the northern Adriatic Sea during May 1993: ***Paracalanus parvus****. The nauplii could not be clearly distinguished from those of Clausocalanus*



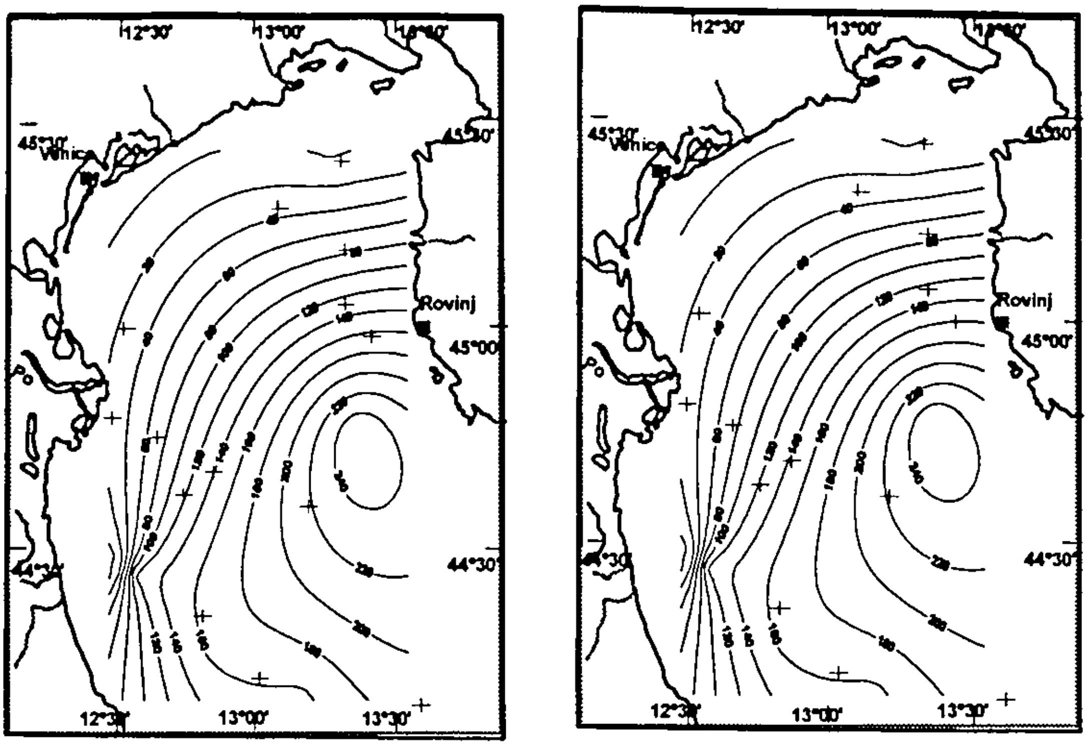
Oithona spp. (CI-VI) [ind m-³]

Oithona spp.(CVI) [Ind m-³]



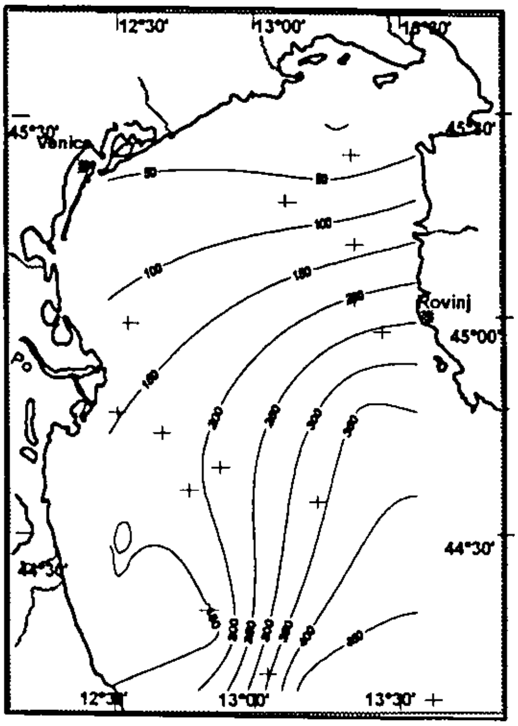
Oithona spp (N) [ind m-³]

Figure 3.1.10c. Spatial distribution of the most common copepods in the northern Adriatic Sea during May 1993: ***Oithona*** spp.



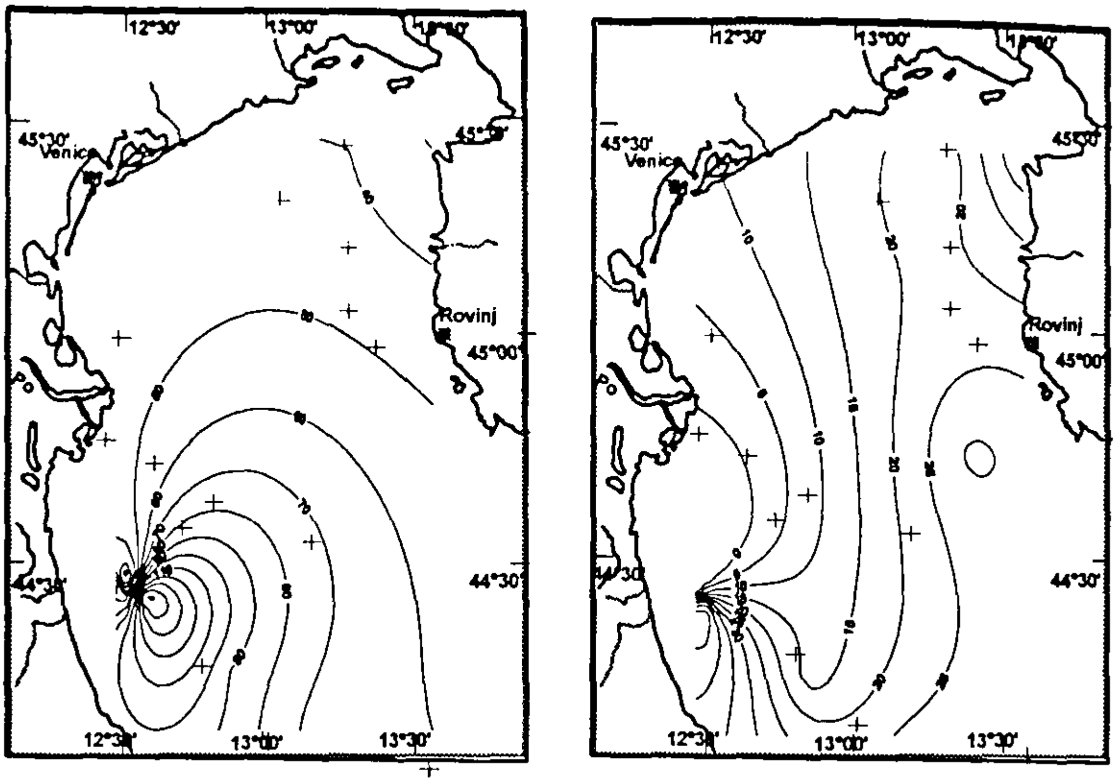
Temora spp. (CI-VI) [ind m-³]

Temora spp.(CVI) [ind m-³]



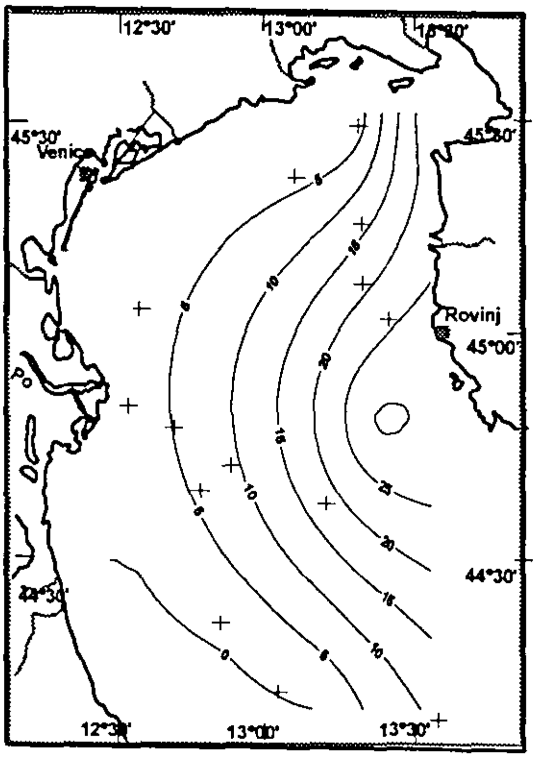
Temora spp (N) [ind m-³]

Figure 3.1.10d. Spatial distribution of the most common copepods in the northern Adriatic Sea during May 1993: ***Temora*** spp.



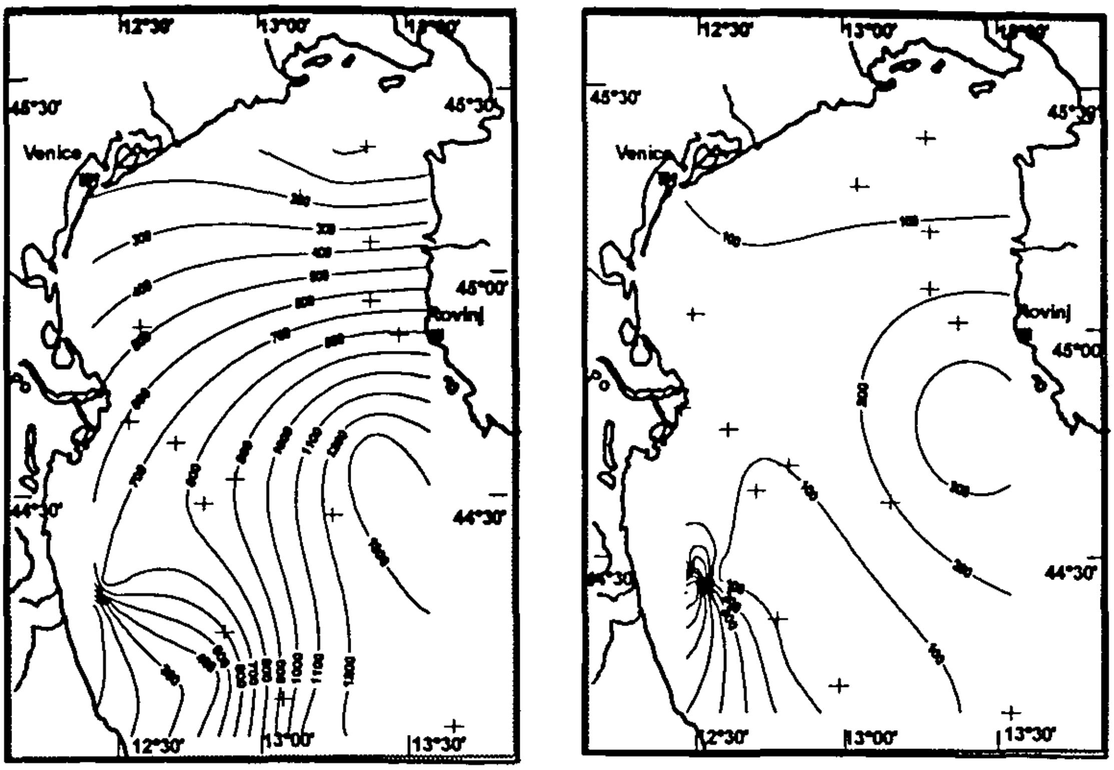
Centropages spp. (CI-VI) ind m^{-3}]

Centropages spp.(CVI) [ind m^{-3}]



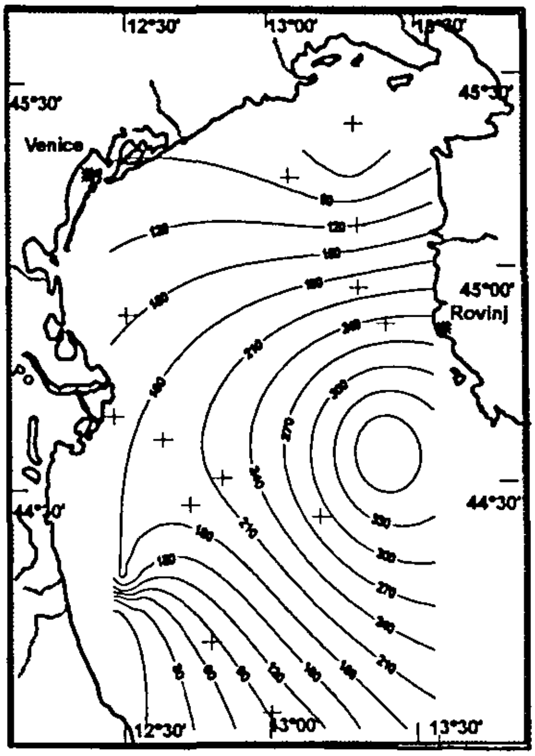
Centropages spp (N) [ind m^{-3}]

Figure 3.1.10e. Spatial distribution of the most common copepods in the northern Adriatic Sea during May 1993: **Centropages** spp.



Oncaea spp.(CVI) [ind m-³]

Podon spp. [ind m-³]



Evadne spp. [ind m-³]

Figure 3.1.10f. Spatial distribution of the most common copepods and Cladocera in the northern Adriatic Sea during May 1993 : **Oncaea spp**, ***Podon* spp** *and* ***Evadne* spp**.

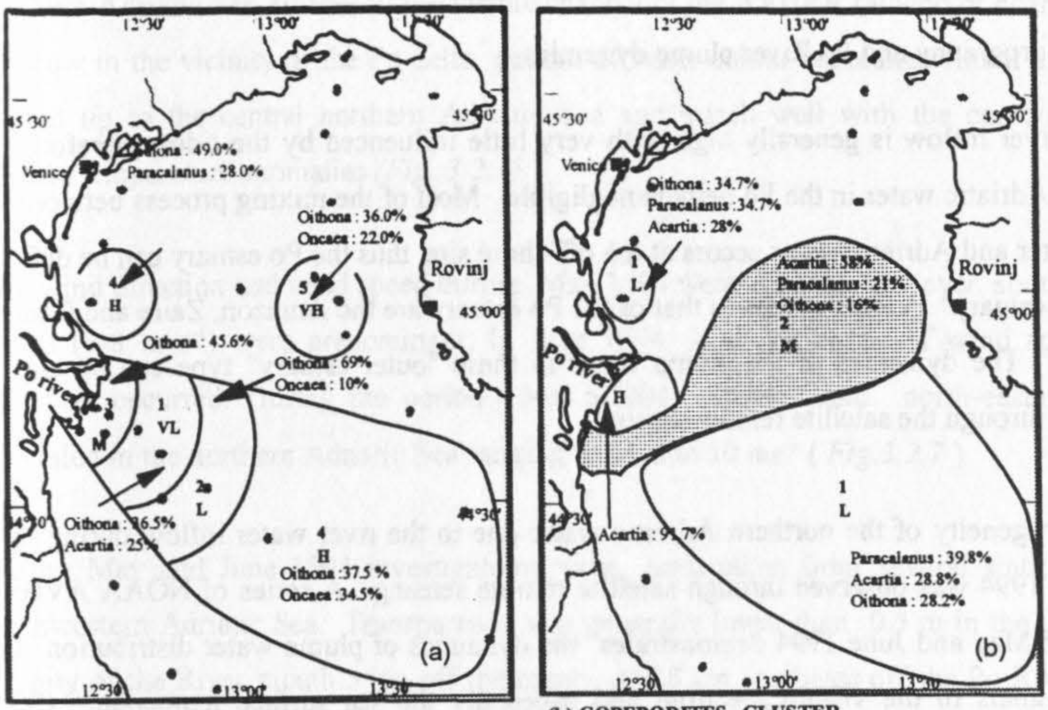
Cluster formation of copepods

Figure 3.12 shows the distribution of copepods and their development stages in the cluster formation during May 1993.

Nauplii : High abundances of nauplii were found in the Po River influenced water at Cluster 1 and 3 (eutrophic waters), dominated by *Acartia* (87%). The total nauplii concentration (> 100μm) ranged between 9700 ind m^{-3} to 15900 ind m^{-3} in this area. In the oligotrophic waters (Cluster 1), however, a low abundance of nauplii was found (on average 2700 ind.m^{-3}), mainly composed of *Acartia* (35.7%), *Oithona* (30%) and *Paracalamu*s or *Clausocalanus* (24.4%) *(Fig.3.1.11a).*

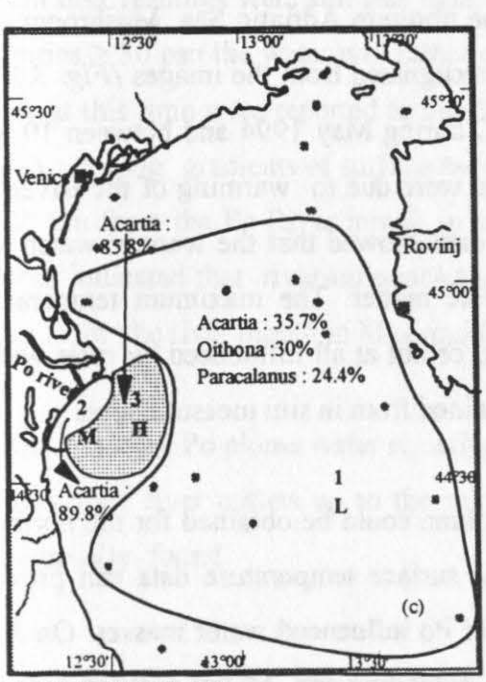
CI-CV (Copepodites) : Cluster 1 (oligotrophic waters) was characterized by high abundance of *Paracalanus parvus* (39.8%), *Acartia clausi* (28.8%) and *Oithona* spp. (28.2%) . The total abundance was 4200 ind m^{-3}. In the eutrophic water of the Po River plume (sub-cluster 3) the copepodite *Acartia clausi* (91.7% or 27000 ind m^{-3}) was dominant *(Fig.3.1.11b).*

CVI (Adults): Clusters 1, 3 and 5 were related to oligotrophic waters and were characterized by a high dominance of the carnivorous *Oncaea* spp.(37.5%) and *Oithona similis, O.nana* and *O.Plumifera.*(34.5%). Total mesozooplankton abundance reached values of more than 6000 ind.m^{-3}. The Sub-clusters 2 and 4 (eutrophic waters) were characterized by a low abundance of adult copepods (3000 ind. m^{-3}). *Oithona* spp. (41%) dominated in this area. *Paracalanus parvus* (28%) and *Acartia clausi* (25%) were also frequently appearing species in eutrophic waters of the plume *(Fig.3.1.11c).*



(a) ADULT COPEPOD CLUSTER

(b) COPEPODITES CLUSTER



(c) NAUPLII CLUSTER

(a) Adult copepods cluster :

1. Very low abundance (mean.2200 ind.m^{-3})
2. Low abundance (mean.2800 ind.m^{-3})
3. Moderate abundance (mean.3100ind.m^{-3})
4. High abundance (mean. 5000 ind.m^{-3})
5. Very high abundance (mean.6300ind.m^{-3})

(b) Copepodites cluster :

1. Low abundance (mean 4200 ind.m^{-3})
2. Moderate abundance (mean 10200 ind.m^{-3})
3. High abundance (mean 7000 ind.m^{-3})

(c) Nauplii cluster

1. Low abundance (mean 2700 ind.m^{-3})
2. Moderate abundance (mean 9700 ind.m^{-3})
3. High abundance (mean 15900 ind.m^{-3})

Figure 3.1.11. Projection map of cluster formation of adult copepods in the northern Adriatic Sea during May 1993. The percentage contribution of the dominant species is presented in every sub-cluster. (a) adult copepods, (b) copepodites and (c) nauplii.

3.2 Estuary processes

3.2.1 Hydrography and Po River plume dynamics

The Po river inflow is generally high with very little influenced by the tides, therefore the effect of Adriatic water in the Po delta is negligible. Most of the mixing process between Po River water and Adriatic water occurs at the off-shore site, thus the Po estuary can be defined as "outer estuary". A similar type to that of the Po estuary are the Amazon, Zaire and Danube estuaries. The dynamics of the plume water in these "outer estuary" type can be clearly observed through the satellite remote sensing.

The heterogeneity of the northern Adriatic water due to the river water inflow during May and June 1994 was observed through satellite remote sensing. A series of NOAA AVHRR images of May and June 1994 demonstrates the dynamics of plume water distribution. The pattern signals in the visible spectrum and especially the sea surface temperature (SST) anomalies very often reached the central part of the northern Adriatic Sea. Mushroom and filament-like patterns, repectively fronts, could be recognized from the images *(Fig. 3.2.1)*. The measured SST varied between 17 and 23 °C during May 1994 and between 19 and 25°C during June 1994. The temperature anomalies were due to warming of the River Po influenced water by solar radiation. Ground truth data showed that the warmer water was associated with lower salinity and higher particulate matter. The maximum temperature difference of water bodies which were more or less, or not at all influenced by river water, were 2°C, both calculated from satellite data and obtained from in situ measurements.

A series of NOAA-AVHRR images from 15 to 23 June could be obtained for the northern Adriatic Sea. This series shows to what extent sea surface temperature data can provide information on the variability and extension of River Po influenced water masses. On June 15 warmer water is distributed around the Po delta, extending app. 60 km east towards the central part of the northern Adriatic Sea. On June 17, warmer water masses can be recognized south of the Po delta and the warmer water observed on June 15 had been moved further east. In the eastern part of the Adriatic Sea the colder water body of the northern Mediterranean water can be seen. This water body has frequently observed during the cruises in this area as dark blue water of high tranparency which is clearly seperated from the River Po influenced waters. The successive images of June 19, 22 and 23 show the further extension of the Po influenced waters, which on June 22 apparently cover the whole northern Adriatic Sea. Images of the visible channel of the AVHRR (albedo of channel 1 and 2) show in the vicinity of the Po delta pattern of water colour anomalies which on June 18 extend up to the central northern Adriatic Sea and match well with the contours of sea surface temperature anomalies *(Fig. 3.2.1)*.

The wind direction and wind speed during May 1994 were variable, however, south-easterly winds (3-8 m s^{-1}) were predominant. In June 1994 high variations of wind speed and direction occurred. During the period 10-20.6.1994, easterly and north-easterly winds prevailed in the northern Adriatic Sea ranging from 5 to 10 ms^{-1} (*Fig.3.2.2*).

During May and June 1994 investigations were undertaken from several stations in the northwestern Adriatic Sea. Transparency was generally lower than 0.5 m in the immediate vicinity of the River mouth 5 km off the coast. At 18 km southeast off the Po River mouth secchi disk readings were still less than 2 m. At "offshore stations" (> 25 km) with surface salinities > 30 psu the water was rather clear (secchi depth > 6 m). The flow rates of the Po River at this time were reported to be 1970 m^3s^{-1} in May and 1860 m^3s^{-1} in June (RAICICH , 1994). Strong gradients of surface salinity (4 - 32 psu) were observed within the distance of 20 km from the Po River mouth in southeastern direction. The salinity values near the bottom indicated that river-influenced salinity anomalies were only detectable up to 18 km away from the river mouth in May and June 1994 (*Fig.3.2.3*).

In this work the Po plume water is defined in relation to the salinity gradient from the lowest salinity near river outlets up to the salinity 26-27 psu, where the main river plume fronts were usually found.

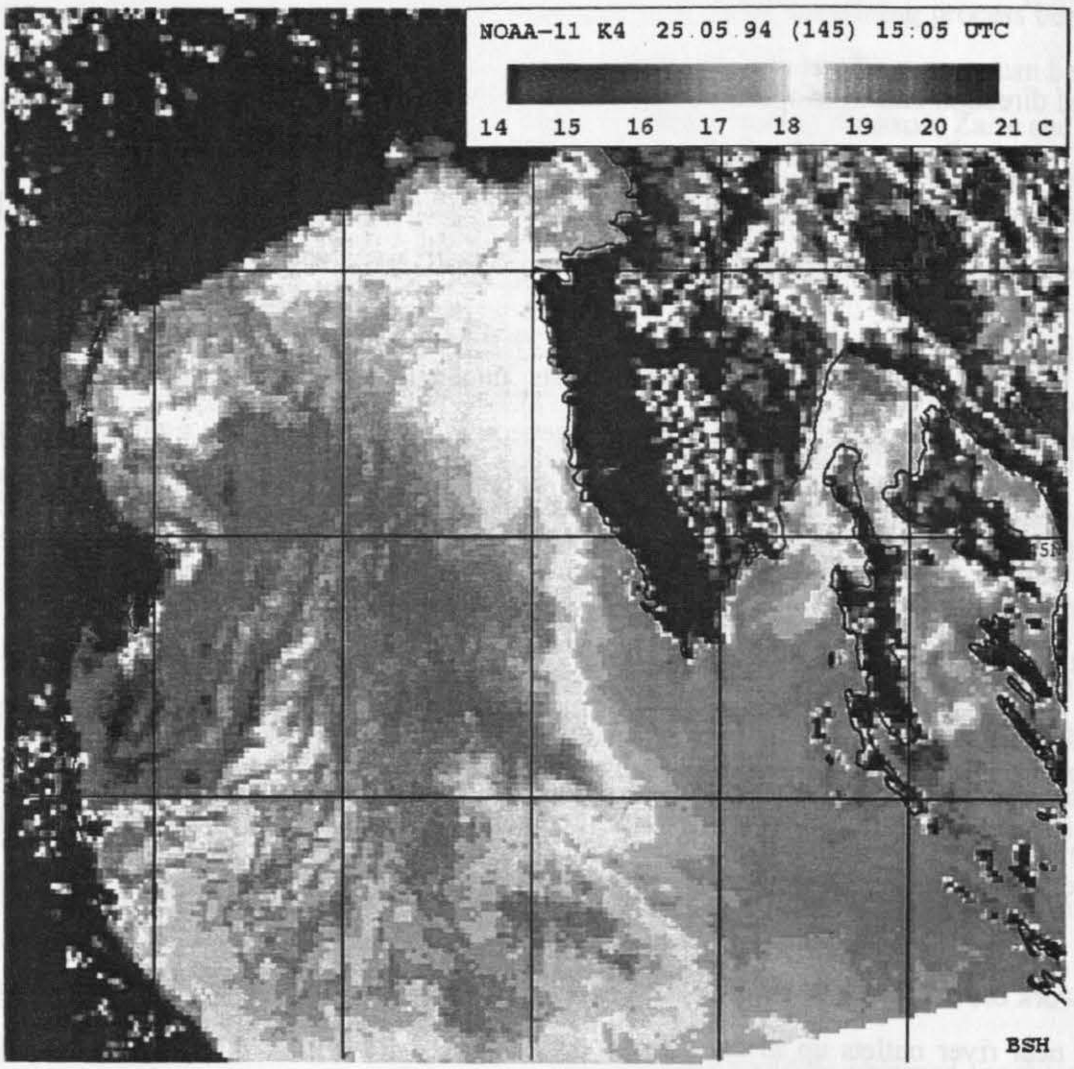


Figure 3.2.1a. The sea surface temperature (SST) image derived from NOAA-AVHRR in the northern Adriatic Sea on 23.05. 1994.

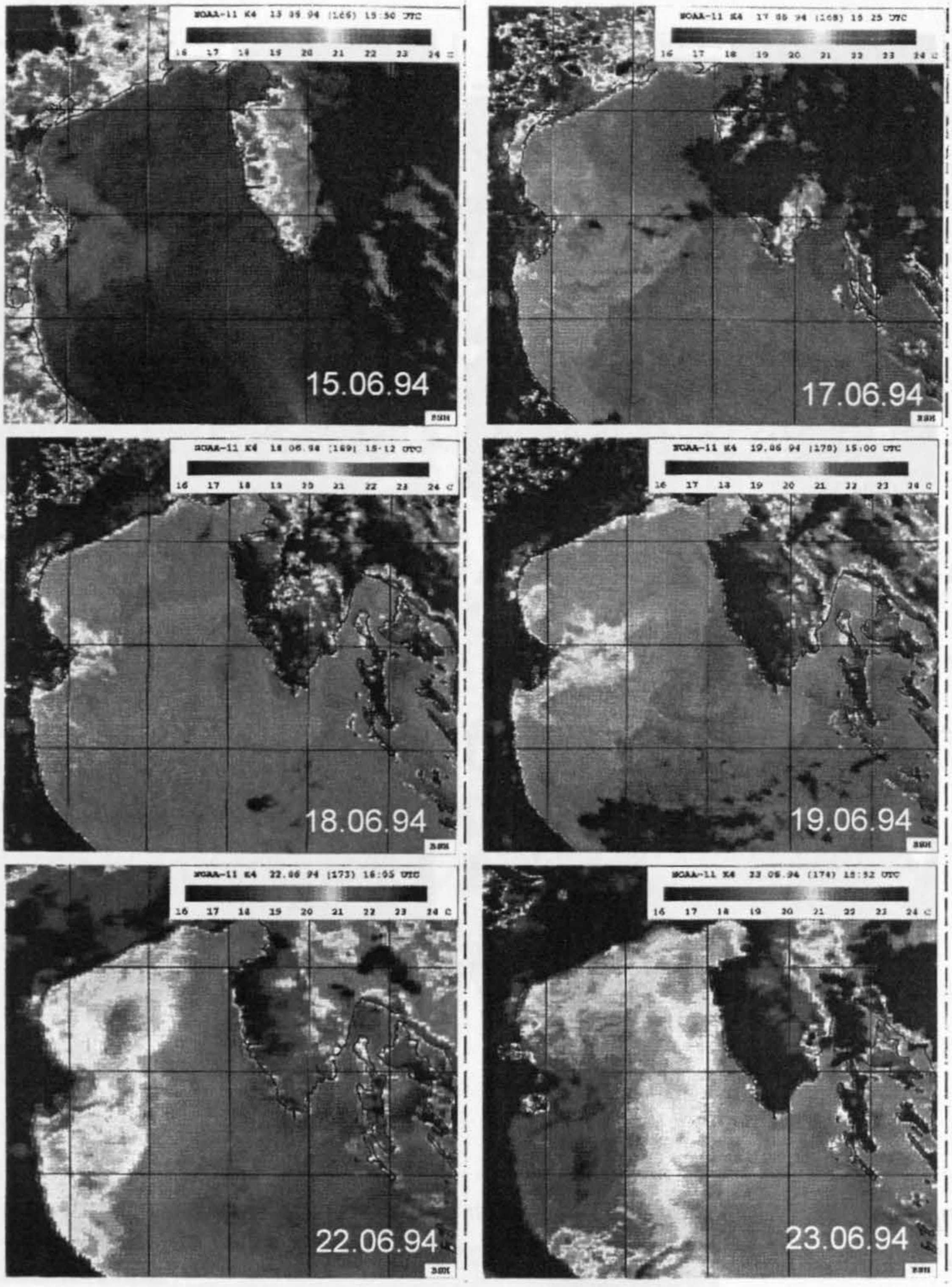


Figure 3.2.1b. Sequence of consecutive sea surface temperature (SST) images of the northern Adriatic Sea during June 1994 derived from NOAA-AVHRR.

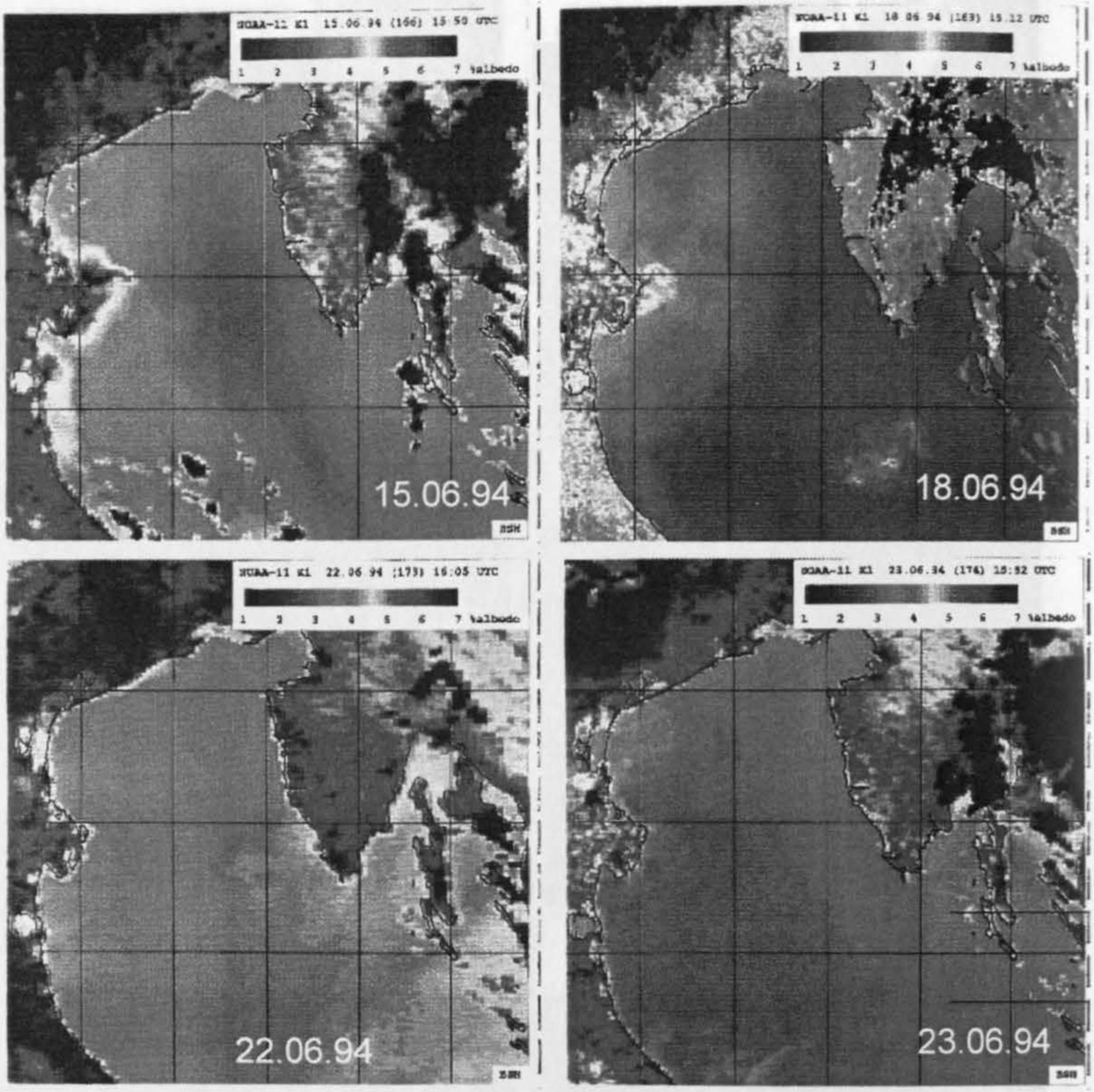


Figure 3.2.1c. Sequence of consecutive water colour images of the northern Adriatic Sea during June 1994 derived from NOAA-AVHRR.

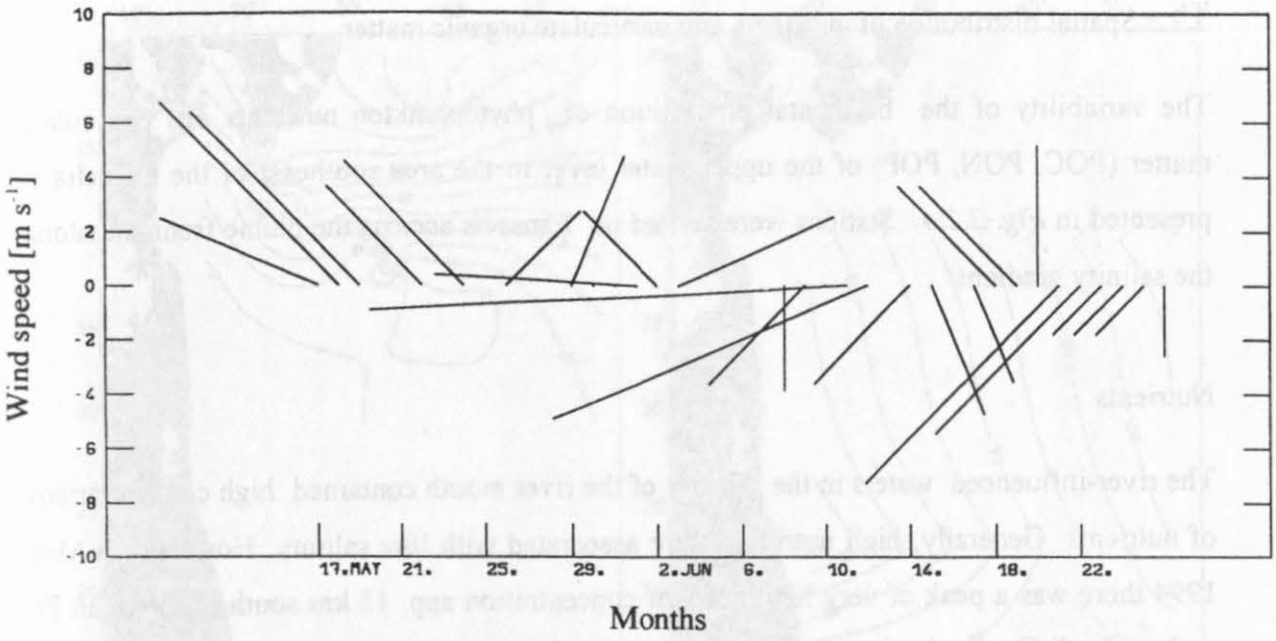
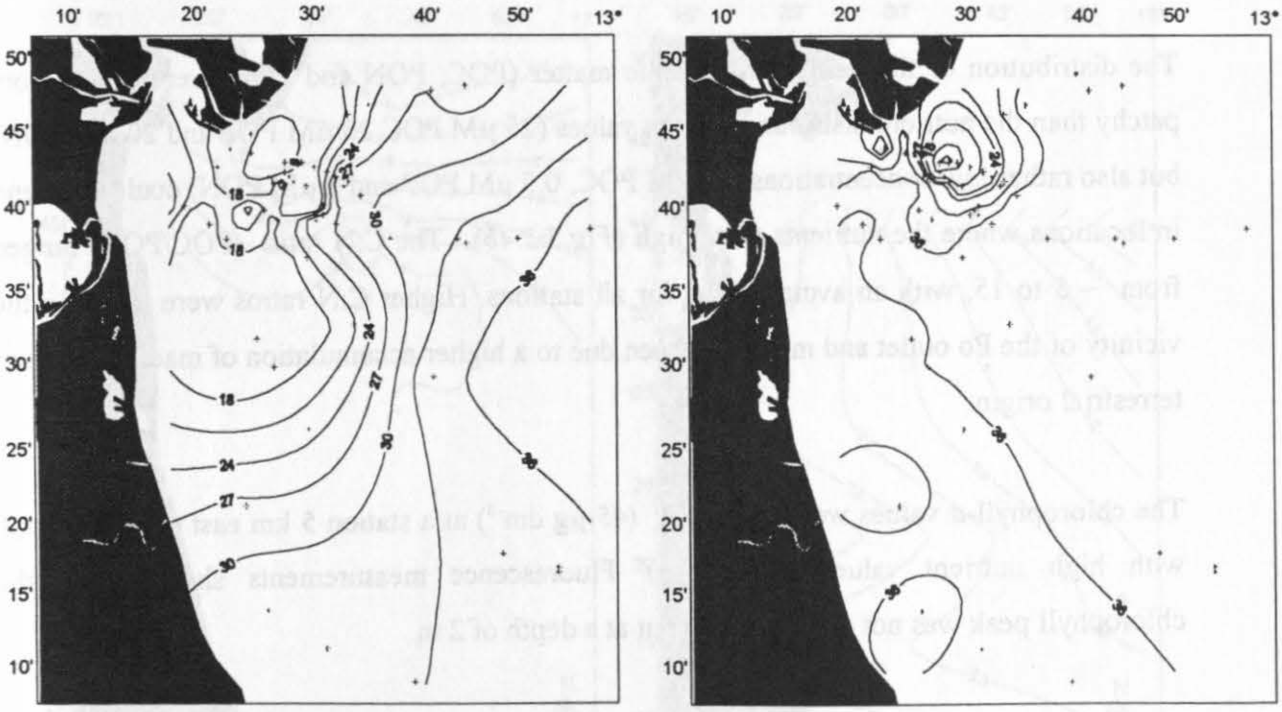


Figure 3.2.2 Daily means of wind speed and direction during May and June 1994 in the northern Adriatic Sea.



(a) Surface salinity

(b) Bottom salinity

Figure 3.2.3. Distribution of surface and bottom salinity in the coastal plume of the Po Estuary in the north-western Adriatic Sea during May and June 1994.

3.2.2 Spatial distribution of nutrients and particulate organic matter

The variability of the horizontal distribution of phytoplankton nutrients and particulate matter (POC, PON, POP) of the upper water layer in the area southeast of the Po delta is presented in *Fig. 3.2.4*. Stations were visited on transects accross the plume front and along the salinity gradient.

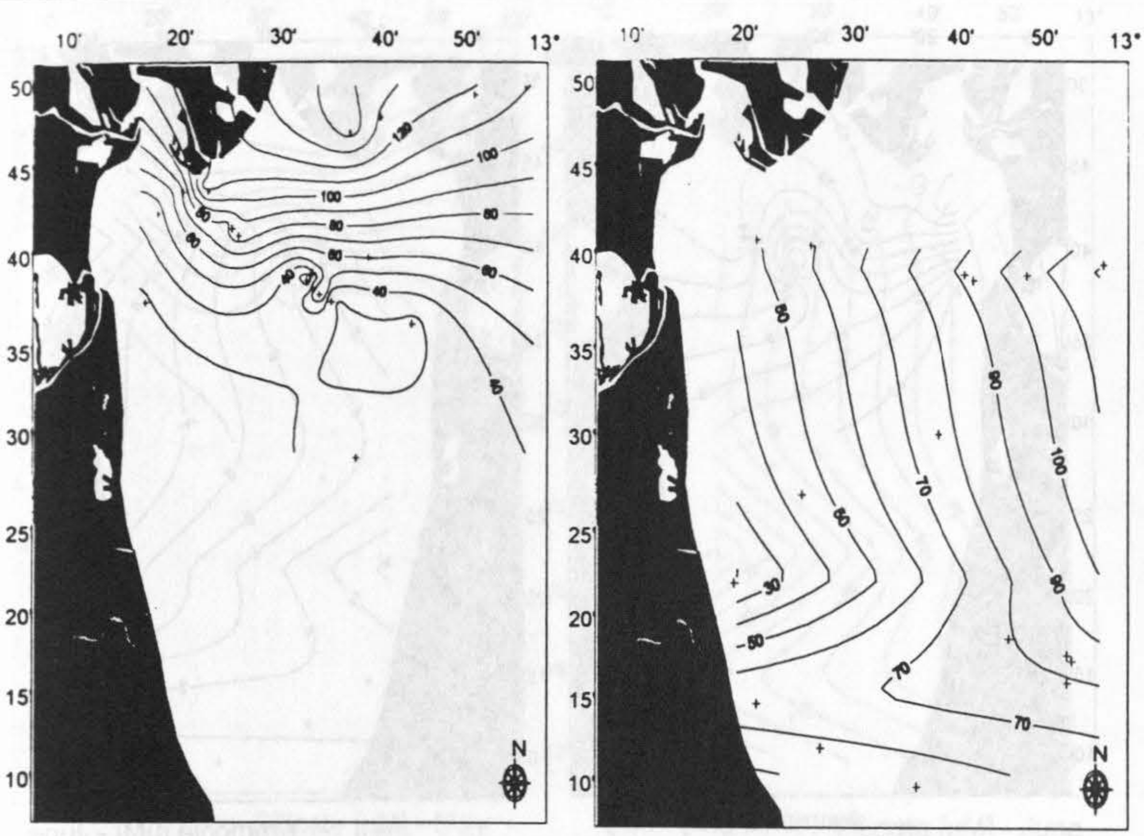
Nutrients

The river-influenced waters in the vicinity of the river mouth contained high concentrations of nutrients. Generally, high nutrients were associated with low salinity. However, in May 1994 there was a peak of very high nutrient concentration app. 15 km south of the main Po outlet (Po di Gnocca) . It was repeatedly observed that the phosphate values decrease much more rapidly than the other nutrients with distance from the peak (*Fig. 3.2.4*a).

Particulate organic matter and chlorophyll-*a*

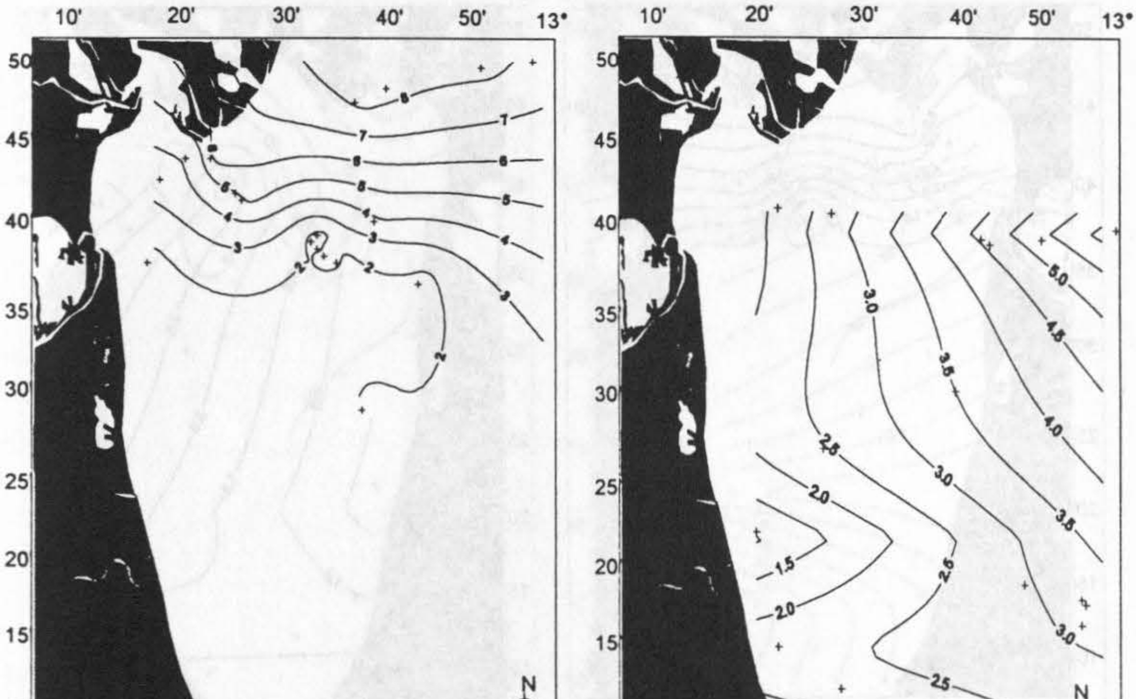
The distribution of the particulate organic matter (POC, PON and POP) were much more patchy than the nutrient distribution. High values (25 µM POC,30 µM POP and 20 µM PON) but also rather low concentrations (25 µM POC, 0.5 µM POP and 8 µM PON) could be found in locations where the nutrients were high (*Fig.3.2.4b*). The C:N ratio (POC/PON) ranged from ~ 5 to 15, with an average of 9 for all stations. Higher C:N ratios were found in the vicinity of the Po outlet and may have been due to a higher accumulation of macrodetritus of terrestrial origin.

The chlorophyll-*a* values were very high (45 µg dm^{-3}) at a station 5 km east of the location with high nutrient values (*Fig.3.2.4c*). Fluorescence measurements showed that the chlorophyll peak was not at the surface but at a depth of 2 m.



Nitrate [µM] - May

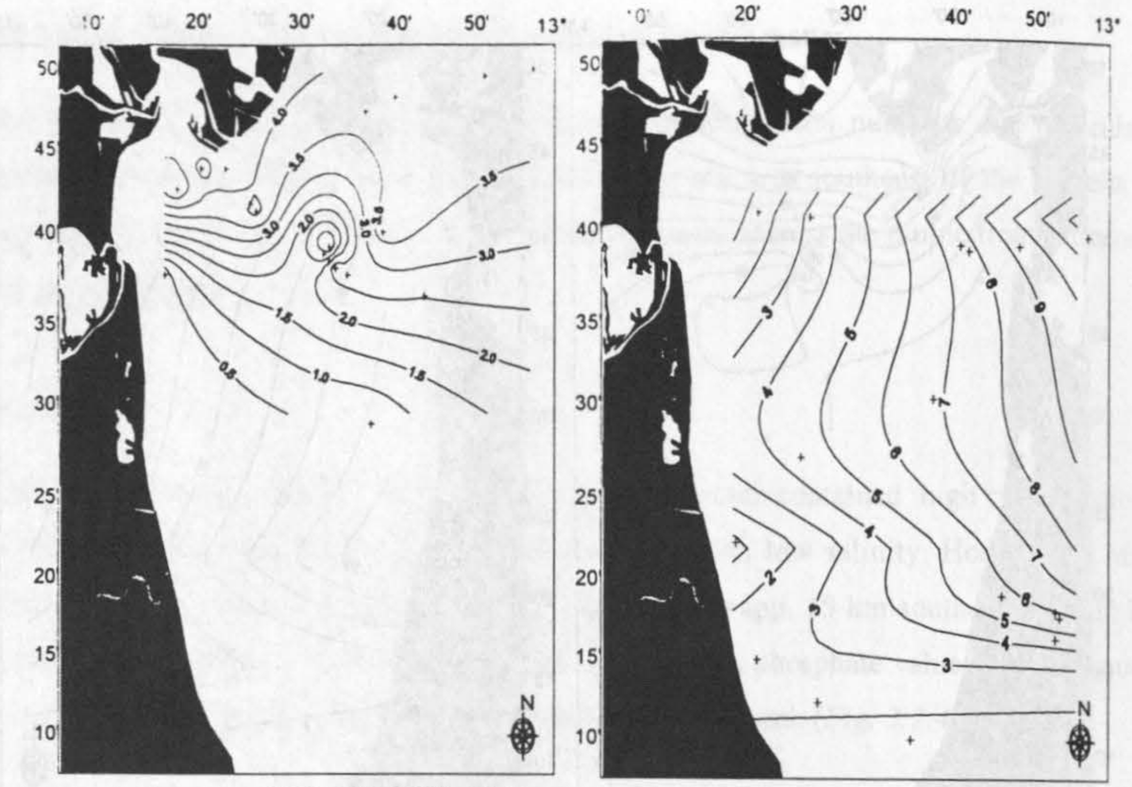
Nitrate [µM] - June



Nitrite [µM] - May

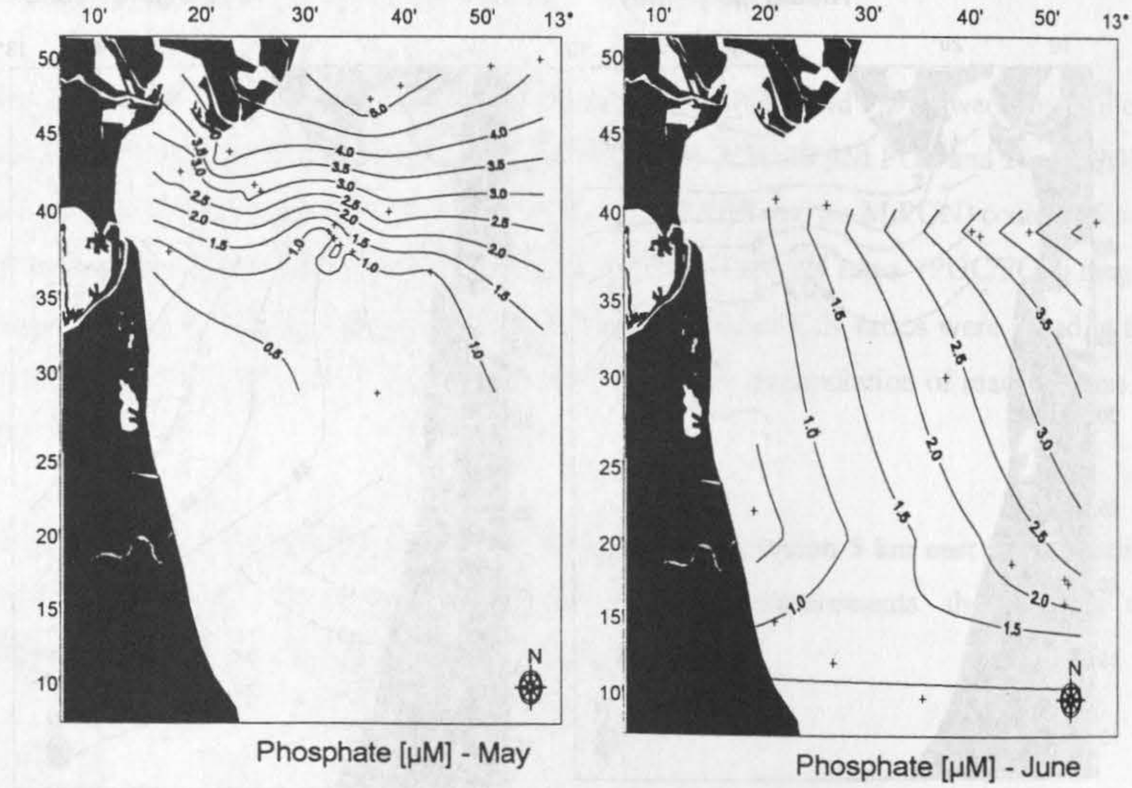
Nitrite [µM] - June

Figure 3.2.4a. Spatial distribution of dissolved nutients [µM] in the coastal plume of the Po estuary in the northern Adriatic Sea during May and June 1994: nitrate and nitrite.



Ammonia [µM] - May

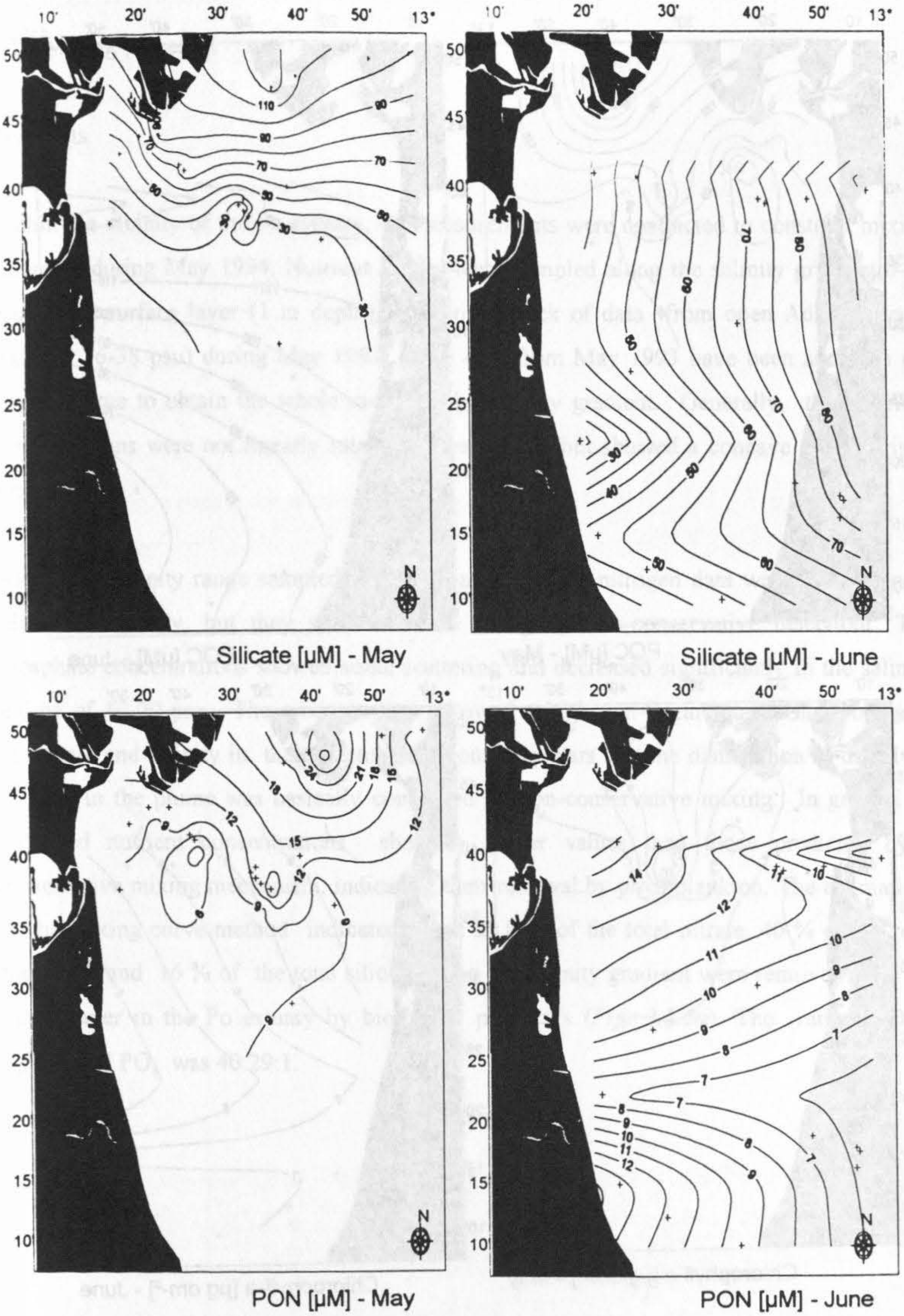
Ammonia [µM] - June



Phosphate [µM] - May

Phosphate [µM] - June

Figure 3.2.4b. Spatial distribution of dissolved nutrients [µM] in the coastal plume of the Po estuary in the northern Adriatic Sea during May and June 1994: ammonia and phosphate.



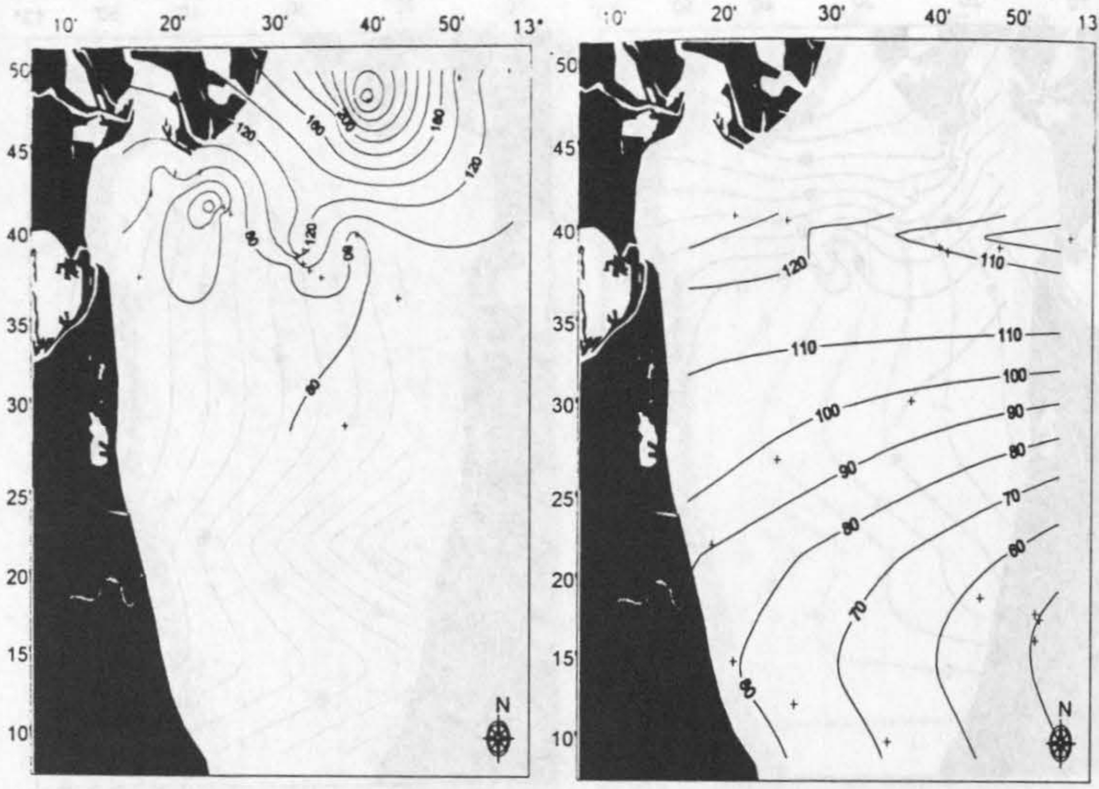
Silicate [µM] - May

Silicate [µM] - June

PON [µM] - May

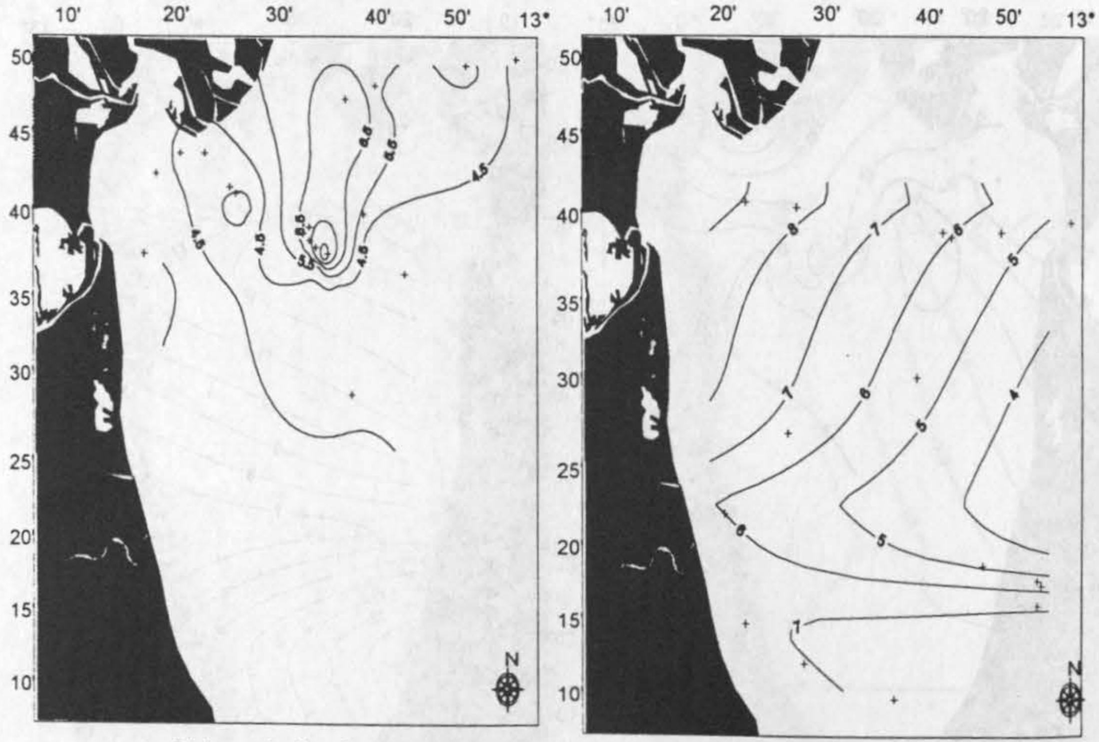
PON [µM] - June

Figure 3.2.4c. Spatial distribution of dissolved nutrients and [µM] particulate organic carbon [µM] in the coastal plume of the Po estuary in the northern Adriatic Sea during May and June 1994: silicate and particulate organic nitrogen (PON).



POC [µM] - May

POC [µM] - June



Chlorophyll-a [µg dm-³] - May

Chlorophyll-a [µg dm-³] - June

Figure 3.2.4d. Spatial distribution of particulate organic carbon [μM] and chlorophyll-a [μg dm^{-3}] nitrogen [μM] in the coastal plume of the Po estuary in the northern Adriatic Sea during May and June 1994.

3.2.3 Mixing processes

Nutrients

Within the vicinity of the Po estuary, 40 measurements were conducted to construct mixing diagrams during May 1994. Nutrient values were sampled along the salinity gradient 0-37 psu in the surface layer (1 m depth). Due to the lack of data from open Adriatic water (salinity 36-38 psu) during May 1994, some data from May 1993 have been added to the mixing curve to obtain the whole range of the salinity gradient. Generally, the nutrient concentrations were not linearly related to the salinity but showed a concave characteristic during May.

Within the salinity range sampled during May 1994, the nitrogen data were almost linear related to salinity, but they still indicated a slightly non-conservative behaviour. The phosphate concentrations showed some scattering and decreased significantly in the salinity regime of 10-20 psu. The mixing curve showed a high non-linear relationship between phosphate and salinity in the Po estuary region. It appears that the distribution of dissolved silicate in the plume was basically controlled by non-conservative mixing. In general all dissolved nutrient concentrations showed lower values than those predicted by a conservative mixing mechanism, indicating their removal by phytoplankton. The estimations by the mixing curve method indicated about 20.8 % of the total nitrate, 40 % of the total phosphate and 16 % of the total silicate along the salinity gradient were removed from the mixed layer in the Po estuary by biological processes (*Fig. 3.2.5a*). The ratio of DIN, H_4SiO_4 and PO_4 was 40:29:1.

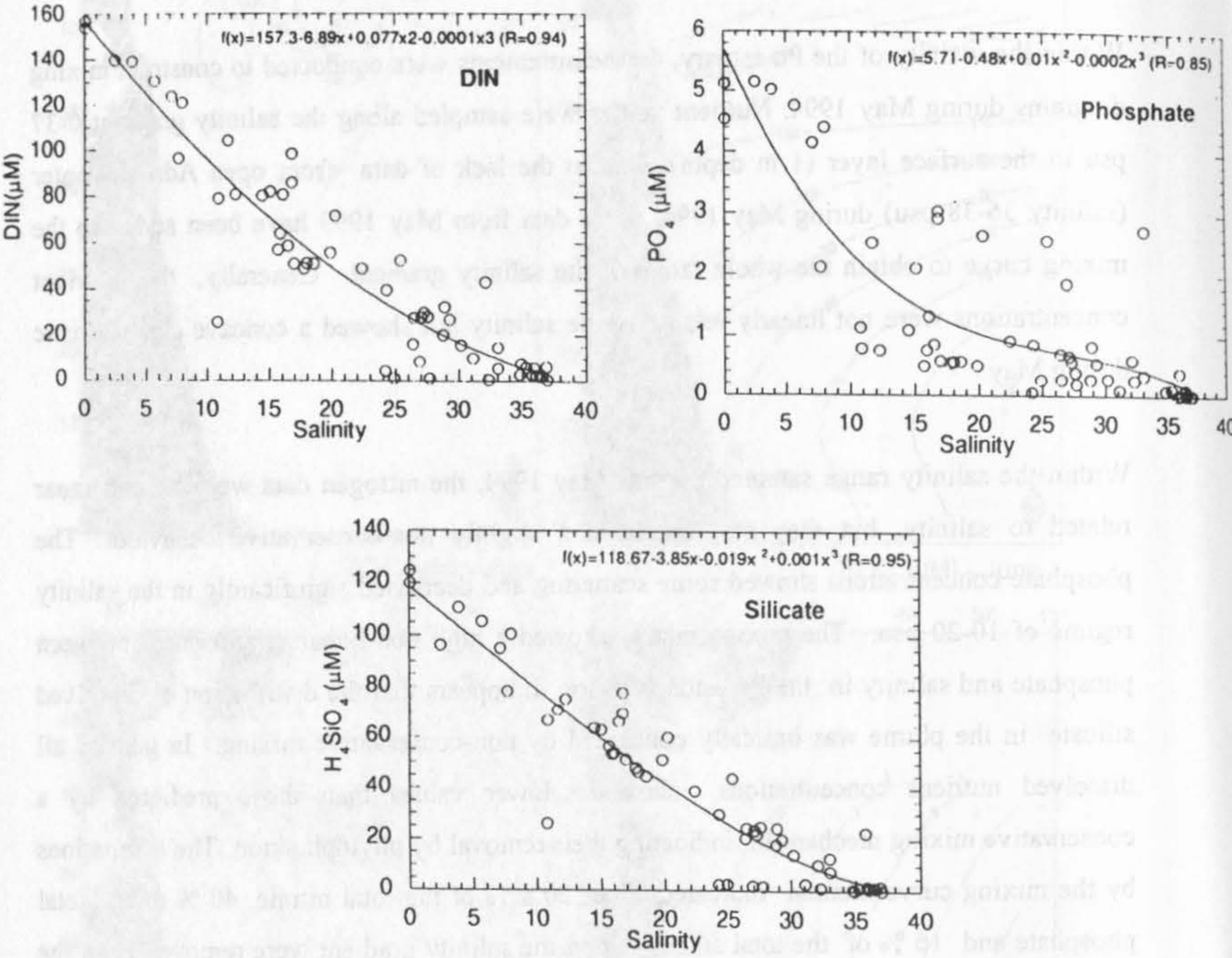


Figure 3.2.5a. Mixing curve for dissolved nutrients (DIN = dissolved inorganic nitrogen, phosphate and silicate) from the Po River mouth to the open Adriatic Sea during May 1994. The curves were fitted by third order polynomial interpolation.

Particulate organic matter and chlorophyll-*a*

The calculated mixing curves of particulate organic matter show a convex relationship suggesting the addition of particulate organic matter in the estuary during the mixing process. The highest values were found at higher salinities (25-35 psu) while the highest removal of nutrients were found in lower salinity regime (10-25 psu). Generally PON did not accumulate during fresh mixing in the vicinity of the Po outlets (*Fig.3.2.5b*). The highest phytoplankton biomass as measured by chlorophyll a was found in a salinity range of 20-30 psu . The ratio of POC/Chl-*a* was 40:1.

Quantitative phytoplankton counts in the vicinity of the Po estuary were difficult due to a lot of detritus components. An example of phytoplankton standing stock representing in the situation in May 1994 at the station 6 (secchi depth ~ 1m, salinity 25.4 psu) is given in *Tab. 3.2.1.*

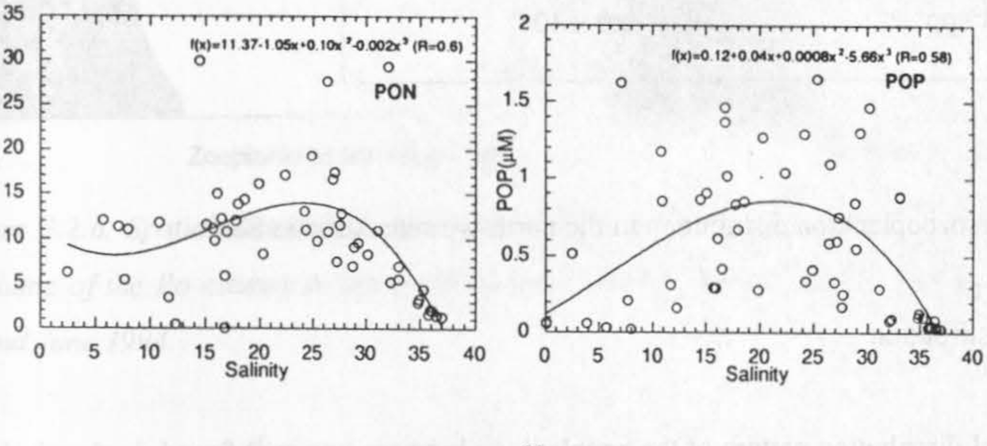


Figure 3.2.5b. Mixing curves for particulate organic nitrogen (PON) and particulate organic nigrogen (POP), particulate organic carbon (POC) and chlorophyll-a from the Po River mouth to the open Adriatic Sea during May 1994. The curves were fitted by third order polynomial interpolation.

Table 3.2.1 Phytoplankton standing stocks at station 6 in the vicinity of the Po estuary.

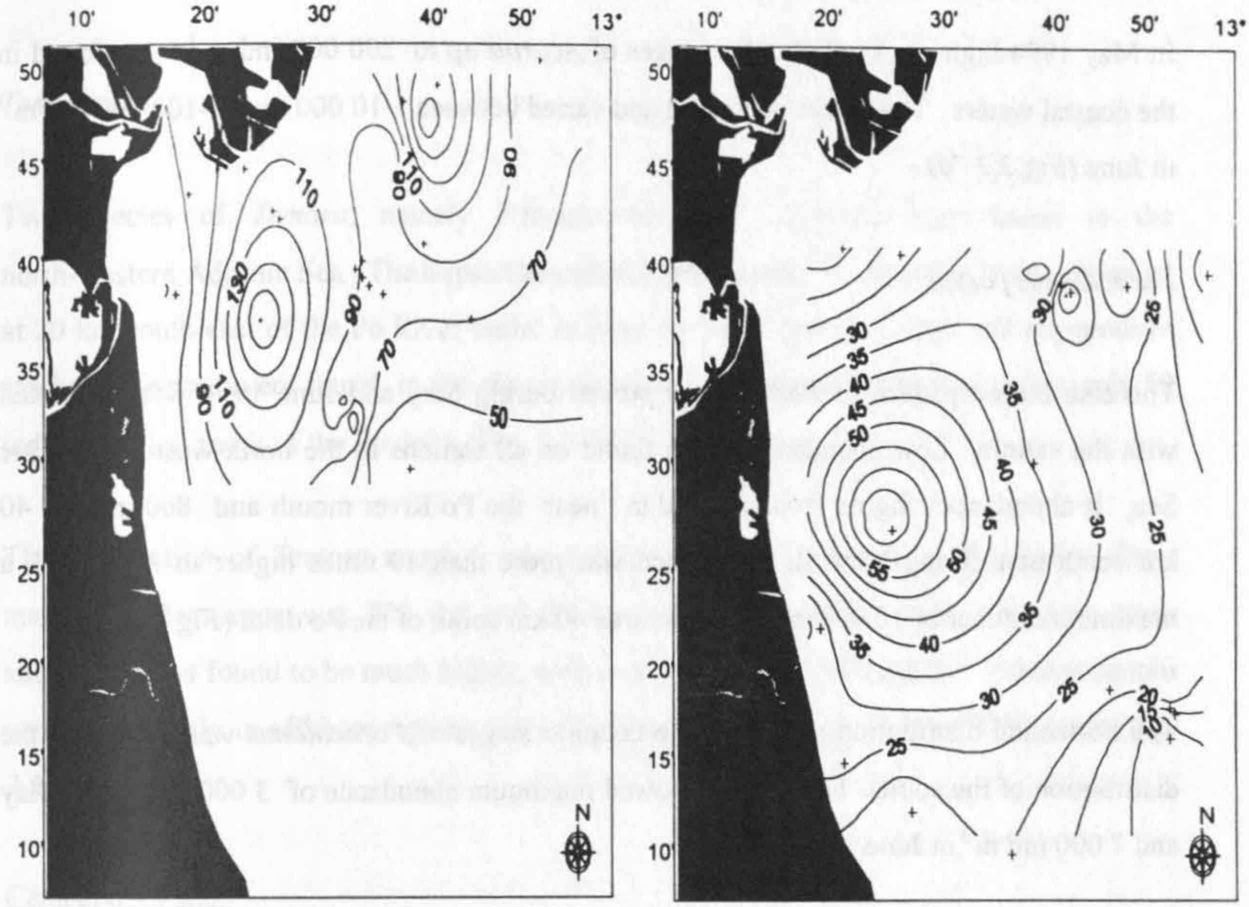
Species	number (cells dm^{-3})
Rhisozolenia alata	3.8×10^3
Thalassionema nitzschioides	2.0×10^2
Cerataulina bergonii	2.0×10^2
Guinardia spp.	2.0×10^2
Rhizosolenia fragilissima	2.0×10^2
Flagellates 0-3 μm	4.7×10^6
Flagellates 3-6 μm	1.1×10^6
Flagellates 6-9 μm	4.1×10^5
Ceratium cf. furca	7.0×10^2
Prorocentrum micans	6.0×10^2
Ceratium tripos	2.0×10^2
Ceratium fusus	1.5×10^2
Hemiaulax cf. hauckii	3.0×10^2
Goyaulax spp.	2.0×10^2

3.2.4 Mesozooplankton distribution in the north-western Adriatic Sea

Spatial distribution

The spatial distribution pattern of the zooplankton biomass (mg m^{-3}) found in the vicinity of Po estuary showed a strong horizontal variability. High concentration of zooplankton biomass (160 mg m^{-3}) occurred off the mouth of the River Po. In June 1994, the zooplankton biomass was found to be lower (25-50 mg m^{-3}) in the area south and south-east of the Po delta. A decreasing gradient in biomass offshore was observed. River inflows from the region Emilia Romagna (Fiume Unity and Fiume Savio) possibly enhanced zooplankton biomass leading to a peak 80 km south of the Po delta *(Fig. 3.2.6)*.

The horizontal distribution patterns of zooplankton abundance (copepodites CI-CVI, nauplii, Cladocera and others) within the upper layer during May and June 1994 in the north-western Adriatic Sea is presented in *Fig. 3.2.7*.



Zooplankton dry weight (May)

Zooplankton dry weight (June)

Figure 3.2.6. Spatial distribution of mesozooplankton dry weight [mg m^{-3}] in the coastal plume of the Po estuary in the north-western Adriatic Sea off the Po delta during May and June 1994.

(1) Copepods

Acartia clausi.

Only one species of *Acartia* spp. was found in the north-western Adriatic Sea. The distribution pattern of *Acartia* was related to phytoplankton-rich water. In May its abundance increased from the River Po mouth to 50 km further south-east located station (5 000 to 25 000 ind.m^{-3}). In June a very high population of *Acartia clausi* (30 000 ind.m^{-3}) could be found only 15 km south of the Po River outlet at a station with a very high phytoplankton standing stock.

In May 1994 high stocks of naupliar stages of *Acartia* up to 200 000 ind m^{-3} were found in the coastal waters . The stocks decreased and varied between ~10 000 and ~100 000 ind m^{-3} in June *(Fig.3.2.7a)*.

Paracalanus parvus

The distribution pattern of *Paracalanus parvus* during May and June 1994 was correlated with the salinity. Low abundances were found on all stations in the north-western Adriatic Sea, It abundance ranging from 100 ind.m^{-3} near the Po River mouth and 800 ind m^{-3} 40 km south-east during May. Its abundance was more than 10 times higher in June, with a maximum number of 10 000 ind m^{-3} in an area 40 km south of the Po delta *(Fig. 3.2.7b)*.

The horizontal distribution pattern of the naupliar stages of *Paracalanus* was similar to the distribution of the adults. The nauplii showed maximum abundance of 3 000 ind m^{-3} in May and 7 000 ind m^{-3} in June 1994.

Oithona spp.

This rather small cyclopoid copepod is represented in the north-western Adriatic Sea by three species *O.similis*, *O.plumifera* and *O.nana*. *O.similis* was found to be the most dominant species (60 %) in the northern Adriatic Sea during May and June. The occurrence of *Oithona* was similar to the distribution of *Clausocalanus* in May, however, an additional occurence was found a few km south of the southern branch of the Po delta (Po di Goro). A maximum number of 4 000 ind m^{-3} could be observed in May and 3 000 ind m^{-3} in June 1994 *(Fig.3.2.7c)*.

The distribution pattern of the naupliar stages of *Oithona* spp. matched that of the older stages CI-CV. Highest values of nauplii abundance occurred at medium salinities (20-30 psu). Nearly no stocks were present at the coastal sites during May. A lower number of nauplii was recorded in the northern part of the observation area during June 1994 *(Fig.3.2.7c)*.

Temora spp.

Two species of *Temora*, namely *T.longicornis* and *T.stylifera* were found in the north-western Adriatic Sea . The highest abundance (maximum : 2 000 ind m^{-3}) was observed at 20 km south-east of the Po River outlet in May. In June, lower of adult and copepodites stocks of *Temora* were found in the observation area. Its maximum abundance was only 50 ind m^{-3} 60 km south of the Po delta *(Fig. 3.2.7d)*.

The distribution of *Temora* nauplii was similar to the distribution of the adults. Their maximum abundance was 800 ind m^{-3} 25 km south-east the Po delta. In June, their abundance was found to be much higher, with a maximum of 7 000 ind m^{-3}. *Temora* nauplii were found only in offshore regions with a minimum distance of 40 km off the coast (*Fig. 3.2.7d*).

Centropages spp.

Two species of *Centropages* (*C.typicus* and *C.kröyer*) were found in the north-western Adriatic Sea. *C.typicus* was mostly caught during May. An abundance peak (300 ind m^{-3}) was observed at a 60 km south-east located station (*Fig.3.2.7e*).

The horizontal distribution pattern of *Centropages* nauplii was related to that of the older stages CI-CVI, and their maximum occurrence (200 ind m^{-3}) was found closer to the Po delta at a station 50 km south-east from the Po River outlet during May. In June their stock reached a maximum (~ 2 000 ind m^{-3}) at a station 80 km south from the southern branch of the Po River (Podi Goro) (*Fig.3.2.7e*).

Oncaea spp.

Two species of the genus *Oncaea* (*O.media* and *O.subtilis.*) were found in the northern Adriatic Sea. An extremely low abundance was observed during May in the vicinity of Po estuary in a radius of 40 km from the Po delta. The highest abundance was found 60 km south-east in May and 60 km south during June 1994 (max: 50 ind m^{-3}). Significant stocks of naupliar stages of *Oncaea* spp. (100 ind m^{-3}) were present in the south-east of the observation area during June *(Fig.3.2.7f)*.

Clausocalanus spp.

The genus of *Clausocalanus* in the Adriatic Sea consists of *C. arcuicornis*, *C.jobei* and *C.furcatus*. Only minor abundances were found during May and June. All 3 species together showed a maximum abundance of 150 ind m^{-3} 30 km south-east of the Po delta in May and of 80 ind m^{-3} 15 km south off the Po River outlet in June 1994 *(Fig.3.2.7g)*.

Corycaeus spp.

This cyclopoid copepod was found 60 km south-east from the Po River outlet during May (80 ind m^{-3}). During June no specimens of this species could be observed in the north-western Adriatic Sea *(Fig.3.2.7g)*.

(2) Cladocera

Three genera of Cladocera (*Podon* spp, *Evadne* spp and *Penilia avirostris*) were found in the northern Adriatic Sea. Their number and distribution pattern was different.

A peak abundance of *Podon* spp.(14 000 ind.m^{-3}) was observed 30 km south from the southern branch of the Po River outlet (Po di Goro) in May 1994. In June, its highest abundance was found at the coastal site of Emilia Romagna with decreasing numbers eastward.

The distribution pattern of *Evadne* spp. showed two peaks (80 ind m^{-3}) at stations located app. 25 km south-east from the Po River outlet in May 1994. In June, an increase of the abundance of *Evadne* was found app. 50 km off the coast of the Emilia Romagna (> 1000 ind m^{-3}) *(Fig.3.2.7h)*.

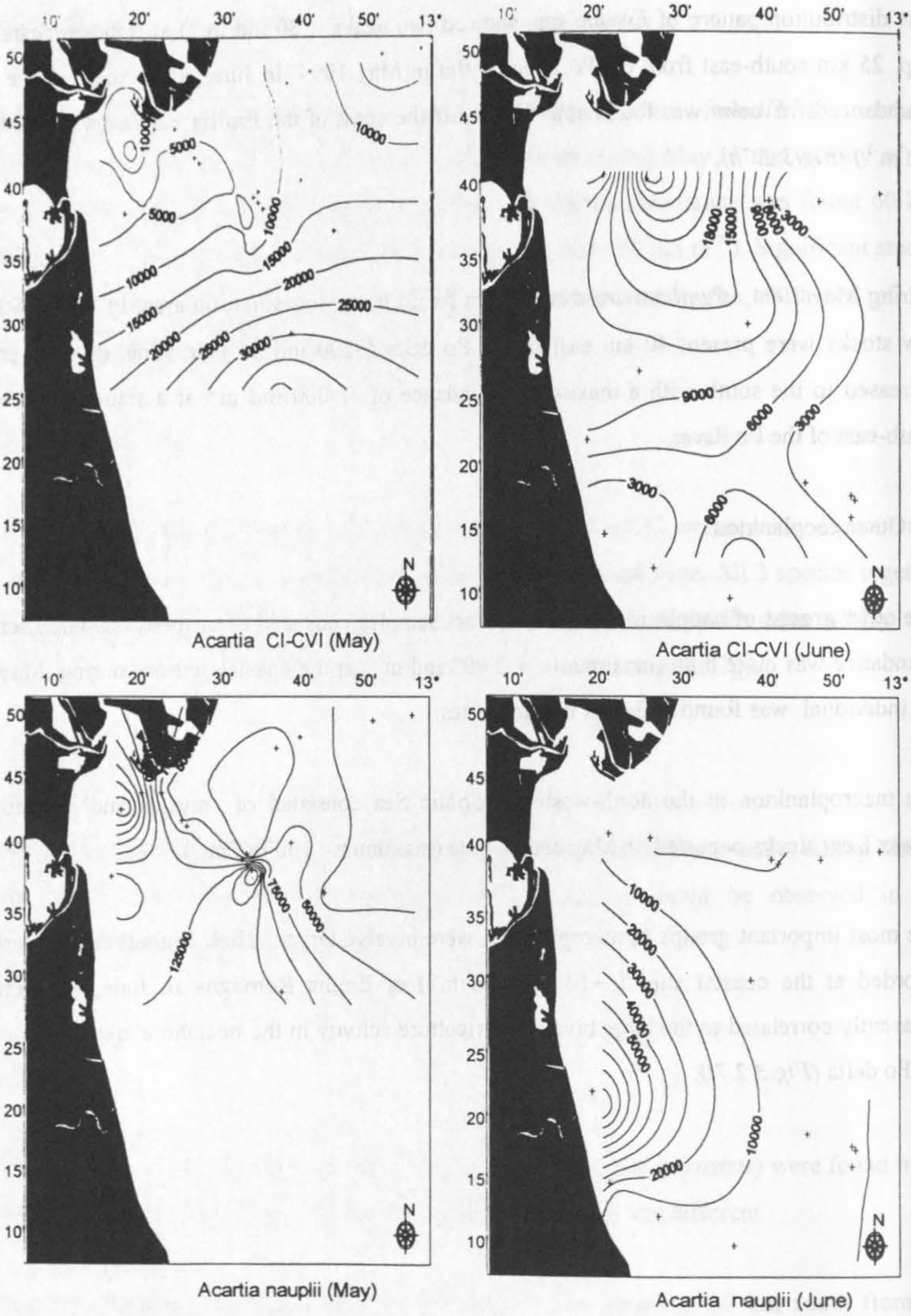
During May 1994, *Penilia avirostris* was not found in the investigation area. In May 1993, low stocks were present 40 km east of the Po delta (~200 ind m^{-3}). In June, its numbers increased to the south with a maximum abundance of 1 000 ind m^{-3} at a station 100 km south-east of the Po River.

(3) Other zooplankton

The other groups of nauplii identified in the net samples consisted of ciripeds nauplii. Their abundance was quite high (maximum : ~ 2 000 ind m^{-3}) at the coastal stations during May. No individual was found at further offshore sites.

The macroplankton in the north-western Adriatic Sea consisted of mysids and penaeids larvae. Low stocks occurred in May and in June (maximum : 100 ind m^{-3}).

The most important groups of meroplankton were bivalve larvae. Their highest stocks were recorded at the coastal sites (~10 000 ind m^{-3}) of Emilia Romagna in June and were apparently correlated to the large bivalve mariculture activity in the nearshore areas south of the Po delta *(Fig.3.2.7i)*.



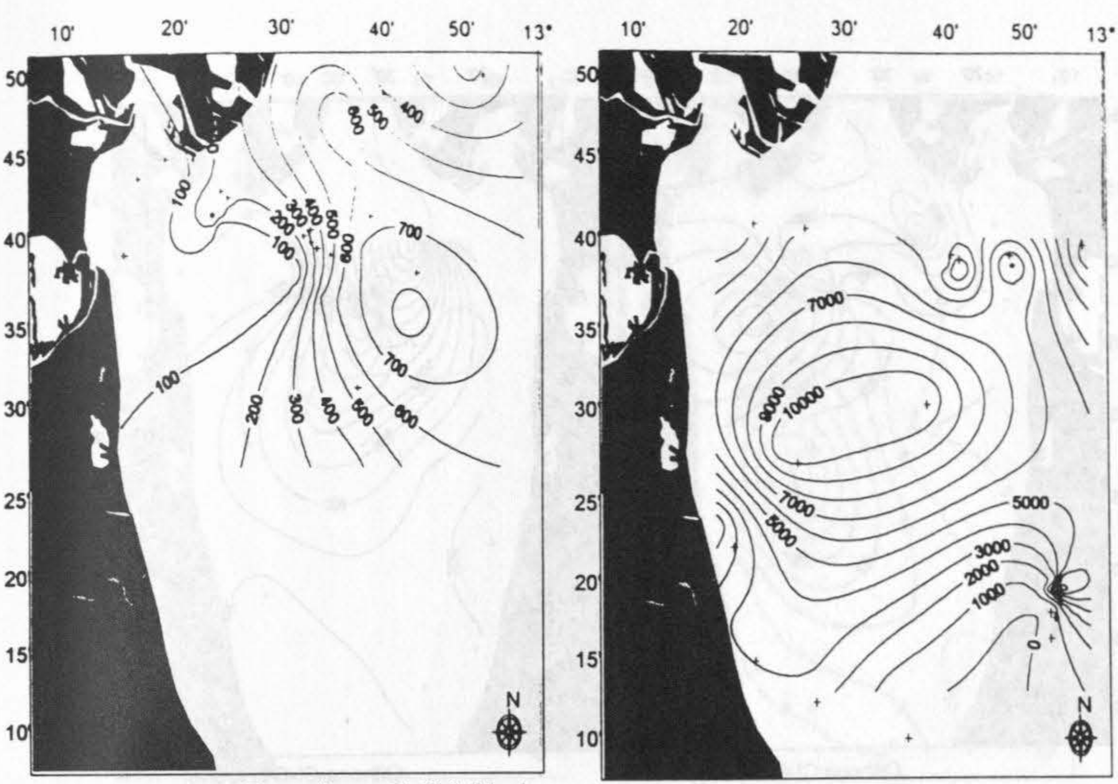
Acartia CI-CVI (May)

Acartia CI-CVI (June)

Acartia nauplii (May)

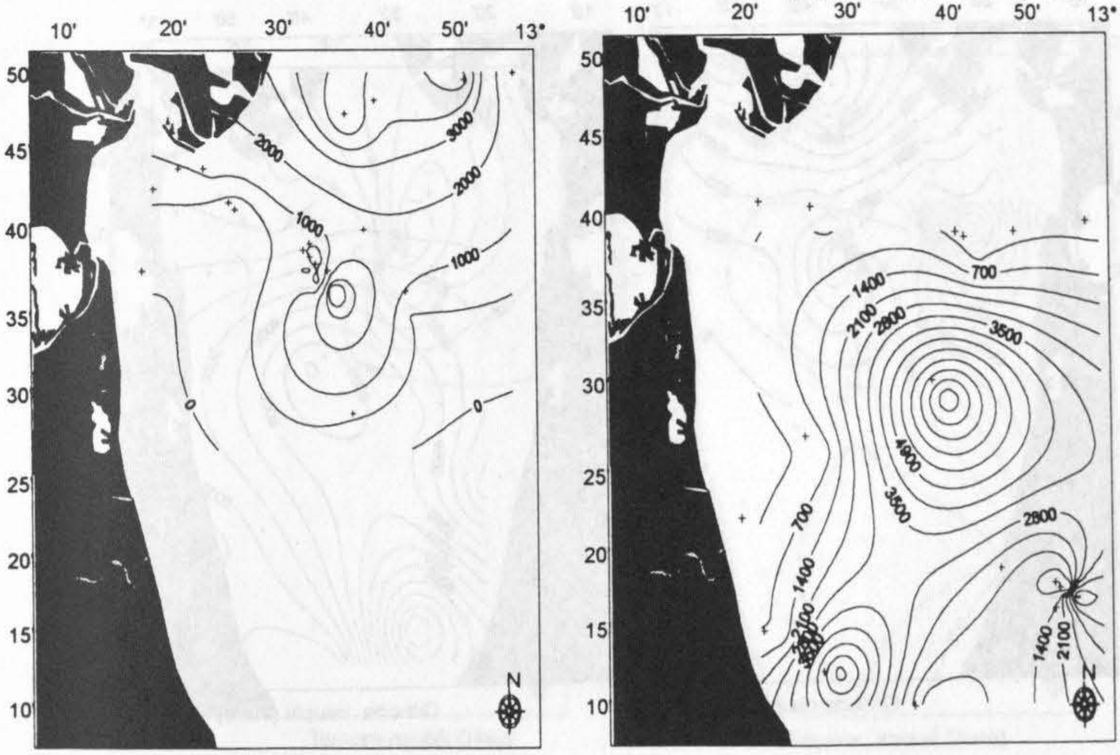
Acartia nauplii (June)

Figure 3.2.7a. Spatial distribution of abundance [ind m^{-3}] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Acartia clausi****.*



Paracalanus CI-CVI (May)

Paracalanus CI-CVI (June)



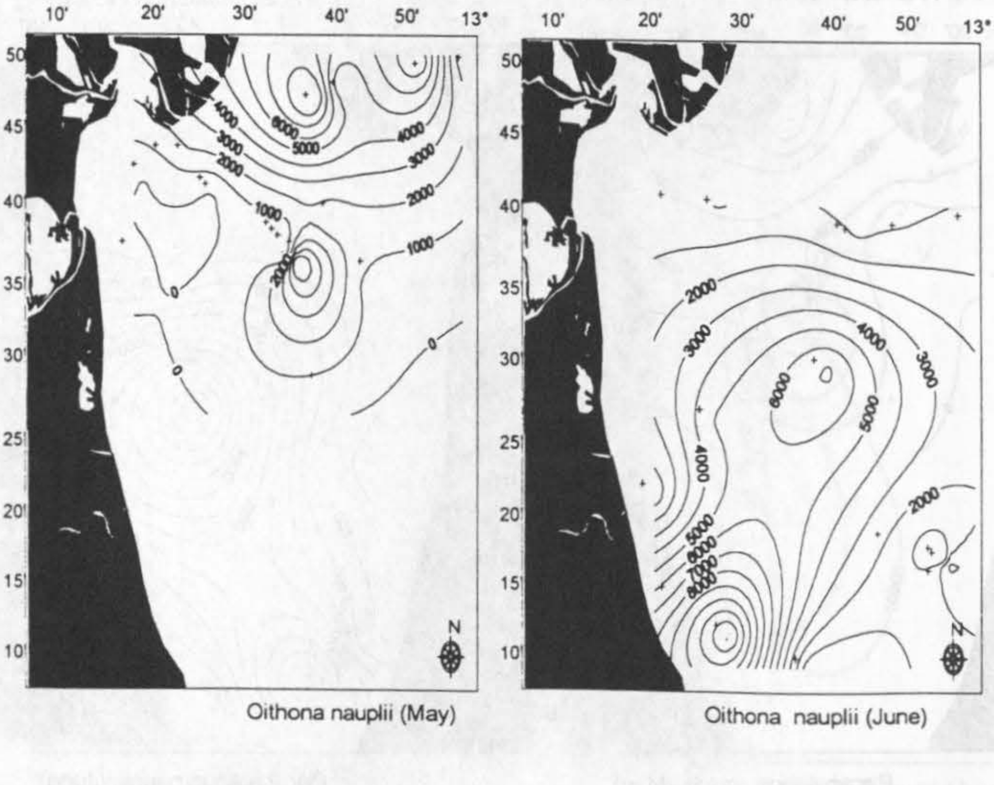
Paracalanus nauplii (May)

Paracalanus nauplii (June)

Figure 3.2.7b. Spatial distribution of abundance [ind m^{-3}] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Paracalanus parvus.***

Oithona CI-CVI (May)

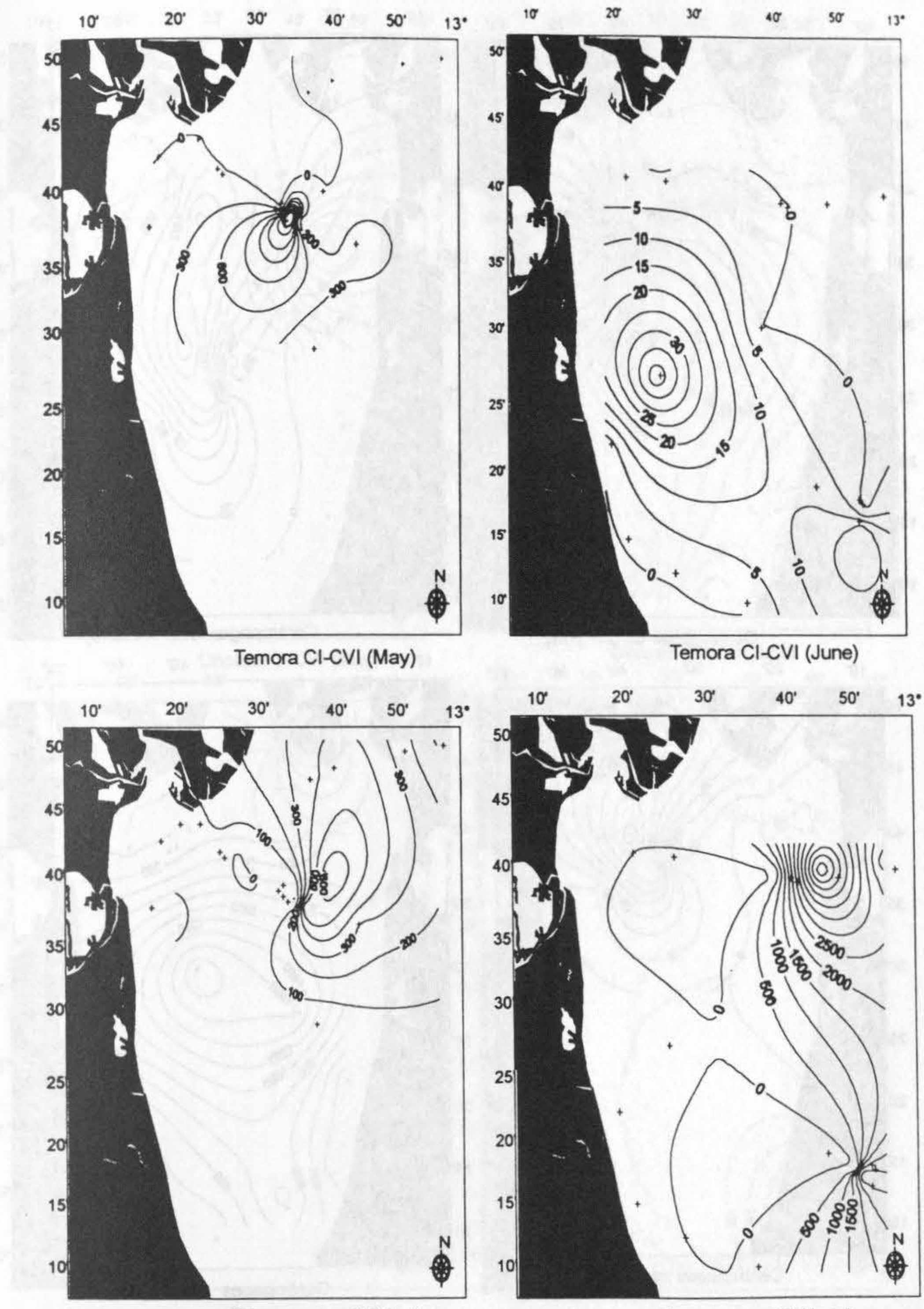
Oithona CI-CVI (June)



Oithona nauplii (May)

Oithona nauplii (June)

Figure 3.2.7c. Spatial distribution of abundance [ind m^{-3}] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Oithona* spp**.



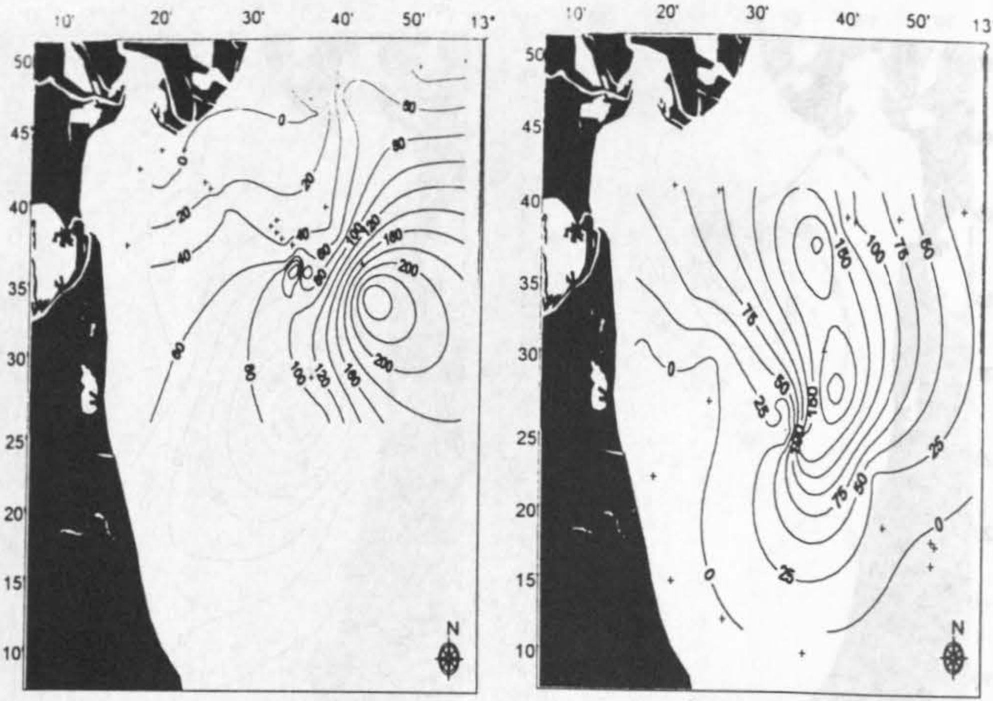
Temora CI-CVI (May)

Temora CI-CVI (June)

Temora nauplii (May)

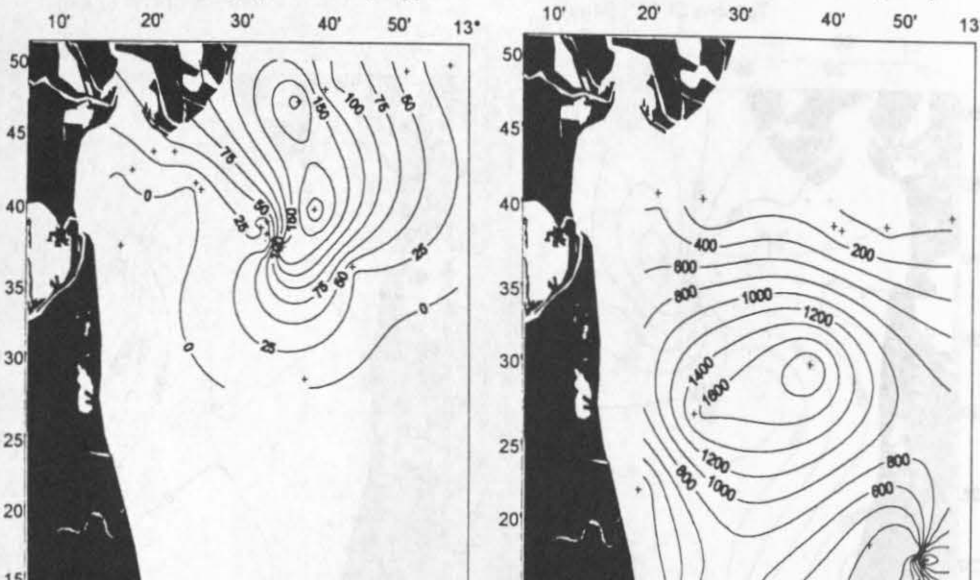
Temora nauplii (June)

Figure 3.2.7d. Spatial distribution of abundance [ind m^{-3}] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Temora* spp.**



Centropages CI-CVI (May)

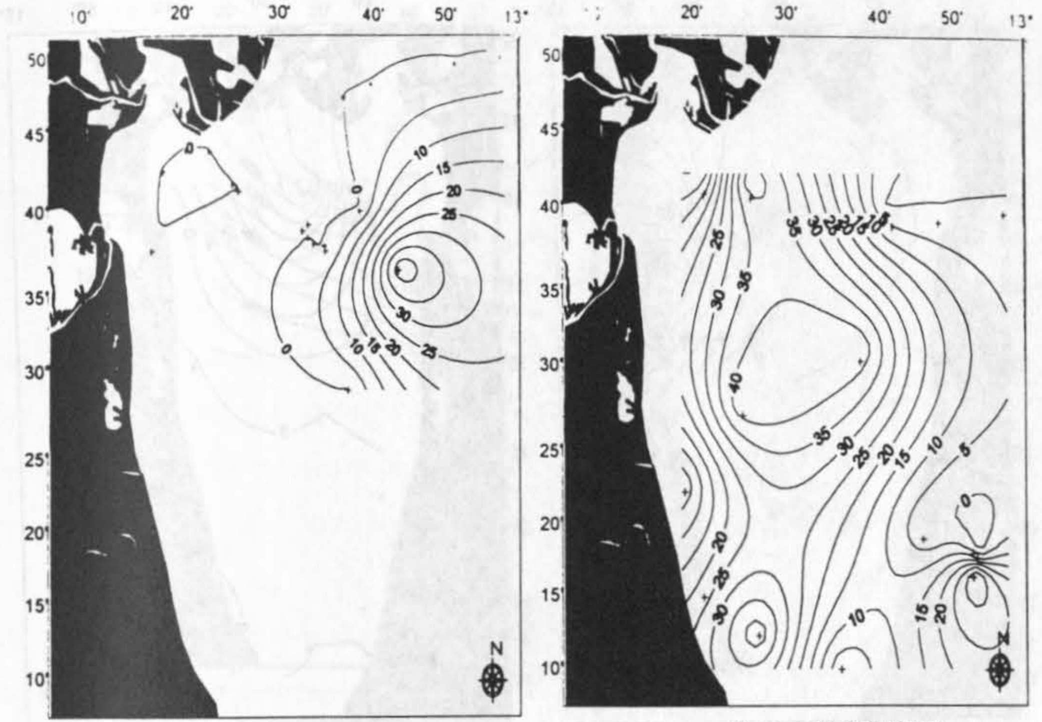
Centropages CI-CVI (June)



Centropages nauplii (May)

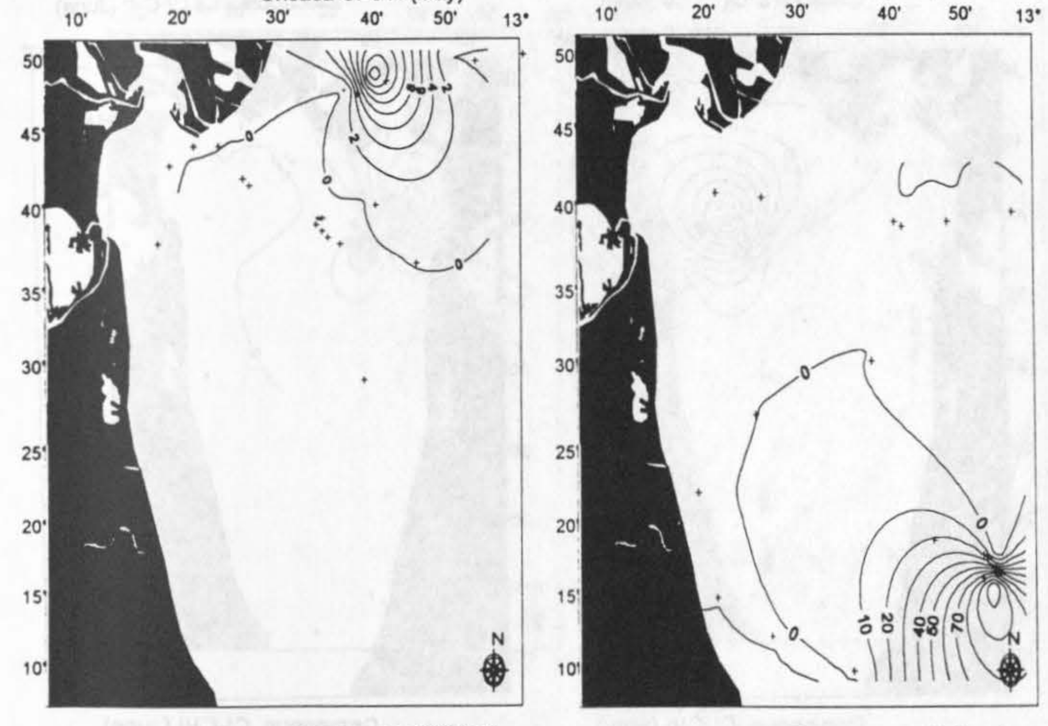
Centropages nauplii (June)

Figure 3.2.7e. Spatial distribution of abundance [ind m^{-3}*] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June* 1994: ***Centropages* spp**.



Oncaea CI-CVI (May)

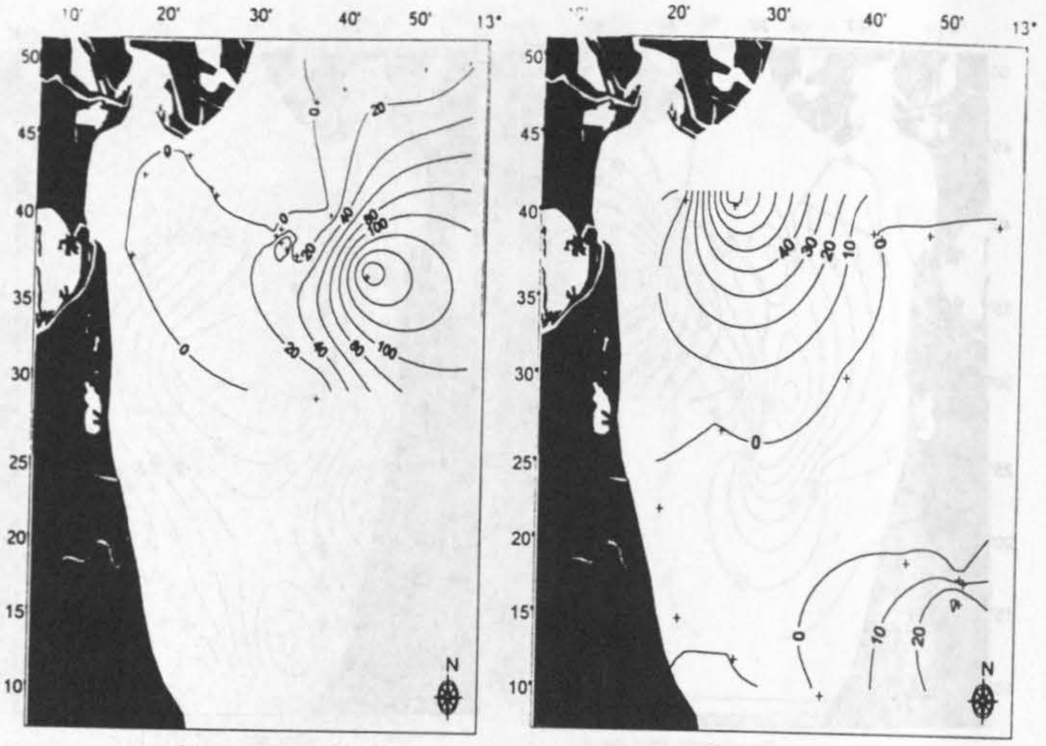
Oncaea CI-CVI (June)



Oncaea nauplii (May)

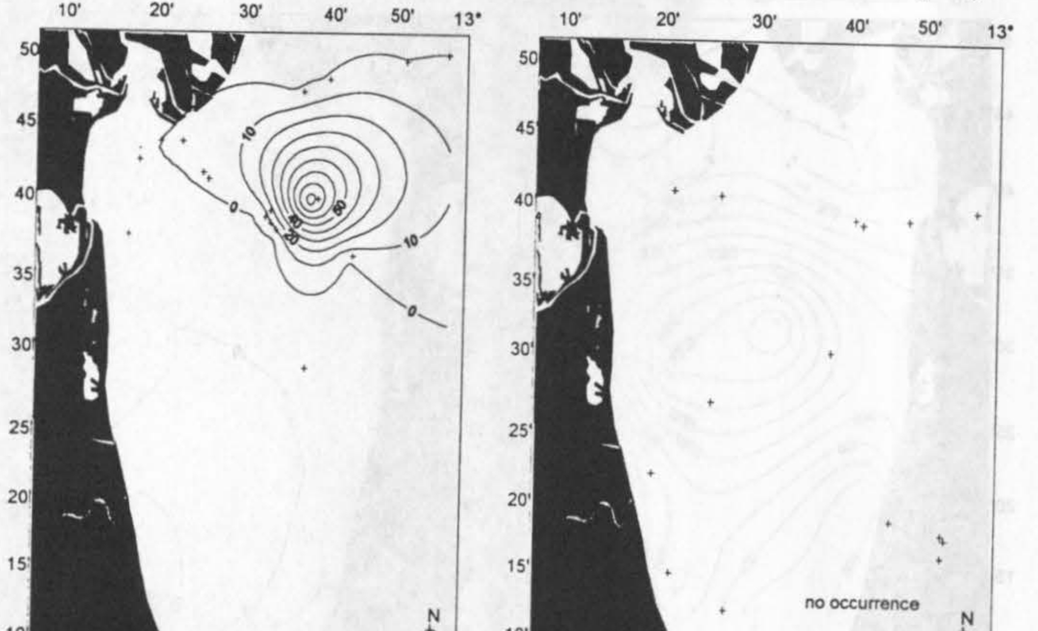
Oncaea nauplii (June)

Figure 3.2.7f. Spatial distribution of abundance [ind m^{-3}] of the most common copepods in the coastal plume of the Po etuary in the north-western Adriatic Sea during May and June 1994: ***Oncaea* spp.**



Clausocalanus CI-CVI(May)

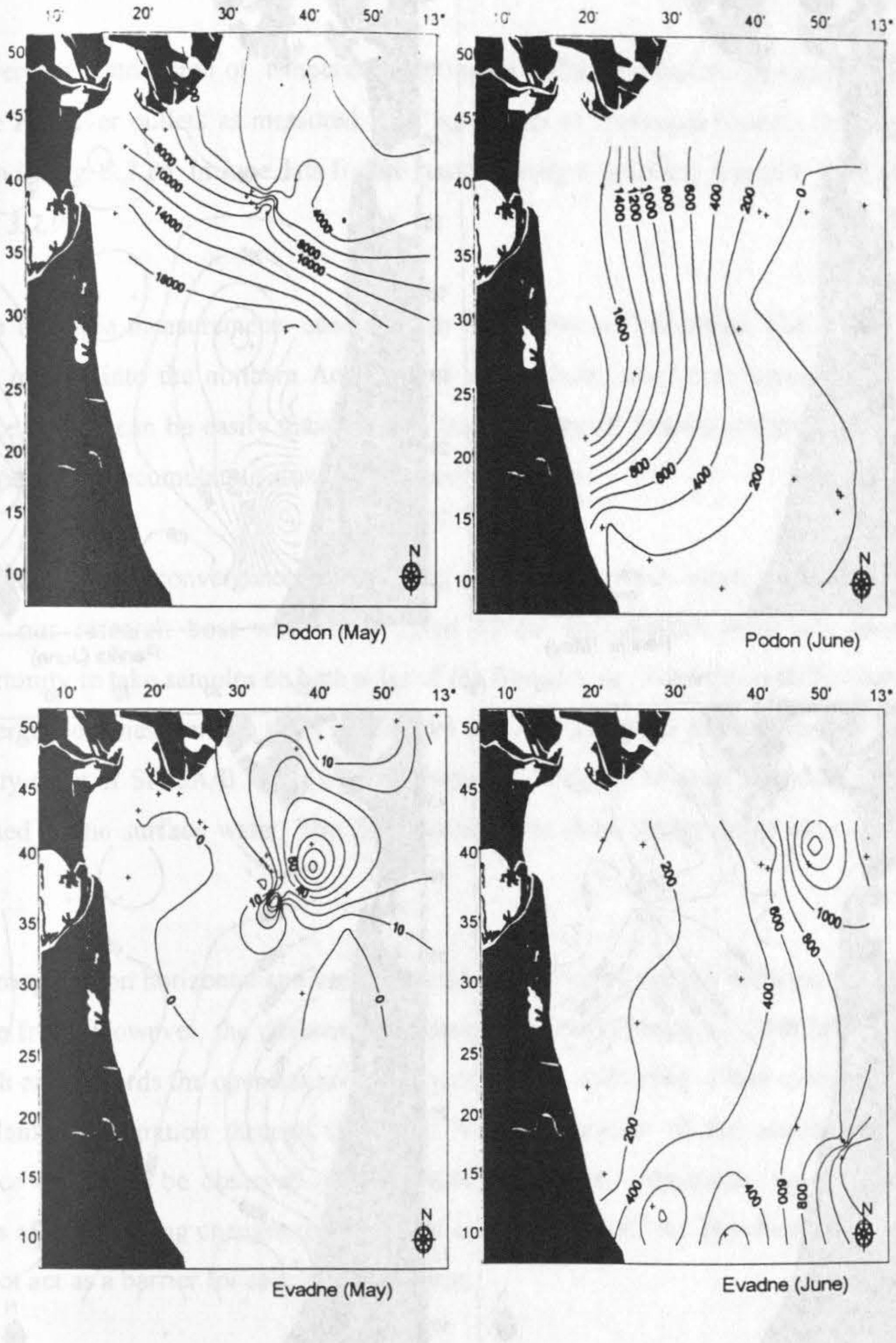
Clausocalanus CI-CVI (June)



Corycaeus CI-CVI (May)

Corycaeus CI-CVI (June)

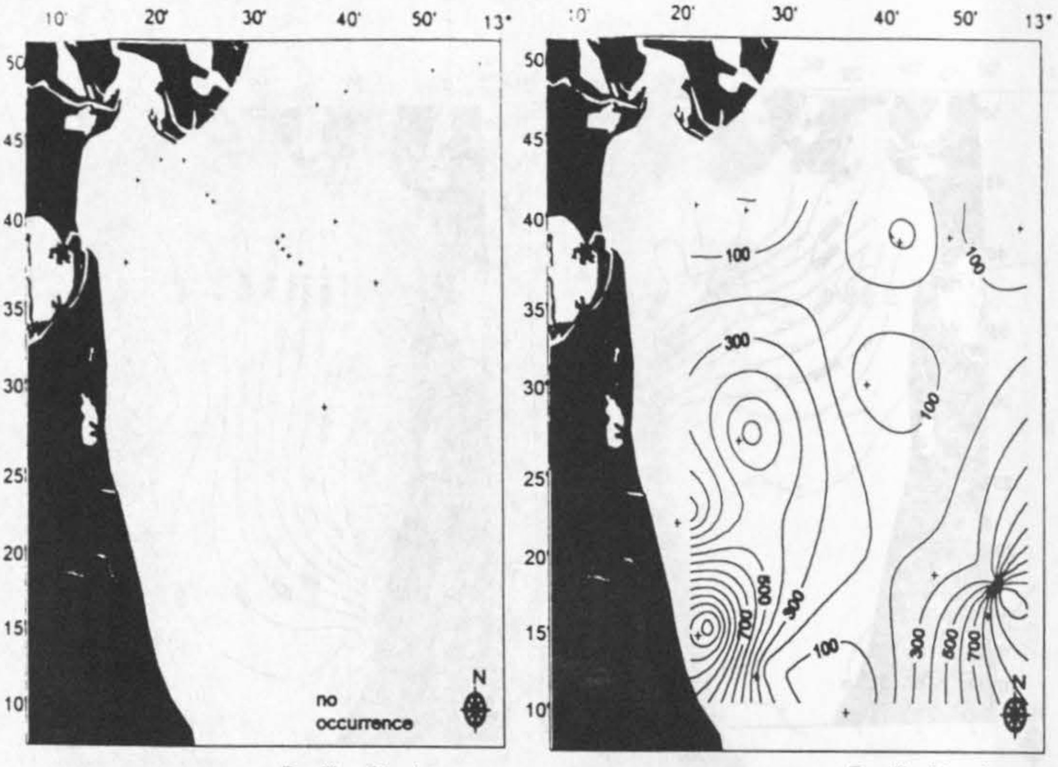
Figure 3.2.7g. Spatial distribution of abundance [ind m^{-3}*] of the most common copepods in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June* 1994: ***Clausocalanus* spp.** *and* ***Corycaeus* spp.**



Podon (May) Podon (June)

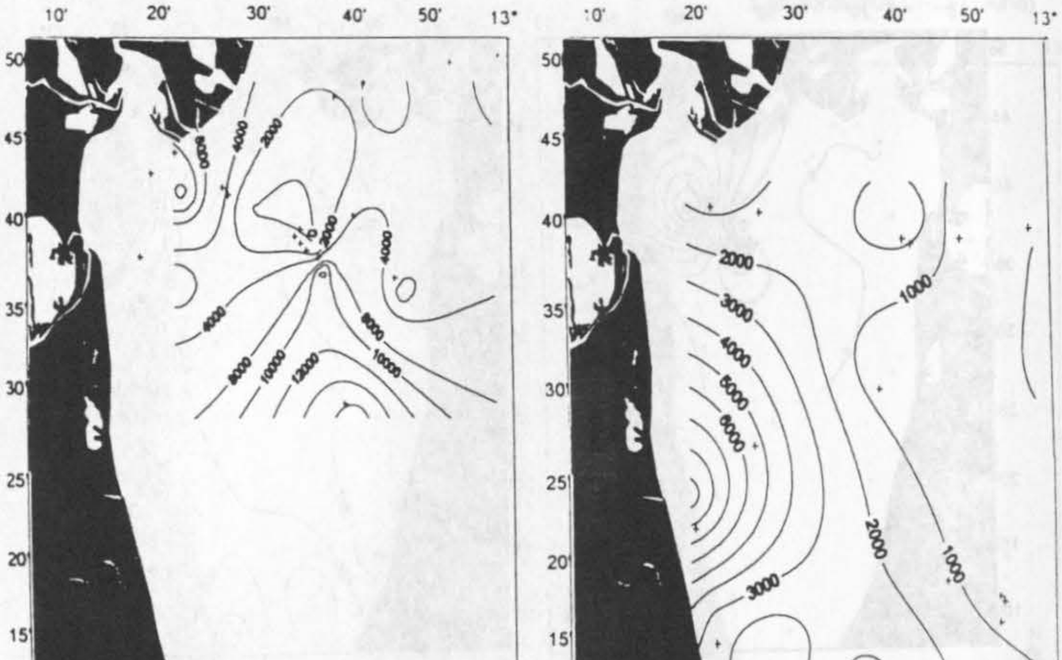
Evadne (May) Evadne (June)

Figure 3.2.7h. Spatial distribution of abundance [ind m^{-3}] of the most common Cladocera in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Podon* spp** and ***Evadne* spp.**



Penilia (May)

Penilia (June)



Bivalve larvae (May)

Bivalve larvae (June)

Figure 3.2.7i. Spatial distribution of abundance [ind m^{-3}] of the most common Cladocera and meroplankton in the coastal plume of the Po estuary in the north-western Adriatic Sea during May and June 1994: ***Penilia avirostris** and* **bivalve larvae**.

Zoplankton distribution at fronts

The vertical distribution of temperature, salinity and fluorescence in the immediate vicinity of the Po River outlets as measured on a north-west to south-east transect in May 1994 is shown in *Fig. 3.2.8a*. In June data from 5 stations along a east-west transect were obtained (*Fig. 3.2.9*).

As an example measurements conducted in May 1994 are presented. The inflow of huge water masses into the northern Adriatic Sea causes fronts and convergence zones near the surface, which can be easily traced by the large amount of floating material, mainly due to river pollution accumulating along the convergence zones.

In some areas the convergence zone was so strong that at times when there was or no little wind, our research boat was firmly fixed to the convergence front and gave us the opportunity to take samples on both sides of the frontal zone. The salinity differences at these convergence zones were up to 11.5 psu (16.1 and 27.6 psu at the surface) in May 1994. The salinity front at St.25A/B is not clearly visible in the figure but can be indicated by isoline directed to the surface water. The fluorescence data show strong differences at the frontal area.

The zooplankton horizontal and vertical distribution showed distinct differences on both sites of the front. However, the differences between the adjacent stations, both towards the river mouth and towards the open sea are much greater, thus indicating either mixing processes or zooplankton migration through the front. An accumulation of the zooplankton near the surface could not be observed in the convergence zone. Apparently the Po River plume fronts affected strong changes in the size of copepod populations. However, the plume fronts do not act as a barrier for species distribution.

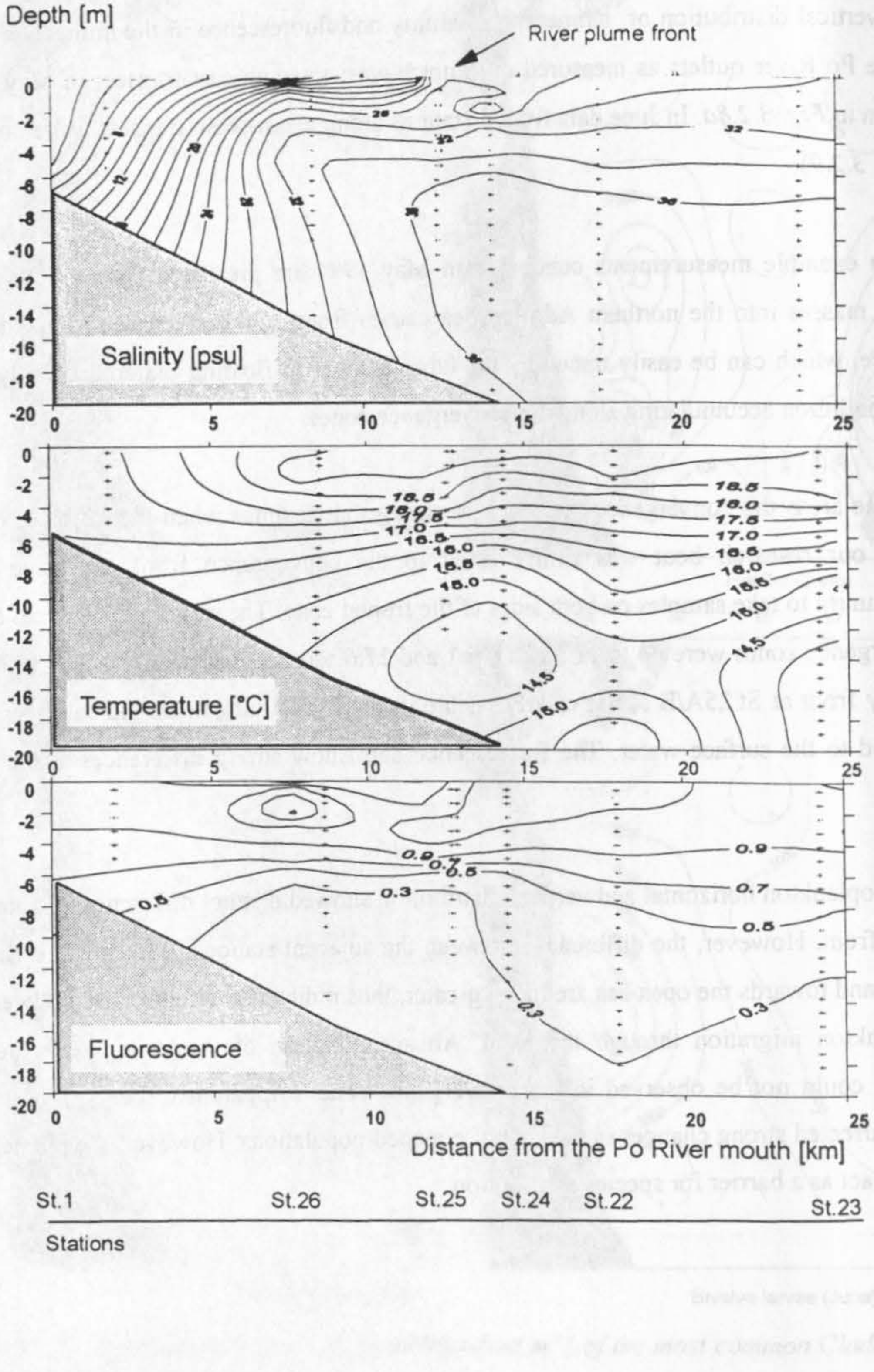


Figure 3.2.8a Vertical profiles of salinity, temperature and fluorescence along a transect in the vicinity of the Po estuary in the north-western Adriatic Sea during May 1994.

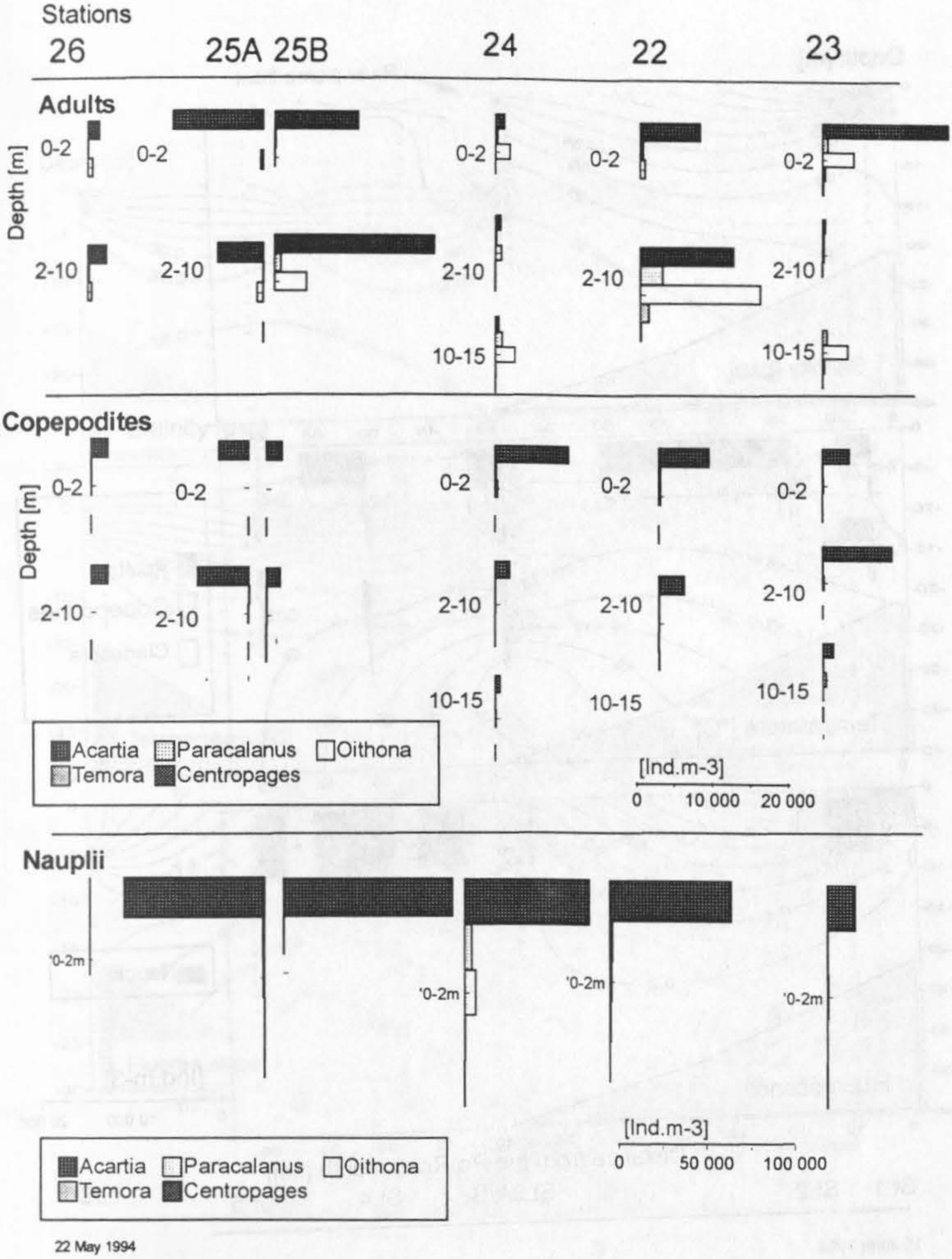
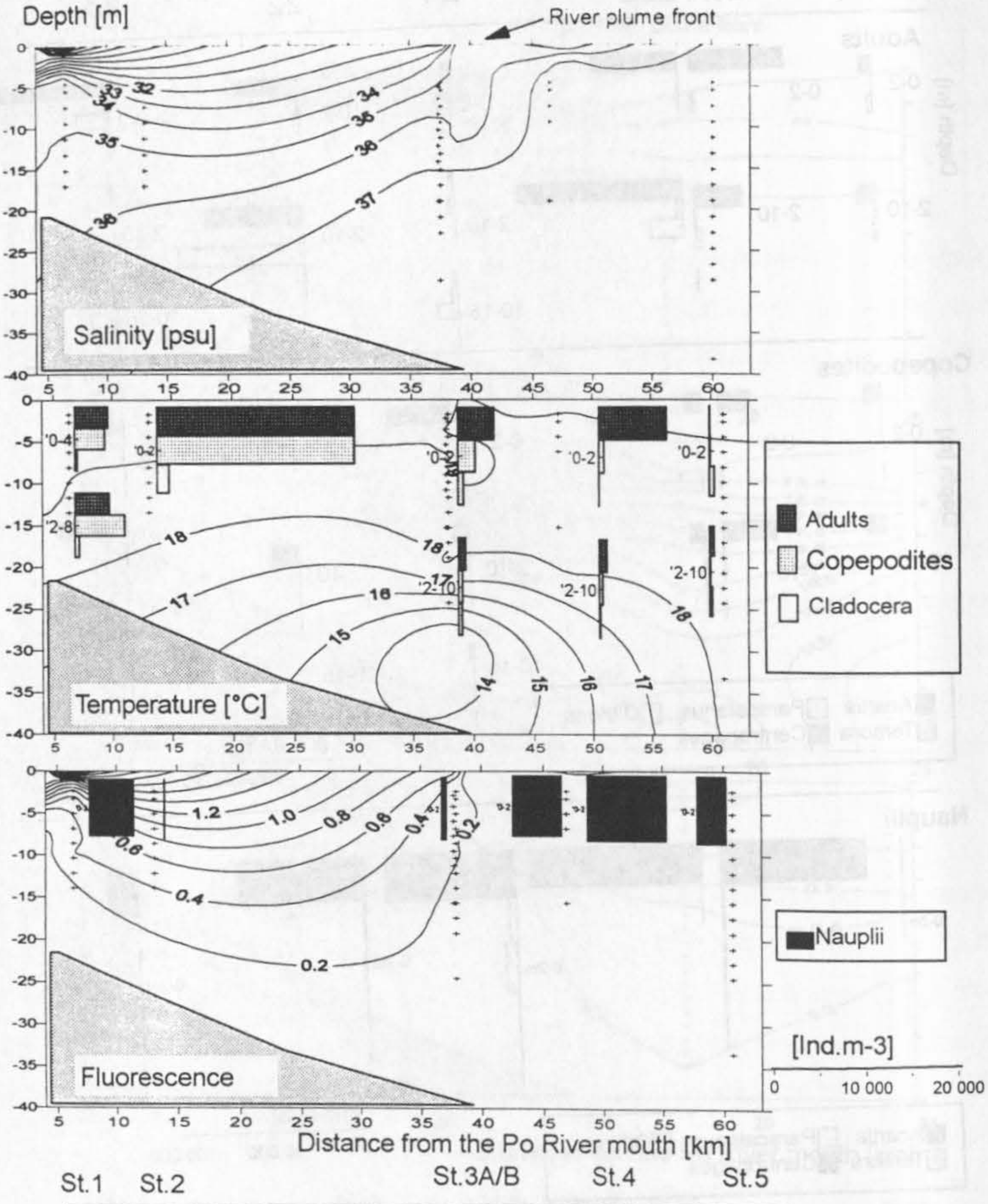


Figure 3.2.8b. Vertical profile of copepods along a transect in the vicinity of the Po Estuary in the north-western Adriatic Sea during May 1994.



15 June 1994

Figure 3.2.9. Vertical profiles of salinity, temperature, fluorescence and copepod abundance [ind m^{-3}] along a transect in the vicinity of the Po estuary in the north-western Adriatic Sea during June 1994.

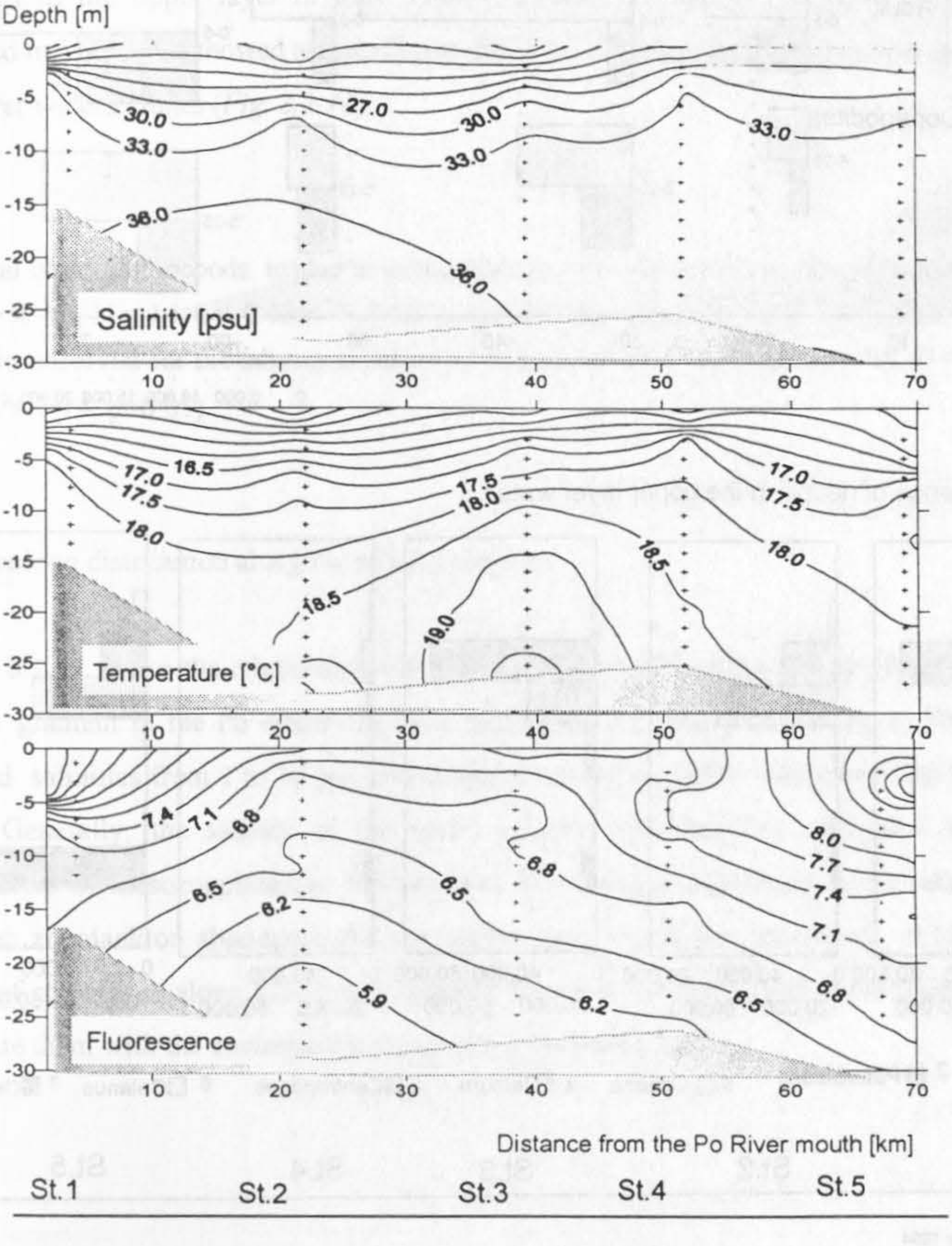


Figure 3.2.10a Vertical profiles of salinity, temperature and fluorescence along a transect in the vicinity of the Po estuary in the north-western Adriatic Sea during November 1994.

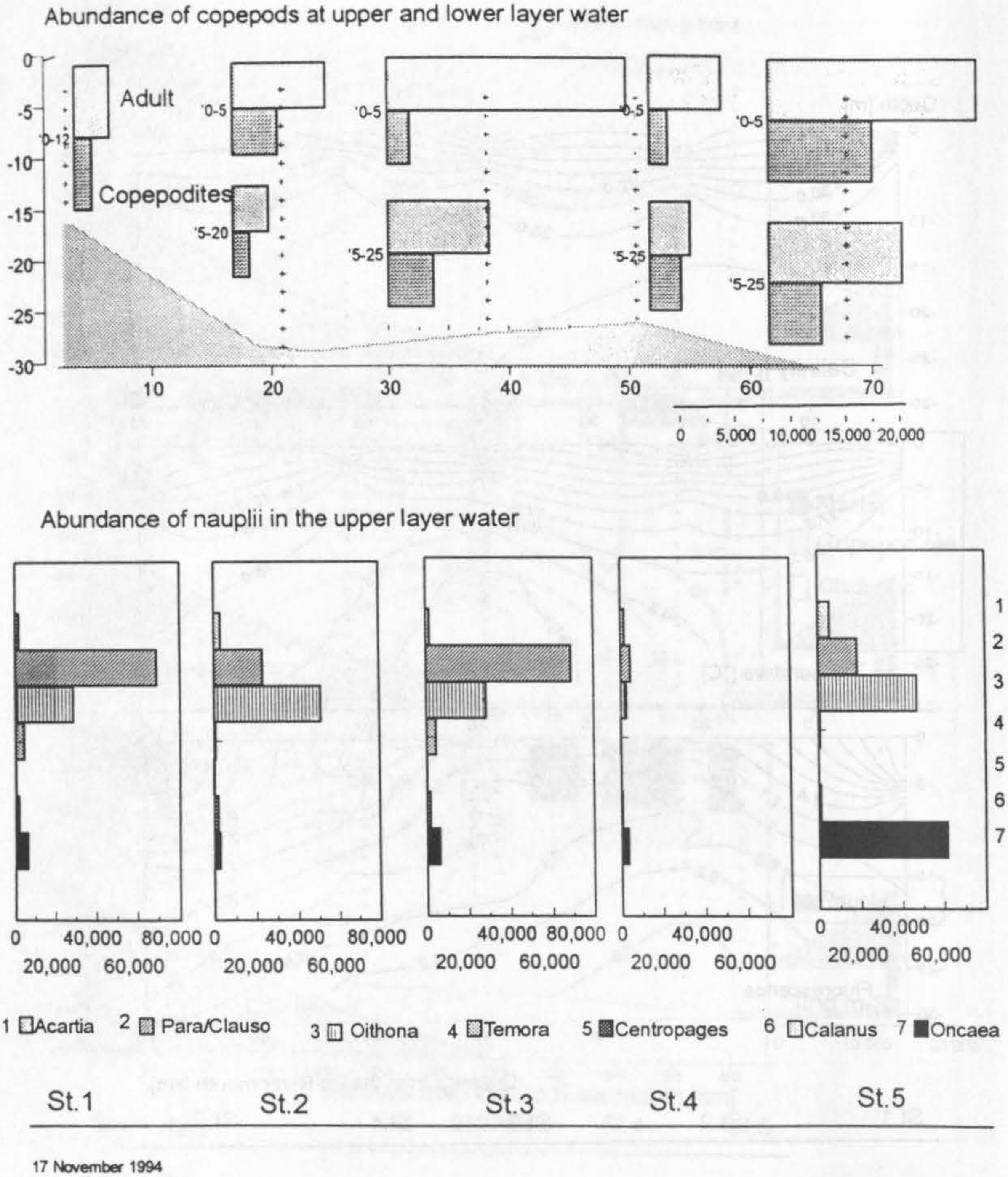


Figure 3.2.10b Vertical profiles of the common copepods along a transect in the vicinity of the Po estuary in the north-western Adriatic Sea during November 1994.

Vertical profiles of mesozooplankton

Significantly higher abundances of adult *Centropages* spp (Htest = 1.8, N=18, p= 0.10; λ^2= 2.1, p= 0.15) and *Podon* spp (Htest= 6.57, N= 18, p=0.01; λ^2 = 5.55, p= 0.01) were observed in the upper layer in May 1994. The other frequently occurring zooplankton recorded in May 1994 showed no significant differences in abundance between the upper and the lower water column (*Fig. 3.2.11*).

The total of adult copepods tended to accumulate in the upper layer of the water column (Htest= 4.45 , N = 14, p = 0.03;λ^2 = 7.14, p = 0.01). The same pattern of vertical distribution was also observed for the adult population of *Paracalanus parvus* (Htest = 4.44, N =14, p = 0.03; λ^2= 7.14, p=0.01).

Zooplankton distribution along the salinity gradient

Figure 3.2.12 shows the relationship between dominant zooplankton taxa or groups and the salinity gradient in the Po estuary in May and June 1994. The observations in May 1994 covered salinities from 1 to 30 psu and observations in June 1994 salinities from 20 to 37 psu. Generally, the salinity of the water column was positively correlated with the abundances of mesozooplankton. Nevertheless, there was no significant linear relationship between zooplankton abundance and the salinity gradient. It was attempted to locate the peaks of abundance along the salinity gradient by means of polynomial curve fitting and to correlate them with the environment parameters (*Appendix 3.2.6*).

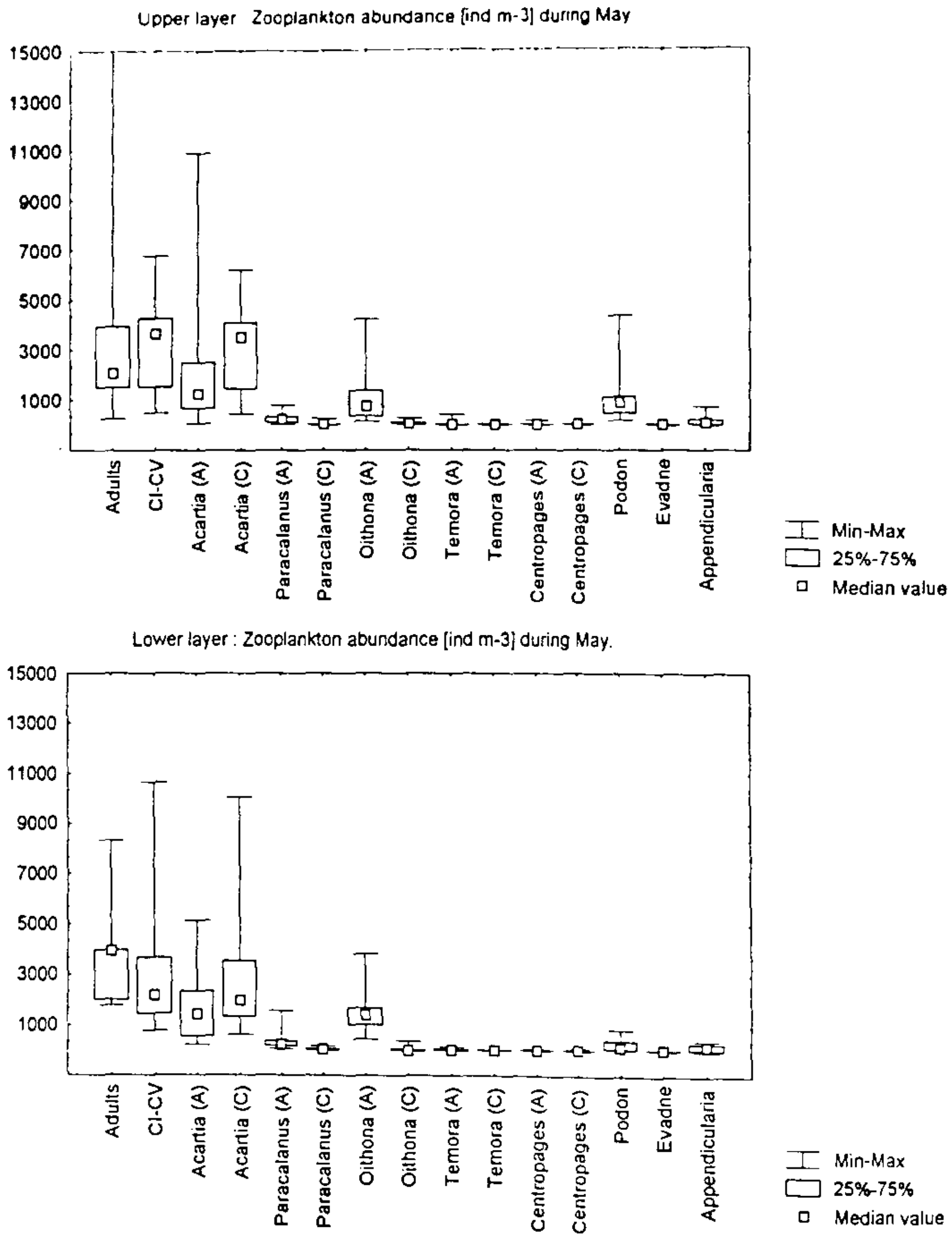
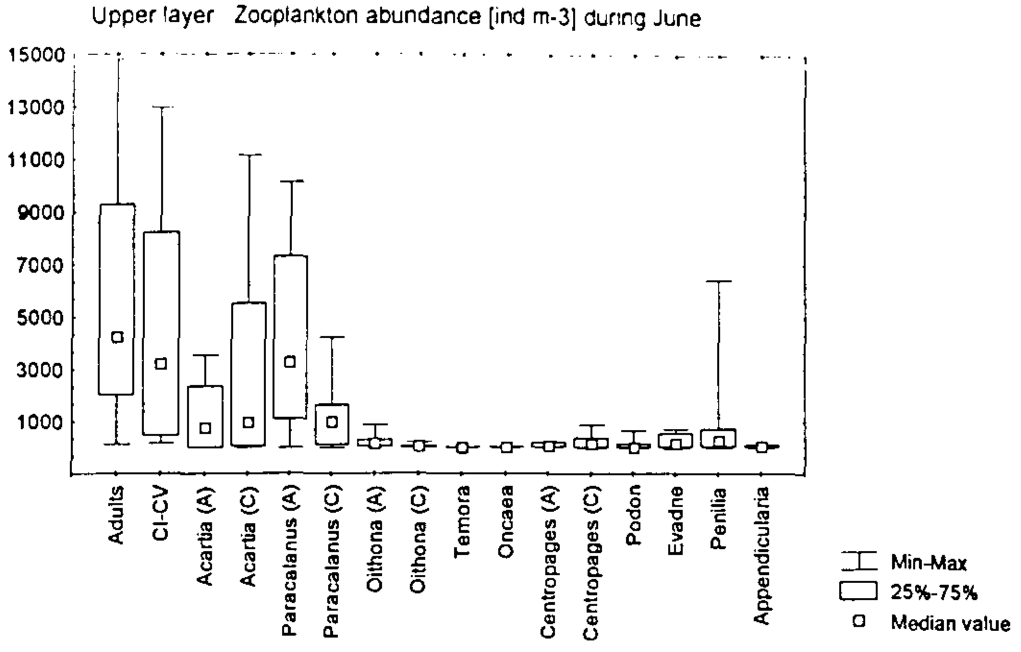


Figure 3.2.11a. Median of mesozooplankton abundance in the upper and lower layer of the north-western Adriatic Sea during May 1994. A = adults and C = copepodites



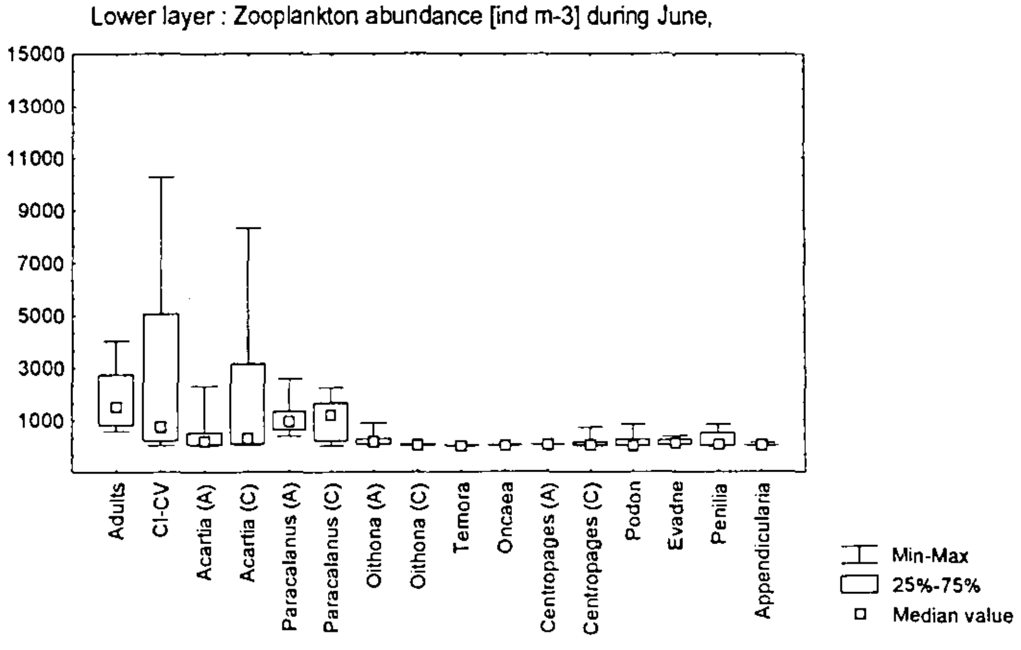


Figure 3.2.11b. Median of mesozooplankton abundance in the upper and lower layer of the north-western Adriatic Sea during June 1994. A = adults and C = copepodites

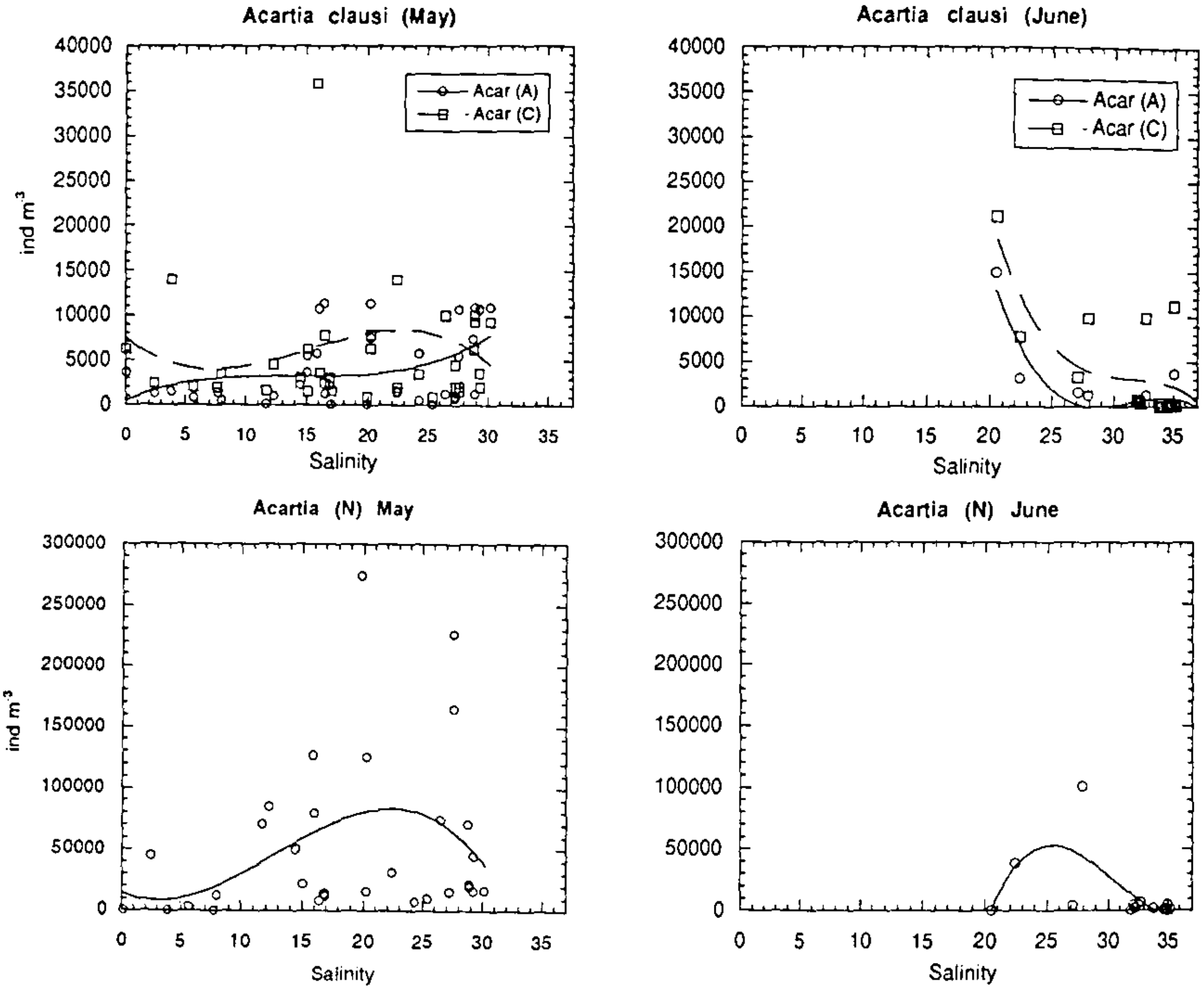
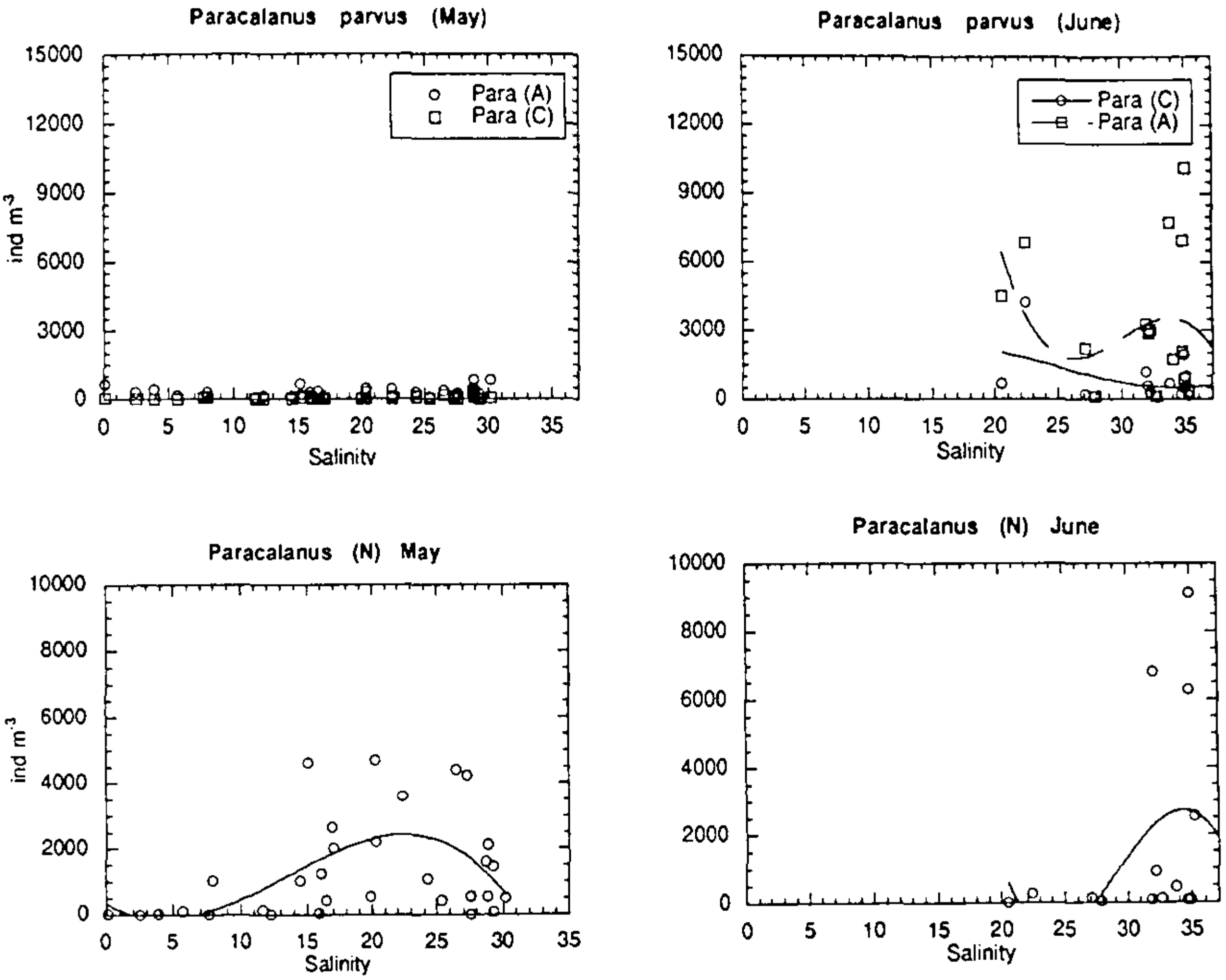


Figure 3.2.12a. Distribution of frequently occurring copepods : ***Acartia clausi*** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. Polynomial equations are presented in Appendix 3.2.6. A = adults, C = copepodites and N = nauplii.*



Paracalanus parvus (May)

Paracalanus parvus (June)

Paracalanus (N) May

Paracalanus (N) June

Figure 3.2.12b. Distribution of frequently occurring copepods : ***Paracalanus parvus*** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. A = adults, C = copepodites and N = nauplii.*

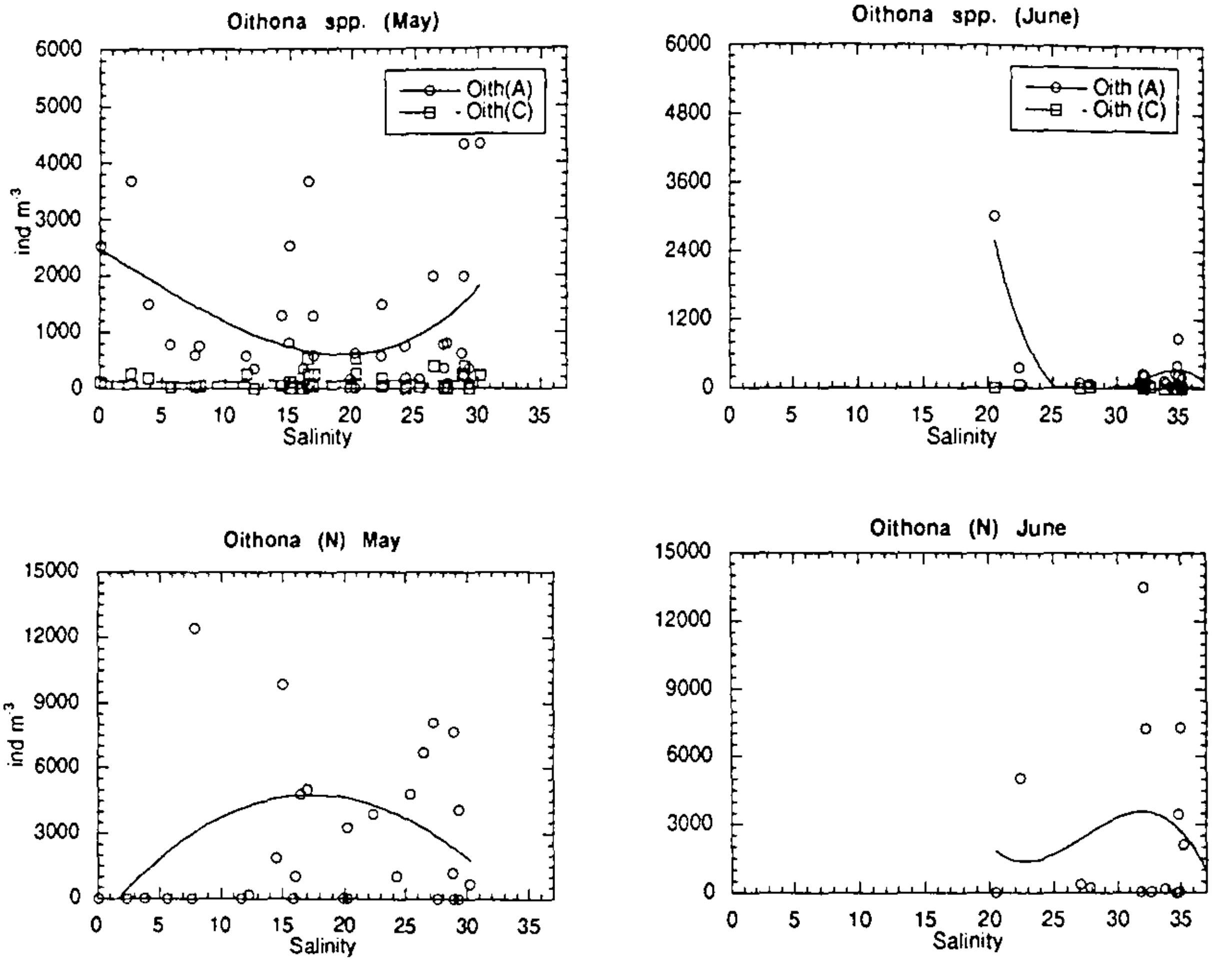


Figure 3.2.12c. Distribution of frequently occurring copepods : ***Oithona*** **spp.** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. A = adults, C = copepodites and N = nauplii.*

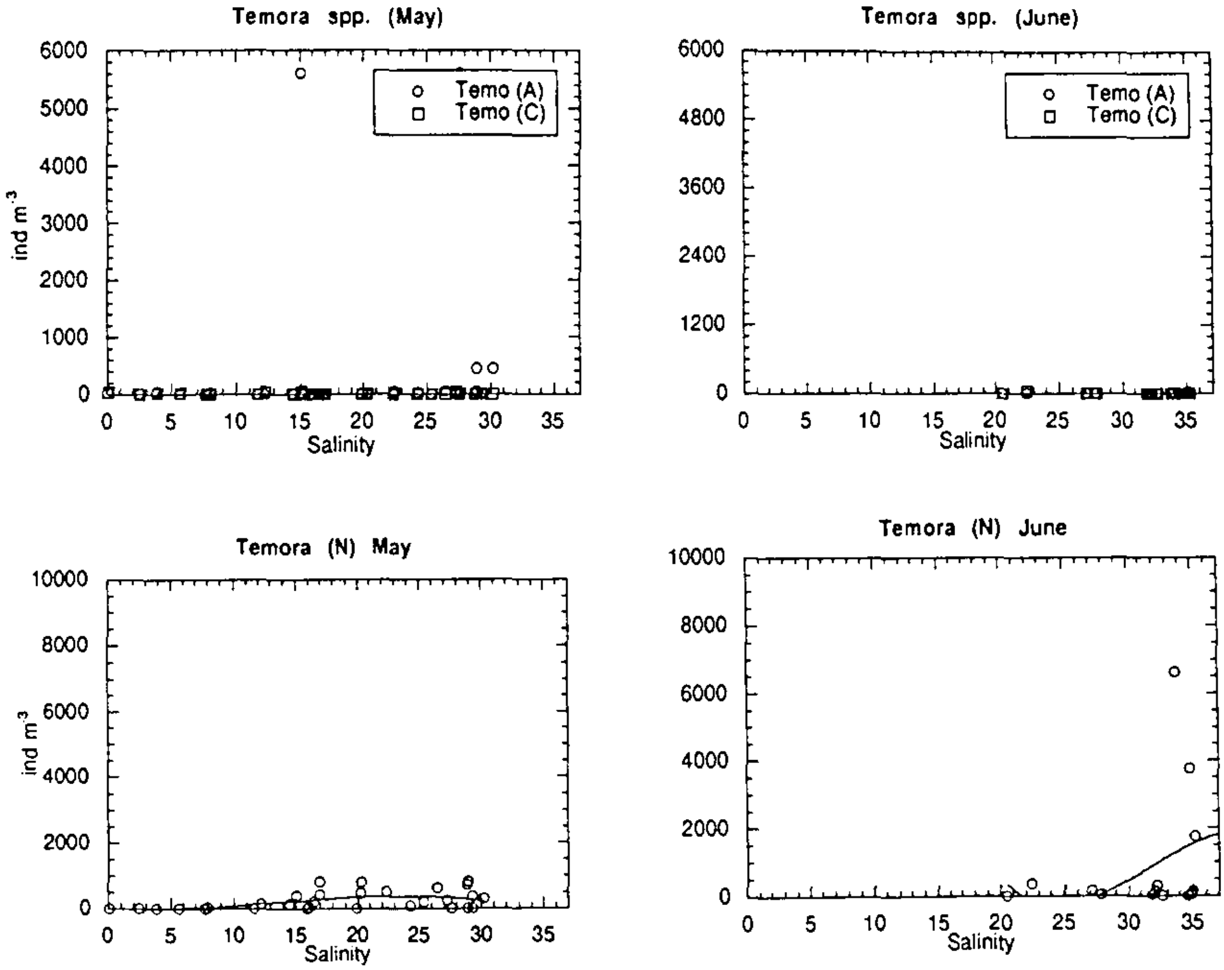


Figure 3.2.12d. Distribution of frequently occurring copepods : ***Temora*** **spp.** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. A = adults, C = copepodites and N = nauplii.*

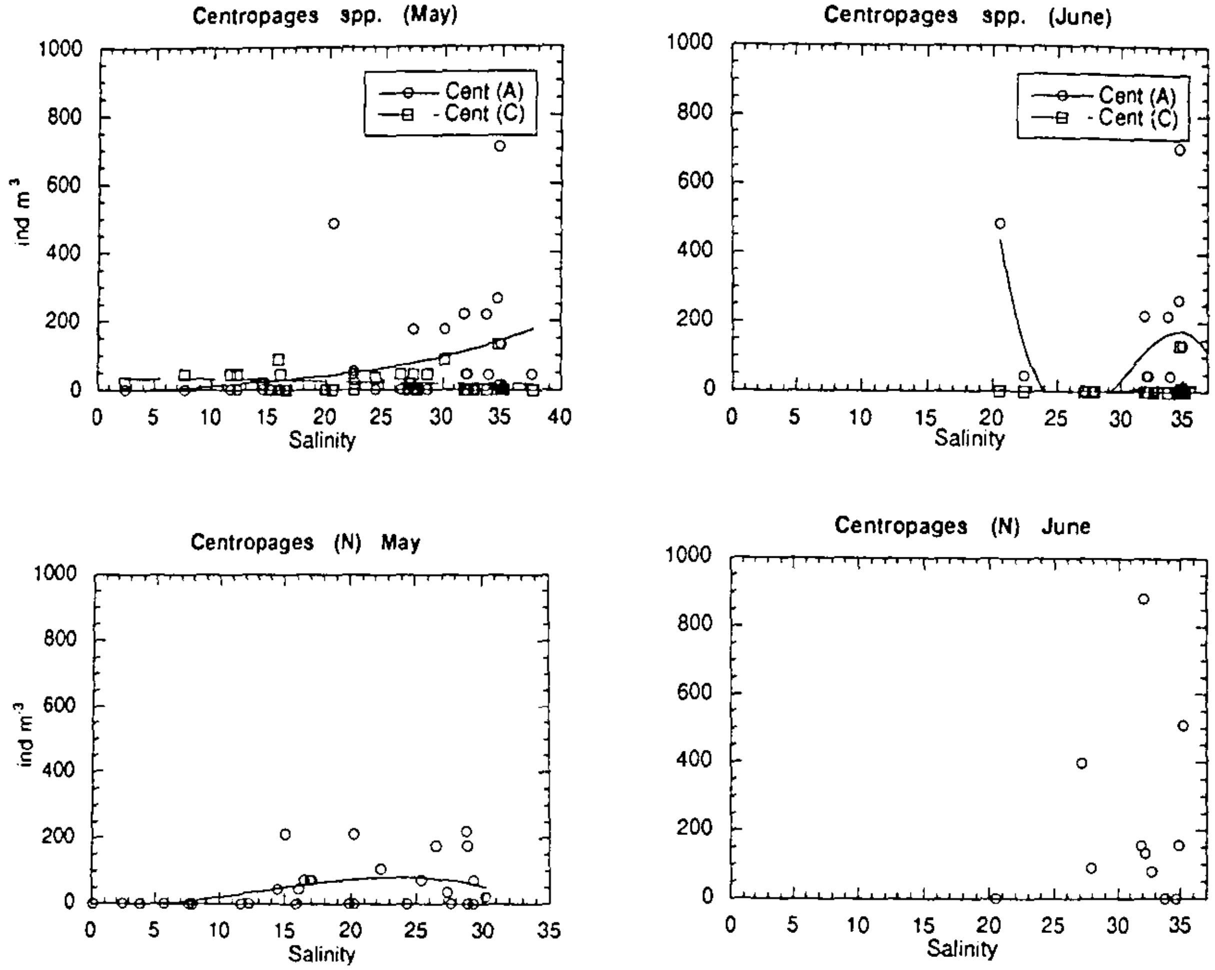


Figure 3.2.12e. Distribution of frequently occurring copepods : ***Centropages*** **spp.** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. A = adults, C = copepodites and N = nauplii.*

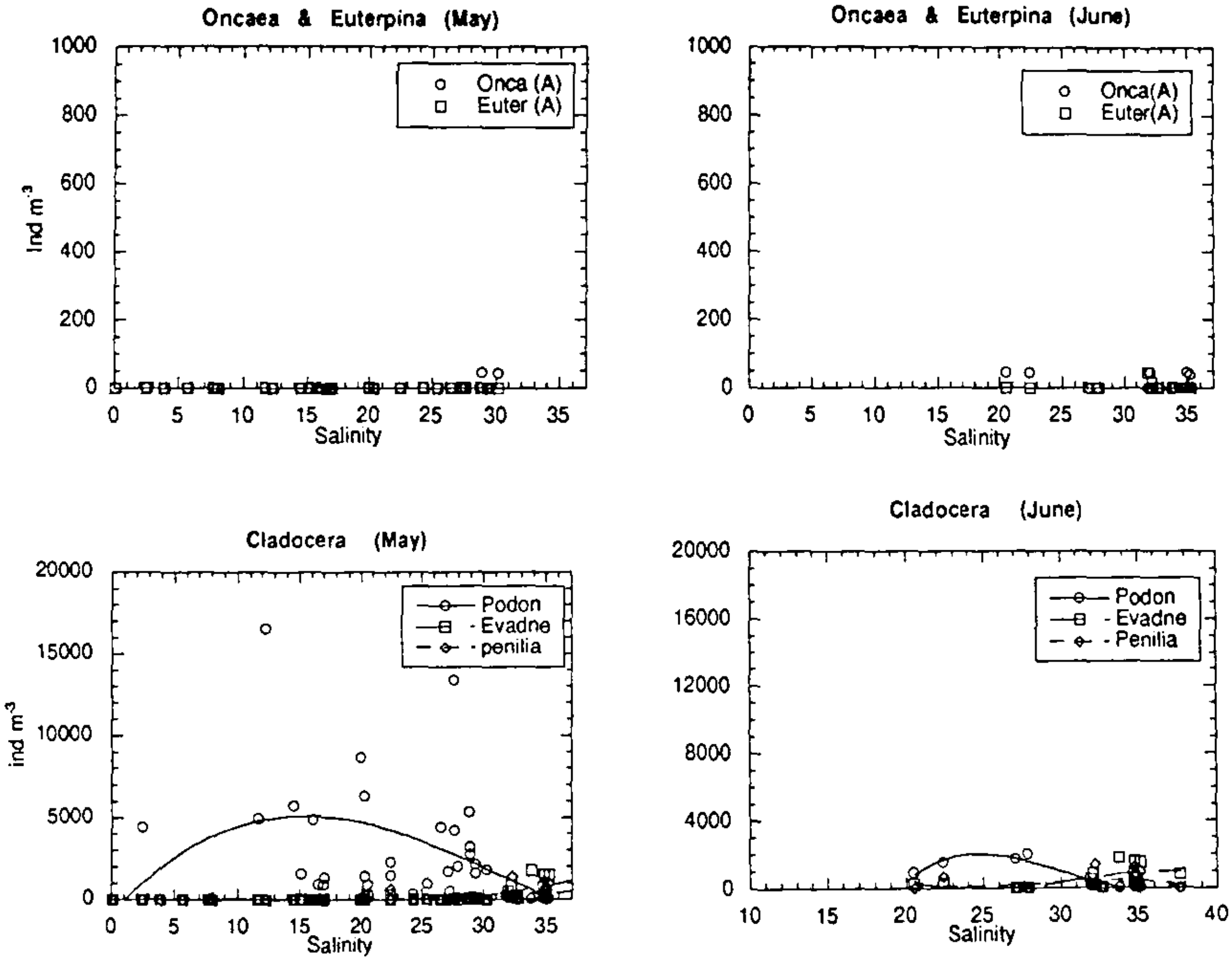


Figure 3.2.12f. Distribution of frequently occurring copepods : (1) **Oncaea** spp. *and* **Euterpina acutifrons**, *(2) Cladocera:* **Podon** spp., **Evadne** spp. *and* **Penilia avirostris** *along the salinity gradient during May and June 1994. Curve fitting by means of polynomial interpolation. A = adults, C = copepodites and N = nauplii.*

(1) Copepods

Acartia clausi

The assemblage of *Acartia clausi* reached a peak (10 000 - 20 000 ind m^{-3}) within the salinity range of 15 to 25 psu during May and June. The adult population and copepodite stages showed a similar pattern of distribution with respect to the salinity gradient. Higher numbers of copepodite stages were found compared with the adult population during May and June. The distribution of naupliar stages was also similar to that of older populations, a peak of abundance occurred within the salinity range of 15 to 27 psu. In June, the naupliar density was low.

Paracalanus parvus.

Both the adult and the copepodite population of *Paracalanus parvus* exhibited minor concentrations during May (< 1 000 ind m^{-3}), and a homogenous distribution was noticeable within intermediate salinites. In June, however, its distribution within the salinity 20 to 37 psu was found to be patchy, and showed a maximum concentration in open waters (salinity > 35 psu). The nauplii of *Paracalanus* reached their peak of abundance (~ 4 000 ind m^{-3}) within an intermediate salinity (15- 27 psu) during May 1994 ; unfortunately, no samples were taken in the open waters. In June, a maximum abundance of *Paracalanus* nauplii occurred in the high-saline waters. A significant decrease of copepodite and nauplii abundance of *Paracalanus parvus* was recorded within the salinity of 25 - 30 psu in May and June 1994.

Oithona spp.

The dominant species during May and June 1994 was *O.similis*, occurring within the whole salinity range. Its distribution was found to be heterogenous. The concentrations of the adult population varied between 2 000 - 4 000 ind m^{-3}, while the copepodite population was found to be lower than 1 000 ind m^{-3}. A patchy distribution along the salinity gradient was also detected for the naupliar stage of *Oithona* occurring at salinities higher as 10 psu.

Temora spp.

The adult and copepodite population of *Temora* were rarely caught during May and June 1994. The concentration of naupliar stages of *Temora* steadily increased with increasing salinity from 10-35 psu, its concentration was ~ 1 000 ind m^{-3} during May. A higher abundance (~ 4 000 ind m^{-3}) of the naupliar stages was observed in June at the highest salinity regime.

Centropages spp.

The concentrations of the copepodite stages of *Centropages* spp. were higher than those of the adults. However, their total abundance was only < 1 000 ind m^{-3} during May and June 1994. In the higher salinity regime of 35 psu, a maximum of 700 ind m^{-3} was recorded. During May and June 1994, a peak of the *Centropages* nauplii (900 ind m^{-3}) was found at the salinity of 33 psu.

Euterpina acutifrons

Euterpina acutifrons occurred in low abundance (50 ind m^{-3}) and was found only at the higher salinity regime (> 30 psu) during May and June 1994.

Oncaea spp.

O.media and *O.subtilis* were not detected at lower salinities during May 1994. Small populations (50 ind m^{-3}) were found at salinities > 20 psu.

Total copepods and copepod nauplii

The abundance of total copepods (adults and copepodites) increased steadily along the salinity gradient in May and June 1994 from ~ 5 000 ind m^{-3} ~ 15 000 ind m^{-3}.

(2) Cladocera

This group consisted of *Podon* spp., *Evadne* spp. and *Penilia avirostris*. *Podon* spp. was found to be dominant within this group, its maximum abundance was observed at intermediate salinities (10-27 psu), and ranged from 5 000 - 15 000 ind m^{-3}. In the high-saline water (salinity > 30 psu) *Evadne* spp. and *Penilia avirostris* were much more abundant than *Podon* spp. No stocks of *Podon* spp. were found at salinities > 30 psu.

3.2.5. Results of the Principal Component Analysis (PCA)

Principal Component Analysis was employed using 35 and 33 biological descriptors, with physical and biological parameters as complimentary variables taken during May and June 1994, respectively (*Fig. 3.2.13a-b*).

By plotting ordinates on the 3 mean axes, it was possible to determine groups of biological descriptors and to classify them with reference to their correlation coefficients and factor loadings. In order to simplify the interpretation, only the strongest key categories of each group having a signicant value in the factor loading will be described. These were chosen on the basis of salinity, temperature, chlorophyll or fluorescence.

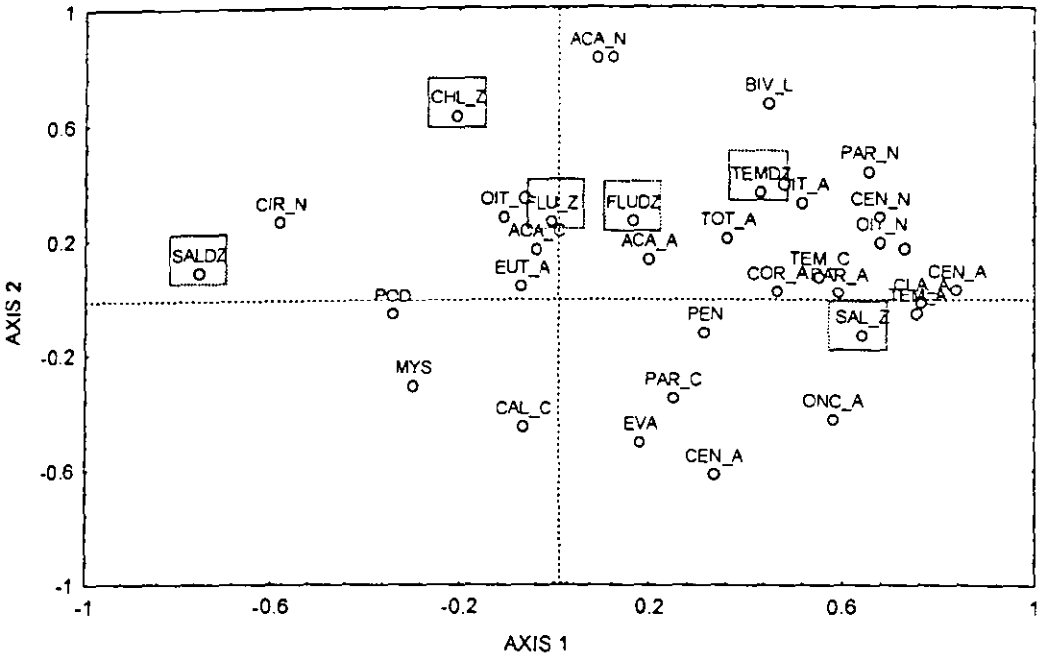
PCA of May 1994

Axis 1 very clearly indicates the significant separation between salinity and chlorophyll-*a* concentrations. Axis 1 represents oceanic waters characterized by higher salinities; stratification of the water column is expressed by the gradient between the sea surface temperature and lower water temperature (dT/dZ). The organisms which have a significantly positive correlation in the factor loading were *Clausocalanus* spp adult (A), *Centropages* spp (A) and *Temora* spp nauplii, copepodite and adult (N,C and A). Both *Oncaea* spp. (A) and *Penilia avirostris* showed a positive relation too, but without significance.

Axis 2 demonstrates the influence of a typical eutrophied regime characterized by a higher phytoplankton biomass. High values of chlorophyll-*a*, respectively fluorescence, were positively correlated with this axis, and therefore in opposition to salinity. A positive correlation with the magnitude of the salinity gradient (dS/dZ) and chlorophyll gradient (dChl/dZ or dFlu/dZ) was found in this area, which therefore was classified as river-influenced eutrophication area. The organisms most favoured were copepod nauplii. The population of copepod nauplii in May was dominated by *Acartia* nauplii (95%). Some adult copepods, like *Acartia clausi*, and meroplankton were also positively correlated with axis 2, though not statistically significant.

Axis 3 represents the influence of temperature in the water column, as indicated by a positive correlation of the mean temperature along this axis. *Calanus* spp (C) and *Penilia avirostris* favoured the water with high salinity. *Paracalanus parvus* (C) , *Evadne* spp., *Centropages* spp, (A) and *Oncaea* spp. showed a positive correlation with temperature.

PCA of May 1994 (Axis 1 vs 2):



PCA of May 1994 (Axis 2 vs 3):

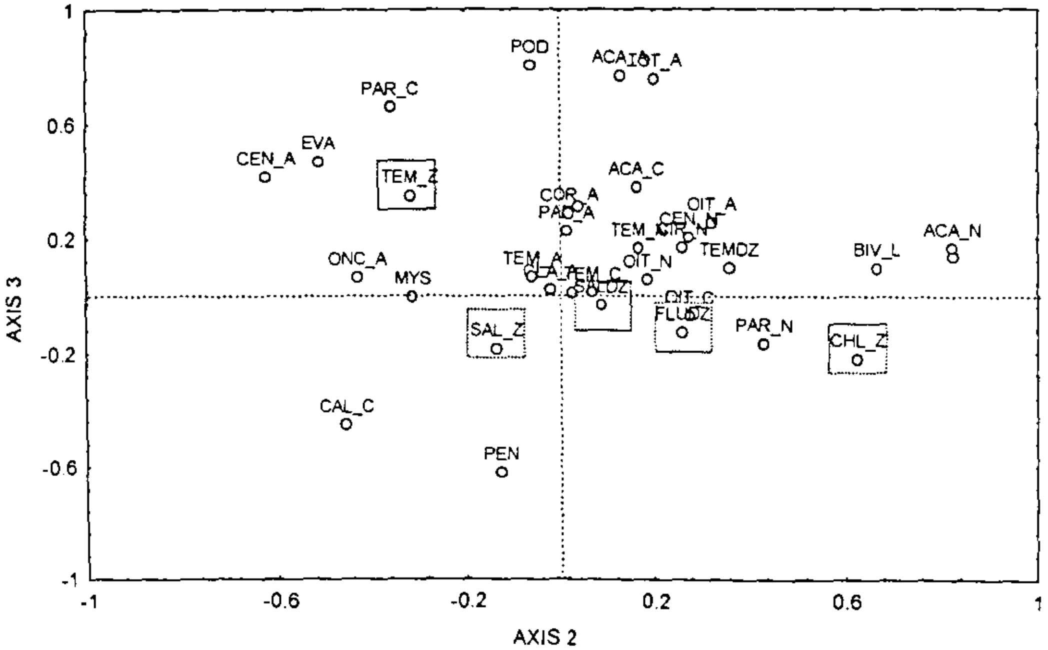


Figure 3.2.13 Principal component ordinates of the May 1994 cruise for environmental parameters and 35 biological descriptors. Codes of variables are listed in Table 3.2.2. (a) *Axis 1 vs 2 ; (b) Axis 2 vs 3*

Table 3.2.2 Component loading for the principal component analysis of zooplankton data illustrated in Fig. 3.2.13 during May 1994. Components were extracted from a covariance matrix based on log (n+ 1) transformed data. The Axes were rotated using the Varimax method. (A), (C) and (N) represent adult, copepodites and nauplii, respectively. Bold print = significant. Unit of variables : abundance (log ind m^{-3}), salinity (psu), temperature (°C), chlorophyll-a (µg dm^{-3}) and fluorescence (arbitrary unit).

Variables	Axis 1	Axis 2	Axis 3	Log. mean abundance	Std.dev.
ACA_A (Acartia clausi)	0.201	0.128	**0.766**	3.35	0.50
PAR_A (Paracalanus parvus)	0.594	0.010	0.223	2.35	0.48
CLA_A (Clausocalanus spp.)	**0.764**	-0.020	0.017	0.59	0.89
OIT_A (Oithona spp)	0.522	0.322	0.252	3.09	0.32
CEN_A (Centropages spp.)	**0.838**	0.023	0.005	0.82	0.84
TEM_A (Temora spp.)	**0.756**	-0.063	0.062	1.01	1.13
ONC_A (Oncaea spp.)	0.583	-0.428	0.063	0.50	0.66
COR_A (Corycaeus spp.)	0.469	0.016	0.284	0.10	0.40
EUT_A (Euterpina acutifrons)	0.069	0.036	0.309	0.13	0.37
TOT_A (total adult copepods)	0.367	0.201	**0.754**	3.65	0.35
EVA (Evadne spp.)	0.182	-0.508	0.466	1.38	1.28
POD (Podon spp.)	-0.339	-0.063	**0.801**	3.05	0.53
PEN (Penilia avirostris)	0.320	-0.128	-0.624	0.13	0.55
ACA_C (Acartia clausi)	-0.038	0.162	0.374	3.51	0.32
PAR_C (Paracalanus parvus)	0.253	-0.355	0.658	1.13	0.81
OIT_C (Oithona spp.)	-0.105	0.275	-0.073	1.64	0.64
TEM_C (Temora spp.)	0.554	0.065	0.008	0.56	0.59
CEN_A (Centropages spp.)	0.338	-0.619	0.414	1.37	0.45
CAL_C (Calanus spp.)	-0.066	-0.454	-0.453	0.34	0.67
CIR_N (cirripeds nauplii)	-0.581	0.259	0.165	1.69	0.63
MYS (mysids)	-0.296	-0.313	-0.006	0.94	0.74
SAL_Z (mean salinity)	0.643	-0.137	-0.188	29.31	4.81
TEM_Z (mean temperature)	-0.293	-0.316	0.347	17.00	1.25
FLU_Z (mean fluorescence)	-0.007	0.257	0.171	0.76	0.29
CHL_Z (mean chlorophyll)	-0.205	**0.624**	-0.222	6.89	4.69
SALDZ (salinity difference)	**-0.753**	0.084	-0.034	2.03	1.49
TEMDZ (temperature difference)	0.436	0.359	0.094	0.38	0.16
FLUDZ (fluorescence difference)	0.168	0.259	-0.128	0.14	0.35
ACA_N (Acartia clausi)	0.091	**0.822**	0.161	4.44	1.21
PAR_N (Paracalanus parvus)	0.657	0.431	-0.169	2.47	1.29
OIT_N (Oithona spp.)	0.682	0.185	0.053	2.11	1.66
TEM_N (Temora spp.)	**0.731**	0.165	0.162	1.56	1.23
CEN_N (Centropages spp.)	**0.680**	0.273	0.201	1.03	1.04
TOT_N (total copepod nauplii)	0.125	**0.824**	0.133	4.49	1.21
BIV_L (bivalve larvae)	0.453	0.665	0.094	3.12	1.08
Variance	**6.61**	**5.70**	**9.91**		

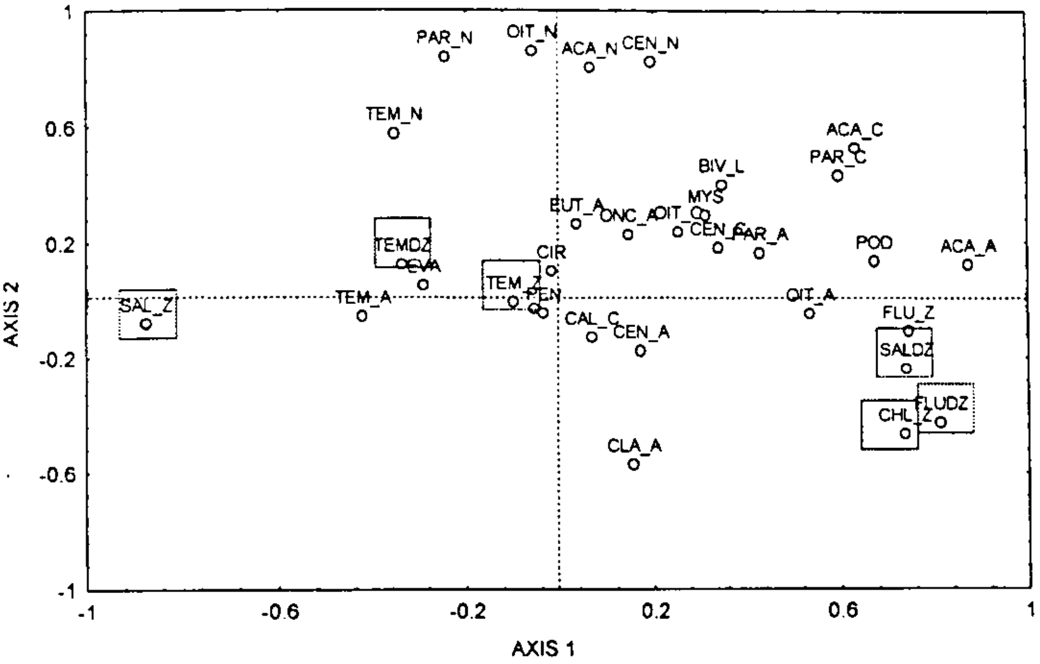
Axis 1 is positively correlated with eutrophied water characterized by high biomass of phytoplankton as measured by chlorophyll and fluorescence. The freshwater influence was noticeable in this area, reflected by the significantly negative correlation coefficient ($r^2 = -0.87$) of salinity and significantly positive correlation ($r^2 = 0.75$) with chlorophyll in axis 1. The highest difference between upper and lower water salinity (dSalinity, $r^2 = 0.75$) was observed in this area. *Acartia clausi* was significantly correlated with this axis indicating that it was the most common animal in the eutrophied water during June. Other zooplankton like *Paracalanus parvus* (C), *Podon* spp, *Oithona* spp (A) were associated with this area, but without significance.

Axis 2 represents a strong assemblage among the copepod nauplii. The naupliar stages of *Acartia clausi, Paracalanus parvus, Oithona* spp. and *Centropages* spp. show a significant positive correlation in the factor loading for axis 2. The PCA analysis indicates that these naupliar stages were not correlated with a very high biomass of phytoplankton. They prefer an intermediate salinity regime (*Fig. 3.2.14*).

Axis 3 characterizes a significant positive correlation with *Oncaea* spp ($r^2 = 0.80$). This area shows a high stratification (dT/dZ and dS/dZ) and medium chlorophyll concentration. The animals which were found positively correlated with this area were *Evadne* spp, cirriped nauplii, *Paracalanus parvus* (A), *Centropages* spp (A) and *Oithona* spp (A).

PCA of June 1994 (Axis 1 vs 2):

PCA of June 1994 (Axis 1 vs 2):



PCA of June 1994 (Axis 2 vs3):

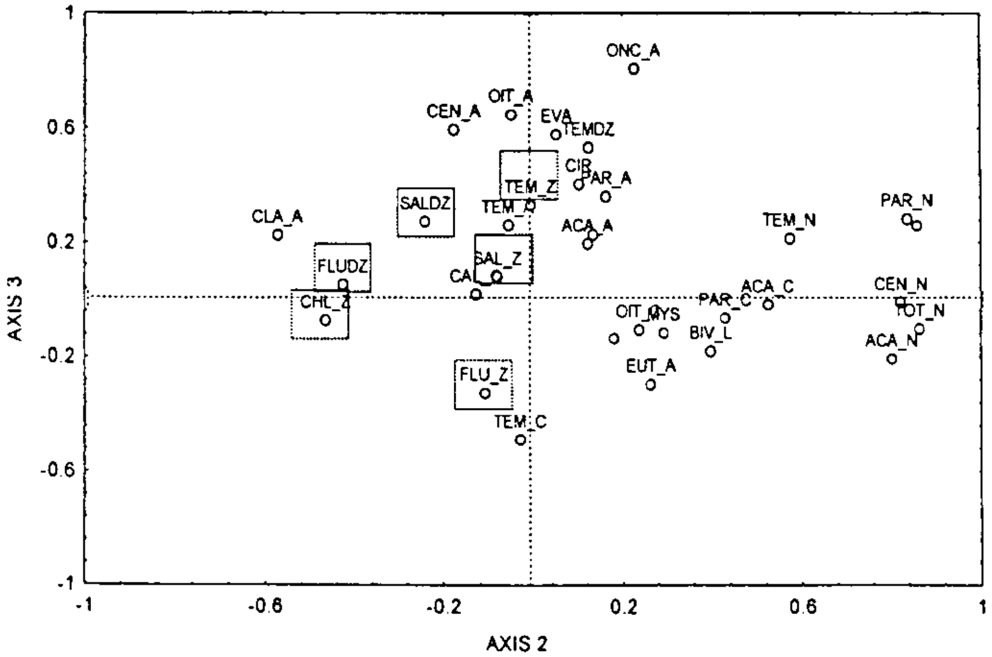
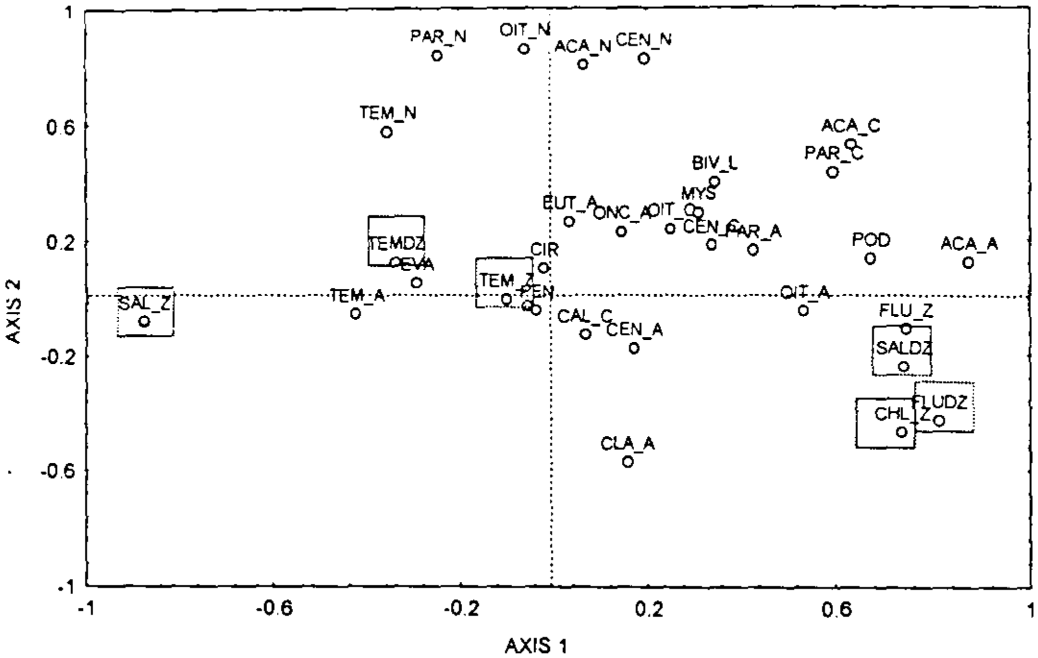


Figure 3.2.14 Principal component ordinates of the June 1994 cruise for environmental parameters and 33 biological descriptors. Codes are listed in Table 3.2.3. (a) Axis 1 vs 2; (b) Axis 2 vs 3.

PCA of June 1994 (Axis 1 vs 2):



PCA of June 1994 (Axis 2 vs3):

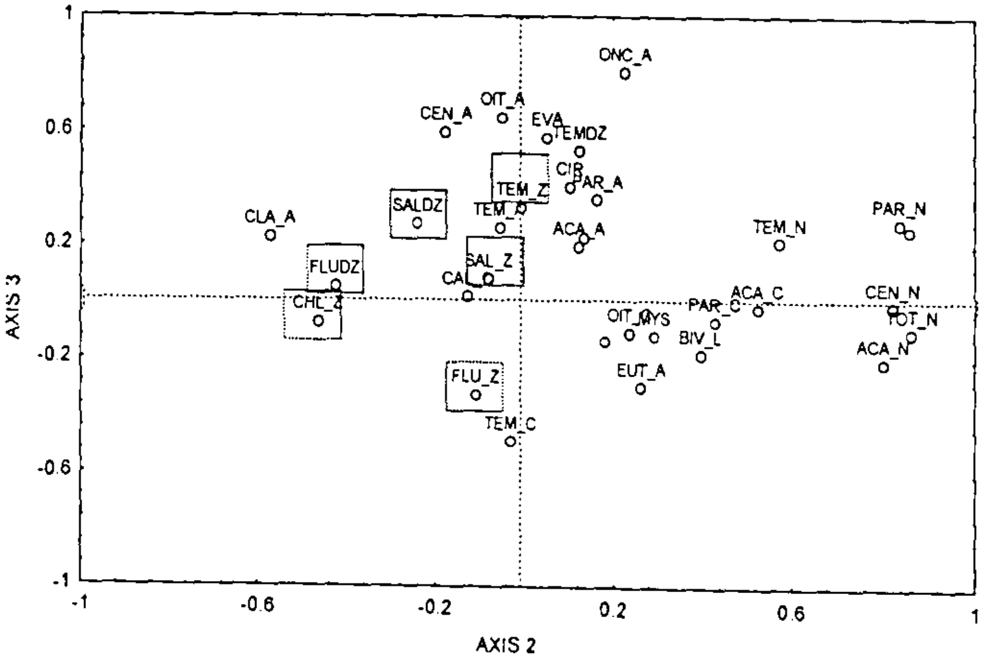


Figure 3.2.14 Principal component ordinates of the June 1994 cruise for environmental parameters and 33 biological descriptors. Codes are listed in Table 3.2.3. (a) Axis 1 vs 2; (b) Axis 2 vs 3.

3.3 Seasonal variations

An attempt was made to study the response of the zooplankton and phytoplankton dynamics in the north-western Adriatic Sea to the freshwater inflow from the River Po. A fixed station at 20 nm offshore from the Po River mouth (Position : 44.6 °N/12.5°E) was sampled during different seasons (*Fig. 2.1.8*). The flow regime of the River Po which affects the sampling station amounts to 1 000 to 1 200 m^3 s^{-1} during winter and late summer, and 2000 to 2500 m^3s^{-1} during early spring and autumn (Raicich 1994).

3.3.1 Hydrography, nutrients and phytoplankton

Seasonal variation of sea surface temperature (SST) and phytoplankton pigments are presented in *Fig. 3.31a,b*. The pattern of SST distribution was related to the variability of the Po River plume which was to a large extent dependent on the Po River discharge. The time series of the thermal infra-red images indicates that the plume is warmer than the ambient water of the northern Adriatic Sea during the period April to September and colder than the ambient water from November to March.

The historical CZCS images showed that two pronounced patterns of the seasonal pigment distribution can be observed. In summer, an offshore spreading of pigment can be depicted from the image and correlated with the warmer river-influenced water. During winter and spring, there was a characteristic confinement of colder river-influenced water which was correlated to a coastal strip with higher pigment concentration in the north-western Adriatic Sea. Sturm (1992) stated that there was no seasonally restricted pattern of pigment distribution derived from CZCS data, as both patterns may occur in summer and winter.

(1) Winter

During winter the water is well mixed at the surveyed location (*Fig.3.3.2*). A homogenous salinity (37 psu) and temperature (8°C) was recorded in the water column in January and

March 1995. A nearly homogenous profile of nitrate (5.8 to 6.3 µM) and silicate (3.7 to 4.3 µM) was measured in January. The phosphate profile, however, showed a peak in the upper layer (0.3 µM) followed by a sharp decrease in the deeper water column. Higher concentrations of nutrients with a sharply decreasing gradient down to the bottom layer were observed in late winter (March), ranging from 14.9 to 0.5 µM nitrate, and 5 to 0.5 µM silicate.

The phytoplankton biomass (chlorophyll-*a*) showed very high values in January, and two pronounced peaks , with a main peak at the surface (51.3 µg dm^{-3}) and a secondary peak in the bottom layer (47.7 µg dm^{-3}). As the winter progressed, decreasing values of chlorophyll-*a* were recorded in March, but still two pronounced peaks in the upper layer (12.3 µg dm^{-3}) and in the bottom layer (4.4 µg dm^{-3}) occurred. The highest primary production during winter measured were 200-250 µg C dm^{-3} h^{-1} with a high assimilation ratio (mean : 4 µg C µg Chl-*a*$^{-1}$ h^{-1}). Diatoms were the main constituent of the winter phytoplankton population. Phytoplankton species analysis (< 55 µm) indicated that diatoms (*Asterionella japonica*, *Chaetoceros* spp., *Coscinodiscus* spp, *Cerataulina pelagica*, *Gunardia placcida*, *Hemiaulax hauckii*, *Nitzschia seriata*, *Rhizosolenia* spp., *Skeletonema costatum*, *Thalassionema nitzschioides* and *Thalassiothrix frauenfeldii*) and dinoflagellates (*Ceratium* spp., *Diplopsalis* spp, *Prorocentrum* spp and *Protoperidinium* spp.) were frequently found in January.

(2) Spring

During spring the hydrographic profile was characterized by low salinity water at the surface spreading offshore due to high freshwater inflow from the River Po. Due to low salinity (30 psu) at the lower layer a halocline occurred at 5 m depth at this station. At the beginning of spring (April), the Po River inflow brought an enormous nutrient load into the northern Adriatic basin. A peak of silicate and phosphate concentration was found in the sub-surface layer (10 m) of this station with 72.5 µM and 1.8µM, respectively. The nitrate concentration reached its maximum value (127.1 µM) at the surface. Higher biomass of phytoplankton (55 µg dm-3 Chl-*a*) and a primary production of 37 µg C dm^{-3}h^{-1} was accompanied by a simultaneous decrease of silicate (32.2 µM) and phosphate (0.28 µM) in the upper layer. The assimilation ratio in the upper layer was 0.6 µg C µg Chl-a^{-1}h^{-1} at the beginning of spring.

The phytoplankton community was dominated by diatoms (*Chaetoceros* spp., *Coscinodiscus* spp, *Gunardia placcida*, *Hemiaulax hauckii*, *Rhizosolenia* spp, *Skeletonema costatum*, *Thalassionema nitzschioides*, and *Thalassiothrix frauenfeldii*). Dinoflagellates (*Ceratium* spp, *Gonyaulax* spp., *Protoperidinium* and *Pyrophacus* spp.) were less abundant in April.

In spring the nutrient profiles generally decreased within the water column. The diatom bloom was less pronounced in June, when the chorophyll-***a*** concentration was < 5 µg dm^{-3} in the upper layer. A decrease in the predominance of phytoplankton biomass from near the surface to the lower water column above the halocline was recorded from the fluorescence signal. In late spring, a phytoplankton succession occurred leading to dominance of dinoflagellates, namely : *Ceratium* spp, *Dinophysis cf.rotundatum*, *Gymnodinium* spp, *Prorocentrum* spp and *Protoperidinium* spp. The above mentioned species of diatoms were still present but less abundant *(Fig.3.3.2)*.

(3) Summer

An only minor Po River influence was reflected by the occurrence of higher surface salinity (33-35 psu). A strong thermal stratification characterized this season. A deep thermocline occurring at 20 m was recorded in September.

Although the euphotic zone reached down to the bottom layer, the phytoplankton biomass remained very low throughout the water column (mean : 0.5 mg.m^{-3}) due to rather low nutrient concentrations. The surface concentration amounted to only 4 µM nitrate, 0.1 µM phosphate and 3.8 µM silicate. The average assimilation ratio in the upper layer was 10 µg C µg Chl-a^{-1}h^{-1}*(Fig. 3.3.2)*.

(4) Autumn

A high freshwater inflow affected the station. Lowest surface salinities recorded were 13 psu in November and 18 psu in December. The shallow mixed layer (depth 2m) was characterized by a lower temperature than the water below.

The increase of nutrient concentrations in November and December (surface values: 10.2 to 144 µM nitrate, 0.1 to 0.44 µM phosphate and 11.1 to 35.3 µM silicate) was accompanied by an increase of phytoplankton biomass from 2.1 to 4.1 µg dm^{-3} Chl-***a*** in November and from 23.8 to 26.6 µg dm^{-3} Chl-***a*** in December. The high fluoresence signal but low total chlorophyll-***a*** concentration in November indicated that flagelattes dominated the phytoplankton population instead of diatoms. In late autumn (December), the diatom *Thalassiotrix mediterranea* dominated the phytoplankton population. Diatoms : *Asterionella japonica, Chaetoceros* spp, *Nitzschia seriata, Rhizosolenia cf.alata, Thalassionema nitzschioides* and *Thalassiothrix frauenfeldii* and dinoflagellates : *Ceratium* spp, *Dinophysis cf.caudata, Gonyaulax* spp, *Prorocentrum micans* and *P. diabolus* were also present in December. The assimilation ratio reached 1.2 µg C µg Chl-a^{-1}h^{-1}during autumn.

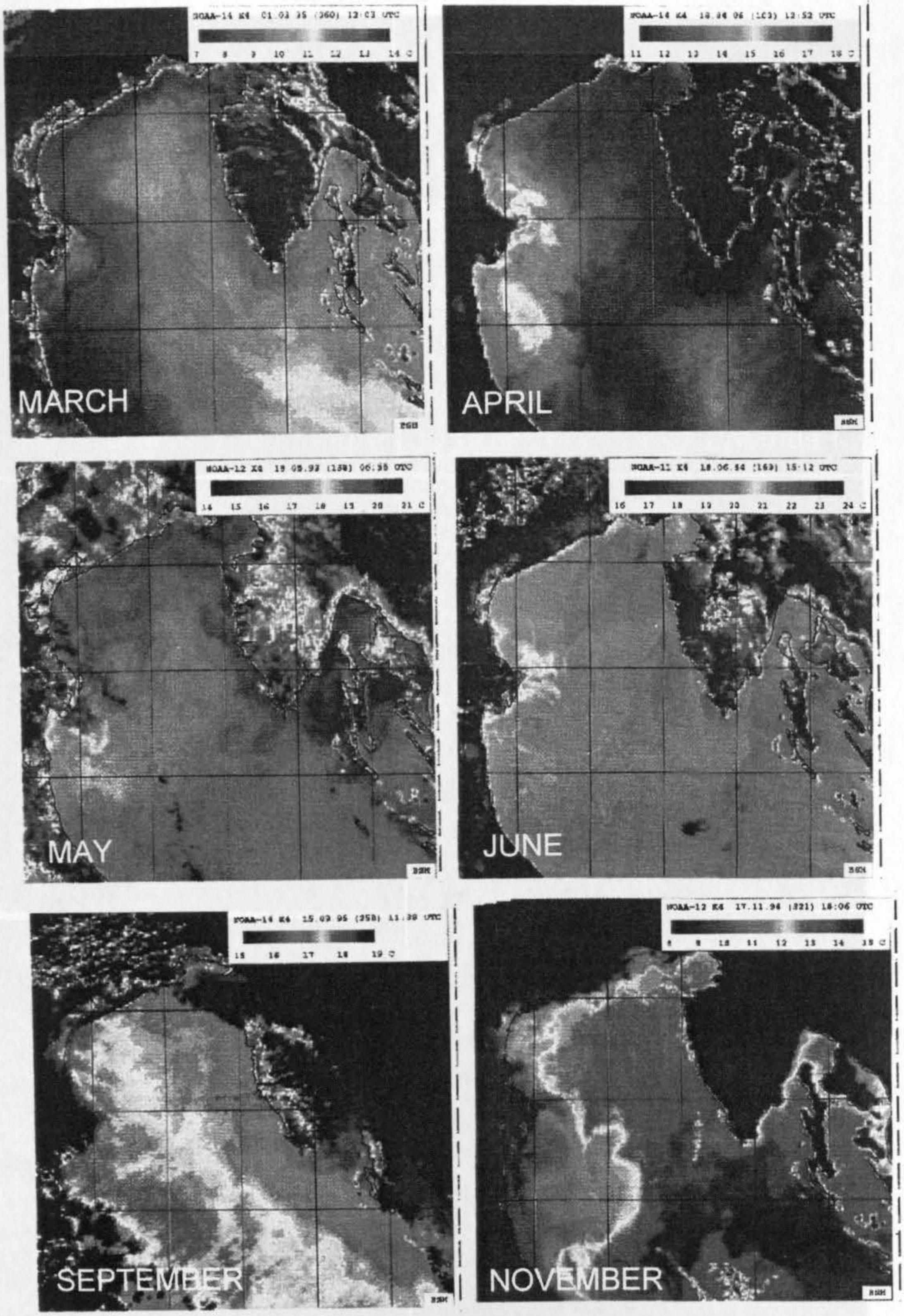


Figure 3.3.1a. Seasonal variability of sea surface temperature in the northern Adriatic Sea, derived from NOAA-AVHRR during the present study.

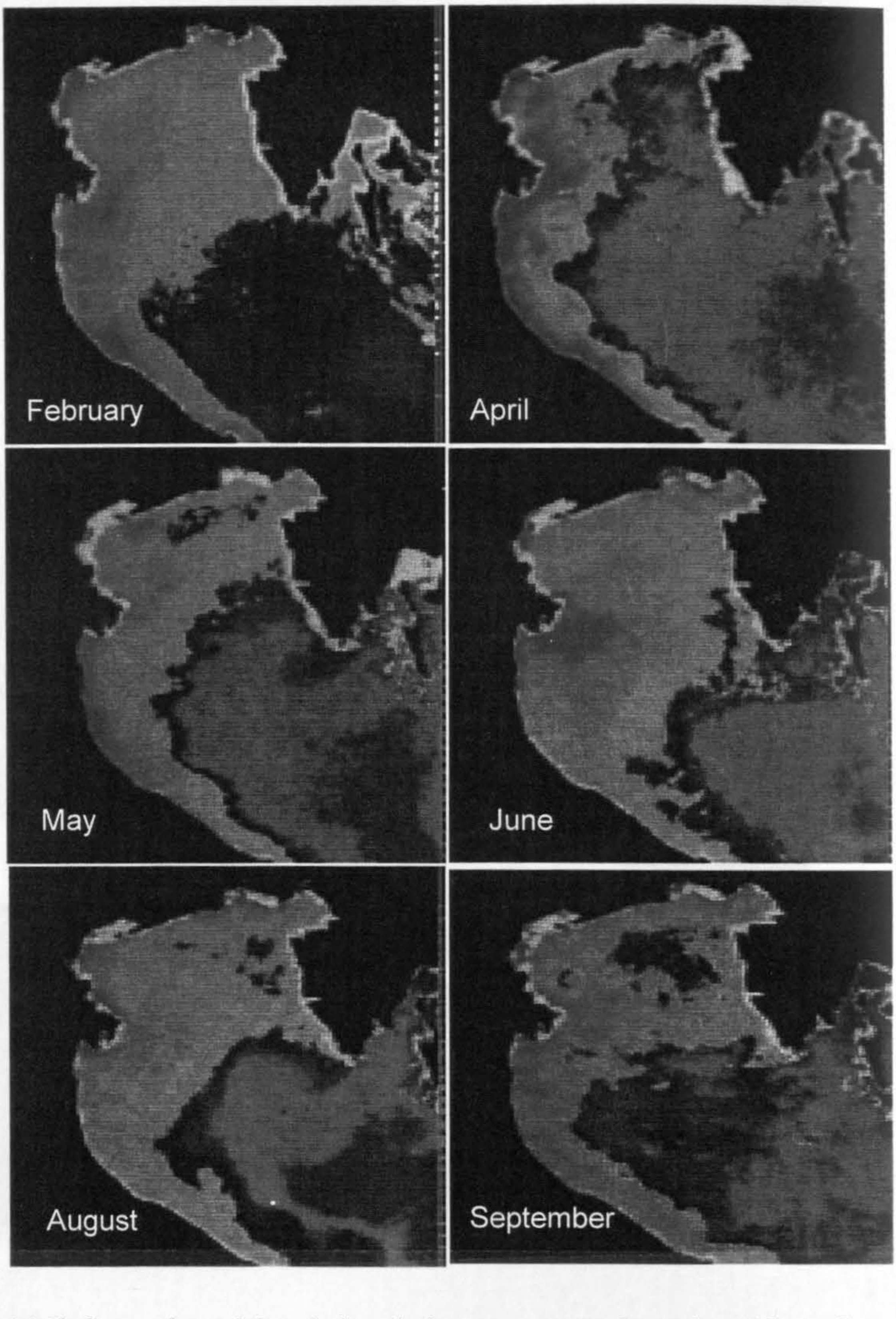


Figure 3.3.1b. Seasonal variability of phytoplankton pigments in the northern Adriatic Sea, derived from historical CZCS data (Coastal Zone Color Scanner) during 1980. Red and blue color indicate higher and lower pigment concentrations, respectively.

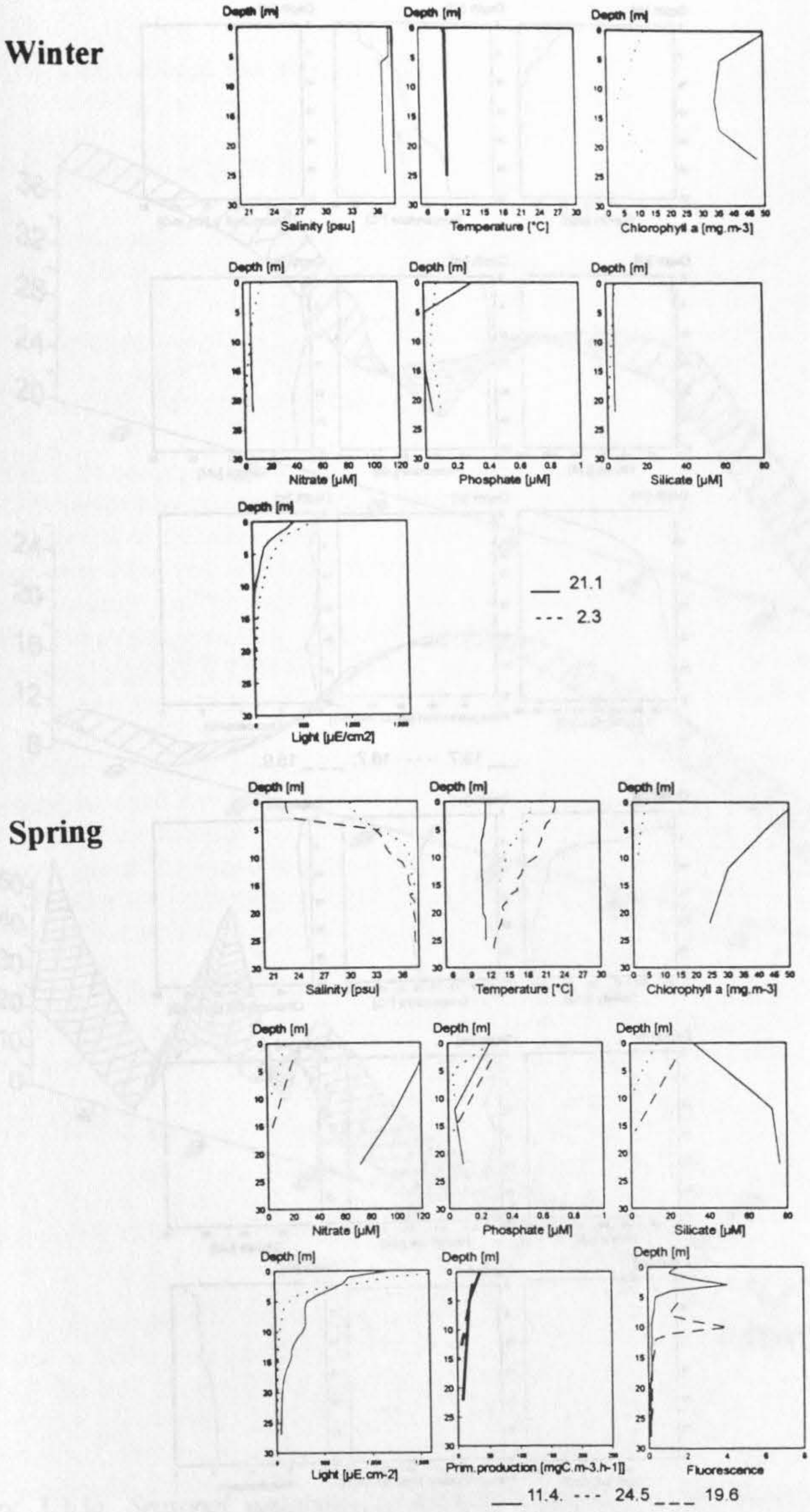


*Figure 3.3.2a Seasonal variability of vertical profiles of physical, chemical and biological parameters in the north-western Adriatic Sea: winter and spring (*1995).

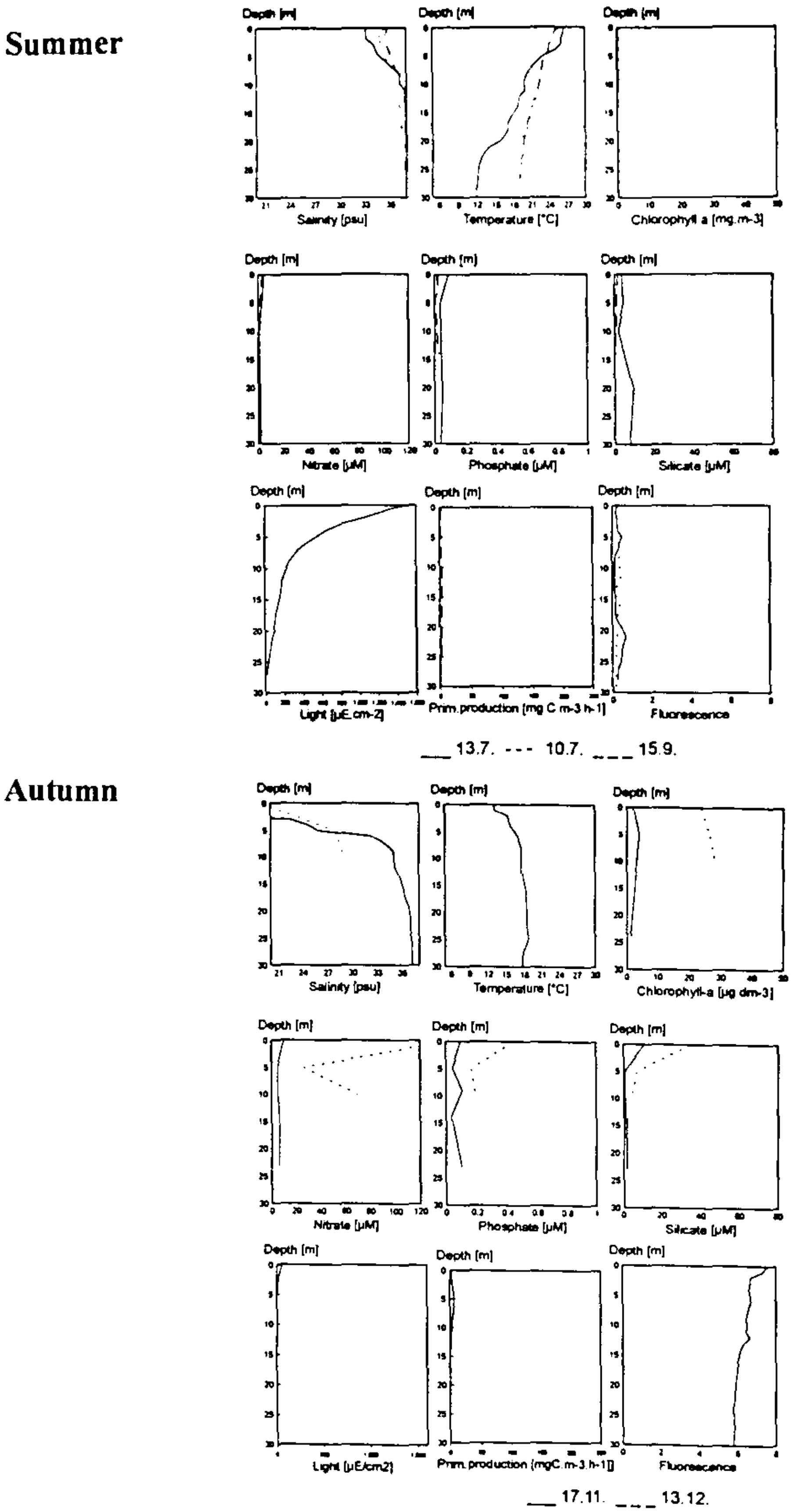


Figure 3.3.2b. Seasonal variability of vertical profiles of physical, chemical and biological parameters in the north-western Adriatic Sea: summer (1995) and autumn (1994).

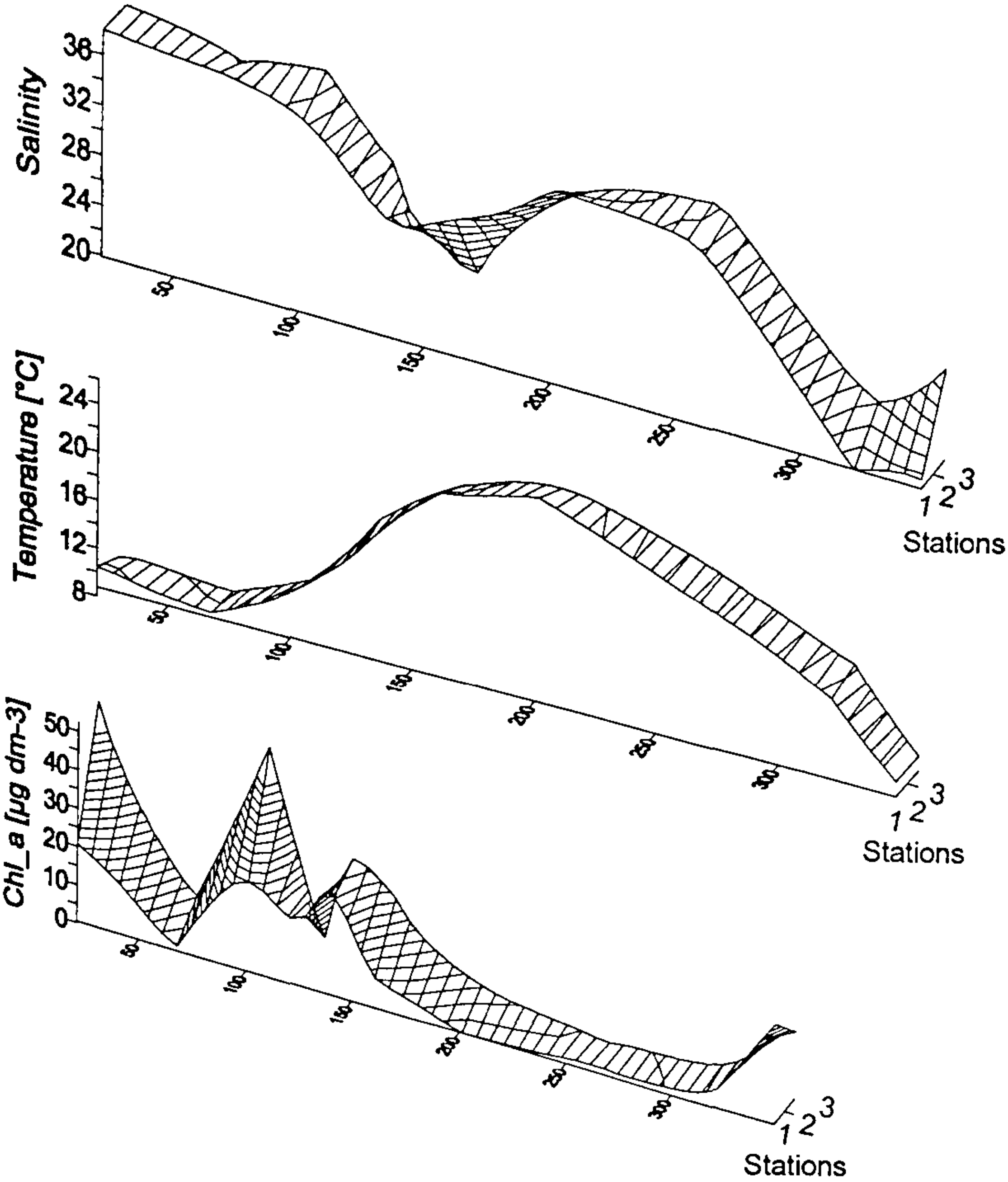


Figure 3.3.3a. Seasonal variability of salinity, temperature and chlorophyll-a at three stations in the northwestern Adriatic Sea. The data show the seasonal cycle in the mixed layer.

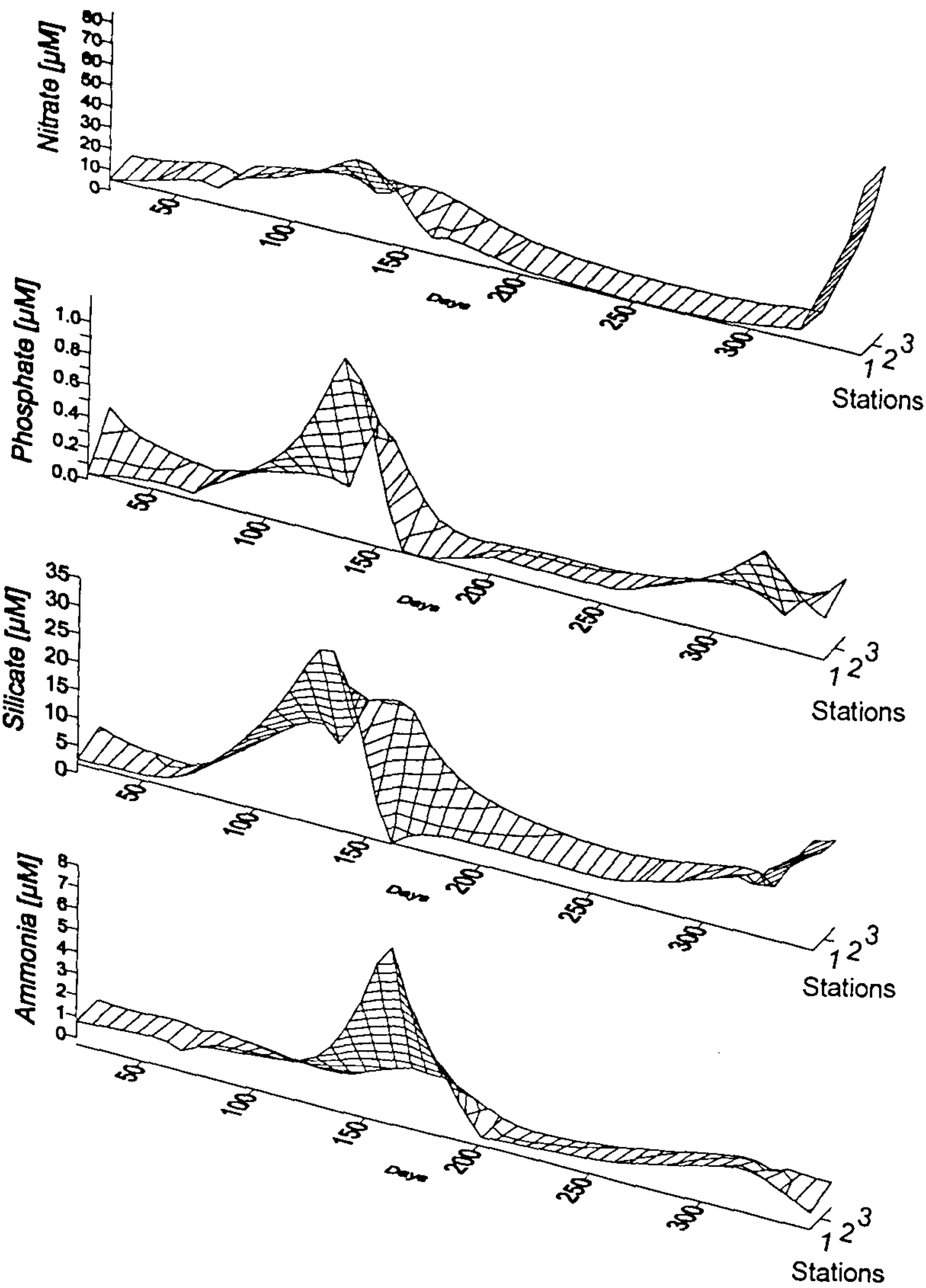


Figure 3.3.3b Seasonal variability of nitrate, phosphate, silicate and ammonia at three stations in the northwestern Adriatic Sea. The data show the seasonal cycle in the mixed layer.

3.3.2 Zooplankton variation and succession

Faunal variation illustrated by PCA

The seasonal and spatial zooplankton abundance and community structure in the northern Adriatic Sea during 1993 to 1995 is summarized and compared with the principal component analysis *(Figure 3.3.4 ; Table 3.3.1)*. The logarithm of zooplankton abundance from the fixed station and two to three samples from other stations were used to represent a group of stations on each date. Two groups of stations were then projected according to their axis (axis 1 and 2) in the components ordination.

This analysis illustrates that the difference of the zooplankton community structure or abundance between two groups of stations is not simply due to the timing of the succession; moreover they have different domains in the PCA projections. Two significant faunal differences were observed at the fixed stations. The similar magnitude of the abundance (significant loading ~ 0.7*on axis 1) was found for spring (day 67 to 130) and autumn (day 258 - 346); these compared well with zooplankton population at the beginning of sommer (significant loading at axis 2 for day 159 and 200) . The other group of stations (stations are plotted with circle) showed a clear trend of seasonal variation of zooplankton abundance.

The results of faunal difference were detected by factor loading; a significant faunal difference was indeed recorded between spring (significant loading ~ 0.7* at axis 1) and autumn (significant loading ~ 0.7* on axis 2). As shown in the axis projection, the zooplankton abundance variation was sometimes quite high, for example on day 67 (March) and 348 (December), possibly related to higher river inflow; however, the variability between the adjacent stations is relatively small compared with the temporal variations.

At all stations, the temporal development was represented by a movement to the left along axis 1, starting from May (day 130) to September (day 255), then turning to the right along the same axis. Because the principal component 1 (Axis 1) is positively related to the zooplankton biomass and to most taxa, especially to those with the highest abundance, this distribution pattern generally reflects an increase or decrease in biomass, respectively.

Faunistic grouping with respect to the environment

The PCA was carried out with 23 biological descriptors and with environmental parameters introduced as complimentary variables *(Table 3.3.1)*. It was possible to determine and to classify 7 faunistic groups of biological descriptors. In order to interpret the relation between the biological descriptors and the complimentary variables, salinity and temperature as hydrographical parameters and chlorophyll *a* as biological parameter, they were projected as the axes 1,2 and 3 (*Fig.3.3.5*).

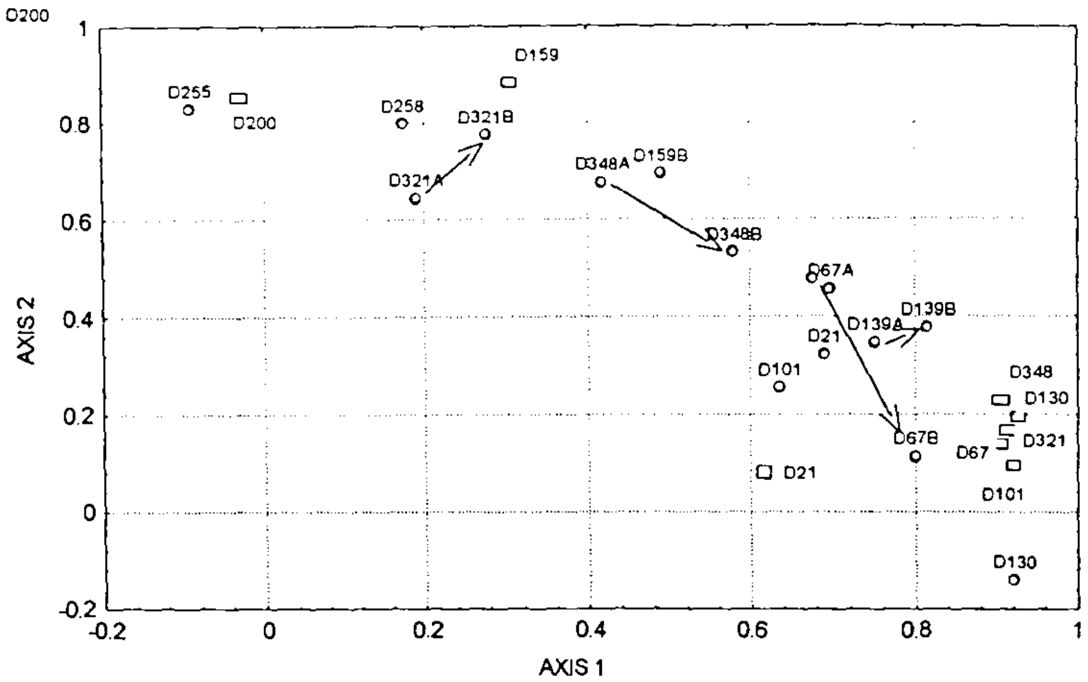


Figure 3.3.4 Principal components ordinates of stations at the fixed station (square) and the neighbouring stations (circle) in the northern Adriatic Sea. Labels are days of the year. Arrows demonstrate the relative distance in the axis projection of the PCA between two stations.

The following 7 faunistic groups were used:

H1: Nauplii of *Acartia clausi*, *Paracalanus parvus* and total copepod nauplii.
H2: Zooplankton biomass (AFDW), *Acartia clausi* (CI-CVI) and total copepods (CI-CVI).
H3: *Oithona* spp (N), *Temora* spp (N), *Centropages* spp (N), *Clausocalanus* spp (CI-CVI)and *Temora* spp (CI-CVI), *Corycaeus* spp and *Sagitta* spp.
H4: *Paracalanus parvus* (CI-CVI), *Oncaea* spp (CI-CVI), *Centropages* (CI-CVI) and Appendicularia.
H5: *Evadne* spp, *Penilia avirostris* and *Euterpina acutifrons*.
H6: *Oithona* spp (CI-CVI).
H7: *Podon* spp.

Table.3.3.1. Component loading for the principal component analysis of seasonal zooplankton and environmental data illustrated in Fig.3.3.5 . Components were extracted from a covariance matrix based on log (n+1) transformed data. Axes were rotated using the Varimax method. (A), (C) and (N) represent adult, copepodites and nauplii, respectively. Bold print = significant relationship.

Variables	Axis	Axis	Axis
	1	2	3
(Salinity)	-0.115	-0.209	-0.089
(Temperature)	-0.464	0.581	0.415
(Chlorophyll-*a*)	-0.187	-0.400	-0.214
N0$_3$ (Nitrate)	-0.121	-0.470	-0.180
PO$_4$ (Phosphate)	-0.380	0.344	0.178
SI0$_3$ (Silicate)	-0.277	-0.283	0.413
NH$_4$ (Ammonia)	-0.304	0.237	-0.155
AFDW (zooplankton biomass)	0.441	0.040	0.599
ACA_N (Acartia clausi-nauplii)	**0.815**	-0.232	0.028
ACAR (Acartia clausi -CI-CV)	0.156	-0.108	**0.740**
PAR_N (Paracalanus parvus -nauplii)	**0.937**	-0.003	0.038
PARA (Paracalanus parvus -CI-CVI)	0.175	0.562	0.467
OIT_N (Oithona spp.- nauplii)	**0.676**	0.142	0.055
OITH (Oithona spp.-CI-CV)	0.028	-0.293	0.612
TEM_N (Temora spp.-nauplii)	**0.793**	0.133	0.227
TEMO (Temora spp.-CI-CVI)	0.435	0.470	0.081
CEN_N (Centropages spp.-nauplii	**0.700**	0.260	0.364
CENT (Centropages spp.- CI-CVI)	0.121	0.378	0.628
COPE_T (total copepod nauplii)	**0.920**	-0.117	-0.013
ONCA (Oncaea spp.-CI-CVI)	0.325	0.465	-0.007
CLAU (Clausocalanus spp.-CI-CVI)	0.620	0.311	0.142
EUTE (Euterpina acutifrons)	0.038	**0.755**	-0.250
CORY (Coryceaus spp.)	0.562	0.363	-0.004
COPE_T (total copepods)	0.255	0.131	**0.876**
EVAD (Evadne spp)	-0.168	**0.757**	-0.052
POD (Podon spp)	-0.443	0.167	0.626
PENI (Penilia avirostris)	0.004	**0.893**	0.104
APPE (Appendicularia)	0.207	0.330	0.320
SAGI (Sagitta spp.)	0.556	0.526	-0.042
BIVA (Bivalve larvae)	-0.203	-0.413	0.619
Variance	**6.50**	**4.95**	**4.32**

Axis 1- Salinity, chlorophyll *a*, silicate and nitrate are located in the negative domain of axis 1. On the contrary, most of the copepod nauplii have significantly positive loading coefficients along axis 1. Thus, the total zooplankton biomass (AFDW) was closely related to the main zooplankton components : *Acartia clausi* occurred oppositely to high salinity water, high chlorophyll *a*, silicate and nitrate. The zooplankton groups H1 and H3 were not correlated with high chlorophyll-*a* and nutrients . Therefore this axis represents the situation in late autumn at the beginning of winter, characterized by high river inflows carrying high nutrients loads, thus very high chlorophyll *a* concentration occur during this time of the year in the northern Adriatic Sea.

Axis 2- The influence of high water temperature is demonstrated clearly by this axis. Temperature, phosphate and ammonium were correlated positively with axis 2. The biological predictors of group H5 including Cladocera (*Evadne* spp, *Podon* spp and *Penilia avirostris*) were strongly linked to high temperature (warmer months). Moreover, most of the biological predictors were found positively correlated within axis 2, namely : H4 (*Paracalanus parvus* (CI-CVI), *Oncaea* spp (CI-CVI), *Centropages* (CI-CVI) and Appendicularia) and H3 (*Oithona* spp (N), *Temora* spp (N), *Centropages* spp (N), *Clausocalanus* spp.(CI-CVI), *Temora* spp (CI-CVI), *Corycaeus* spp and *Sagitta* spp. Therefore, axis 2 represents a summer system.

Axis 3- This axis shows which of the biological variables were affecting the zooplankton community structure. The abundance of the main zooplankton component with respect to the zooplankton biomass, *Acartia clausi* (~70% of total copepod abundance) was strongly correlated with this axis. A spring system is related to this axis. High zooplankton biomass and high bivalve larvae were recorded within lower salinity water in the northern Adriatic Sea.

Temporal changes of the biological descriptors

Group H1: The nauplii of *Acartia clausi* were one of the frequently occurring species during the year with a density of 30 000 ind m^{-3} from autumn to late spring; no nauplii were found in summer. Therefore, in the north-western Adriatic Sea, a negative correlation of the *Acartia* nauplii ($r = -0.4^*$) and total nauplii ($r = 0.41^*$) with temperature existed, but a positive correlation (r = 0.4*) was found between the naupliar stage and the older generation. Within the group H1, the seasonal variation of the main components of the copepod nauplii (*Paracalanus, Oithona, Temora* nauplii) showed a similar pattern as the naupliar stage of Acartia. The annual pattern of the naupliar stage of copepods related closely to the chlorophyll variation, although there was no significant correlation. Most of the naupliar stages were stongly correlated with the older stages (copepodite stages). A negative correlation between density of copepod nauplii with phosphate (r = - 0.41*) and between the density of *Paracalanus* nauplii with silicate (r = - 0.31*) were recorded *(Fig. 3.3.6).*

Group H2: *Acartia clausi* (CI-CVI) was the main component of zooplankton biomass, supported by a strong correlation of the *Acartia* biomass with zooplankton biomass (r = 0.4*) and with total copepod biomass (r = 0.7**). A peak of 12 600 ind m^{-3} (70 % of total copepod biomass) occurred in late spring (May); its contribution to the total zooplankton biomass was ~ 90 mg C m^{-3}. At the beginning of spring, minimum values of 10 ind m^{-3} represented only 1 % of total copepod number. Therefore, during spring the contribution of *Acartia clausi* is negligible. The correlation of *Acartia clausi* with the chlorophyll-*a* was very strong, a relatively strong negative correlation existed with salinity (r = -0.36*) and higher silicate concentration (r = 0.36*). *Acartia* is known to survive in low chlorophyll waters and is present during the year adapting to various forms of food. Therefore it can be considered as omnivorous (*Fig. 3.3.6b*).

Group H3: The copepod *Temora* spp. (*T. longicornis* and *T.stylifera*) reached a population level of ~ 3 000 ind.m^{-3} and attained 40% of the zooplankton abundance in late summer. Their naupliar stages also belonged to this group. The seasonal pattern of *Temora* spp. and their stages was strongly linked to its food, thus an active consumption of chlorophyll ***a*** was deducted from the significant negative correlation beetwen them (r = - 0.55 **). Other copepods that occurred in group H3 were *Clausocalanus* spp and *Corycaeus* spp.; both showed a similar annual variation as *Temora* spp. All members belonging to this group H3 showed were negatively correlated with nitrate (r = -0.33*).

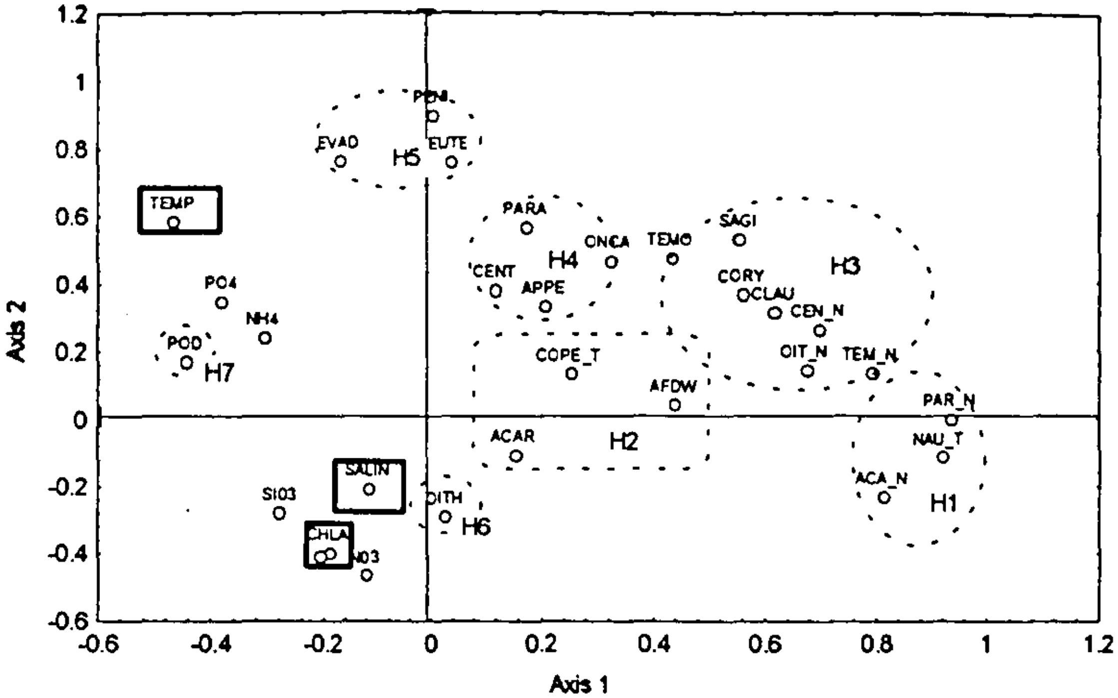


Figure 3.3.5a. Principal component analysis conducted with 23 biological descriptors and environmental variables. Projection of Axis 1 and Axis 2.

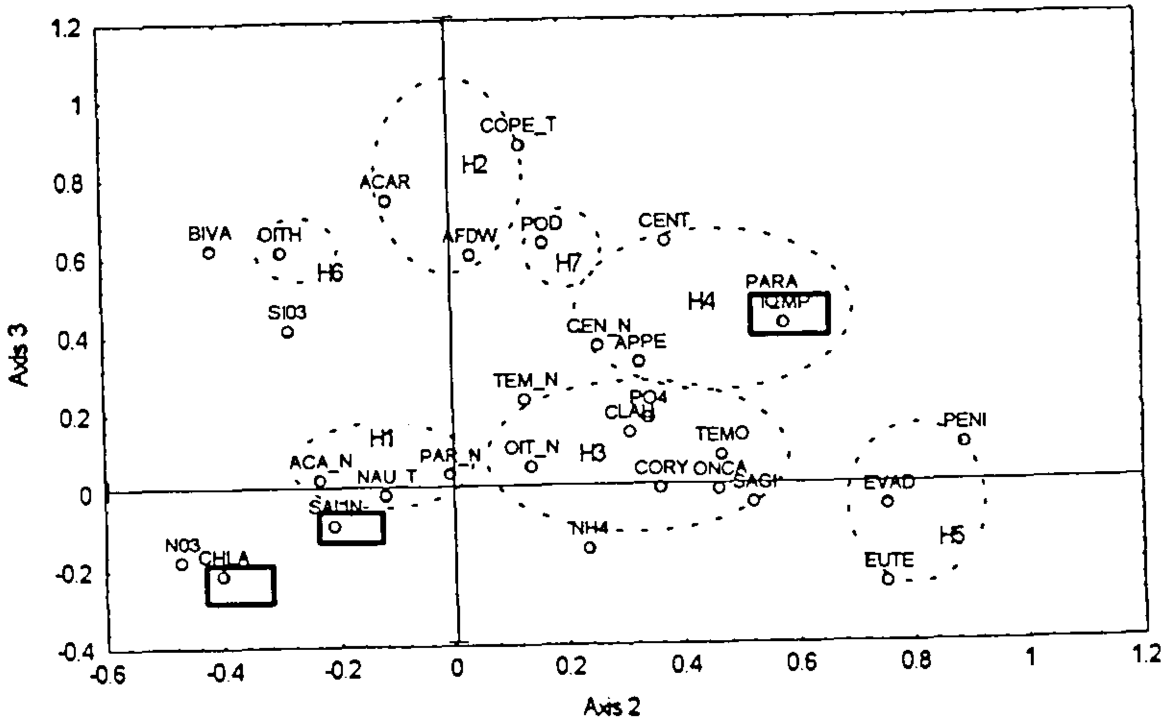


Figure 3.3.5b. Principal component analysis conducted with 23 biological descriptors and environmental variables. Projection of Axis 2 and Axis 3.

The non-copepod member of this group was *Sagitta* spp. which were totally absent during spring. This animal, is known to be carnivorous, showed a weakly negative correlation with chlorophyll-*a*. A significant correlation (r = 0.55**) was recorded between Sagitta and a corresponding *Paracalanus* nauplii.

Group H4: The annual variation of *Paracalanus parvus* was relatively homogenous. Its maximum abundance 10 000 ind m^{-3} occurred in autumn and was obviously correlated with temperature (r = 0.46*). For *Oncaea* spp. (dominant species *O.media*) in the same group, the correlation with temperature was not as strong; however, a significant negative correlation with salinity existed (r = -0.43*). *Paracalanus parvus* was correlated weakly with chlorophyll-*a*. This species is known to be omnivorous or even detritivorous. The annual variation of *Oncaea* showed also a peak in autumn (3 500 ind m^{-3}) and adult *Oncaea* carrying eggs dominated. *Centropages* spp (dominant : *C.typicus*) was closely related to this group, while its biomass moderately correlated with temperature (r = 0.3). The contribution of *Centropages* was less important (200 ind m^{-3}) for the total copepod population during the year. The non-copepod Appendicularia (*Oikopleura* spp.) known to be herbivorous, and correlated negatively with chlorophyll-*a* (r = -0.4*) and nitrate concentrations (r = -0.4*).

Group H5: *Euterpina acutifrons* represented this group. Its geographical distribution is wide. In the northern Adriatic Sea, it recruits successfully from late summer to autumn, possibly related to the availaibility of prey, such as nauplii and microzooplankton. Cladocera *Evadne* spp (*E. nordmanni*, *E. tergestina* and *E. spinifera*) and *Penilia avirostris* were also present in this group; their abundance increased between summer and autumn. The correlation coefficient reached r = 0.6** for *Evadne* spp with water temperature and r = 0.7 for *Penilia avirostris* with water temperature. In mid-summer, *Penilia avirostris* was found to be strongly abundant (10 000 ind m^{-3}), indicating good development conditions under the influence of lowest freshwater inflows. This was indicated by a significant negative correlation of r = -0.4* for *Penilia avirostris*/nitrate and r = -0.4 for *Penilia avirostris*/chlorophyll-*a*.

Group H6: Three species of Oithona were present (*O. similis*, *O. plumifera* and *O. nana*) in this group and they strongly correlated with high salinity (r = 0.45*). A high biomass was recorded for the young generation of *Oithona* spp. (3 000 - 4 000 ind m^{-3}) in late winter. Mature females carrying eggs were frequently found in autumn (November).

Group H7: The Cladocera *Podon* spp. (*P. polyphemoides* and *P. leucarti*) represented this group. Very high abundances (3 000 - 4 000 ind m^{-3}) occurred at the beginning of spring; their stock decreased slowly towards the summer, and then suddenly dropped in the autumn. Like the other Cladocera in the group H5, *Podon* spp correlated strongly with water temperature ($r = 0.7^{**}$) and the nutrients ($r = 0.5^{*}$ for *Podon*/phosphate and $R = 0.5^{*}$ for *Podon*/silicate).

Zooplankton succession

(1) Copepods

Acartia clausi

The abundance of the naupliar stages of this species was high, with an annual mean of 300± 50 ind m^{-3} (26 % of the total number of copepod nauplii on an annual average), and a main maximum in spring during March-May (~ 20 000 ind m^{-3}). However, a significant drop in its biomass (>1 000 ind m^{-3}) was recorded in April. A secondary peak occurred in autumn during November-December (3000 ind.m^{-3}). After the spring maximum, the abundance of *Acartia* nauplii dropped, and no specimens were found in June. The abundance of *Acartia* nauplii again increased from late summer (September) to the end of autumn (*Fig.3.3.6b*).

The distribution pattern of the copepodites and adults of *Acartia clausi* (CI-CVI) followed its nauplii distribution during the year. The annual mean was ~ 1 300 10 ind m^{-3} (29 % of the total copepod number on an annual average). *Acartia clausi* (CI-CVI) showed a succession of three peaks during the year, i.e. in March (5 000 ind.m^{-3}), in May (13 000 ind m^{-3}) and in November (7000 ind m^{-3}). As observed for its naupliar biomass, a decrease was also recorded for the CI-CVI population in April, leading to the lowest abundance found. A second peak of a mixed population of *Acartia clausi* (different copepodite stages) occurred in

May and contributed about ~ 90 % of the copepod population at the same time. The development of the *Acartia* population from its naupliar stages to its copepodite stages took place after spring, indicated by the gradual removal of the successive stages of this species from CI to CV during the progression of the summer months. *Figure 3.3.7* shows two periods of recruitment of *Acartia clausi*. The winter generation was recruited by the nauplii in autumn; the spring generation was discernible from the hatching of its nauplii in March. The oldest population of *Acartia clausi* was recorded in July, represented by the CV-CVI stadium. Unfortunately, there are no data from August. The biomass of the male population was strongly correlated with chlorophyll-***a*** (r = 0.42*) as shown by two peaks of the sex ratio in May and November.

Paracalanus parvus

The annual mean density of *Paracalanus parvus* nauplii (300 40 ind m^{-3}) was significantly more variable (variation coeff. : 66%) than the mean number of *P.parvus* (CI-CVI), which showed smaller fluctuation (800 4 ind m-^{3}, with variation coeff. : 20%) throughout the year (*Fig.3.3.6c*).

A sharp decrease of the naupliar biomass occurred in April (10 000 ind m^{-3}), while in June a complete removal was observed. Thereafter, it recovered again in September (2 000 ind m^{-3}) and reached its maxima in November (70 000 ind m^{-3}). During winter its abundance ranged from 3 000 to 5 000 ind m^{-3}. The fluctuation of the naupliar stage of *P.parvus* was attributed to the temperature; in the colder months higher numbers of naupliar stages were recorded (r = - 0. 35*). Due to taxonomic difficulties, the abundance of *Clausocalanus* nauplii added to that of *Paracalanus* nauplii.

Paracalanus parvus (CI-CVI) was present throughout the year, with a peak abundance occurring in November (~ 10 000 ind.m^{-3}). An increasing abundance was recorded from spring to autumn strongly correlated with temperature. The numbers of males were very high in the colder months (r = - 0.61** for sex ratio/temperature), showing peaks in December and March.

Oithona spp.

The seasonal distribution pattern of the *Oithona* nauplii was similar to that of the other copepod nauplii, with peaks in spring (max : 50 000 ind m^{-3} in April) and in late summer (20 000 ind m^{-3} in September). The absence of naupliar stages of this genera was recorded in March, June - August and December. Therefore, a very high variation coefficient of their abundance (44 %) was calculated (*Fig.3.3.6d*). Three *Oithona* species were sampled in the northern Adriatic Sea : *O. similis*, *O. nana* and *O. plumifera*. The mean annual abundance of these species was 400 ind m^{-3} and they contributed to 10 % of the total copepods throughout the year. The total *Oithona* species decreased almost linearly from spring (max : 4 800 ind m^{-3} in May) to late autumn (min : < 100 ind m^{-3} in December). The mean contribution of each species to the population structure of the genus was for *O. similis* (45 %) , *O. plumifera* (28 %) and *O. nana* (27 %).

An annual cycle could not be clearly identified due to the overlapping of the three species. However, a temporal shift in the average seasonal cycle of *O.similis* was recognized. *O.similis* (mean : 2 100 ind m^{-3}) and *O.nana* (mean : 200 ind m^{-3}) showed quite a high number during summer, whereas *O. plumifera* was almost absent. During an average annual cycle, *O. similis*, *O. nana* and *O. plumifera* followed each other with a maximum abundance in spring-summer (April-July), summer (June-July) and autumn-winter (November-March), respectively. The mature females of *Oithona* species with egg sacs were frequently found from late summer (July) to autumn (November). Males were present during winter, as shown by the high sex ratio (*Fig.3.3.6e*).

Temora spp.

The genus Temora comprised of *T.stylifera* and *T.longicornis*. Two similar abundance peaks (~ 1 000 ind m^{-3}) of their naupliar stage were recorded during spring and autumn. No naupliar stocks were present in summer. The nauplii of both *Temora* species accounted for 15 % of the mean annual abundance of the total copepod nauplii assemblages (*Fig.3.3.6f*).
Their annual mean contribution to the total copepod standing stock was relatively small (mean : 50 ind m^{-3} or ~ 1%). Three peaks of their stocks were observed in March (~ 200 ind

m^{-3}), May (~ 500 ind m^{-3}) and September (~ 1 500 ind m^{-3}). Therefore, its variation coefficient was very high (60 %). Males frequently occurred in autumn, as indicated by the peak of sex ratio, and they were strongly correlated with lower salinity ($r = -0.4^*$).

Centropages typicus

The naupliar stages of *C.typicus* contributed only 11 % of the five dominant copepod nauplii throughout the year. The annual density of its nauplii was ~ 100 ind m^{-3}. The maximum of its nauplii occurred in autumn (November), whereas negligible values were recorded during winter (*Fig.3.3.6g*).

The average seasonal cycle of its abundance was very small (20 8 ind m^{-3}) and contributed less than 1% to the total abundance of copepods. The seasonal cycle of abundance of the older stages (CI-CVI) varied from winter to spring and showed a slow increase in spring and a maximum lasting from July to November (100 ind m^{-3}). In autumn, the stock was highly dominated by males.

Oncaea spp.

The average annual contribution of the *Oncaea* species (*O. media* and *O. subtilis*) was small (~ 1%); their annual mean was ~ 25 ind m^{-3}. An increasing abundance of *Oncaea* was recorded from July (~ 10 ind m^{-3}) to November (~ 1 000 ind m^{-3}). In winter, their stock was maintained at around 100 ind m^{-3}, whereas no specimens were recorded during spring (*Fig.3.3.6e*).

Clausocalanus spp.

The mean annual contribution of the *Clausocalanus* species to the total copepod abundance was negligible. Two peaks of abundance were recorded (~ 1 000 ind m^{-3}), in spring (April) and autumn (November). A minimum abundance of *Clausocalanus* was observed during summer (*Fig.3.3.6h*).

Euterpina acutifrons

A major contribution of *E.acutifrons* to the total copepod abundance was observed during summer. A maximum occurred in July (~ 3 000 ind m^{-3}), whereas its mean annual contribution was less important. The mature female of *E.acutifrons* carrying eggs dominated its autumn population (*Fig.3.3.6h*).

Corycaeus spp.

Coryacaeus species were mostly found between autumn and summer. Their maximum reached only ~ 100 ind m^{-3} (*Fig.3.3.6h*).

(2) Cladocera and other zooplankton

Cladocerans were responsible for the major peak of total zooplankton abundance in summer primarily due to *Penilia avirostris* (~ 50 %) and, to a lesser extent, to *Evadne* spp and *Podon* spp. A sharp increase of the *P.avirostris* population was recorded in July, thereafter its population was relatively stable with 10 000 ind m^{-3} in November, while its stock dropped in December (*Fig.3.3.6i*).

The *Podon* species appeared in late spring (May). Their stocks were 2 000 ind m^{-3}; thereafter a slight decrease was recorded during summer. No specimen of *Podon* was caught during winter (*Fig.3.3.6i*).

The *Evadne* species reoccurred in April. Their number increased during the summer months with a maximum reached in September (500 ind m^{-3}). Similar to other Cladocera groups, *Evadne* was not found during winter (*Fig.3.3.6i*).

Appendicularia.

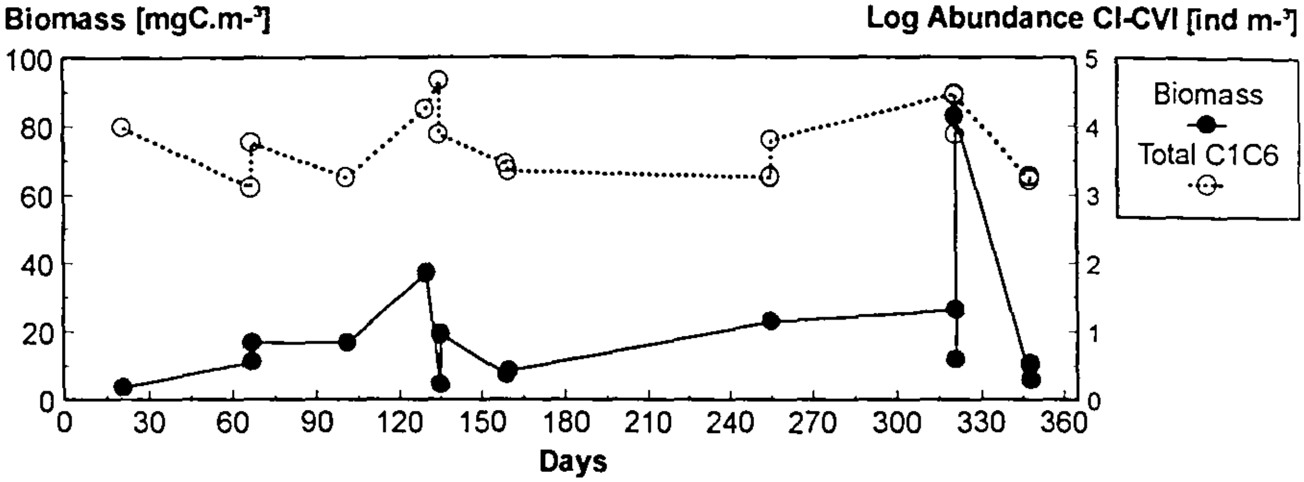
The planktic tunicates (*Oikopleura* spp. and *Fritillaria* spp.) were present throughout the year, with four maxima of similar abundance (~ 300 ind m^{-3}). In Mediterranean waters, the Appendicularia was reported to be dominant in winter (MAZZOCHI & RIBERA D'ALCALA 1995). However, during this survey there were no sufficient data available to depict their seasonal cycles due to very low and scattered numbers (*Fig.3.3.6j*).

Sagitta spp.

The annual mean contribution of the genus *Sagitta* was very small. Their annual cycle showed two peaks at the beginning of spring (~ 100 ind m^{-3}) and in autumn (~ 20 ind m^{-3}). No animal was caught from May to September (*Fig.3.3.6j*).

Meroplankton

Bivalve larvae were the most important component of the meroplankton group in the northern Adriatic Sea, especially during spring. Their maximum was recorded in May (~1000 ind.m^{-3}). Their number decreased toward the end of summer. They occurred in low numbers towards autumn and winter (*Fig.3.3.6j*).



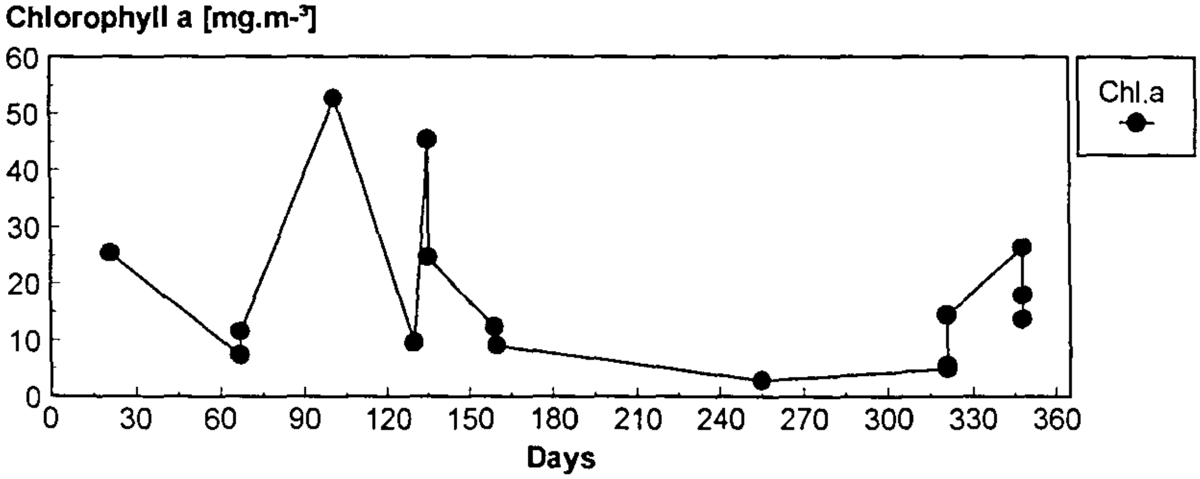


Figure 3.3.6a. Seasonal variation of zooplankton biomass, copepod abundances and chlorophyll-a in the north-western Adriatic Sea. Position of the station in Fig. 2.3.1. (page 12)

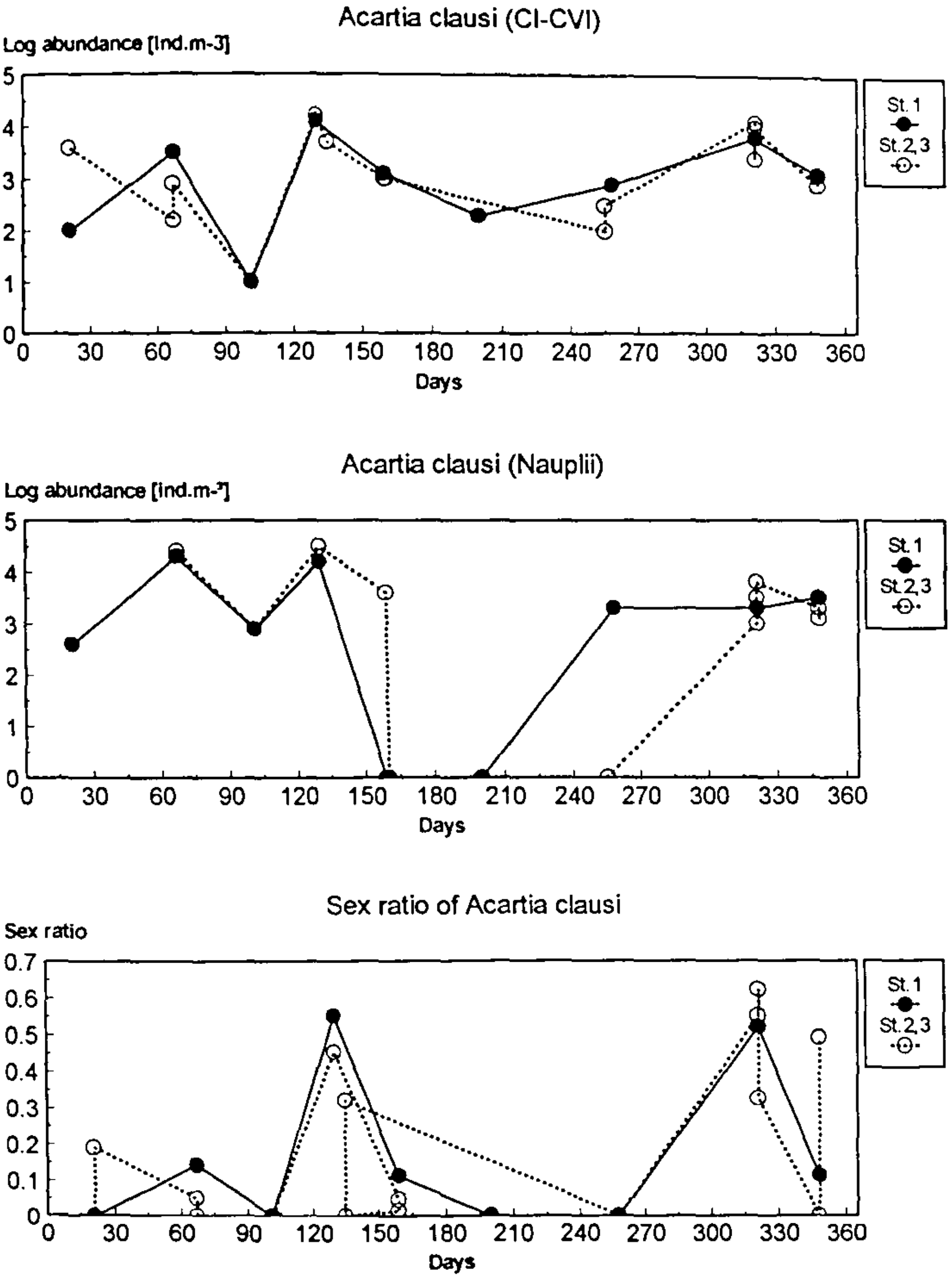


Figure 3.3.6b. Seasonal variations of abundance of the most common copepod and its sex ratio (male/adults) in the north-western Adriatic Sea: ***Acartia clausi***

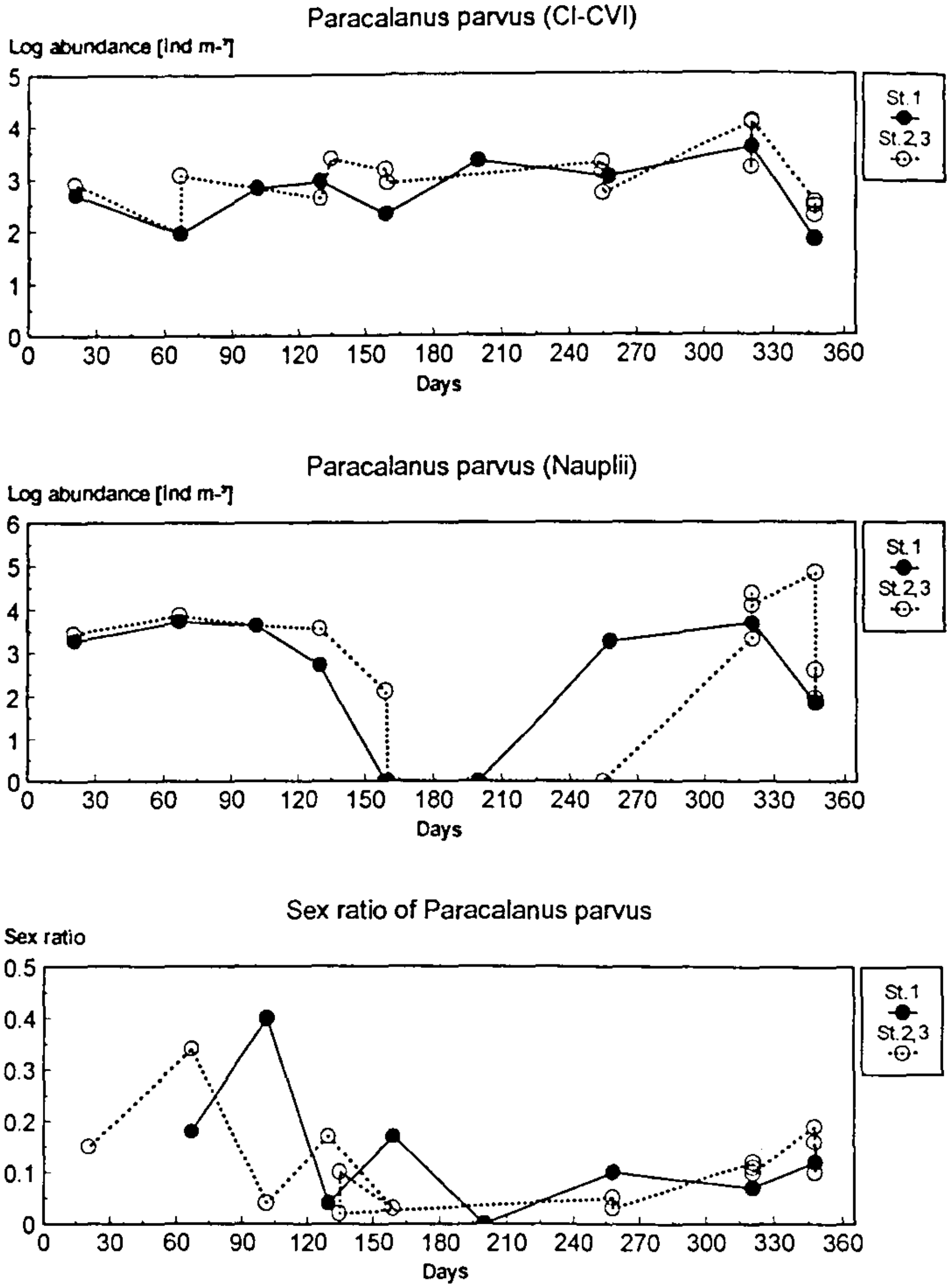


Figure 3.3.6c. Seasonal variations of abundance of the most common copepod and its sex ratio (male/adults) in the north-western Adriatic Sea: ***Paracalanus parvus***

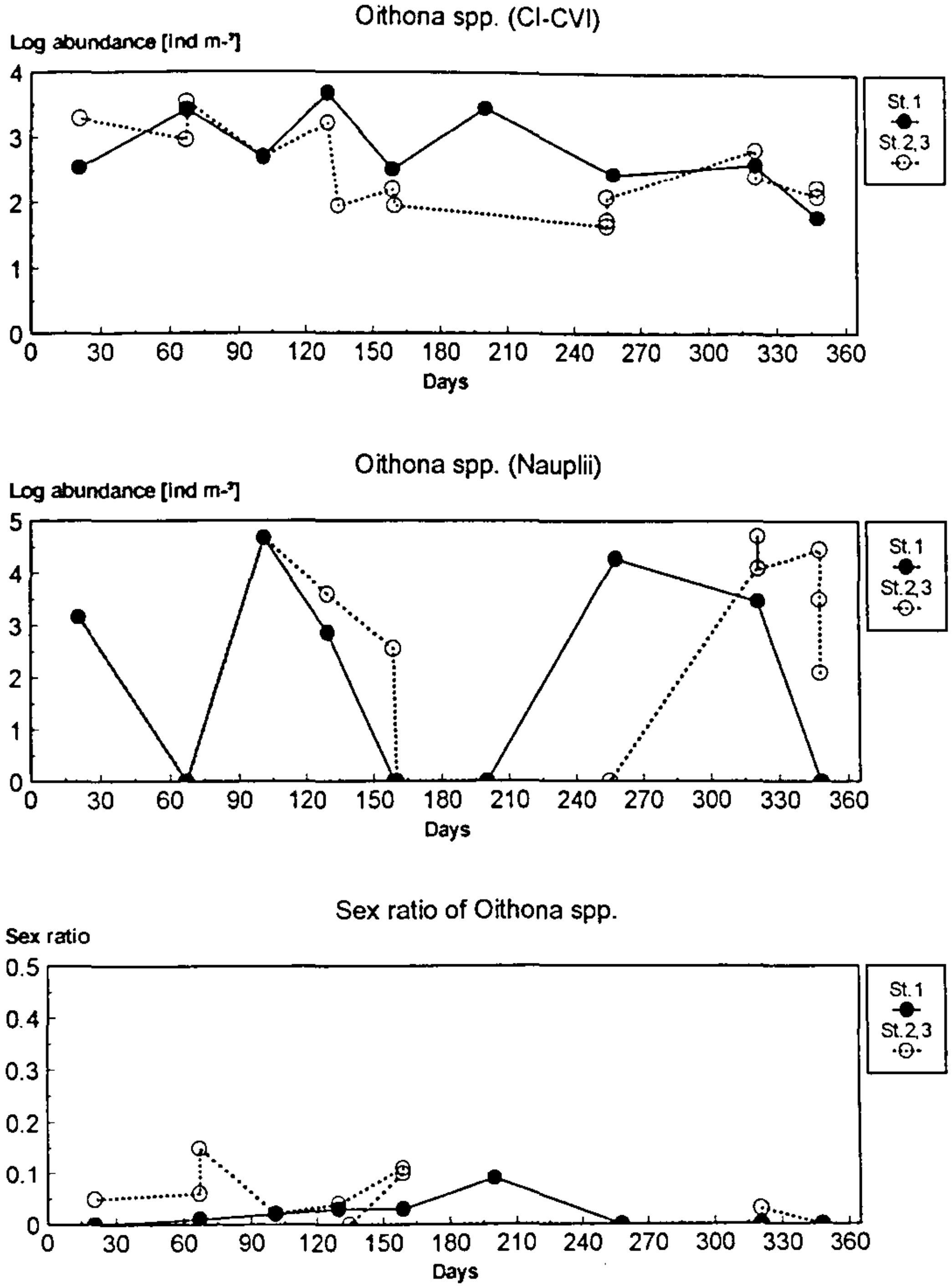


Figure 3.3.6d. Seasonal variations of abundance of the most common copepod and its sex ratio (male/adults) in the north-western Adriatic Sea: ***Oithona spp.***

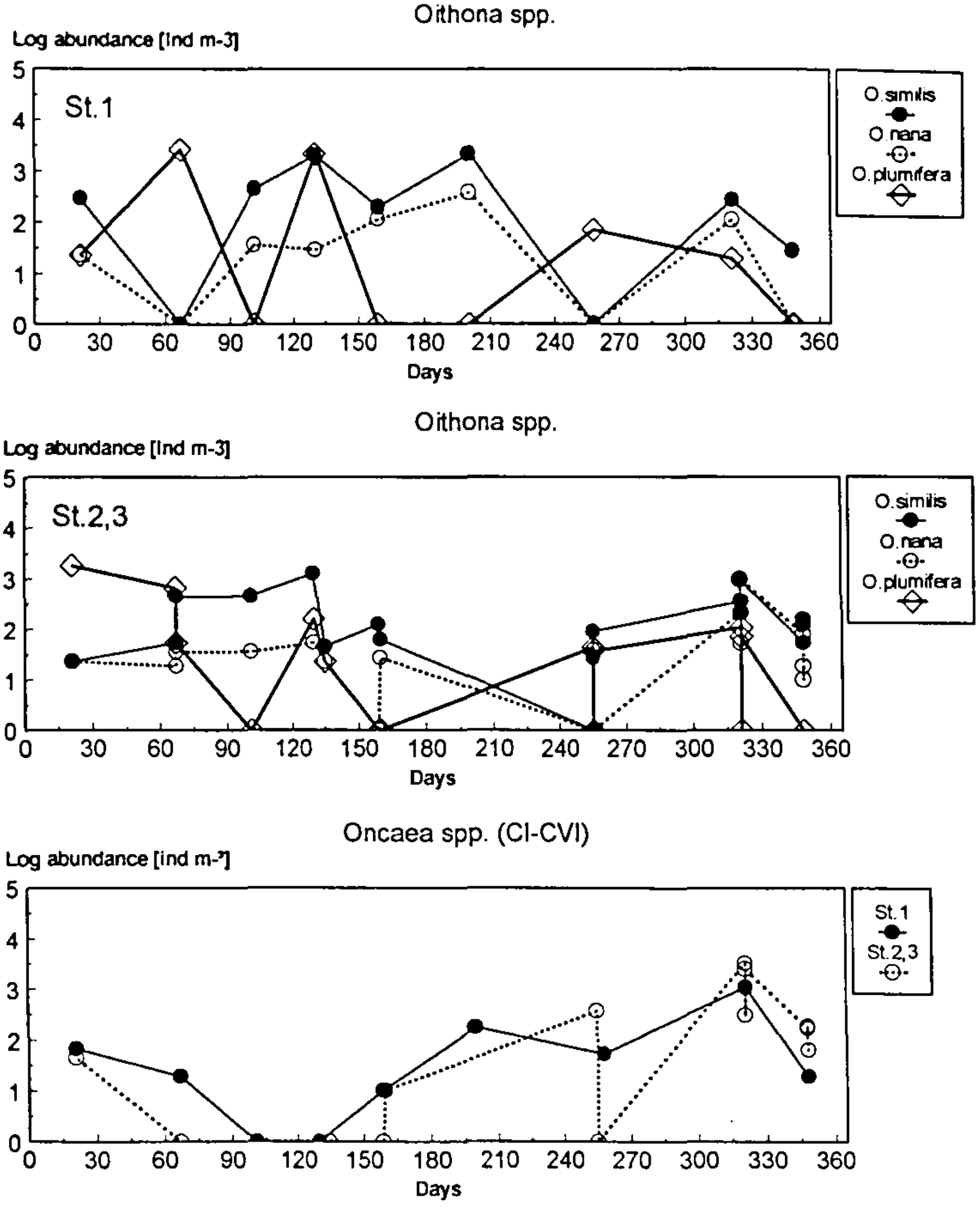


*Figure 3.3.6e. Seasonal variations of abundance of the three species of **Oithona spp.** and **Oncaea spp.** in the north-western Adriatic Sea.*

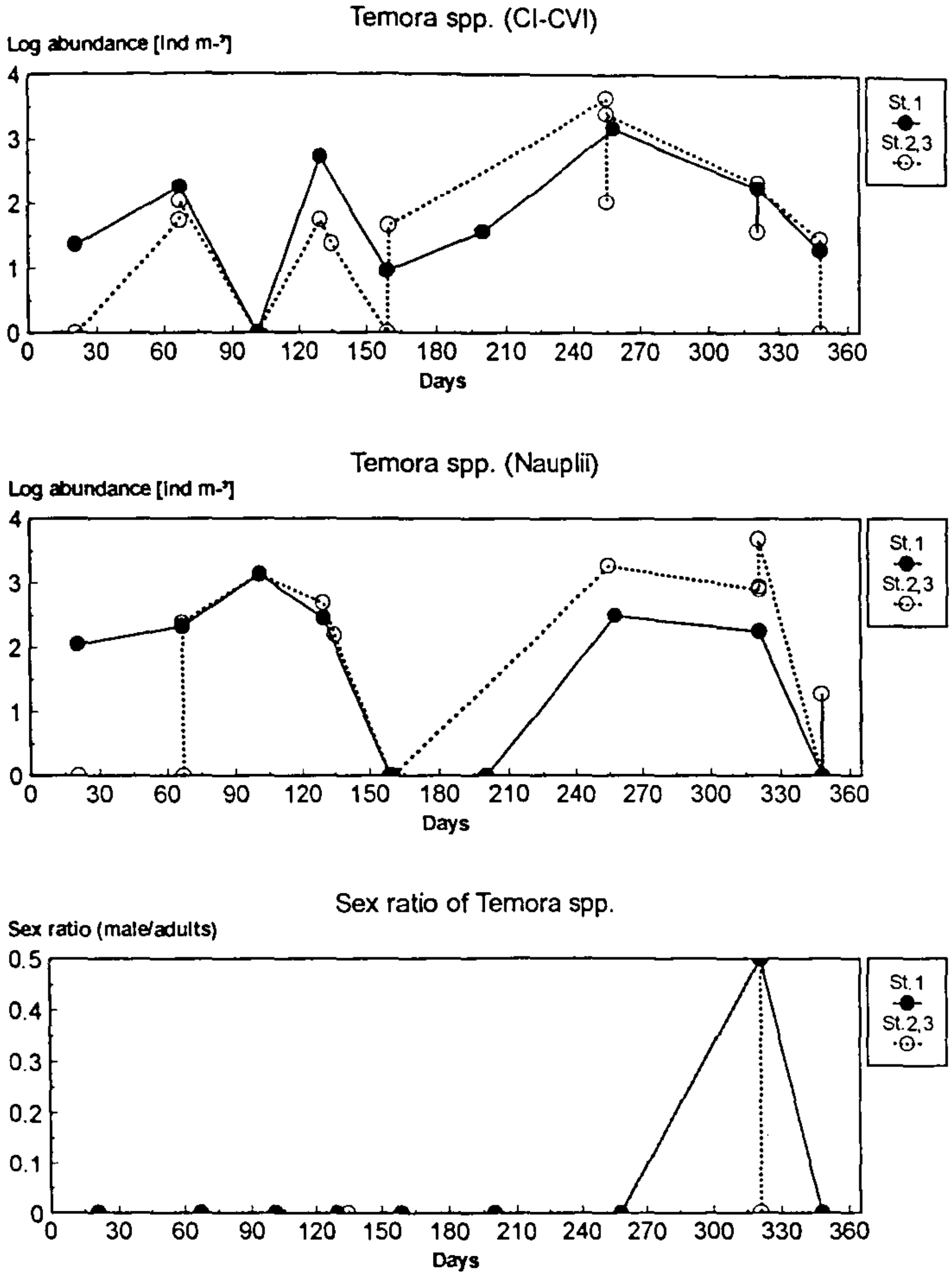


Figure 3.3.6f. Seasonal variations of abundance of the most common copepods and its sex ratio (male/adults) in the north-western Adriatic Sea: ***Temora spp.***

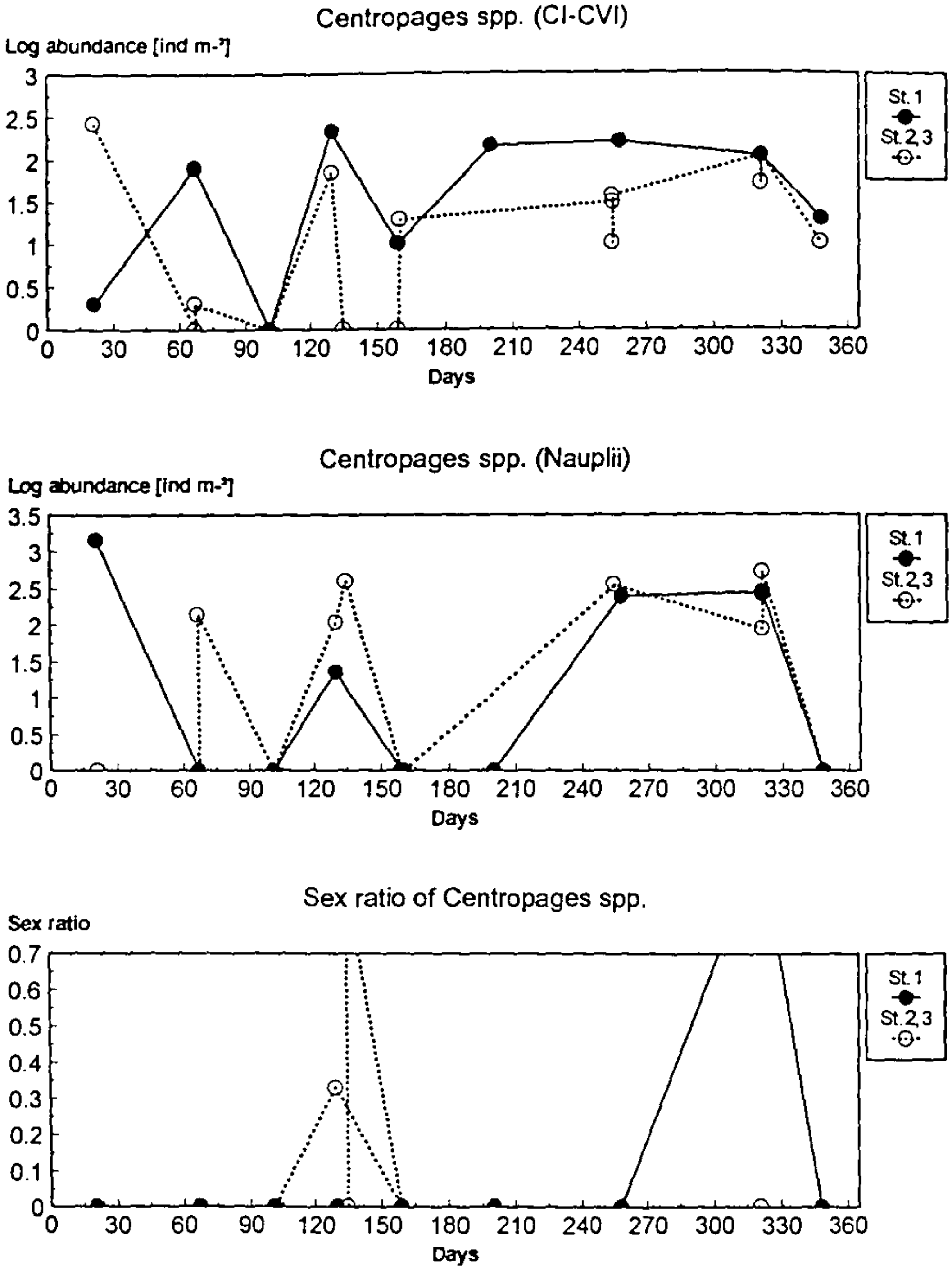


Figure 3.3.6g. Seasonal variations of abundance of the most common copepods and its sex ratio (male/adults) in the north-western Adriatic Sea: ***Centropages typicus***

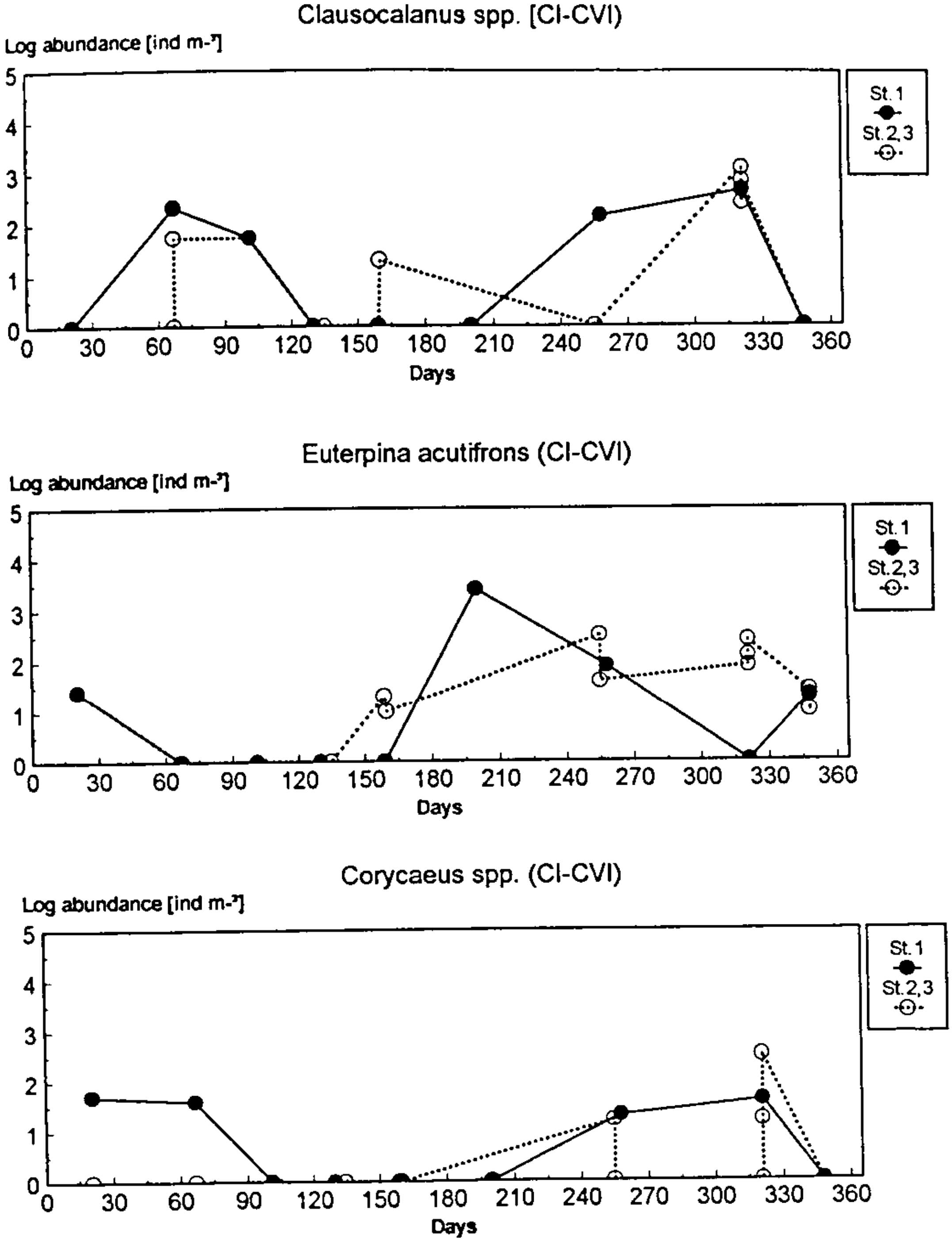


Figure 3.3.6h. Seasonal variations of abundance of the most common copepods in the north-western Adriatic Sea: ***Clausocalanus spp., Euterpina acutifrons*** *and* ***Corycaeus spp.***

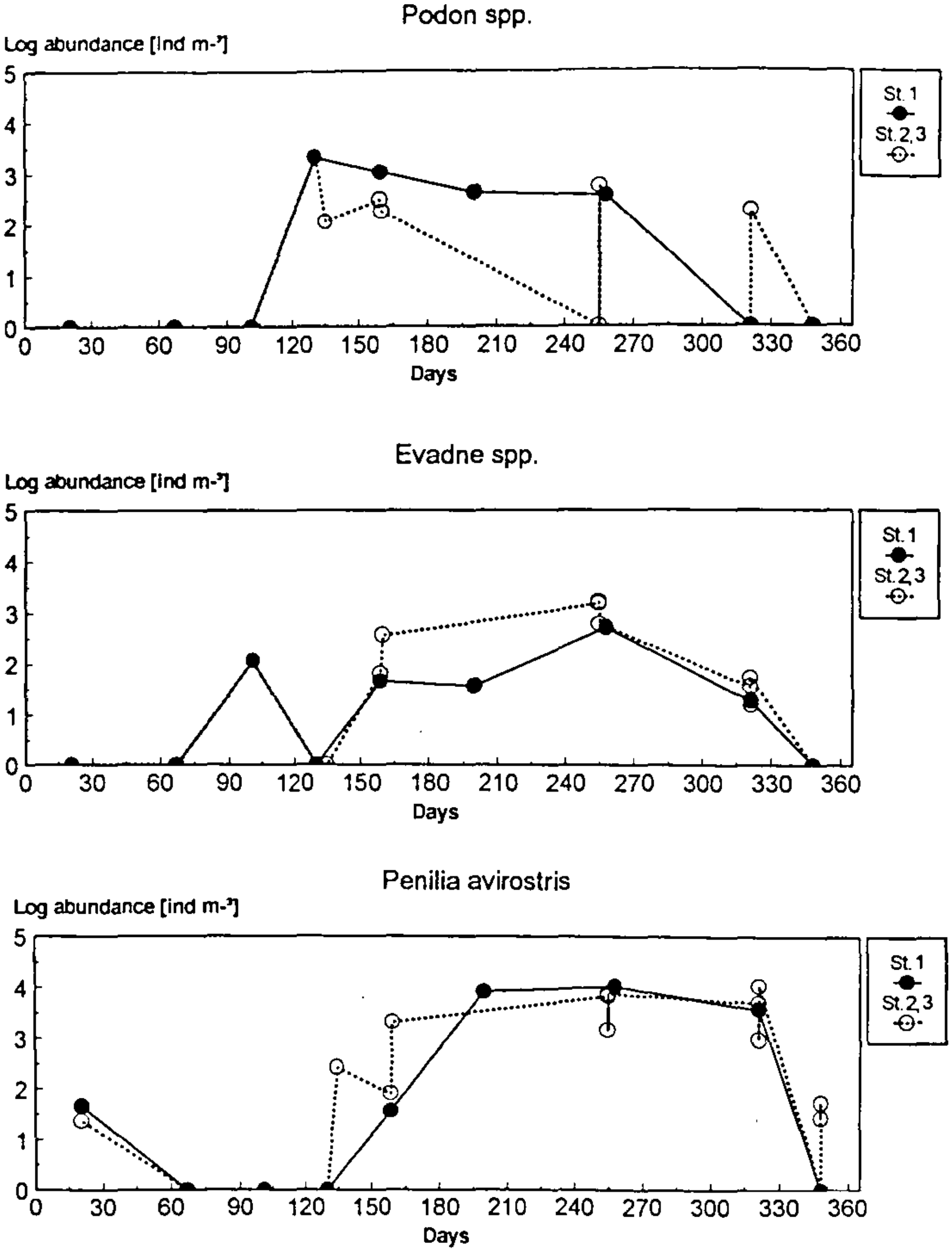


Figure 3.3.6i. Seasonal variations of abundance of Cladocera ***Podon spp., Evadne spp.*** *and* ***Penilia avirostris*** *in the north-western Adriatic Sea.*

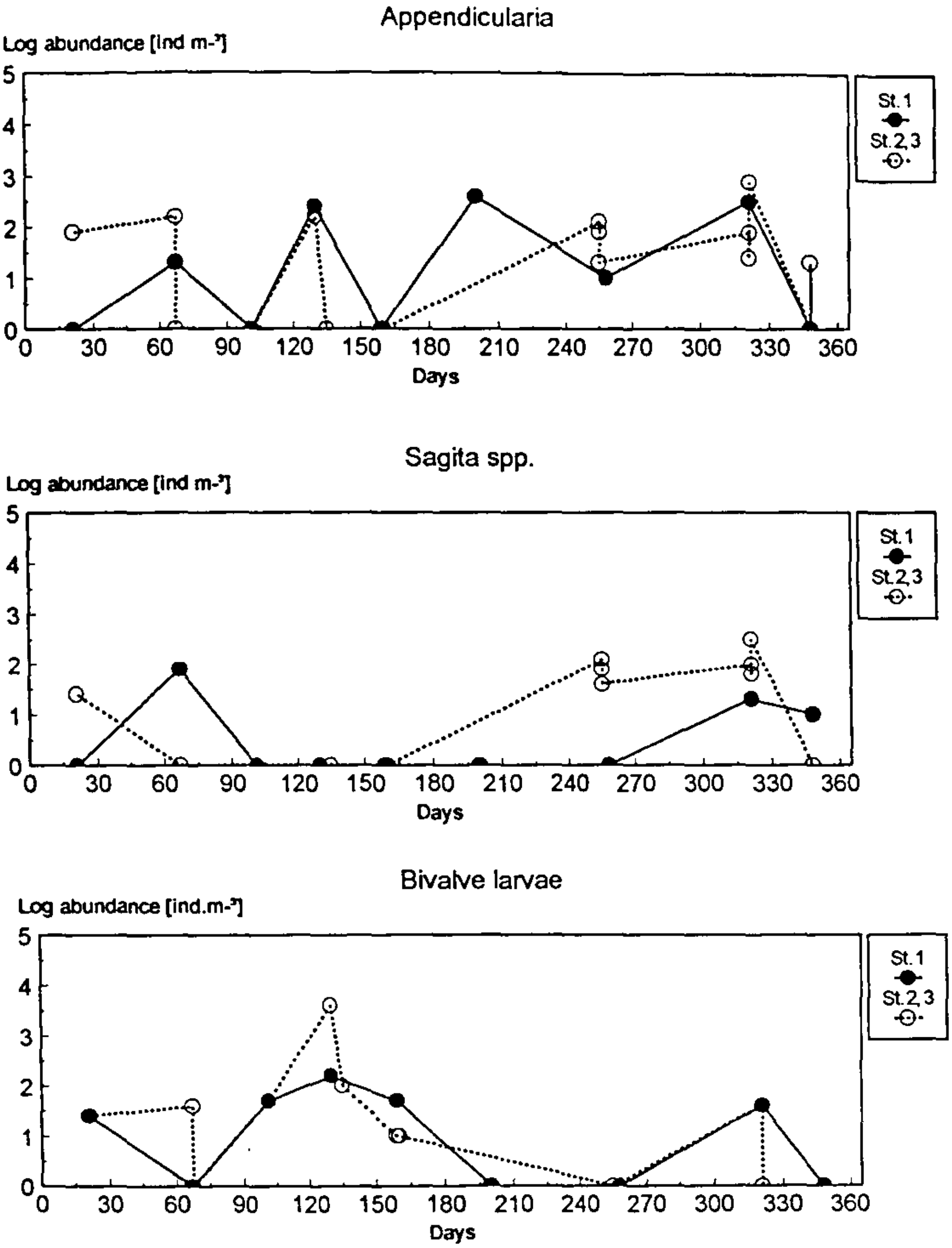


Figure 3.3.6j. Seasonal variations of abundance of ***Appendicularia.****,* ***Sagitta spp.*** *and* ***Bivalve larvae*** *in the north-western Adriatic Sea.*

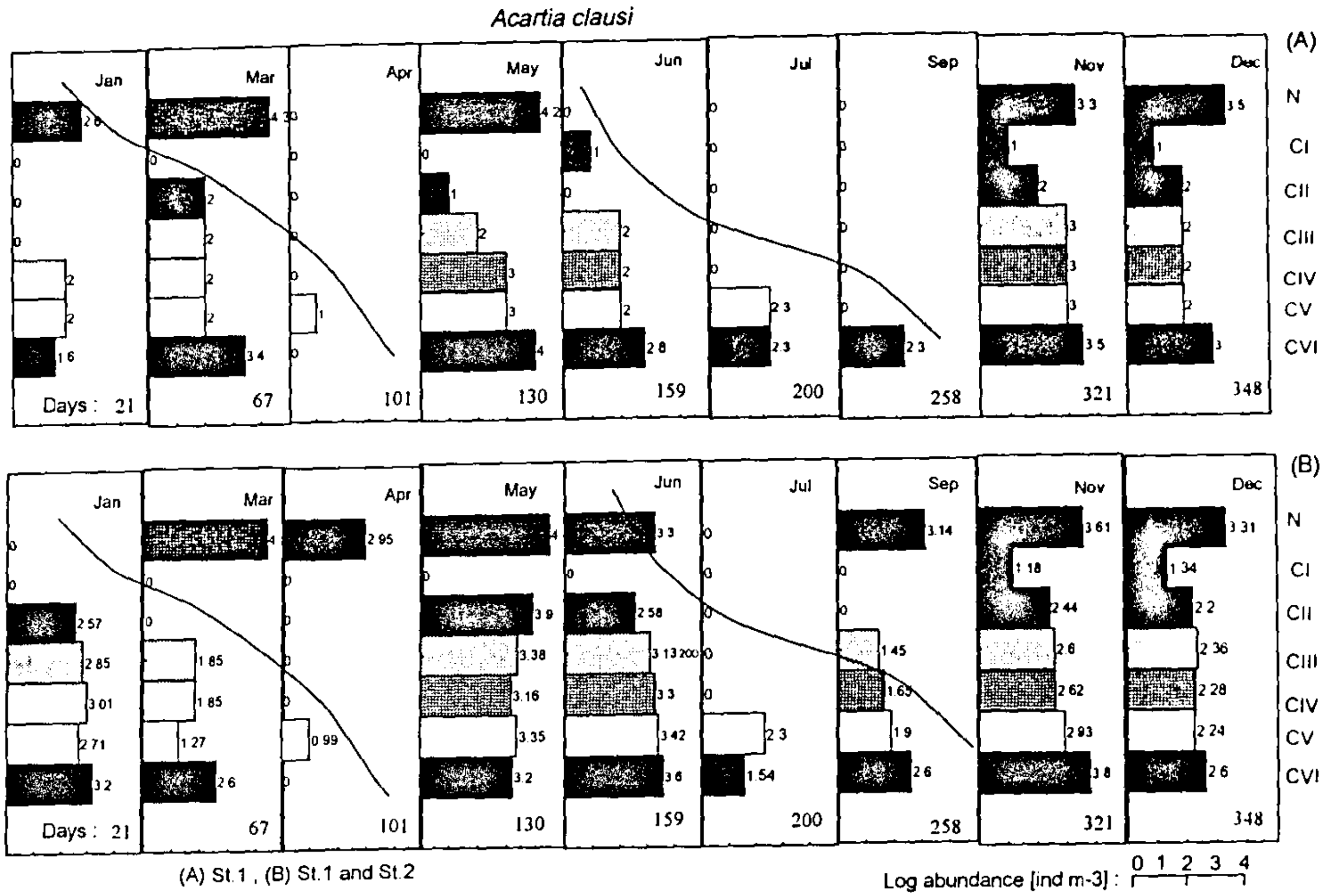


*Figure 3.3.7 Abundance of the developmental stages of **Acartia clausi** during the year in the north-western Adriatic Sea, showing two main recruitment periods. (a) Station 1 and (b) Station 2 and station 3*

4. DISCUSSION

4.1 Critical evaluation of methods

4.1.1 Selection of sampling stations

The investigation of the zooplankton distribution in the northern Adriatic Sea was undertaken within the framework of an EU-Environment research project (MARE) aiming towards assessing the influence of River Po eutrophication on harmful microalgae. Because of limited ship time, the zooplankton sampling programme had to be adjusted to the needs of the eutrophication project. This is why only one major (2 weeks) investigation in the northern Adriatic Sea in May 1993 could be conducted. All the other investigations were done on one-day cruises using a fast-running 20 m guard-boat of the Guardia di Finanza. With this boat it was possible to visit stations along transects from the mouth of the estuary towards the east, and south-east during one day. However, only days with calm weather had to chosen for these cruises to allow sampling from the rather small boats. On some occasions we had to interrupt the sampling programme due to strong upcoming winds.

One of the main tasks of the phytoplankton investigations was to trace the phytoplankton production induced in the ageing river water. So far the sampling programme was well adapted to investigate zooplankton reactions on river-borne phytoplankton eutrophication. However, our results show that for investigating zooplankton population dynamics, a station grid with fixed stations covering the northern Adriatic Sea would have led to further valuable information, especially if the sampling frequency would have been high.

4.1.2 Determination of water bodies for sampling from satellite images

Satellite images of the northern Adriatic Sea exhibit distinct patterns of temperature anomalies mainly caused by the Po water inflow. Evaluation of historic Ocean Color images from the Coastal Zone Color Scanner (CZCS) (BARALE *et al* 1986) show that high turbidity and chlorophyll signals correlate with higher temperatures. Since no actual ocean color satellite images were available during the investigations, we had to utilize sea surface temperature data of the NOAA-AVHRR sensor for detecting water bodies influenced by river water input with subsequent eutrophication (*Fig.3.3.1b*). Originally, when we planned our investigations, we expected the SeaWiFs ocean color sensor to be in operation. However, the launching of this sensor was repeatedly delayed and is up to today not in service.

The NOAA-AVHRR sensor receives also sea surface information in its visible bands. We have elaborated some of this information from the northern Adriatic Sea in May 1993, May 1994 and June 1994 using a chanel 1 and 2 albedo (*Fig.2.1.1* and *Fig.2.2.1*). These images exhibit suspended material including plankton when the surface concentration is high and when atmospheric disturbance permits water-derived signals to reach the satellite. In the case of Po estuary plume, ocean color anomaly signals can be obtained mainly from the immediate neighbourhood of the Po delta.

Our insitu investigations have shown that transects undertaken along satellite detected temperature gradients usually follow chlorophyll gradients. This is due to the fact that particles, especially those with pigments (phytoplankton) as well as dissolved matter, are responsible for an increased conversion of solar radiance into heat (SATHYENDRANAT & PLATT 1986). An example for phytoplankton are the accumulations of Cyanobacteria in the Baltic Sea (KAHRU *et al*1994). However, in the northern Adriatic Sea we have repeatedly found water bodies in which, according to the high temperature, we should expect high phytoplankton standing stocks, but we hardly found any phytoplankton. Instead we found very high concentrations of copepods. Apparently these water bodies were originally heated up due to a high phytoplankton concentration, but the zooplankton had removed all the phytoplankton through grazing in a rather short time.

In general, the method to utilize near real-time sea surface temperature data to decide on the position of stations within the Po estuary plume has proven a useful tool to identify different water bodies influenced by eutrophication. In our case we could obtain images through tranfer of data from the satellite receiving station DFD-DLR in Oberpfaffenhofen to the computer center of the University of Bologna in Ravenna, with the delay of 1 or 2 days. In future, the DFD-DLR-GISIS system developed in 1996 will take care that real-time tranfer of NOAA-AVHRR SST data will be available through the public telephone service, which is important for investigations in the Po Estuary plume. The highly variable hydrography in the northern Adriatic sea requires real-time satellite information if a specific water body is to be sampled. Images from consecutive days previous to sampling can provide useful information on the history of such a river water influenced water body.

4.1.3 Heterogeneity and variability in the Po estuary plume areas

The Po estuary plume can not be considered as a distinct estuarine water body extending into a certain direction with well defined degrees of river water dilution. For the river plume of the Po is :

(1) determined by the delta character of water outlet with 5 main branches with different water flowrates (Cati 1981; Raicich 1994) depending on the weather, or rain events, in the catchment area.

(2) strongly dependent on the current situation in the northern Adriatic Sea, depending mainly on wind direction and speed of general advection processes (Clement *et al* 1987), but also on tidal advection, though tides play a minor role in the northern Adriatic Sea.

(3) influenced by the rather shallow topography of the north-west Adriatic Sea which leads to a fast horizontal expansion of the Po water masses.

(4) affected by other river inflows, especially south of the Po delta contributing 20 % of the riverine inflow into the northern Adriatic Sea.

All these parameters act together and produce fronts as well as specific river water influenced water bodies which move rather fast in different directions within the northern Adriatic Sea, and mix with other water masses. This strong heterogeneity of water masses makes it very difficult not only to follow specific water bodies for determining zooplankton development in the La Grangian way but also to explain the development of zooplankton populations.

The general circulation pattern in the northern Adriatic Sea can be explained as an cyclonic gyre, which in its eastern part is affected by the oligotrophic northern Mediterranean water being advected to the north. In its western part, the gyre is mixed with river water. Part of this moves eastwards and another part is advected southwards (*Fig.2.1.1*). Marchetti *et al*

(1982) cited JEFTIC (1993) have shown some examples of the near-shore circulation derived from model calculations with different wind directions in summer and winter (*Fig. 4.1.1*) Especially the winter results correlate well with our observations of near-coastal southern advection of river influenced water. The vertical distribution of water masses is also related to the horizontal variability. However, a relatively constant extension of the halocline or thermocline, respectively, could be observed during the different cruises.

(a) Summer
(no winds)

(a) Summer
(SE winds)

(a) Summer
(NE winds)

(a) Winter
(any wind)

Figure 4.1.1. Dynamics of near-shore circulation with respect to wind directions (after MARCHETTI *et al* 1982).

The bottom water layer showed at different stations distinct and often very strong current velocities in different directions. These could be noticed from a sudden swift of the zooplankton net in a distinct direction when lowered. Unfortunately, nothing is known about the current direction and velocity of the northern Adriatic bottom currents.

In the immediate vicinity of the Po estuary outlets, a strong near-bottom compensation current in the direction of the river mouth could be repeatedly observed. At three occassions the current within a vicinity of 4 km from the Po outlet (Po di Goro) was so strong that the zooplankton net acted as drift anchor pulling our working boat (500 kg) in the direction of the river mouth. The compensation currents in the Po estuary plume area may be responsible for an efficient zooplankton transport towards low-saline and high-nutrient water masses with the respective consequences for recruitment and growth. It could be interesting to find out up to which dilution different zooplankton species and their development stages are able to tolerate low salinities, which may affect their recruitment and growth conditions.

4.1.4 Zooplankton sampling and biomass determination

During the survey in May 1993, zooplankton was sampled with a 100 µm net, therefore the smaller nauplii < 100 µm were caught. Later on, a 200 µm net and additionally a 55 µm net were used to sample copepods > 200 µm (CI-CVI) and also copepod nauplii > 55 µm. Therefore the zooplankton biomass obtained in the studies from 1994-1996 could not be compared with the biomass estimation in May 1993.

POSTEL *et al* 1991 used a mesh size of 55 µm instead of 100 µm in a WP-2 net and obtained an up to 4 times higher number. In this study, the young stages of small copepods (*Oithona* spp, *Oncaea* spp and *Paracalanus parvus*) are not quantitatively retained by a mesh size of 200 µm. The disadvantage of using nets with small mesh sizes is that the larger zooplankton organism are likely to escape due to the effect of the increased pressure wave during hauling (KANKAALA 1984). This is probably true especially for the smaller nets with a closing mechanism. The larger carnivores found in the northern Adriatic Sea, such as Chaetognata and copepods *Candacia armata* or *Pontella mediterranea* may only rarely be caught due to their ability to escape from the net opening.

Net clogging could also lead to an underestimation of zooplankton abundance (ARON 1962). The probability of net clogging was high in the vicinity of the river outlets and in the areas of strong eutrophication. Clogging in the northern Adriatic Sea is also possible due to the frequent appearance of marine snow, especially in areas of high chlorophyll content and in deeper layers (HORSTMANN *et al* 1996 in press). For this reason different mesh sizes were employed in this investigation.

The plankton patchiness in the sea can be affected by different factors (Steele 1976 ; Steele & Henderson 1992). The effect of patchiness in the estimation of zooplankton abundance is expressed as variation coefficient Since in most cases the zooplankton was sampled by a single haul, we have to keep in mind that the variation coefficient of 22-44 % (Cassie 1963) or 35 % (Helcom 1991) has to be considered in the interpretation of the zooplankton abundance. Our investigation in the northern Adriatic Sea and in the Po estuary show that a high variability of zooplankton abundance was correlated with environmental factors.

The daily migration of zooplankton is espected to have little effect on the analysis of vertical distribution, since all planktological surveys in this study were conducted during daylight. Moreover, the six major copepod species in the northern Adriatic Sea are small species and considered non-migrating, as also observed in the Gulf of Lion (Kowenberg 1993).

Due to the high number of organisms in most of the net samples, it was not possible to count the whole sample. A Rotary splitter was applied for samples taken with the WP-2 net from the whole water column during May 1993. It was finally decided to analyse 1/32 sub-samples, since a higher splitting could lead to severe errors (Longhurst & Siebert 1967). Later on, a modified Folsom splitter was used to split the smaller zooplankton samples. Dahmen (1995) tested the splitter that we used and found no significant difference (χ^2 - test) between sub-samples. To avoid the effect of aggregation of organisms, the samples were shaken and aerated before splitting. The determination of ash-free dry weight (AFDW) has been recomended as the most meaningful method for estimating zooplankton biomass (Beers 1976). Omori (1978) stated that the dry weight (DW) and AFDW are still appropriate as a measure for zooplankton biomass. However, methodological limitations due to the conversation factors, aggregation of materials and contribution of detritus should be taken into account in biomass measurements (Lenz 1973; Beers 1976). Weight loss due to the conservation of zooplankton samples is also a source of error (Omori 1978; Uye 1982). In this work, zooplankton samples were preserved with 4 % buffered formaldehyde, therefore some weight loss should be taken into account using correction factors (Giguere *et al* 1989). Nevertheless, the observed losses of both dry weight and carbon become constant within one month of storage (Omori 1978). We did not apply a correction factor because our main interest was in biomass variations. However, a loss of 30 % should be considered for converting the figures in absolute values.

FONDA UMANI (1994) stated for *Acartia clausi* in the Gulf of Trieste, northern Adriatic Sea, that different dry weight values, respectively C/N ratios are related to different seasons of the year. She found maximum dry weight values for *Acartia clausi* (7.5 µg dry weight/ind) in January and minimum in zooplankton species values in July (2.5 µg dry weight/ind). A summer biomass minimum was also found in the Kiel Bight (MARTENS 1976). Other factors such as developmental stages, sex and food avalibility also affect the dry weight and chemical composition (DURBIN & DURBIN 1978). A correction factor of 0.5 was used to convert AFDW into carbon content (LENZ, 1974; HIROTA 1981 ; SCHNEIDER 1989).

4.1.5 Data analysis

Both cluster analysis (CA) and principal component analysis (PCA) provide statistical methods for studying the joint relationships of variables and intercorrelations. One can describe the pattern of relationships among the objects (individuals, sampling units or taxa) by ordination (reduction of a matrix of distances or similarities among the objects to one or few dimensions) or by cluster analysis (classification of the objects into hierarchical categories on the basis of a matrix of inter-object similarities).

In this study, cluster analysis was used to classify groups, in terms of regional distribution in the northern Adriatic Sea, of hydrographical parameters (salinity, temperature and density) and biological parameters (chlorophyll-*a* and zooplankton abundance) judged to be similar according to a distance or similarity measure. Some disadvantages of using CA should be taken into account, since the properties were coded as instable data (MCCULLOCH & JAMES 1990), therefore an appropriate transformation of data was important (MUMM1991). We used CA to analyse the regional grouping of different zooplankton assemblages in terms of spatial distribution. CATALETTO *et al* (1995) employed cluster analysis for classifying long-term aggregations of zooplankton taxa in the Gulf of Triest, northern Adriatic Sea, whereas MORALES 1993 applied it for both the spatial distribution and aggregation of zooplankton taxa in the north-eastern Atlantic.

The PCA considers only linear combinations of the variable. It is not able to discover nonlinear combinations (PIELOU 1984, MCCULLOCH & JAMES 1990). In this study, PCA was used to trace the change of a biological descriptor (zooplankton abundance) during a one-year period. The PCA demonstrated clear relationships between hydroclimatic conditions and zooplankton in the Mediterranean (LE FEVRE-LEHOERFF *et al* 1995).

4.2 Estuary processes

Mixing diagrams (property-salinity plots are widely used to investigate the general distribution patterns of dissolved constituents within estuaries. They indicate whether an element is removed or added during the mixing of waters of different salinities.

The mixing diagram method (BOYLE *et al.* 1974) was applied to quantify the influence of estuarine plume zones on the tranfer of land-derived material to the open northern Adriatic Sea. The mixing diagram method can be used to locate the region of conservative and non-conservative mixing; however the method does not give information on the processes causing this non-conservative behaviour. Some authors emphasize the restricted applicability of this concept, because the end member concentrations are set constant in time (LISS 1976; WOLLAST & DUINKER 1982; SHARP *et al* 1984). Linear (conservative) property-salinity distribution are only expected when the time scale of variability for the mixing member is greater than the hydrodynamic residence time of the estuary (CIFUENTES *et al* 1991). The use of this approach as a basis for estimating removal or addition of solutes during estuarine mixing, as presented e.g. by BOYLE *et al* (1974) and OFFICER & LYNCH (1981) is questionable in large river systems and estuaries due to the complex spatial and temporal scales of mixing processes as well as the multiple fresh water sources of many large rivers (deltas). Therefore, besides the distribution of dissolved inorganic nutrients the corresponding particulate organic matter (particulate organic nitrogen and total particulate phosphate) was considered to give complementary information on nutrient patterns (HUMBORG 1997). The processes that control particles are more complex than those that control the distribution of solutes. However, a negative deviation of dissolved inorganic nitrogen (DIN) and phosphate in combination with a positive deviation of particulate organic nitrogen and total particulate phosphate from the conservative mixing line points towards an apparent production of particulate organic matter at the expense of nutrients during estuarine mixing. In *Fig.3.2.5* the theoritical distribution of nutrients and the corresponding particulate matter is shown, when nutrients are tranformed into particles during mixing.

Some transects accross the Po estuary plume fronts (*Fig. 3.1.4*, *Fig.3.2.4* and *Fig. 3.2.5*) showed peaks of nutrients and chlorophyll-*a* in the intermediate salinity region ('plume front areas'). The increase of nutrients, respectively chlorophyll-*a*, may due to entrainment from beneath the plume. This phenomenon is similar to that of "upwelling", since a significantly lower surface temperature was observed. EDMOND *et al* (1981) and DAGG & WHITLEDGE (1991) found a similar "nutrient trap" phenomenon along the transects across the Amazon and Mississippi plume areas, respectively. This phenomenon might be the reason for the strong scattering of data in the mixing curves.

In the case of the northern Adriatic Sea, silicate and dissolved inorganic nitrogent (DIN) were found to exhibit a nearly conservative behaviour in the area below 10 psu. Sinks were indentified within the salinity regime of 15 to 20 psu and above 25 psu within the Po estuary plume for silicate and for DIN and amounted to 16 % and 21 %, respectively. Phosphate, however, showed a strong uptake above 8 psu with 41 %. HUMBORG (1995) found a nutrient removal of 21% for DIN, 26 % for silicate and 12 % for phosphate in the salinity range of 0-18 psu in the Donau estuary. This shows that phosphate is taken up rapidly when the eutrophication process starts. If we consider an N/P ratio of 40 in the vicinity of the Po estuary, it is evident that phosphate is limiting for algal growth because a N/P ratio of 16 (Redfield ratio) is needed. Severe limitation of phosphate for algal growth is also stated by HERNDL (1992), who assumes a seasonal polysaccharide excretion of phytoplankton due to P-limitation in the northern Adriatic Sea. The N/P ratio as well as alkaline phosphatase activity is always very high indicating phosphate as limiting nutrient for phytoplankton growth in the northern Adriatic Sea (AZAM & HORSTMANN, pers.comm).

Non-conservative processes affecting nutrients, especially phosphate, are particle adsorption and exchange accross the sediment-water interface (NIXON 1981, FANNING *et al* 1982 and FROELICH 1988). For the Adriatic Sea the fate of the relatively high phosphate loads (20 000 t a^{-1}) is not known.

In general, removal of nutrients was correlated with increase of phytoplankton biomass, measured as chlorophyll-*a* and POC in the Po estuary plume. Near the Po River mouth a lower phytoplankton biomass (chlorophyll-*a* = 5 µg dm^{-3}) was observed compared to the phytoplankton biomass at the stations 5 km off the Po estuary mouth (chlorophyll-*a* = 15-20 μg dm^{-3}), probably due to light limitation by suspended riverborne particles. Reduction of primary productivity due to high turbidity and resulting light limitation through river discharge is a well known phenomenon (CHIUREN *et al* 1988; ROBERTSON *et al* 1993 and MORRIS *et al* 1995). Near the river mouth a similar value of chlorophyll-*a* concentration (5 μg dm^{-3}, HUMBORG 1995) was observed in the Danube in May. The relatively high chlorophyll-*a* concentration in the Po outlets may also be due to limnic phytoplankton growth in the river or the delta.

4.3 Eutrophication and zooplankton in the northern Adriatic Sea

4.3.1 Spatial distribution

Based on the results of the May 1993 investigation, we can identify 3 different areas respectively water masses, in the northern Adriatic Sea (*Fig.3.1.8*), A: the north-western part of the northern Adriatic Sea, B: the eastern part and C: the area south of the Po delta.

Zooplankton distribution in the northern Adriatic Sea shows differences in the faunistic assemblage in the different water masses associated with the plume. The low abundance of development stages of calanoid copepods at Site B relative to Sites A and C, and the dominance of *Oncaea* spp.and *Oithona*.spp at Site B, support the conclusion that the 3 sites represent a distinct environment for mesozooplankton. The conditions at Sites A and C (dynamic thermocline/halocline) may be favourable for the production of calanoid copepods as inferred from the high concentration of their developmental stages (nauplii and CI-V stages). Enhanced copepod production has been documented in areas with high chlorophyll-*a* concentrations by RICHARDSON (1985) in the Skagerrak frontal area and by RUNGE (1985) in the Puget Sound. In the Mississippi estuary plume, the copepods nauplii are assosiated with chlorophyll-*a* concentration, although no significant correlation between their abundance and chlorophyll-*a* was observed (DAGG 1991).

Lower abundance of copepod developmental stages observed at Site B reflect limited primary production. Site B is an oligotrophic area where primary production is limited. In the Adriatic Sea, defined regions characterized by specific plankton communities will change according to the weather conditions and current advection and should not be considered as fixed topographic regions.

In summer, the strong density stratification inhibits the transport of regenerated nutrients from the bottom to the upper layer and limits primary production. No significant differences in species composition of adult copepods were observed in the 3 sites, although a higher number of older developmental stages of copepods (CV-CVI) were found in the northwestern part of the northern Adriatic Sea. This observation is confirmed by studies on the salinity tolerance of copepods (VON VAUPEL-KLEIN & WEBER 1975). The copepod *Acartia clausi* and *Oithona similis* are examples for species with a wide horizontal distribution in the northern Adriatic Sea due to its higher tolerance of changing environments. *Acartia clausi*, however, does not normally occur in low-saline water (KRAUSE *et al* 1995). *Acartia clausi* is a neritic form that has been frequently found in the North Sea as well as in the Mediterranean and Black Sea (WIBORG 1955).

4.3.2 Correlation of phytoplankton and zooplankton

The correlation between zooplankton abundance and phytoplankton concentration offers several possibilities to interpret phytopankton/zooplankton interactions:

(1) A positive correlation shows that there is a high phytoplankton standing stock and productivity and the grazers are attracted by, respectively have developed in, this phytoplankton rich environment ('bottom-up controlled').

(2) A positive correlation, however, can also be due to the fact that the zooplankton does not feed on the dominant phytoplankton species due to size or taste restrictions but on smaller size-fractions and protozoa. This can preferably happen in areas which are influenced by anthropogenic eutrophication. The zooplankton community is not adapted to take advantage of a growing bloom of a specific alga.

(3) A negative correlation can indicate that the zooplankton has removed almost all phytoplankton ('top-down controlled'). At fast turnover rates, the primary productivity can still be high.

(4) A high predator pressure on herbivorous zooplankton can be another reason for a negative correlation.

(5) A negative correlation can also be found when high zooplankton populations originating from estuarine eutrophication areas are mixed into oligotrophic waters like in the central- and north-eastern Adriatic Sea.

In limnic environments there is 'bottom-up' control during spring, and close to the eutrophication sources, and 'top-down' control during summer and far from the source of eutrophication characteristic.

For the discussion of the zooplankton/phytoplankton interrelation in the Po estuary, we should also include the data for dissolved nutrients and salinity. Water bodies with low salinity and high nutrient close to the river outlets certainly are freshly eutrophied areas, which promote phytoplankton and zooplankton growth. A high-saline water with low nutrients and high phytoplankton usually represents a water body in which new production has depleted the nutrients.

There is one more factor, which is apparently important for the interpretation of the observed zooplankton/phytoplankton interrelation, namely the water temperature.

On May 17, 1993 at Station 393, we took samples in a distinct warm water body where the temperature exceeded the surface temperature of the surrounding areas by 1.2 °C as derived from NOAA-AVHRR. The satellite derived temperature data agreed with the insitu measurements on the same date. In this warmer water body, we expected high chlorophyll-***a*** concentrations. However, the chlorophyll values were low (0.5 mg chl-***a*** m^{-3} and primary productivity of 0.7 mg C m^{-3}h^{-1}). We observed at this station a very high number of adult copepods ~ 6 300 ind m^{-3} (*Fig.2.1.1* presents the satellite image and *Fig.3.1.9, Fig.3.1.11* the zooplankton distribution). On June 23, 1994 at Station 12 and 13, we also found low chlorophyll concentrations of < 1 mg chl-***a*** m^{-3} and a significantly higher abundance of dominant copepod species (*Acartia clausi* and *Paracalanus parvus*) than at the neighbouring stations (*Fig.3.1.1* presents the satellite image and *Fig.3.2.6* zooplankton distribution). In spring and summer 1994/95 and 96, we repeatedly found warmer water bodies with high zooplankton abundances within the Po estuary, appearently water masses which were originally affected by the River Po eutrophication.

We explain the phenomenon of high surface temperature and high zooplankton standing stock in the northern Adriatic Sea during spring and summer in the following way : Warming up of near-surface water by solar radiation takes place near the river outlets, where there is particle- rich river water, and further away from the river mouth, where increased phytoplankton development as a consequence of eutrophication occurs. The halocline near the river outlets additionally helps to maintain the heat in the upper layer.

When zooplankton populations develop in the eutrophic water bodies, a depletion of phytoplankton due to grazing can occur, but their remains in the water bodies maintain a high temperature. We found several examples for this phenomenon, but satellite data were available only on two occasions.

Typical examples for the combination of high temperature with high chlorophyll-***a*** concentration could be observed in May 1993, e.g. at Station 399 with a surface chlorophyll-***a*** content of 3.8 mg chl-***a*** m^{-3}. We found a high number of larval stages of copepods at this station (*Fig 2.1.1* and *Fig 3.1.9).* On June 15, 1994 at Station 2, we observed a very high abundance of zooplankton (50 000 ind dm^{-3}) in the Po estuary at a higher water temperature (+1.5° C) than the surrounding water with a very high surface chlorophyll-***a*** concentration (24 mg m^{-3}).

The zooplankton observation in May 1993 in the northern Adriatic Sea shows that the high biomass of phytoplankton close to the Po River coincides with a high zooplankton biomass. The average zooplankton biomass (AFDW) in the eutrophic area of the northern Adriatic Sea during May 1993 was ~ 6 mg C m^{-3}. FONDA UMANI *et al* (1989) and BENOVIC *et al* (1984) measured 12 mg C m^{-3} for the northern Adriatic Sea, including the Gulf of Trieste, in summer. Our lower values may be due to the young stages (nauplii and CI-CV stages) of copepods, which (mean abundance of copepodites = 6 100 ind m^{-3} and of nauplii = 10 500 ind m^{-3}) dominated during May 1993.

The most abundant copepods found in the northern Adriatic Sea during May 1993 are rather small species. KOWENBERG (1993) stated that these are non-migrating species with different feeding strategies: *Oithona similis, Oncaea spp,Oithona nana,* and *Oithona plumifera* are carnivorous. *Acartia clausi, Centropages spp., Temora spp.* and *Paracalanus* *parvus* are omnivorous. The abundance of and copepodite stages of the omnivorous *Centropages spp.* is positively correlated ($r = 0.81$, $p < 0.05$) with phytoplankton abundance. The number of adult omnivorous *Acartia clausi* and herbivorous *Paracalanus parvus* also showed a positive correlation ($r = 0.82$, $p < 0.01$) with phytoplankton abundance. In those clusters, in which mainly herbivorous copepods were abundant, the carnivorous *Oithona spp.* and *Oncaea spp.* were also present (*Fig. 3.1.9*). Longhurst (1985) and Madhupratap *et al* (1993) found similar situations in the eastern Pacific Ocean and eastern Arabian Sea, respectively.

The adult copepods showed mostly a negative correlation with the chlorophyll-*a* concentration ($r = -0.73$, $p < 0.03$). This may be due to the fact that the carnivorous copepods found their prey 'the herbivorous' copepods after they had diminished the phytoplankton. But omnivory can also explain the higher number of adults in the more oligotrophic waters. Our findings require an additional investigation on the stomach content for identifying the predominant food items. Preliminary studies on the nutrition of copepods in the Adriatic Sea (Kastela Bay, Yugoslavia) by Homen & Regner (1977) showed that food of dominant copepods depended largely on variations of the phytoplankton composition. Marasovic & Regner (1979) stated that the gut contents of dominant copepods in the central Adria completely depended on the species composition of the phytoplankton community.

The investigation in May 1993 showed that the phytoplankton distribution exhibited a distinct pattern in the northern Adriatic Sea. A maximum diatom density of 15 00 x10^3 cells dm^{-3} (dominant species: *Cyclotella* spp, *Nitzschia delicatissima*, *Rhizosolenia* spp and *Chaetoceros* spp) was found in the area south of the Po delta, whereas a peak concentration of dinoflagellates (100.x.10^3 cells dm^{-3}, dominant: *Ceratium* spp.) was observed near the main outflow of the River Po. Degobbis (1989) reported that the chain-forming diatom *Chaetoceros* dominated the northern Adriatic Sea during May, with maximum densities near the Po delta. However, there was no significant correlation between the abundance of herbivorous nauplii and total phytoplankton abundance, total diatom abundance and total chlorophyll-*a*. Some diatom species, however, show a significant positive correlation with the abundance of nauplii, e.g. *Asterionella spp.* ϕ35-60μm ($r = 0.95$, $p < 0.01$), *Bacillaria paradoxa* $\phi\mu$m 70-250 ($r = 0.84$, $p < 0.01$), *Schroederella delicatula* ($r = 0.84$, $p < 0.01$), and *Rhizosolenia fragilissima* ϕ 8-70 µm ($r = 0.68$, $p < 0.05$).

It is questionable whether the nauplii have a selective feeding preference for a distinctive cell size. POULET *et al* (1994) stated that the shape and ornamentation of the diatom cells can reduce ingestion and the aggregation of cells can modify the available food size spectrum and behaviour of the copepods. TURNER & TESTER (1989) reported that several copepod species in the Missssissippi River plume show no size selectivity.

Together with GOTSIS-SKRETAS (Mare Project, pers.comm.) investigations on phytoplankton size fractions in relation to standing standing stock and primary productivity were undertaken. The investigation showed that there is more picoplankton (< 2 µm) in oligotrophic waters. While nano- (2-20 µm) and microphytoplankton (> 20 µm) was more abundant and mainly responsible for the primary productivity in eutrophic waters of the northern Adriatic Sea in May 1993 (*Fig. 3.1.7*). *Figure 4.3.1* shows a comparison between the relative significance of size-fractionated chlorophyll-*a* and primary production in eutrophic waters (Station 386 and 399) and oligotrophic waters (Station 393 and 395).

The zooplankton data show that the distribution pattern of copepodite stages and nauplii were similar to the distribution pattern of the larger size fraction of phytoplankton, whereas the distribution pattern of adult copepods was similar to that of the picoplankton. This high coincidence of nauplii in eutrophic waters indicates a fast development of eggs, larval stages and adults due to high availability of phytoplankton and or microzooplankton. It is well known that egg production and population size are food-limited in calanoid copepods (SULLIVAN & RITACCO 1985 and BAN 1994).

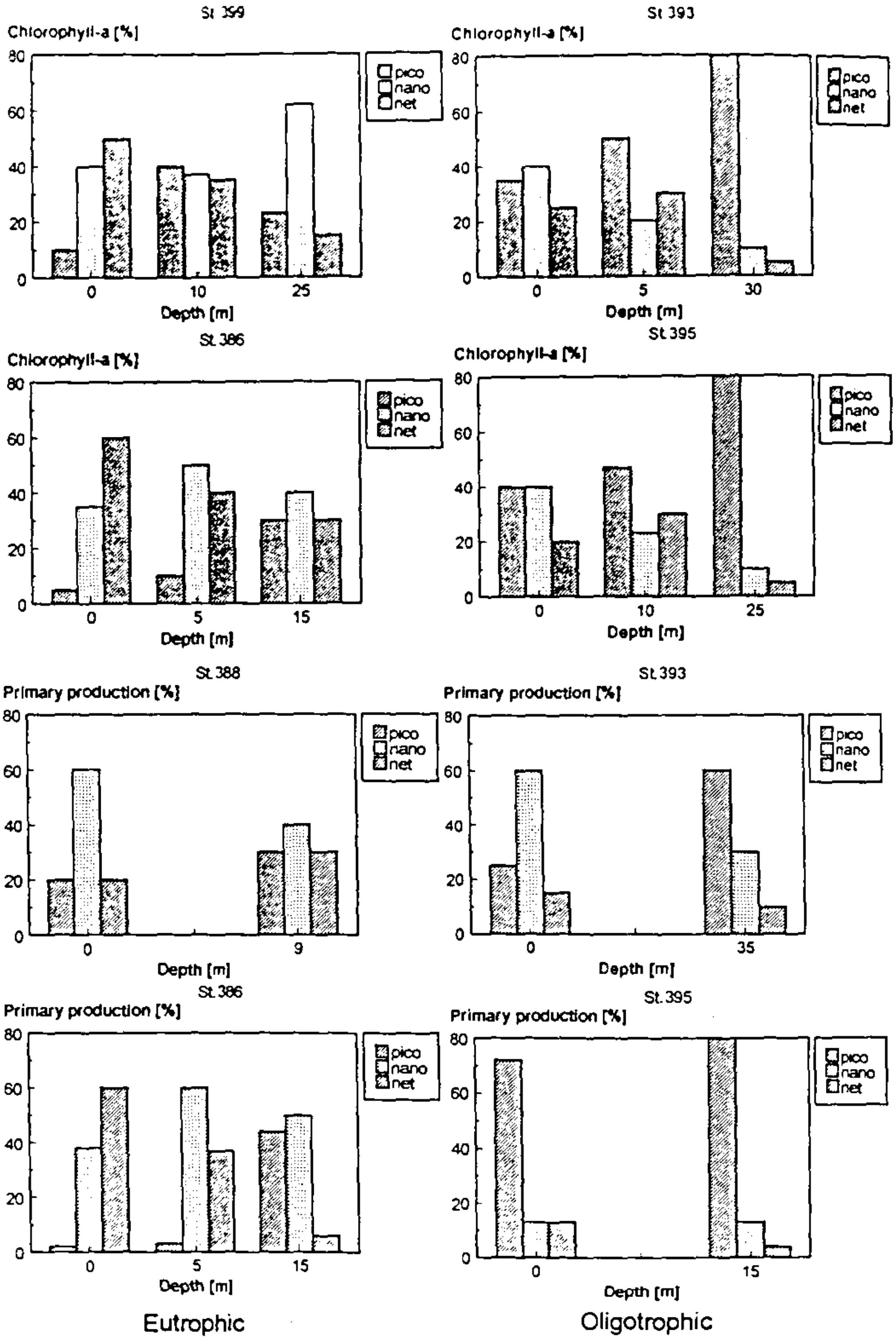


Figure 4.3.1. An example of the relative proportion of size-fractions of chlorophyll-a and primary productivity in eutrophic (St.388, St.399 and St.386) and oligotrophic (St.393 and St.395) water in the northern Adriatic Sea during May 1993 (after Gotsis-Skretas *&* Wiryawan, *un publ.data of Mare Project).*

The high concentration of nauplii (mean = 6 000 ind m^{-3}), copepodite stages (mean = 11 000 ind m^{-3}) and adult copepods (mean = 4 250 ind m^{-3}) amounted to a zooplankton biomass of 6 mg C m^{-3} of zooplankton. The relatively low zooplankton biomass could not benefit from the high phytoplankton production (10 - 40 mg C $m^{-3}d^{-1}$, the maximum value of 230 mg C $m^{-3}d^{-1}$ at St.396 is excluded) in the eutrophic waters. This indicates that the potential grazing in the eutrophic water of the northern Adriatic Sea was very low. The high proportion (~ 50 % of the copepod abundance) of the euryhaline, carnivorous *Oithona* spp. in the eutrophic water can be considered as competitor of the dominant omnivorous species *Acartia clausi* reducing the grazing impact in the eutrophic waters. However, we can only show the low potential grazing impact derived from the phyto/zooplankton biomass proportion during this investigation. Generally, the grazing impact amounts to < 10 % of the daily primary production during spring (e.g in the northern Atlantic, DAM *et al* 1993 and in the northern Pacific, TSUDA & SUGISAKI, 1994). The conditions of the spring phytoplankton bloom in natural environments are in many aspects comparable to eutrophication conditions in estuaries in summer. The relatively low grazing pressure by mesozooplankton is reported from other eutrophic areas, e.g Narragansett Bay (DEASON 1980; STEARNS *et al* 1987) and the plume area of the Rhone estuary (GAUDY *et al* 1990), where the grazing potential of zooplankton "did not affect the community structure of phytoplankton significantly". Phytoplankton with a high growth rate, such as diatoms, may be little affected by grazers in the northern Adriatic Sea. This can also be seen in the mesocosm experiments undertaken in the framework of the MARE Project (GRANELI *et al* 1996 and TURNER *et al* 1996, project report) where the interacting effects of nutrient addition and mesozooplankton grazing on phytoplankton growth and community succesion was investigated. The experiment results can be summarized as follows : when the phytoplankton communities of the northern Adriatic Sea are allowed to develop under nutrient-enriched conditions, zooplankton grazing cannot keep up with phytoplankton growth. The omnivorous adult copepods tended to be cannibalistic to the nauplii. We may therefore conclude that in highly eutrophicated waters of the northern Adriatic Sea, zooplankton grazing does not play a significant role for the phytoplankton growth, which is basically 'bottom-up,' being controlled by the availability of nutrients. However, when phytoplankton blooms have aged and zooplankton population has increased, it will control phytoplankton growth.

In the oligotrophic waters the carnivorous species *Oithona* spp and *Oncaea* spp dominated of the adult zooplankton population up to 70 % in May 1993. Their prey is apparently the microzooplankton including copepod nauplii.

Our investigation in May 1993 along a transect from the Po estuary mouth (St.399) to the open Adriatic Sea (St.395) showed a high variation of zooplankton abundance. Station 396 (50 km off the Po River mouth) can be considered as 'a frontal station' because the physical and also phytoplankton parameters showed significant changes in this area. At this station, the abundance of herbivorous nauplii was similar to the adjacent stations (station 387 and station 395), although chlorophyll-*a* values were high. Thus a favourable trophic situation can occur in the frontal area (LE FEVRE *et al* 1986), even if the zooplankton concentration was average. UYE *et al* (1992) found a similar situation at the tidal fronts in the Inland Sea of Japan. According to these authors, the frontal environment is not always a good place for recruitment of herbivorous copepods due to high mortality of eggs. In the northern Adriatic Sea the formation and maintenance of fronts apparently is a rather short process, which zooplankton population did not have sufficient time to adjust to or to react to.

The distribution of dissolved organic carbon (DOC) showed that the distribution pattern of DOC coincides with the distribution pattern of particulate organic carbon (POC) and chlorophyll-*a* in the northern Adriatic Sea (*Fig.4.3.2*). CHIN-LEO & BENNER 1992, CARLSSON *et al* 1993 stated that DOC is most certainly to a large extent degraded by bacteria in the river plume. The higher bacterial production in this area will also increase the production of bacteriovores such as heterotrophic flagellates and ciliates (*Fig. 3.1.3*). FONDA UMANI *et al* (1990) stated that a high production of microzooplankton has been observed in the western part of the Adriatic Sea, affected by the outflow of the Po River. This increased production of microzooplankton may well be the reason for the observation that omnivorous and carnivorous zooplankton dominates the mesozooplankton at an intermediate distance from the Po River outlet. A poor correlation between the amount of autotrophic food and the response of copepods in term of abundance was observed in the northern Adriatic Sea. What can be learned is that the food web based on the microbial loop also occurred in the northern Adriatic Sea. LENZ (1992) stated that a strong grazer control is a characteric of the microbial food web in oligotrophic regions. A high content of dissolved organic carbon (~ 100 µM) in the oligotrophic region of the northern Adriatic Sea with a high proportion of canivorous zooplankton supports this hypothesis.

Our observations using an underwater video system in June 1994/1995 showed that the highest concentration of marine snow aggregates related to the thermocline. The marine snow hung just below the thermocline in the oligotrophic water of the northern Adriatic Sea during summer (HORSTMANN *et al* 1996, in press). The sub-surface maximum concentration of marine snow was also reported by LAMPITT *et al.* (1993) in the north-eastern Atlantic. ASPER (1986) stated that the accumulation pattern of marine snow is more affected by advective input from the shelf.

Additional zooplankton samplings during the present study were undertaken using a closing net at the depths, where the maximum marine snow concentration was found. *Oithona* spp. encountered ~ 70 % of the zooplankton numbers attaching at the marine snow aggregates. Copepod nauplii were also encountered frequently in the marine snow aggregates in the northern Adriatic Sea. ALLDREDGE (1982) found that marine snow consist of cyanobacteria and picoplankton. A possible explanation for the association of that copepod with marine snow could be related to the carnivorous feeding on microzooplankton including copepod nauplii. Since crustacean zooplankton do ingest marine snow particles (LAMPITT *et al.* 1993) therefore such feeding of copepods on marine snow could be a significant short-cut in the food chain pathway in the oligotrophic northern Adriatic Sea.

Detritus materials contained in the fraction of POC may also contribute as food source for copepods in the eutrophic area of the northern Adriatic Sea (*Fig.3.1.3*). Detritus as source of food for copepods has been stated by several autors (PAFFENHÖFER & STRICKLAND 1970; POULET 1976, LENZ 1977 and ROMAN 1984). Data on detritus ingestion from the Po Estuary do not exist.

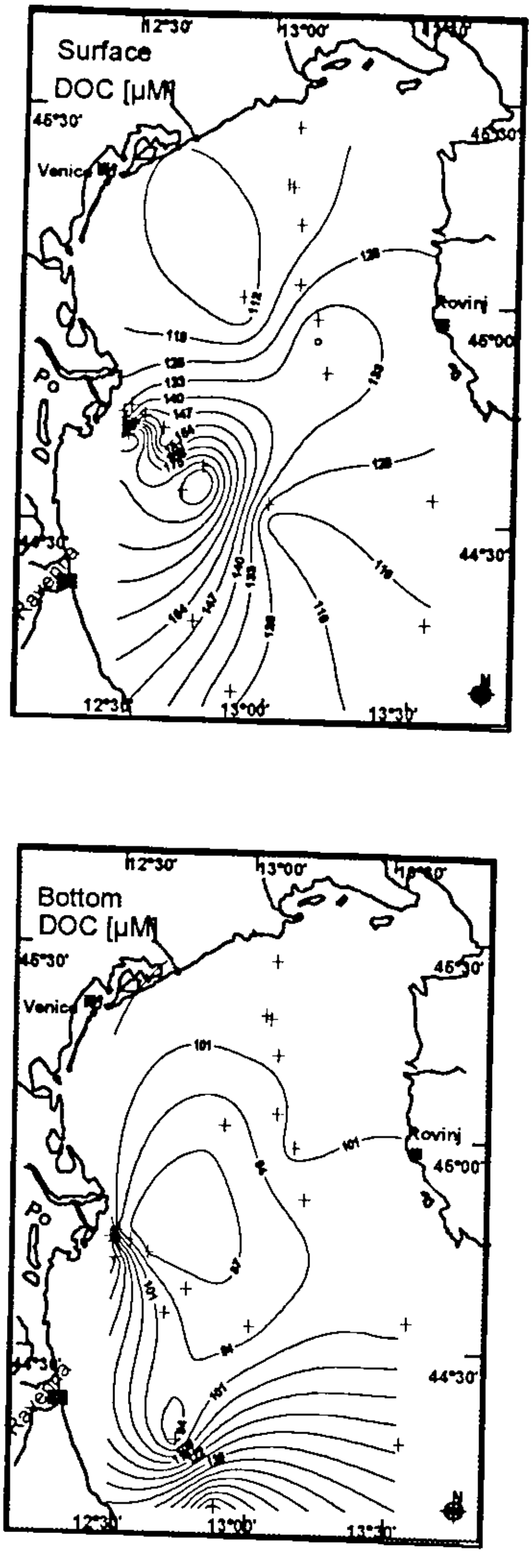


Figure 4.3.2 Distribution of dissolved organic carbon (DOC) in the northern Adriatic Sea (Horstmann & Dersen, unpubl.data from MARE Project)

Summarizing the typical zooplankton population at the three sites in the northern Adriatic Sea, we find a high abundance of copepods and their larval stages, dominated by *Acartia clausi,* in the eutrophic regions in the south-western part of the Po Delta. The oligotropic region at the eastern part in the open northern Adriatic Sea was characterized by a high abundance of copepodites (CI-CVI) and adult copepods dominated by *Oncaea* spp.

4.4 Zooplankton distribution in the Po estuary

4.4.1 Spatial and vertical distribution

The zooplankton distribution in estuaries is classically known to depend largely on special physical factors: e.g.temperature (CASTEL *et al* 1983), salinity (c.f.BAKKER & DEPAUW 1975, COLLINS & WILLIAMS 1981), flushing and mixing (SOLTANPOUR GARGARI & WELLERHAUS 1985; CASTEL & VEIGA 1990). Its distribution could also be affected by biotic factors such as food availability, competition and predation (c.f.BURKILL & KENDALL 1982 and BARETTA & MAISCHAERT 1988). Both environmental variability and trophic interactions may play an important role in the regulation of zooplankton populations in the Po estuary.

The principal component analysis (PCA) supports the hypothesis that the zooplankton assemblages depend on the interaction between abiotic and biotic factors. We used the estuarine zonation scheme Venice System (ANONYMOUS 1959) to determine the habitat preference of the mesozooplankton of the northern Adriatic Sea within the Po River plume. The classification consist of a limnetic (0-0.5 psu), oligohaline (0.5-5 psu), mesohaline (5-18 psu), polyhaline (18-30 psu) and euhaline (> 30 psu) zone.

In the lowest salinity range (0.2-5 psu) near the Po Estuary outlets, the zooplankton assemblages were characterized by the copepod *Oithona similis* and its larval stages, *Acartia clausi* and its larval stages and the cladoceran *Podon* spp. However, *O.similis* has a rather wide distribution pattern and was found in the northern Adriatic Sea from 0.2 to 37 psu. *O.similis* is known as a boreal euryhaline species and a common copepod in oceanic and neritic regions (BLANNER 1982 ; ANGEL & SMITH 1995).

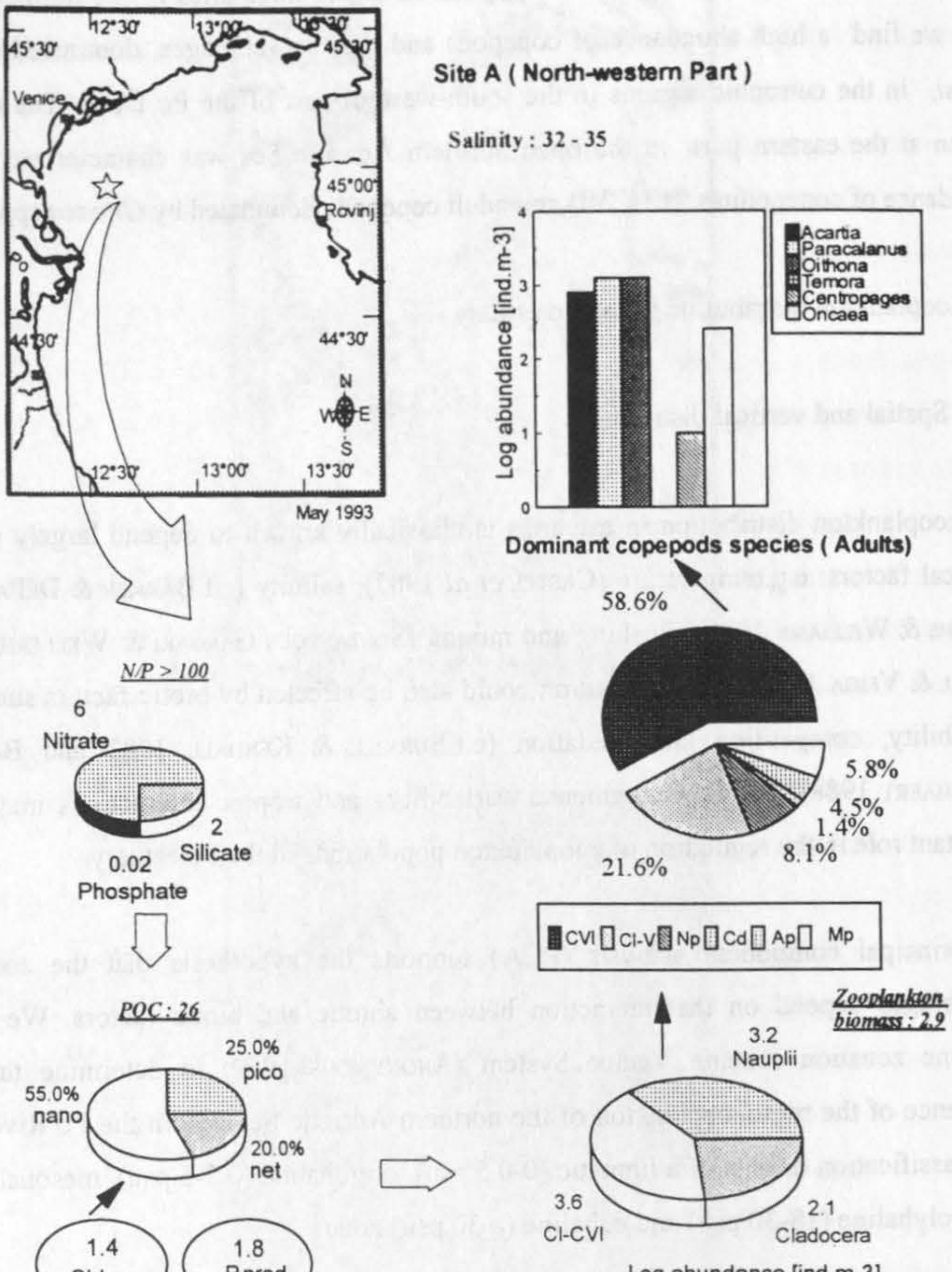


Figure 4.3.2a. Schematic overview of the environmental conditions and the composition of the plankton food web at three sites in the northern Adriatic Sea. Site A: North-western Part. Unit measurements : Nutrient concentrations [µM], chlorophyll-a [µg dm^{-3}], primary production [µg C m^{-3}h^{-1}], zooplankton biomass [mg C m^{-3}] and zooplankton abundance [ind m^{-3}].

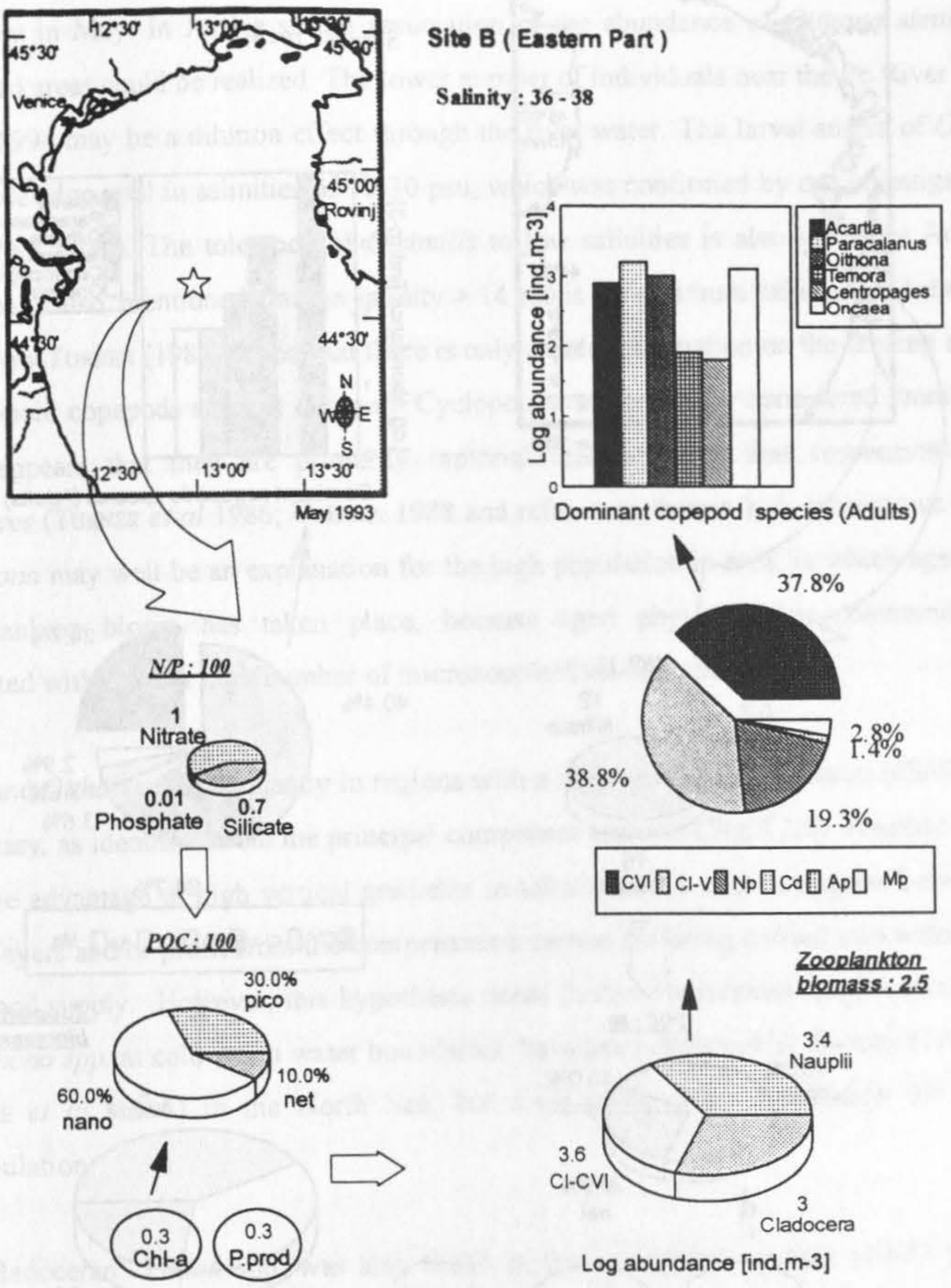


Figure 4.3.2b. Schematic overview of the environmental conditions and the composition of the plankton food web at three sites in the northern Adriatic Sea. Site B: Eastern Part. Unit measurements : Nutrient concentrations [μM], chlorophyll-a [μg dm^{-3}], primary production [μg C m^{-3}h^{-1}], zooplankton biomass [mg C m^{-3}] and zooplankton abundance [ind m^{-3}].

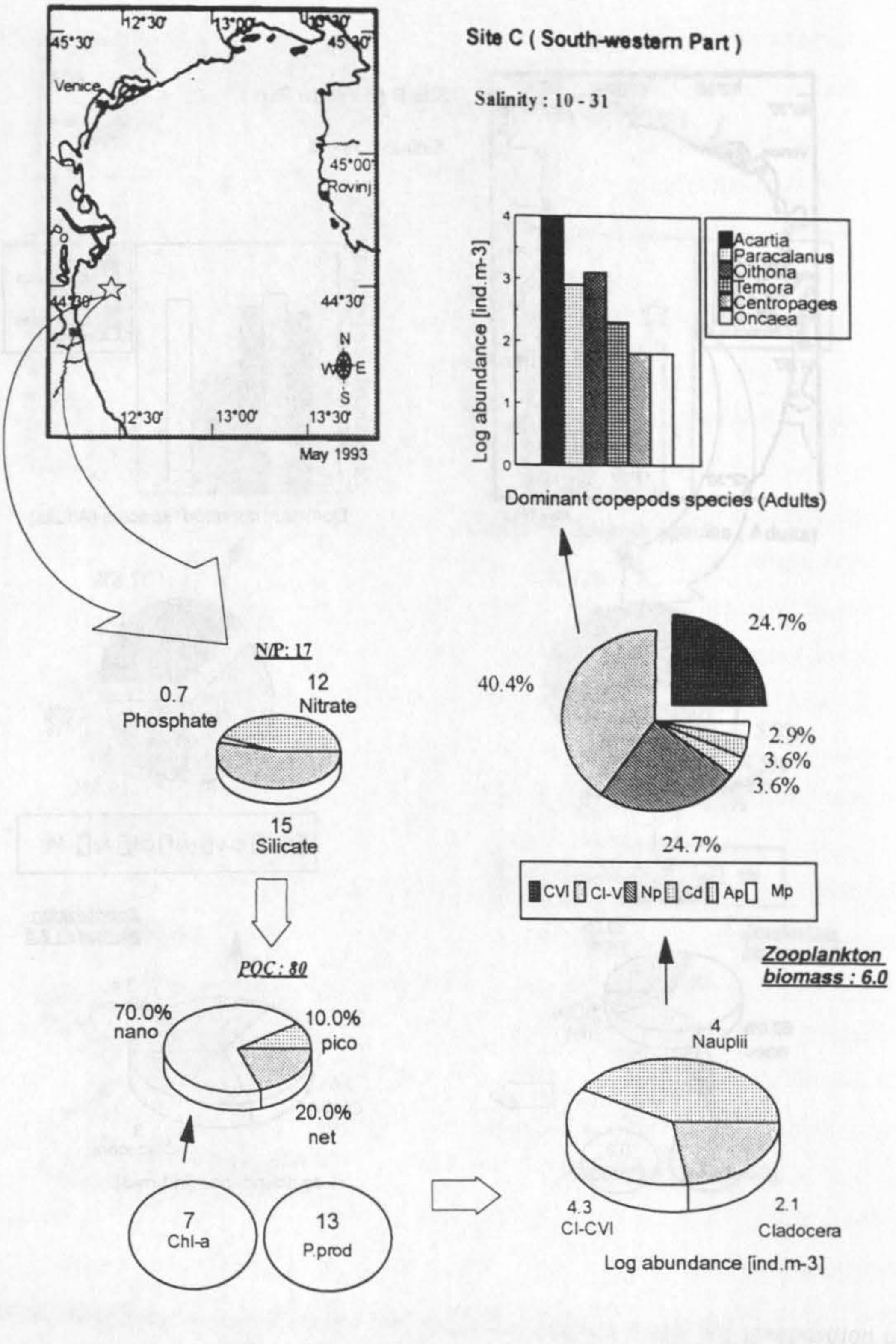


Figure 4.3.2b. Schematic overview of the environmental conditions and the composition of the plankton food web at three sites in the northern Adriatic Sea. ***Site C: South-western Part.*** *Unit measurements : Nutrient concentrations [µM], chlorophyll-a [µg dm^{-3}], primary production [µg C m^{-3}h^{-1}], zooplankton biomass [mg C m^{-3}] and zooplankton abundance [ind m^{-3}].*

There was no specific distribution pattern of adults in relation to the salinity gradient in the Po estuary in May. In June a strong association of the abundance of *Oithona similis* and eutrophied areas could be realized. The lower number of individuals near the Po River mouth in May 1994 may be a dilution effect through the river water. The larval stages of *Oithona* seem to develop well in salinities of 15-30 psu, which was confirmed by our investigation in June (*Fig.3.2.12c*). The tolerance of *O.similis* to low salinities is also stated by ACKEFORS (1981), who also mentioned that the salinity > 14 psu is the optimum habitat for *O.similis*.
In a review TURNER (1984) stated that there is only a little information on the feeding ecology of cyclopoid copepods such as *Oithona*. Cyclopoids are generally considered omnivorous, but it appears that they are primarily raptorial feeders rather that suspension-feeding herbivores (TURNER *et al* 1986; UCHIMA 1988 and references therein). A carnivorous feeding of *Oithona* may well be an explanation for the high population in area, in which ageing of a phytoplankton bloom has taken place, because aged phytoplankton communities are associated with a rather high number of microzooplankton including nauplii.

We found *Oithona* also frequently in regions with a high vertical stratification (dS/dZ) in the Po estuary, as identified from the principal component analysis (*Fig.3.2.5*). Possibly *Oithona* can take advantage of high vertical gradients in salinity and is able to migrate between two water layers and/or profit from the compensation current for being carried into waters with a high food supply. However, this hypothesis needs further verification. High concentrations of *Oithona spp.* at cold-warm water boundaries have been observed by HANSEN (1960) and KRAUSE *et al* (1995) in the North Sea, but there is no clear explanation for such an accumulation.

The cladoceran *Podon* spp. was also found in the low salinity regime (10-27 psu). The population maximum of *Podon* was found in eutrophied waters. Unfortunately very little is known about the feeding ecology of *Podon*, and the marine cladocerans in general (TURNER 1984). TURNER (1988) stated that *Podon polyphemoides* feeds on diatoms or heterotrophic microflagellates. KIM *et al* (1989) found *S. costatum* and other centric diatoms in the gut of *Podon*. *Ceratium* was also found in the gut of *Podon* (MOREY-GAINES 1979). The contribution of *Podon* to the zooplankton population in the northern Adriatic Sea was still low in May and June, but it was high from July to September. Due to the assumed omnivorous feeding of

Podon, its grazing potential on phytoplankton was estimated to be low in the eutrophic area during May/June.

Adult *Acartia clausi* were also frequent in the oligohaline area near the Po outlets, while their nauplii were mainly found in the mesohaline area. Both development stages of *Acartia* had their maximum in salinities between 17-30 psu in May. One month later in June, there were only few individuals found in the euhaline (> 30 psu) water. Apparently the population of the *Acartia clausi* developed well in the vicinity of the Po outlet in polyhaline waters in the northern Adriatic Sea, although *A.clausi* is not to be considered a low-saline water species (WIBORG, 1955; KRAUSE *et al*, 1995). The distribution pattern of *Acartia* was similar to that of *Oithona*, which showed a high tolerance to strong salinity gradients. The accumulation of adult *A.clausi* and *Oithona* spp near the river outlet is probably due to the transport by a compensation current in the lower water layer, while small zooplankton organisms like the nauplii of these species are transported downstream.

The PCA shows that in the Po estuary the effect of salinity and chlorophyll content on the distribution of *Acartia* was stronger than that of temperature .in May and June. This may be due to a relatively low variation in temperature (mean = 18 ±3° C). SULLIVAN & MCMANUS (1986) stated that in the Narragansett Bay the hatching success of *A.hudsonica* (*A.clausi*) was negatively correlated with the temperature 18 to 20°C, and no hatching took place above 20°C. A significant reduction of *Acartia* nauplii number was observed from May to June, while the number of the older stages (CI-CVI) remained almost constant during the same period in the north-western Adriatic Sea. Thus the nauplii may have been exposed to a high mortality. Higher stocks of nauplii found during May and June most likely indicate higher egg production rates during the month before. Egg hatching and nauplius development time are much faster during the summer because of warmer temperatures. MILLER *et al* (1977) stated that the naupliar development of *Acartia tonsa* from NI to NVI would require 2 days in summer and about 4 days in spring in the Mississippi plume water. Since the lower salinity and higher phytoplankton standing stocks (also indicating a high microzooplankton concentration) are correlated, it is difficult to determine which factor really influences the population dynamics of the zooplankton.

The copepod *Paracalanus parvus* and its naupliar stages occurred in mesohaline (> 15 psu) to euhaline waters, where high chlorophyll-*a* was found. *Paracalanus* belongs to euryhaline coastal forms which are common inhabitants of temperate neritic assemblages (GAUDY 1985). The pattern of its distribution is similar to that of *Acartia* possibly due to the similarity of their feeding habit as omnivores.

The copepod *Centropages* spp. and its nauplii occurred also in mesohaline (>15 psu) to euhaline regions. *Centropages typicus* is also a neritic copepod in the northern Adria, whereas *Centropages kroyeri* is known to be frequent in the central and southern Adriatic Sea (VUCETIC 1973). Gut content analysis of *Centropages typicus* in the Adriatic Sea showed that its diet consists of a mixture of diatoms and microzooplankton depending on the composition of phytoplankton community structure in the waters (REGNER & MARASOVIC 1983). In the vicinity of the Po River plume, the young stages of *Centropages* were found to be more abundant than the adults during May and June. Its contribution to the zooplankton population was very low (~ 2%) and showed a significant negative correlation with the degree of eutrophication in May and June. *Podon* spp and *Evadne* spp. showed a positive correlation with the degree of eutrophication, while *Penilia avirostris* was always only found far from the eutrophied waters during May and June. *P.avirostris* is known as a small filter-feeder. It was abundant in the oligotrophic waters. FONDA UMANI (1992) and MALEJ (1980) decribed summer zooplankton maximum of *Penilia* in Gulf of Triest and at Bay of Kopper, respectively. They found that the zooplankton population in these areas was dominated up to 80 % by *Penilia avirostris* during summer.

A few individuals of *Oncaea* spp.(mainly *O.media*) were found in the euhaline water during May. In June, however, also occurred in the polyhaline water at 20 psu. HURE *et al* (1980) characterized *Oncaea* spp. as an oceanic species only to be found in the southern Adriatic Sea. In May and June its population maximum was associated with a high temperature stratification. Possibly *Oncaea* spp can be used as an indicator of the influence of Mediterranean water in the northern Adriatic Sea. Its distribution pattern apparently excludes the high degree of eutrophication in the north-western Adriatic Sea.

In the highest salinity area the carnivorous copepod *Euterpina acutifrons* was predominant in the northern Adriatic Sea. During May and June, *E.acutifrons* was observed in a limited area within the euhaline zone. This species is known as a neritic form and is frequently found in the warmer seas (cf.WELLS 1970). The contribution of *E.acutifrons* to the zooplankton population was low in May and June. The mature females of *E.acutifrons* were frequently observed during autumn and found to concentrate in warmer water bodies. In the northern Adriatic Sea, its distribution as neritic species together with to the cladocera *Penilia avirostris* was observed, which can be related to its common nutrition habits.

Two distinct assemblages of zooplankton could be observed in the northern Adriatic Sea : A zooplankton community which was associated with estuarine water and corresponding high content of particulate organic matter, including chlorophyll-*a*, and another community which was associated with high-saline oligotrophic waters.

LE FEVRE (1986) stated that many zooplankton species are found to be abundant in fronts, including larval stages of nektonic organisms (GOVONI & GRIMES 1992, and references therein). Fish shoals tend to be congregated in the fronts too (UDA 1973; NISHIZAWA & TANIGUCHI 1988). The plume fronts may exhibit either clear-cut effects on plankton distribution (KRAUSE *et al* 1986; MACKAS & LOUTTIT 1988) or not (GAUDY *et al* 1990). Our observations of zooplankton distributions along three transects across the Po River plume fronts showed strong size changes in copepod populations (*Fig.3.2.10*). Apparently the plume fronts do not acts as a barrier for zooplankton species distribution.

A 'plume' is not a homogeneous water body but consists of various lenses of water masses which are moved by wind and tides. A more detailed information on the reaction of zooplankton on estuarine processes needs detailed hydrographic observations including the processes of advection and mixing. LEVASEUR *et al* (1992) mentioned that hydrodynamic, biological and chemical factors interact in such a complex way that the observed species distribution depends to a large extent on sampling strategy as well as on sampling frequency and the numbers of station.

4.4.2 Seasonal variations

The principal component analysis (PCA) shows that there was a high variation of zooplankton abundance between three sampling sites in the northern Adriatic Sea, but the seasonal variation was even stronger. The variation of zooplankton abundance between stations may reflect differences in salinities, however, the zooplankton species composition was similar. This analysis demonstrates that the zooplankton abundance and community structure changed gradually throughout the year corresponding to the temporal changes in temperature and/or salinity (*Fig. 3.3.4* and *Fig. 3.3.6*).

The pattern of seasonal distribution of zooplankton in the northern Adriatic Sea is characterized by two abundance maxima : one in late spring (May) dominated by copepods CI-CVI and a second peak in autumn dominated by Cladocera (November). The distribution of copepod nauplii, however, shows two peaks in April and September. We found a similarity of the seasonal zooplankton distribution pattern in the northern Adriatic Sea with other areas in the Mediterranean reported by SCOTTO DI CARLO & IANORA (1983). Investigations in the Gulf of Naples by MAZZOCCHI & RIBERA D'ALCALA (1995) showed that the minimum of copepod abundance was recorded in January (~300 ind m^{-3}) and maximum (~3 000 ind m^{-3}) in August. In the Gulf of Trieste, SPECCHI & FONDA UMANI (1981) reported that the minimum of copepod abundance was found in December/January (~ 200 ind m^{-3}) and maximum (~ 4 000 ind m^{-3}) in June. A similar seasonal variation of abundances to that in the Gulf of Trieste was also reported in the Bay of Kopper by MALEJ (1980). Our observations at the three stations located in the northern Adriatic Sea showed that the minimum copepod abundance (~1 200 ind m^{-3}) occurred between December and January and the maximum (~ 20 000 ind m^{-3}) in May (Fig. *3.3.6a*). The apparent secondary peak of copepod abundance (~10 000 ind m^{-3}) in November could indicate a typical seasonal distribution in the northern Adriatic Sea. There is clear evidence that the high Po River discharges in autumn lead to eutrophication and generate a higher copepod abundance.

A comparison of copepods numbers from the northern Adriatic Sea with those of other temperate estuarine systems, e.g.Naragansett Bay (USA) show that the abundance of *Oithona spp* and *Paracalanus parvus* in summer in the Naragansett Bay was only 100 - 200 ind m^{-3} (cf.MILLER, 1983). In the eutrophic area of the northern Adriatic Sea these two species made up 200 - 1000 ind m^{-3} and 300 - 1100 ind m^{-3}. The abundance of *Acartia clausi* in the Northern Adriatic Sea during May 1993 (3000 - 9000 ind m^{-3}) was comparable to the above mentioned area (5000 ind m^{-3}). The abundance of copepods in the northern Adriatic Sea, however, was lower compared to tropical estuarine systems. In Cochin backwaters and Vellar estuary the counts copepods in summer 92 000 ind m^{-3} and 18 000 ind m^{-3} respectively (MADHUPRATAP 1987).

The figures of zooplankton abundance reported here are in the range of abundance estimates from other European estuaries, e.g : Westerschelde, Ems and Gironde (*Table 4.1.1*). We were mainly interested in variations of zooplankton abundance. Such a comparison of the zooplankton abundance in varying investigations may still be applicable, although it is hampered by sampling over different depth intervals and using different nets and mesh sizes. Copepod nauplii dominated the zooplankton in the Po estuary, as they do in other estuares such as Wilson Inlet, Australia (GAUGHAN & POTTER 1995). However, the peak abundance of nauplii (~ 300 000 ind m^{-3}) in the Po estuary was significantly lower than that reported in the Wilson Inlet estuary (~ 600 000 ind m^{-3}) during spring and summer. The monthly mean abundance of copepod nauplii was also lower than that recorded in the Wilson Inlet estuary (*Table 4.1.1*). LUKATELICH *et al* (1987) stated that the higher densities of zooplankton in the Wilson Inlet estuary may be related to agricultural nutrient enrichments within the catchment area, and retention of nutrients being favoured by the restricted water exchange with the ocean. The water exchange in the Po River estuary, however, is governed by near-shore circulation of water masses.

Table. 4.1.1. Mean standing stocks of copepods and copepod nauplii (ind m^{-3}) and mesh size used for sampling in the northern Adriatic Sea with a selection of other temperate estuaries.

Mesh size (µm)	Estuaries	Mean abundance of zooplankton (ind m^{-3})	Mean abundance of copepod nauplii (indm^{-3})	References
200/55	Po Estuary	7 800	30 900	Present study (May)
200/55	Po Estuary	3 000	2 100	Present study (June)
200/55	Northern Adriatic (Po River Plume)	3 400	6 400	Pesent study (copepods)
71	Vally of Comacchio, Northern Adriatic		28 950	Ceccherelli &Ferrari (1982)
200	Rhone River Plume	400	included	Gaudy&Lochet (May)
55	Westerschelde	7 750	-	Soetaert&Van Rijwijk (1993; mean copepod,spring-summer)
200	Ems-Dollard	8 000	-	Sautour&Castel (1995;May-June, copepods)
200	Gironde	3 000	-	Sautour&Castel (1995;May-June,copepods)
55	Wilson Inlet,Australia	50 000	147 160	Gaughan&Potter (1995;annual mean,copepods)
64	Biscayne Bay,N.America	25 500	7 305	Roman et al (1983)
64	San Fransisco Bay	104 000	5 500	Ambler et al (1985)
73	NeuseRiver, USA	34 530	< 600	Mallin (1991; copepods)
76	Peconic Bay	52 500	26 000	Turner (1982;copepods)
76	MounthopeBay,USA	90 000	-	Toner (1981, copepos)
150	Newport estuary,USA	4 900	-	Thayer et al (1974)
153	Narragansett	28 100	5 795	Hulsizer (1976)
150	North Inlet,USA	9 200	1 333	Lonsdale&Coull (1977)

The seasonal distribution pattern of Cladocera in the northern Adriatic Sea was found to be similar to that of other areas in the Adriatic Sea, e.g. Gulf of Trieste and Bay of Kopper (maximum ~ 6 000 ind m^{-3}) or other parts of the Mediterranean, e.g. in Saronikos Gulf (maximum ~ 4 000 ind m^{-3} ; SIOKOU-FRANGO 1996). However, the abundance peak of total Cladocera in summer was significantly higher (~ 12 000 ind m^{-3}) in the northern Adriatic Sea compared to those of other areas. We found not only higher abundances of Cladocera, but also that their occurrence in the northern Adriatic Sea lasted much longer than in the oligotrophic Gulf of Naples, where MAZZOCCHI & RIBERA D'ALCALA (1995) found them from July to September. In the northern Adriatic Sea, however, we observed them from May to January.

Among the Cladocera, *Penilia avirostris* was found to be extremely abundant within the summer zooplankton populations (50 % of total zooplankton abundance). *P.avirostris* is known as omnivorous, since this species is able to feed on bacteria and heterotrophic nanoflagellates and dominates even in the oligotrophic environment (TURNER *et al* 1988). PAFFENHÖFFER & ORCUTT (1988) stated that *P.avirostris* is able to filtrate smaller particles. SCHNEIDER & LENZ (1987) reported that *P.avirostris* is a significant grazer of small particles in the upwelling area off north-western Africa. In the northern Adriatic Sea, *P.avirostris* take advantage of the abundance of food by propagation through parthenogenesis during the warmer months.

The principal component analysis shows that the copepod nauplii exhibit similar seasonal patterns of distribution and a significant correlation with the chlorophyll-***a*** concentration, especially with the autumn phytoplankton bloom. *Acartia clausi* CI-CVI showed a succession of three peaks during the year (March, May and November), which negatively correlated with chlorophyll-***a*** peaks throughout the year. The copepodite stages of *A. clausi* CI-CV (70 % of the total copepod abundance) were the only ones which showed a correlation with the phytoplankton bloom in spring. The correlation between the abundance of the larval stages of *A.clausi* indicates that the survival of nauplii is probably related to the presence of sufficient edible particles of suitable size. BERGGREEN *et al* (1988) stated that the optimum particle size and the upper size limit for *Acartia* nauplii were 7-14 µm and 70 µm, respectively, instead of 14-70 and 250 µm for adults. From an investigation of chemical content (carbon and nitrogen) of *A.clausi* in the northern Adriatic Sea (Gulf of Trieste) by

FONDA UMANI (1994), it is shown that the summer diet mainly consisted of dinoflagellates and nanoflagellates, while its spring diet was mainly composed of diatoms. We found a positive correlation between the sex ratio and abundance of *A.clausi* in the northern Adriatic Sea, can be interpreted as a homeostatic mechanism for the regulation of the population. ZABALLA AND GAUDY (1996) reported a homeostatic mechanism for *Acartia tonsa* in the eutrophic area of La Habana Bay (Cuba). During periods of low abundance, *A.clausi* exhibits a higher proportion of females for increasing egg production in the northern Adriatic Sea. The second generation of *A.clausi* in the northern Adriatic Sea, indicated by higher abundance of its nauplii, was clearly observed (*Fig.3.3.7*). Therefore *A.causi* was also found to be abundant during winter.

During summer *Temora stylifera* was dominant (40 % of the total copepod abundance). A typical summer peak of the abundance of *Temora* was reported in the Gulf of Naples by MAZZOCCHI & RIBERA D'ALCALA (1995). Although there is an association between seasonal copepod abundance and chlorophyll concentration, a shift of peaks between them is frequently observed, leading to a poor correlation (*Fig. 3.3.6*). The temporal zooplankton/phytoplankton interaction in the northern Adriatic Sea can be explained as follows: the copepod abundance is associated not only with the actual chlorophyll content but also with the amount of chlorophyll, which has not been grazed during the development of the stocks. Therefore a time-lag reaction of zooplankton to its food availability was frequently observed due to the different development time. The late spring/summer maxima of zooplankton abundance in the northern Adriatic Sea, however, coincided with low (<5 µg dm^{-3}) and high (~ 30 µg dm^{-3}) chlorophyll concentrations. In late autumn, the decline of zooplankton abundance is frequently associated with high food concentrations. Thus the phytoplankton standing stocks remains underexploited in the same way as in the following spring.

Our seasonal data are clearly insufficient to resolve significant trends in either number and community structure. However, the present analysis indicates the important seasonal interaction of zooplankton and its developmental stages with environment factors. We could not estimate development time of the copepod stages. A combination of different approaches (ecological, physiological and behaviour studies) and a higher sampling frequency would be needed for a complete analysis of zooplankton succession.

Summarizing, we find the following picture for the seasonal cycle of plankton in the northern Adriatic Sea. In winter a high phytoplankton biomass and production is observed, whereas zooplankton biomass is still low. In spring, the water is characterized by high nutrient concentrations followed by a high phytoplankton and zooplankton biomass. In summer, a low zooplankton biomass dominated by Cladocera is observed. In autumn, the highest discharge from the Po River occurs followed by an increase of phytoplankton biomass. The highest zooplankton biomass dominated by *Acartia clausi* is observed in autumn *(Fig. 4.3.3)*.

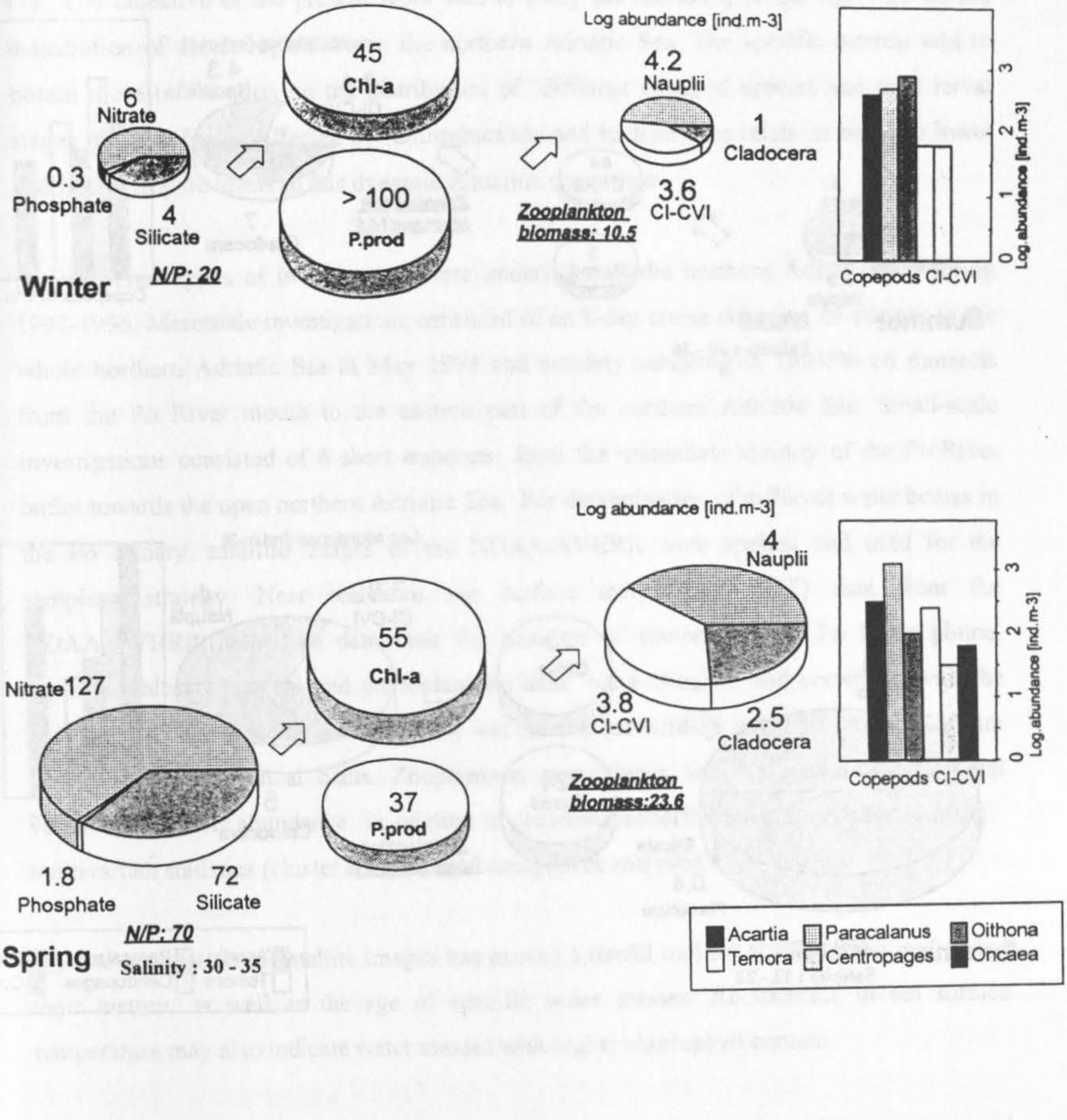


Figure 4.3.2a. Schematic overview of the characteristic seasonal zooplankton distribution in relation to the environmental parameters in the northern Adriatic Sea: ***Winter and spring situation****. Unit measurements : Nutrient concentrations [µM], chlorophyll-a [µg dm^{-3}], primary production [µg C m^{-3}h^{-1}], zooplankton biomass [mg C m^{-3}] and zooplankton abundance [ind m^{-3}].*

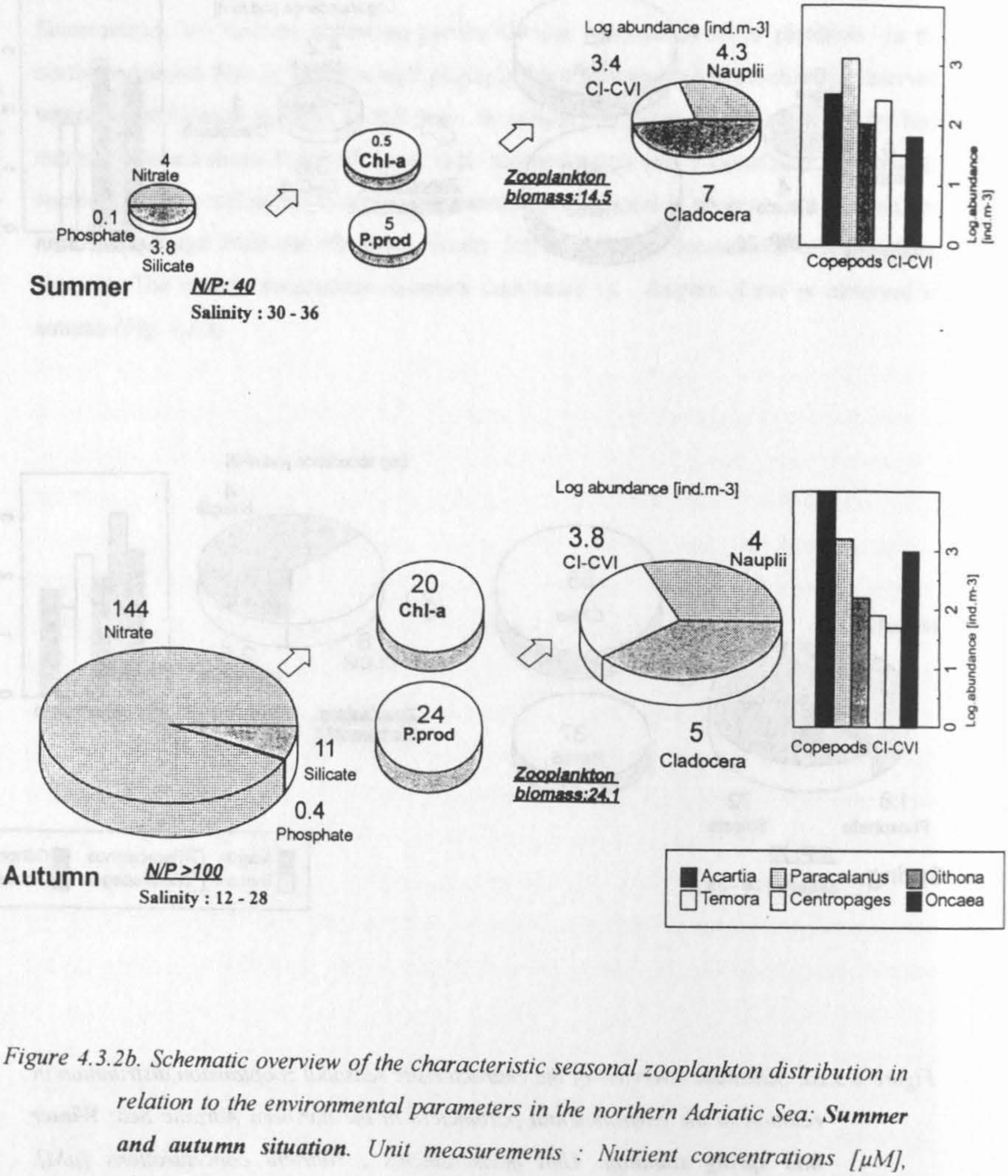


Figure 4.3.2b. Schematic overview of the characteristic seasonal zooplankton distribution in relation to the environmental parameters in the northern Adriatic Sea: ***Summer and autumn situation****. Unit measurements : Nutrient concentrations [µM], chlorophyll-****a*** *[µg dm^{-3}], primary production [µg C m^{-3}h^{-1}], zooplankton biomass [mg C m^{-3}] and zooplankton abundance [ind m^{-3}].*

5. SUMMARY

(1) The objective of the present work was to study the influence of the River Po on the distribution of mesozooplankton in the northern Adriatic Sea. The specific interest was to obtain more information on the distribution of different copepod species and their larval stages in water bodies affected by eutrophication and to determine relations between lower and higher trophic levels in this dynamic estuarine ecosystem.

(2) Different types of investigation were undertaken in the northern Adriatic Sea during 1993-1996. Mesoscale investigations consisted of an 8-day cruise covering 25 stations in the whole northern Adriatic Sea in May 1993 and monthly sampling in 1994/96 on transects from the Po River mouth to the eastern part of the northern Adriatic Sea. Small-scale investigations consisted of 6 short transects from the immediate vicinity of the Po River outlet towards the open northern Adriatic Sea. For determination of different water bodies in the Po estuary, satellite images of the NOAA-AVHRR were applied and used for the sampling strategy. Near real-time sea surface temperature (SST) data from the NOAA-AVHRR helped to determine the position of stations in the Po River plume. Hydrographical, chemical and phytoplankton data were obtained and correlated with the zooplankton data. Zooplankton sampling was carried out with 55 µm, 100 µm and 200 µm plankton nets in vertical hauls. Zooplankton assemblages and the spatial and temporal variability of their abundance in relation to environmental factors were evaluated using multivariate statistics (cluster and principal component analysis).

(3) The application of satellite images has proven a useful tool for tracing water bodies and their history, as well as the age of specific water masses. An increase in sea surface temperature may also indicate water masses with higher chlorophyll content.

(4) The northern Adriatic Sea is stratified in summer and mixed in winter. Heterogeneity and variability is always higher in spring than in summer and winter. The distribution of nutrients and chlorophyll in the Po estuary depends on the complex hydrography and on the flow rates of the River Po.

(5) A simple nutrient budget which results from all investigations on 50 stations in the northwestern Adriatic Sea suggests that the pelagic food web is to a large extent supported by external contributions of nutrients from the Po River. In most samples, the N/P ratio was much higher than 16. The N/P ratio of 20-50 (up to 70) indicates a marked surplus of nitrogen and phosphorus deficiency. Within the immediate neighbourhood of the Po estuary, up to 75 % of the nutrients were removed and converted into particulate organic matter.

(6) The phytoplankton size distribution showed the predominance of picoplankton (< 2 µm) in the oligotrophic waters in the central and north-eastern Adriatic Sea. The microphytoplankton (>20 µm) was mainly represented by diatoms and responsible for the primary production in the eutrophic waters. Patches of high phytoplankton standing stock which can be contributed to an increased production were frequently observed at 20-30 km east and southeast of the Po River mouth.

(7) The abundance of adult copepods was correlated with oligotrophic waters, while their larval stages were positively correlated with eutrophic waters. In the highly eutrophied waters of the northern Adriatic Sea, the zooplankton grazing potential apparently did not play any significant role for the phytoplankton growth, which was basically 'bottom-up' controlled by the availability of nutrients. In the oligotrophic waters of the central and north-eastern Adriatic Sea a 'top-down' control of phytoplankton was observed. The dissolved organic carbon (DOC) was high in oligotrophic waters, pointing to a microbial food web based on the 'microbial loop' in this areas.

On several occasions a high copepod abundance could be observed, which was correlated with a distinctly warmer water body characterized by a lower phytoplankton biomass than in surrounding areas. This phenomenon, detected from the satellite sea surface temperature data and proved by in-situ measurements, indicated that the grazing effect of zooplankton was also high.

(8) The copepods *Acartia clausi*, *Oithona similis*, *Centropages* spp, *Temora stylifera*, . and Cladocera *Podon* spp were found to be abundant during May. At this time high concentrations of nauplii (*Acartia*, *Temora* and *Oithona*) were observed.

Investigations on the spatial distribution of zooplankton in the Po estuary showed that a habitat preferences and tolerance of zooplankton to salinity, temperature and chlorophyll changes. *Acartia clausi* (CI-CVI) dominated during May-June (50 % of total adult copepods) and was associated with warmer water ('plume water') without exessive phytoplankton biomass (chlorophyll-***a***). In June, the abundance of copepod nauplii was lower and they were frequently found in the eutrophication area of the northern Adriatic Sea. *Oncaea* spp. accumulated at the frontal areas with increasing numbers towards the high-saline water.

(9) Investigations along the transects from the Po River mouth to the open Adriatic Sea following the salinity gradients showed a high abundance of total mesozooplankton at distances between 20 to 30 km off the Po River mouth. The highest abundance of adult copepods as well as their larval stages occurred at salinities of 25-30 psu, and was associated with high chlorophyll-***a*** (5-15 µg dm^{-3}) and intermediate levels of nutrients. Horizontal variation of abundance depends on the species investigated. The plume waters with higher food availability (phytoplankton biomass) apparently play an important role in enhancing the zooplankton standing stock and production. Fronts in the Po River plume did not show strong borderlines for mesozooplankton distribution.

(10) Seasonal variations of total copepod nauplii (*Acartia clausi*, *Paracalanus parvus*, *Oithona* spp, *Temora* spp and *Centropages* spp.) populations in the northern Adriatic Sea showed a bimodal pattern, with a major peak in spring (April) and a secondary peak in late summer (September). The naupliar stages of *Acartia clausi* and *Centropages* spp. showed a similar temporal pattern of distribution, characterized by a high variability of their numbers in March. The seasonal abundance of naupliar stages of *Oithona* species showed highest numbers in April. Since the development from nauplii and copepodite stages to adults occurs rapidly in the northern Adriatic Sea, our sampling frequency (max. 1 month) could not trace the succession of different stages.

(11) Seasonal distribution of copepods CI-CVI showed a main peak (20 000 ind m^{-3}) in late spring (May) and a secondary peak (12 300 ind m^{-3}) in late autum (November). The dominant copepods *(Acartia clausi*, *Paracalanus parvus Oithona* spp., *Temora* spp and *Centropages* spp.) were present throughout the year. A distinct succession of Cladocera

starting with *Podon* spp. in May, *Evadne* spp. in June and *Penilia avirostris* in July was observed. *Penilia avirostris* was responsible for a major peak of total mesozooplankton in summer.

(12) The highly variable hydrography in the northern Adriatic Sea requires much higher sampling frequencies for obtaining more detailed knowledge of zooplankton population dynamics. Real-time satellite information from scanners recording sea surface temperature and ocean colour are required to get more information on specific water bodies and their history.

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APPENDIX

Bio-Data

Abbreviations

Appendix 3.1.1. Physical, chemical and biological parameters (cruise R/V Poseidon 16-23.5.1993)

Appendix 3.1.2. Abundance of mesozooplankton (cruise R/V Poseidon 16-23.5.1993)

Appendix 3.1.3. Abundance of copepodites and nauplii (cruise R/V Poseidon 16-23.5.1993)

Appendix 3.1.4. Biomass of mesozooplankton (cruise R/V Poseidon 16-23.5.1993)

Appendix 3.2.1. Physical, chemical and biological parameters (cruise May-June 1994)

Appendix 3.2.2. Abundance of adult copepods and Cladocera during cruise in May 1994

Appendix 3.2.3. Abundance of adult copepods and Cladocera during cruise in June 1994

Appendix 3.2.4. Abundance of copepodites, nauplii and other mesozooplankton cruise in May 1994

Appendix 3.2.5. Abundance of copepodites, nauplii and other mesozooplankton cruise in June 1994

Appendix 3.2.6. Polynomial curve fitting between zooplankton and salinity gradients

Appendix 3.3.1. Physical, chemical and biological parameters (seasonal cruises 1994-1996)

Appendix 3.3.2. Mesozooplankton abundance (seasonal cruises 1994-1996)

Bio-Data

Name : Budy Wiryawan

Place and Date of Birth : Tegal, 23 December 1962

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Occupation : Academic staff at the Faculty of Fisheries
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Status : Married
Endang Liesnawati (wife)
Adriane Widyaningdita (daughter, 7yrs old)
Adrian Satriaji (son, 3 yrs old)

Education:

1981 Graduated from High School in Tegal, Indonesia.

1986 Graduated from the Faculty of Fisheries,Bogor Agricultural University
B.Sc. thesis: System analysis for tuna fishery in Indonesia.

1987- Education staff member in the Faculty of Fisheries, Bogor Agricultural University (IPB) with the following past activities:

(1) Lecturing and supervising practical work of students

(2) Research and cooperation with other Institutions

(3) Training : - Data analysis and interpretation in social research in Indonesian Open University (1986)

-Application of remote sensing for fishery in Indonesian Aerospace Institute (1987)

- Fish stock assessment in Lowestoft Marine Research Institute, England (1988)

1989	Post Graduate Diploma in Fisheries Management from the Humberside Polytechnic, Grimsby, England. Assessment work on the application of satellite remote sensing for fishery in Indonesia.
1990	Master of Science in Tropical Coastal Management from the University of Newcastle upon Tyne, England. M.Sc thesis : "The growth record of Flounder (*Platichthys flesus*) and the effect of pollution in the Tyne estuary".
1992 Jakarta	DAAD fellowship : Language training course at Goethe Institut and Mannheim (PNdS Certificate).
1993	Post graduate student (Doktorand) at the 'Institut für Meereskunde an der Universität Kiel. Member of the EU-Environmental project MARE (Microalgae of the Adriatic REgion) in the northern Adriatic Sea.

ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
AFDW	Ash-free dry weight
BSH	Bundesamt für Seeschiffahrt und Hydrographie
CA	Cluster Analysis
Chl-***a***	Chlorophyll-***a***
CIMAR	Centro Investigatión en Ciencias del Mar y Limnologia
CTD	Conductivity Temperature Depth
CZCS	Coastal Zone Color Scanner
DFD	Deutsches Fernerkundungs- Datenzentrum
DLR	Deutsche Luft- und Raumfahrtbehörde
DW	Dry weight
EU	European Union
Fluor	Fluorescence
FWG	Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik
IOW	Institut für Ostseeforschung Warnemünde
ISIS	Intelligentes Satellitendaten Informationsystem
MARE	Microalgae of the Adriatic REgion project
net	Net microphytoplankton
N	Nitrogen
Nad	The northern Adriatic current
nano	Nanoplankton
Np or (N)	Nauplii
NOAA	National Oceanic and Atmospheric Administration (U.S.A)
NO_2	Nitrite
NO_3	Nitrate
NH_4	Ammonia
OTS-WTW	Oxygen Temperature Salinity Probe
P	Phosphorous
PCA	Principal Component Analysis
POM	Particulate organic matter
PO_4	Phosphate
PON	Particulate organic nitrogen
POC	Particulate organic carbon
pico	Picoplankton
Q-mode	Station-species matrix
SeaWiFS	Sea Wide Field Sensor
SST	Sea surface temperature
SPSS	Statistic Programm for Social Science software
T-S	Temperature and Salinity
WIM	Windows Image Manager software
W-Mad	The Western-Middle Adriatic Current
WP 2	Working Party 2 (Unesco)

Abbreviations for Zooplankton

(A)/Ad	Adult
Ap	Appendicularia
Acar	Acartia
(C)/Cop	Copepodite stages
CI-CVI	Copepodite developmental stages 1-6
Cala	Calanus
Cd	Cladocera
Cent	Centropages
Clau	Clausocalanus
Cory	Corycaeus
Euter	Euterpina
Evad	Evadne
Mp	Meroplankton
(N)/Nau	Nauplii
Oith	Oithona
Onca	Oncaea
Para	Paracalanus
Pod	Podon
Peni	Penilia
Pseudo	Pseudocalanus
Temo	Temora

Appendix 3.1.1. Physical, chemical and biological parameters (cruise 16-23.5.1993 in the northern Adriatic Sea).

Station & Date	Position	Time	Depth [m]	Temp. [°C]	Salinity [psu]	Oxygen in % Satur.	Oxygen [mgdm^3]	Ammonia [μM]	Nitrate [μM]	Nitrite [μM]	Phosphate [μM]	Silicate [μM]	Chl-a [μg/dm^3]	Prim.prod. [μg C/dm^3/h]	POC [μM]	PON [μM]	POP [μM]
05/16/93																	
384	44°96.9' N	0:37	0	20.1	36.9			0.33	5.69	0.53	0.00	1.73	0.48		12.75	1.51	0.02
384	13°54.9' E		10	19.8	36.9			0.11	4.72	0.37	0.00	0.97	0.19		12.98	1.59	0.04
384			20	12	36.9			0.00	3.81	0.63	0.00	1.11	0.17		17.70	1.91	0.04
384			40	11.8	37			0.10	5.33	1.00	0.10	1.99	0.24		14.68	1.72	0.06
05/16/93																	
385	44°33.5' N	8:40	2	20.6	31.1	146.9	10.83	0.23	7.67	1.89	0.10	2.74	7.33	7.06	130.18	10.93	0.29
385	12°42.4' E		10	12.5	35.9	121.6	10.24	0.08	4.78	0.89	0.02	1.42	1.59	1.02	66.01	4.74	
385			18	11.3	36.3	114	10.01	0.12	3.99	0.79	0.02	2.57	1.06	0.70	28.35	2.46	0.06
385			27	10.6	36.6	109.3	9.59	0.16	4.36	0.42	0.00	2.79	1.18	0.77	18.40	1.93	0.08
385			32	10.7	36.7	85.8	7.53	0.68	4.30	1.26	0.10	6.77	1.73	1.20	51.02	5.86	0.19
05/16/93																	
386	44°43.5' N	13:16	0	21.5	27	148.2	10.99	0.33	5.16	2.95	0.19	1.86	4.10	4.64	140.14	16.60	0.33
386	12°26.3' E		5	19.8	32.4	125.3	9.42	0.33	7.23	1.21	0.01	0.53	3.61	2.62	60.65	7.85	
386			10	16.2	34.6	100.2	8.03	1.24	5.31	0.47	0.02	2.83	1.88	1.49	50.19	4.97	0.26
386			15	13.1	35.5	101	8.51	1.01	3.55	0.89	0.01	4.20	0.80	0.64	23.21	2.72	0.20
386			20	10.5	35.8	90.1	7.91	1.48	1.56	1.00	0.00	5.62	0.82	0.76	21.00	3.05	0.23
05/16/93																	
387	44°46.5' N	15:52	0	22.4	10.7	108.7	8.94	2.07	12.99	10.57	1.12	25.88	7.33	2.11	87.13	11.78	1.17
387	12°27.2' E		3	19.9	31.5	120.7	9.08	0.66	10.69	1.53	0.17	3.05	5.35	24.83	59.35	7.25	
387			5	18.3	34.2	112.8	8.7	0.62	7.32	1.57	0.14	0.49	3.18	5.25	36.33	4.27	0.18
387			10	13.3	35.2	85.7	7.22	2.11	4.79	2.21	0.16	3.10	1.69	2.76	18.64	2.80	0.19

Appendix 3.1.1. Continued

Station & Date	Position	Time	Depth [m]	Temp. [°C]	Salinity [psu]	Oxygen in % Satur.	Oxygen [mgdm^3]	Ammonia [µM]	Nitrate [µM]	Nitrite [µM]	Phosphate [µM]	Silicate [µM]	Chl-a [µg/dm^3]	Prim.prod. [µg C/dm^3/h]	POC [µM]	PON [µM]	POP [µM]
05/16/93																	
388	45°05.8' N	20:42	0	19.6	35.2	120.4	8.85	0.18	5.54	0.79	0.02	1.73	1.40	1.77	26.48	3.31	0.13
388	12°27.4' E		14	11.6	36.1	106.2	9.12	0.05	3.15	0.74	0.00	0.49	0.87	1.25	30.96	2.81	0.06
388			20	11.4	36.1	112.2	9.84	0.00	1.25	0.53	0.00	0.27	0.67	1.04	25.96	2.62	0.03
05/17/93																	
391	45°37.5' N	8.58	0	19.6	36	110.7	8.14	0.07	1.73	0.47	0.00	1.02	0.43	0.46	12.22	1.45	0.04
391	13°15.5' E		8	16.2	36	122.6	9.7	0.00	0.18	0.05	0.01	0.66	0.46	0.71	18.73	2.17	
391			15	12.9	36	114.1	9.61	0.04	0.44	0.32	0.01	1.28	0.36	0.38	12.07	1.43	0.05
05/17/93																	
392	45°26.5' N	11:00	0	20	36.2	112.6	8.27	0.22	1.04	0.32	0.02	1.02	0.29	0.42	12.02	1.42	0.02
392	13°13.5' E		5	15.6	36.2	120.2	9.52	0.16	0.53	0.00	0.02	0.97	0.27	0.45	10.12	2.89	
392			17	13.1	36.2	98	8.24	0.07	0.36	0.32	0.04	1.28	0.43	0.59	9.79	1.40	0.03
05/17/93																	
393	45°03.5' N	14:30	0	20.7	33.7	128.6	9.37	0.21	2.54	2.84	0.38	1.55	0.51	0.73	19.65	2.12	0.04
393	13°20.5' E		5	15.3	36.3	116.8	9.43	0.00	2.06	1.05	0.07	1.50	0.51	0.90	17.09	1.99	
393			25	11.4	36.9	104.9	9.2	0.01	0.08	0.00	0.00	1.95	0.58	0.84	8.04	1.36	0.06
05/17/93																	
394	44°31.8' N	19:53	0	20.3	37	111.2	8.06	0.00	0.30	0.00	0.00	0.00	0.24	0.19	12.11	1.27	0.02
394	13°56.5' E		8	14.6	37	215.8	17.21	0.00	0.14	0.16	0.12	0.31	0.36	0.24	14.61	1.81	
394			18	13.7	37	117.5	9.58	0.00	0.84	1.21	0.00	0.00	0.36	0.16	10.49	1.03	0.02
394			30	12.6	36.8	107.8	9.08	0.07	0.48	0.05	0.01	0.00	0.72	0.25	7.37	1.03	0.04
394			42	11.6	36.9	107.3	9.22	0.00	0.48	0.05	0.12	0.00	0.84	0.31	8.99	1.39	0.04

Appendix 3.1.1. Continued

Station & Date	Position	Time	Depth [m]	Temp. [°C]	Salinity [psu]	Oxygen in % Satur.	Oxygen [mgdm^3]	Ammonia [μM]	Nitrate [μM]	Nitrite [μM]	Phosphate [μM]	Silicate [μM]	Chl-a [μg/dm^3]	Prim.prod. [μg C/dm^3/h]	POC [μM]	PON [μM]	POP [μM]
05/20/93																	
401a	44°47.1' N	11:30	0		31.5			2.32	10.04	2.26	0.33	7.48	3.52	9.92	472.18	5.56	0.99
401a	12°26.7' E		10		35.2			3.38	1.56	0.74	0.13	3.62	2.27	7.16	489.44	5.90	
401b			0		?			4.24	38.87	9.63	2.73	35.49	6.27	18.00	661.72	6.99	0.89
401b			2		30			5.65	12.11	6.79	1.20	12.74	4.67	25.22		10.98	1.63
05/20/93																	
402	45°08.9' N	16:09	0	21.1	34.5	127.8	9.32	0.85	0.22	1.58	0.09	0.53	1.11	2.39	302.40	2.95	0.10
402	13°00.0' E		7	16.9	36.7	118	9.17	0.79	0.00	0.11	0.24	0.58	0.53	0.78	218.81	1.88	
402			13	14.2	36.8	118.9	9.8	0.67	?	6.74	0.05	0.84	0.43	0.62	191.01	1.81	0.09
402			22	12	36.8	112.1	9.63	0.73	0.44	1.16	0.15	1.81	0.77	0.76	245.29	2.42	0.11
402			30	11.7	36.8	99.8	8.57	0.56	0.00	0.16	0.05	2.43	1.20	1.82	256.85	3.94	0.11
05/20/93																	
404	45°40.7' N	8:59	0	21.5	35.8	122.2	8.14	0.84	0.22	0.26	0.00	22.57	0.46	1.20	181.04	2.36	0.05
404	13°39.3' E		4	21	36.6	112.1	8.07	0.89	0.11	0.21	0.07	20.71	0.39	0.62	180.25	2.33	
404			10	16.4	36.6	113.9	9.02	0.87	0.33	0.32	0.08	18.72	0.34	0.79	171.54	1.57	0.05
404			15	14.7	36.6	118.2	9.55	0.85	0.00	0.16	0.00	11.55	0.36	0.74	245.30	2.10	0.06

Appendix 3.1.1. Continued

Station & Date	Position	Time	Depth [m]	Temp. [°C]	Salinity [psu]	Oxygen in % Satur.	Oxygen [mgdm^3]	Ammonia [µM]	Nitrate [µM]	Nitrite [µM]	Phosphate [µM]	Silicate [µM]	Chl-a [µg/dm^3]	Prim.prod. [µg C/dm^3/h]	POC [µM]	PON [µM]	POP [µM]
05/21/93																	
405	45°26.6' N	14:27	0	22.1	31.8	113.8	8.25	1.15	0.50	0.63	0.10	1.28			141.85	1.54	0.03
405	13°13.1' E		5	15	36.8	103.7	8.37	1.21	0.03	0.53	0.13	1.64			129.61	1.34	
405			17	13.8	36.7	117.9	9.72	0.97	0.01	0.47	0.17	2.04			156.18	1.53	0.04
05/21/93																	
406	45°08.4' N	17:24	0	21	35	113.7	8.19	0.86	0.34	0.47	0.11	1.06	0.80	1.45	327.35	3.51	0.08
406	13°17.0' E		3	21	35	116.1	8.37	0.77	0.19	0.37	0.08	1.06	0.55	0.81	244.06	2.41	
406			9	15	35	120.7	9.75	0.82	0.24	0.32	0.10	1.59	0.34	0.53	174.20	1.96	0.04
406			25	11.5	36.5	106.8	9.17	0.76	0.14	0.42	0.09	2.21	0.41	0.72	116.22	1.31	0.05
05/22/93																	
409	44°10.0' N	9.17	0	21.7	33.4	117	8.37	0.57	5.36	0.00	0.26	1.15	1.93	2.57	484.05	4.42	0.10
409	12°47.3' E		8	20.6	33.4	119.8	8.73	0.69	2.76	0.37	0.01	1.19	1.76	0.96	392.37	3.87	
409			13	11.9	35.8	90.8	7.8	1.31	2.27	0.68	0.13	5.27	1.90	1.10	378.68	3.89	0.20
409			16	12.2	35.7	102.5	88	1.22	0.00	0.11	0.04	3.85	1.18	2.05	787.30	6.81	0.13
409			18	12.2	36.4	88.4	7.58	1.72	0.00	0.84	0.03	5.75	1.18	2.13	351.56	3.14	0.14
05/22/93																	
410	43°57.4' N	12:01	0	21.8	33.4	83.4	8.58	0.39	0.00	0.00	0.01	0.75	3.37	3.45	562.20	5.19	
410	12°59.1' E		6	22	33	120	9	0.65	0.48	0.68	0.05	1.24	2.60	3.20	507.30	4.95	
410			10	16	37	74	6	2.08	0.36	0.53	0.03	1.37	1.40	4.60	550.17	6.77	0.16
410			12	12	36	63	5	0.98	0.40	1.21	0.05	6.15	1.49	7.10	561.65	6.60	0.23

Appendix 3.1.2. Abundance of mesozooplankton (cruise : R/V Poseidon 16-23.5.93 in the northern Adriatic Sea)

Species	St.387	St.395	St.396	St.397	St.398	St.399	St.388	St.393	St.394	St.391	St.405	St.404
Copepods (CVI)	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3	n/m^3
Paracalanus parvus	220	486	1600	2400	1000	688	1091	385	96	608	192	286
Centropages typicus	55	26	100	100	100	0	0	31	19	24	0	5
Oithona similis	1044	883	7300	2900	2200	1000	818	1015	462	516	265	944
Oithona nana	1209	1011	5000	2600	1100	750	455	569	144	176	40	37
Oithina plumifera	769	282	5800	3500	1500	313	636	708	135	0	0	0
Acartia clausi	604	26	1000	2300	6500	1563	500	923	231	0	50	80
Calanus helgolandicus	0	51	0	0	0	0	0	0	0	0	0	0
Clausocalanus arcuicornis	0	13	0	0	0	0	0	0	0	0	0	0
Clausocalanus paululus	0	64	0	0	0	125	0	0	0	0	0	0
Pseudocalanus elongatus	0	26	600	0	100	0	45	815	173	0	2	3
Temora longicornis	0	64	1200	500	600	0	0	0	10	0	0	0
Temora stilifera	110	90	100	0	100	0	0	262	163	0	9	3
Evadne nordmanni	1099	26	300	0	300	0	91	0	0	40	0	77
Evadne tergestina	0	90	300	0	0	188	0	62	106	0	0	0
Podon polyphemoides	0	26	300	0	300	563	45	31	19	8	0	0
Podon intermedius	0	13	100	100	0	0	0	31	0	0	0	0
Microsetella rosea	0	13	0	0	0	0	0	46	29	0	0	0
Oncaea spp.	55	1152	2600	5700	2900	750	227	1385	1192	4	5	3
Euterpina acutifrons	0	0	0	100	0	63	23	0	0	0	0	5
Calocalanus pavo	0	0	0	0	0	0		0	67	0	0	0
Total CVI:	5165	4339	26300	20200	16700	6000	3932	6262	2846	1376	563	1443
Cladocera												
Evadne nordmanni	1099	26	300	0	300	0	91	0	0	40	0	77
Evadne tergestina	0	90	300	0	0	188	0	62	106	0	0	0
Podon polyphemoides	0	26	300	0	300	563	45	31	19	8	0	0
Podon intermedius	0	13	100	100	0	0	0	31	0	0	0	0
Total cladocera:	1099	154	1000	100	600	750	136	123	125	48	0	77
Apendicularia	1758	0	141	708	727	1063	1364	15	38	84	28	220
Bivale larlae	1484	538	590	2646	600	688	0	354	96	20	0	0
Gastropod larvae	110	39	26	46	0	313	0	62	77	0	0	0
Total meroplankton:	1593	577	615	2692	600	1000	0	415	173	20	0	0
Macroplankton	0	0	13	0	18	63	0	0	0	0	0	0
Polychaeta larvae	0	0	0	0	0	250	23	0	10	0	0	0

Appendix 3.1.3. Abundance of copepodites and nauplii (cruise: R/V Poseidon 16-23.5.93)

Copepods (CI-CV)		St.387	St.395	St.396	St.397	St.398	St.399	St.388	St.393	St.394	St.391	St.405	St.404
No.	Genus	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]
1	Acartia	11099	713	1269	3262	7045	24938	955	938	192	4	33	45
2	Paracalanus	769	1684	1436	1769	682	813	1182	4400	952	90	151	156
3	Oithona	934	920	910	1000	1068	1188	1182	2492	990	158	207	693
4	Temora	110	78	269	31	182	188	0	646	0	8	0	0
5	Centropages	55	65	90	77	159	63	91	31	1	40	5	29
	Total:	12967	3394	3974	6138	9136	27188	3409	8508	2135	300	396	923

Copepod nauplii		St.387	St.395	St.396	St.397	St.398	St.399	St.388	St.393	St.394	St.391	St.405	St.404
No.	Genus	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]
1	Acartia	8681	544	667	1554	3045	13625	1000	708	202	219	21	135
2	Paracalanus	330	479	808	1154	773	938	136	646	385	12	19	82
3	Oithona	495	1036	487	200	182	1063	636	2415	462	40	12	119
4	Temora	165	479	141	92	114	250	91	369	106	0	9	19
5	Centropages	0	0	0	0	0	0	0	31	58	0	21	24
6	Calanus	0	0	0	0	0	0	0	123	19	8	0	0
	Total:	9670	2539	2103	3000	4114	15875	1864	4138	1154	278	83	379

Appendix 3.1.4. Biomass of mesozooplankton (cruise : R/V Poseidon 16-23.5.93 in the northern Adriatic Sea).

Stations	Depth [m]	Biomass mg C / m3	dry weight [mg/m3]	Stations	Depth [m]	Biomass mg C / m3	dry weight [mg/m3]	Stations	Depth [m]	Biomass mg C / m3	dry weight [mg/m3]
385	0-30	5.75	13.05	393	0-25	5.79	12.80	406	0-4	6.30	14.15
385	0-30	7.52	17.19	394	0-42	2.08	4.59	406	0-4	7.11	14.59
386	0-18	5.13	10.79	394	0-42	1.72	4.00	409	0-7	7.57	17.73
386	0-18	4.33	10.61	395	0-38	2.12	4.27	409	0-7	6.96	15.23
387	0-7	5.03	11.94	395	0-38	2.48	5.36	410	0-11	6.07	13.60
387	0-7	6.31	17.05	396	0-30	2.32	4.77	410	0-11	6.60	14.61
388	0-17	2.93	6.86	396	0-30	2.80	6.19	411	0-11	5.51	12.59
388	0-17	2.89	7.07	397	0-25	3.71	8.51	411	0-11	5.14	11.43
391	0-8	2.08	4.97	397	0-25	2.71	5.89	412	0-10	4.97	11.30
391	0-8	2.26	5.77	398	0-21	3.50	4.74	412	0-10	5.16	10.50
392	0-15	1.72	3.71	399	0-6	4.83	12.13	413	0-5	6.91	14.96
392	0-15	1.67	3.61	399	0-6	4.21	13.26	413	0-5	4.36	11.46
393	0-25	5.20	11.03	404	0-15	3.84	9.44				
393	0-25	5.79	12.80	404	0-15	2.99	7.00				
394	0-42	2.08	4.59	405	0-21	3.55	7.96				

Appendix 3.2.1. Physical, chemical and biological parameters (cruises May and June 1994)

Stations number	Position	Date	Depth [m]	Time	Secchi [m]	Salinity [psu]	Temperature [°C]	Chl-a [µg/l]	Chl-a <20µr [µg/l]	Fluores.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Nitrite [µM]	Ammonia [µM]	PON [µM]	POC [µM]	POP [µM]
1	Po di Goro	19.5.94	0	9.00	0.25	0.1	17	7.42	4.63		5.12	124.64	145.4	7.76	3.62	7.07	8.26	1.69
2	Po di Goro	19.5.94	0	9.30		0.3	17.2	7.33			4.53	119.72	141.69	7.76	4.37	7.7	8.98	1.44
3	Po di Goro	19.5.94	0			3.9	16.9	5.3	8.53		5.02	110.54	127.29	7.76	3.94	8.04	9.39	1.64
4	44 46,70N	19.5.94	0		0.5	5.7	17	5.69	4.08		4.76	105.2	118.72	7.71	3.67	9.1	10.62	0.81
	12 23,70E																	
5	44 46,70N	19.5.94	0		0.6	8	17.2	4.05	3.52		4.4	100.35	109.67	7.16	3.91	8.42	9.83	0.55
	12 24.0E																	
6	44 46,70N	19.5.94	0		0.7	25.4	16.8	5	5.38		2.56	43.85	44.06	3.12	5.09	8.31	9.69	0.53
	12 25.0E																	
7	44 46.67N	19.5.94	0		0.8	7.1	16.9		3.34		4.14	94.88	113.32	6.01	4.24	7.18	8.38	0.46
	12 24.94E		0.5			15.4		4.08										
			1			31.1	15.7											
8	44 46.93N	19.5.94	0		1	16.8	16.5	2.78	4.45		2.91	69.47	77.36	4.59	3.88	no data	no data	0.33
	12 25,87E		1			35.5	15.5											
9	44 46,68N	19.5.94	0		1				5.19		3.03	77.93	89.16	4.92	4.31	8.92	10.4	0.29
	12 26,79E							4.08										
10	44 46,27N	19.5.94	0			20.3	17.2	3.52	4.45		2.64	60.15	63.89	3.72	3.79	7.53	8.78	0.35
	12 27,43E																	
11	44 45,64N	19.5.94	0		1.2	28.9	17.4	4.26			0.83	24.33	28.38	1.35	2.6	8.01	9.35	0.26
	12 28,16E																	
12	44 44,88N	19.5.94	0		1.5	29.3	17.7	5.19	3.89		0.53	19.91	24.62	1.13	1.08	7.58	8.84	0.25
	12 29,65E																	
13	44 49,39N	21.5.94	0	12.00	1	15.1	18.9	5.06	1.93	1.5	2.1	62.94	76.5	2.64	2.81	7.17	8.36	0.9
	12 29.84E		1			25.5	16.7			1.09								
			2			32.1	16.1			0.83								
14	44 49,55N	21.5.94	0		1.6	22.4	18.4	9.52	6.63	1.5	0.91	38.94	46.66	1.87	0.3	6.96	8.12	1.55
	12 32,39E		0.5			25.8	17.5			0.8								
			10			37.1	14.5			0.3								

Appendix 3.2.1. Continued

Stations number	Position	Date	Depth [m]	Time	Secchi [m]	Salinity [psu]	Temperature [°C]	Chl-a [μg/l]	Chl-a <20μm [μg/l]	Fluores.	Phospate [μM]	Silicate [μM]	Nitrate [μM]	Nitrite [μM]	Ammonia [μM]	PON [μM]	POC [μM]	POP [μM]
15	44 51,98N	21.5.94	0	14.00	2	27.3	18.4	5.78	5.06	1	0.56	22	27.99	1.35	0.34	8.01	9.35	0.7
	12 39,74E		0.5			27.5	18.3											
			1			28.2	17.8			0.85								
16	44 53,66N	21.5.94	0	14.25	2	24.3	19.1	4.64	4.04	0.8	0.85	29.71	37.39	1.6	0.61	6.98	8.14	0.91
	12 43 15E		0.5			27.4	18.5											
17	44 44,81N	22.5.94	0	9.50		19.9	18.2	13.01	6.67	1.3	0.5	51.19	52.69	2.06	0.84	7.41	8.64	0.54
	12 17,56E		0.5							2								
			1			22.6	17.4	30.96	20.68	5.5	0.77	42.42	36.88	1.95	0.83	7.37	8.6	1.43
18	44 45,94N	22.5.94	0	10.25		14.5	18	2.89	7.41	0.2	1.08	63.72	74.93	2.72	2.52	9.81	11.45	0.4
	12 20,80E		1			15.2	17.4			0.9								
19À	44 46,86N		0	10.41		2.5	18	5.3	3.56		5.15	95.97	120.96	6.14	12.3	12.38	14.44	0.49
(IN FRONT)	12 23,58E		0.5			4.3	17.2											
19B	44 46,86N		0	10.55	2	11.7	17.7	2.17	2.41		2.5	70.83	93.11	3.26	7.65	13.33	15.55	0.25
OUT FRONT	12 23,58E		0.5			13.4	17.4											
20	44 48,58N		0	11.50		16.5	19.7	8.43	7.97	0.9	0.85	66.26	47.5	3.34	7.61	7.27	8.48	0.64
	12 17,10E		1			17.3	19.4			0.8								
21	44 42,74N		0	12.15		26.4	19.1	5.3	3.71	0.75	0.7	20.39	13.7	1.66	0.86	11.21	13.08	0.38
	12 15,99E		0.5			26.6	19											
			1			33.8	16.5	18.67		1.8	0.52	35.37	31.96	2.12	0.68	7.07	8.24	0.96
22	44 41,47N	24.5.94	0	10.00	280	28.8	19.2	6.02	4.82	1.2	0.27	18.05	18.54	0.92	0.59	7.99	9.32	0.22
	12 31,02E		1			29.4	19.2			1.33								

Appendix 3.2.1. Continued

Stations number	Position	Date	Depth [m]	Time	Secchi [m]	Salinity [psu]	Temperature [°C]	Chl-a [µg/l]	Chl-a <20µm [µg/l]	Fluores.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Nitrite [µM]	Ammonia [µM]	PON [µM]	POC [µM]	POP [µM]
24	44 41.13N	24.5.94	0	11.00	280	26.5	19.2	5.54	4.02	1.23	0.27	24.47	25.81	1.11	0.7	7.81	9.11	0.27
	12 27.09E		0.5			27.4	19.1			1.23								
			8			37	15.2			0.36	0	0.48	1.62	0.19	0.53	8.25	9.63	0.06
25A	44 41.03N	24.5.94	0	12.00	70	16.1	19	6.87	8.03	0.7	1.31	53.68	74.57	2.58	3.55	4.75	5.54	0.63
(IN FRONT)	12 25.61E		1			27.7	19.2			0.8								
25B	44 41.03N	24.5.94	0	12.15	100	27.6	19.2	6.14	6.43	0.8	0.38	24.88	26.25	1.13	0.78	7.62	8.89	0.29
OUT FRONT	12 25.61E		1			28.3				1								
26	44 41.18N	24.5.94	0	12.30	100	7.7	18.7	3.49	4.02	0.35	2.11	78.39	86.85	2.97	6.42	7.06	8.24	0.43
	12 24.96E		0.5			20.9	19.1			1.4								
			5			33.1	17.4	2.77		0.8	0.11	10.29	11.42	0.57	0.62	9.39	10.96	0.12
27	44 41.80N	24.5.94	0	13.05	100	12.3	18.9	8.8	9.64	1.4	0.74	75.19	76.41	3	1.32	7.1	8.28	0.64
	12 17.53E		0.5			12.6	18.7			2								
			1			13.2	18.5	16.14		4	0.93	62.37	73.21	3.03	1.4	7.42	8.66	1.07
			5					3.86		0.54	0.16	0	6.31	0.7	1.51	6.88	8.03	0.15
28	44 30.66N	25.5.94	0	16.40	110	15.9	22.5	9.93		1.7	0.75	53.38	60.33	2.17	1.19	9.64	11.24	0.57
	12 22.40E		0.5			16.9	22.2			1.7								
			5			35.2	17.7	4.24		1.3	0.29	7.49	6.07	0.58	1.08	12.57	14.66	0.18
29	44 33.37N	25.5.94	0	17.25	100	10.9	21.9	14.17		2.4	0.77	66.8	74.02	2.57	2.26	fehlt	fehlt	0.59
	12 19.76E		0.5			10.9	21.9			2.5								
31	44 41.27N	26.5.94	0	9.45	No	No	No	No		1.2								
	12 15.14E		0.5							1.4								
32	44 42.65N	26.5.94	0	9.50	No	No	No	No		1.12								
	12 16.48E		0.5							1.3								
33	44 45.21N	26.5.94	0	10.00	180	15.7	20.4	7.61		0.8	0.49	56.41	53.6	2.52	0.68	7	8.16	0.48
	12 20.78E		0.5			15.7	20.4			1.2								
			1			18.6	20.1			1.7								
			1.5					26.51		4.8	0.55	19.61	14.41	1.02	0.72	7.39	8.62	1.4
			5			34.8	17	2.31		0.3	0.1	2.07	4.63	0.42	0.83	24.35	28.41	0.13
34	44 42.66N	26.5.94	0	10.50	No.	No.	No.	No										
	12 22.43E		0.5															

Appendix 3.2.1. Continued

Stations number	Position	Date	Depth [m]	Time	Secchi [m]	Salinity [psu]	Temp. [°C]	Chl-a [µg/l]	Chl-a <20µm [µg/l]	Fluores.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Nitrite [µM]	Ammonia [µM]	PON [µM]	POC [µM]	POP [µM]
35	44 41,35N	26.5.94	0	11.30	200	17	20.9	9.25		1	0.57	51.13	47.48	2.52	0.68	8.36	9.45	0.52
	12 23,29E		0.5			17	20.9			1.2								
			1.5			22	20.3	11.28		3.6	0.49	44.06	43.71	2.04	0.67	7.77	9.07	0.63
			5			33.4	18.2	0.67		0.8	0.07	3.42	7.31	0.4	0.19	11.41	13.31	0.053
36	44 35,55N	26.5.94	0	13.25	200	18.6	21.2	7.13	7.07	1.1	0.56	44.52	48.72	1.81	0.29	7.36	8.59	0.53
	12 29,59E		0.5							1.3								
			2			20	20.2	7.61		2	0.6	39.95	41.22	2.4	0.47	7.64	8.91	0.41
			5			33	18.4	3.47		0.8	0.15	2.06	5.63	0.49	0.19	11.75	13.71	0.11
			14															
			15			37	13.5			0.1								
37	44 38,19N	26.5.94	0	13.55	200	18	21.4	8.58	7.23	1.1	0.55	46.4	48.22	1.98	0.8	(125ml)	8.36	0.58
	12 24,69E		0.5			18.5	20.6			1.3						7.17		
			2			20.4	20.3	9.83		2.3	0.6	46.33	46.94	2		7.8	9.1	0.53
			5			33	18.3	3.08		0.8	0.12	2.87	8.86	0.45	0.16	10.43	12.16	0.1
38	44 39,81N	26.5.94	0	14.25	180	17.8	20.8	8.96	8.51	1.2	0.53	47.89	46.39	2.28	0.09	(150ml)	11.11	0.51
	12 20,02E		0.5			17.9	20.8			1.4						9.53		
			2			20.8	19.8	12.43		2.4	0.45	44.93	43.37	2.11	0.09	8.2	9.57	0.54
			5			33.2	18.3	6.27		0.9	0.15	14.48	15.09	0.87	0.06	8.2	9.35	0.24
1	44 41,35N	15.06.	0	9.50	180	27.1	19.1	24.67		1.5	0.66	23.61	26.63	0.92	0.35	5.81	6.78	0.81
	12 20,43E		0.5			27.2	19.1			1.8								
			4			32.5	19.2	4.43		0.5						6.36	7.42	0.21
			5			34.3	19.2			0.3	0.29	9.52	8.55	0.3	0.17			
2	44 41,67N	15.06.	0	10.45	50	20.5	19.5	45.3		4.1	1.79	42.43	44.66	1.7	0.9	6.39	7.45	1.57
	12 26,84E		0.5			25.7	19.8			1.6								
3A	44 39.98N	15.06.	0		700	31.9	19.8			0.62	0.33	13.17	16.61	0.4	0.09			
(IN FRONT)	12 42.57E		0.5			33.2	19.6			0.55								
3B	44 40,03N	15.06.	0		1300	34.9	19.1			0.2	0.09	3.4	2.02	0.11	0			
OUT FRONT	12 42,48E		0.5			34.9	19.1			0.2								

Appendix 3.2.1. Continued

Stations number	Position	Date	Depth [m]	Time	Secchi [m]	Salinity [psu]	Temp. [°C]	Chl-a [µg/l]	Chl-a <20µm [µg/l]	Fluores.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Nitrite [µM]	Ammonia [µM]	PON [µM]	POC [µM]	POP [µM]
4	44 40,31N	15.06.	0	12.20	1500	33.8	19.7			0.3	0.42	12.25	11.54	0.4	0			
	12 51,28E		0.5							0.1								
5	44 42,23N	15.06.	0	13.00	2600	37.7	19.3	0.96		0.05	0.26	1.14	0.14	0.02	0	9.6	11.2	0.05
	13 00,11E		0.5			37.7	19.3			0.05								
6	44 31,66N	15.06.	0		800	35	20	1.73		0.23	0.35	3.16	1.92	0.11	0	4.31	5.03	0.08
	12 38,66E		0.5			34.9	19.9			0.22								
7	44 28,23N	15.06.	0		100	22.4	20.9	16.77		1.1	0.92	37.16	35.25	0.93	0.82	5.97	6.97	0.68
	12 26,17E		0.5			22.7	20.6			1.3								
8	44 19,26N	15.06.	0	16.15	200	27.9	20.6	24.67		1.8	1.04	17.54	18.44	1.17	0.23	5.73	6.68	1.59
	12 21,00E		0.5							2.3								
9	44 05,43N	23.06.	0	11.20	350													0.18
	12 33,87E		0			32.7	23.3	1.54		0.34	0.26	8.18	2.14	0.58	1.9	7.97	9.3	
10	44 10,11N	23.06.	Luft	12.05	600													
	12 34,20E		0			32.1	23.8	1.93		0.22	0.19	7.36	0.76	0.1	0.04	7.35	8.58	0.09
			10			34.4	19.5			0.79	0.13	4.47	0.67	0.15	0.12			
11	44 13,39N	23.06.	Luft	13.00	750											6.77	7.9	0.12
	12 24,63E		0			32.2	24.6	2.51		0.28	0.15	7.47	0	0.13	0.06			
			8			35.1	19.7	0.67		0.2						5.66	6.6	0.08
			9			35.1	19.4			0.2								
			10			35.2	19.2			0.2	0.09	3.08	1.48	0.12	0.39			
12	44 17,21N	23.06.	0	14.00	1500	34	25.1	1.16		0.1	0.1	5.21	1.63	0.16	0.37	5.73	6.68	0.04
	12 48,18E		0.2			33.9	24.7											
13	44 16,68N	23.06.	0	15.00	1900	34.7	24.3	0.87		0.07	0.19	4.26	1.1	0.15	0.31	5.24	6.12	0.06
	12 54,62E		0.2			34.8	24.1											
			5			35.1	21	fehlt		0.1	0.07	2.76	0.67	0.15	0.44	6.14	7.17	0.06
			10			36.9	19.1	fehlt		0.08	0.07	3.1	0.53	0.09	0.42			0.02
14	44 14,45N	23.06.	Luft													6.37	7.43	
	12 55,09E		0			35.2	24.1	fehlt		0.12	0.18	3.94	0.8	0.12	0.23			0.09
			3			35.5	22.7	0.58		0.08	0.06	3.19	0.48	0.07	0.11	3.62	4.23	0.05
			10			36.2	20.2	0.48		0.11	0.06	2.49	0.45	0.11	0.26	5.33	6.21	0.04

Appendix 3.1.2. Continued.

Copepods (CI-CV)		St.387	St.395	St.396	St.397	St.398	St.399	St.388	St.393	St.394	St.391	St.405	St 404
No.	Genus	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]
1	Acartia	11099	713	1269	3262	7045	24938	955	938	192	4	33	45
2	Paracalanus	769	1684	1436	1769	682	813	1182	4400	952	90	151	156
3	Oithona	934	920	910	1000	1068	1188	1182	2492	990	158	207	693
4	Temora	110	78	269	31	182	188	0	646	0	8	0	0
5	Centropages	55	65	90	77	159	63	91	31	1	40	5	29
	Total:	12967	3394	3974	6138	9136	27188	3409	8508	2135	300	396	923

Copepod nauplii		St.387	St.395	St.396	St.397	St.398	St.399	St.388	St.393	St.394	St.391	St.405	St.404
No.	Genus	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]	[n/m^3]
1	Acartia	8681	544	667	1554	3045	13625	1000	708	202	219	21	135
2	Paracalanus	330	479	808	1154	773	938	136	646	385	12	19	82
3	Oithona	495	1036	487	200	182	1063	636	2415	462	40	12	119
4	Temora	165	479	141	92	114	250	91	369	106	0	9	19
5	Centropages	0	0	0	0	0	0	0	31	58	0	21	24
6	Calanus	0	0	0	0	0	0	0	123	19	8	0	0
	Total:	9670	2539	2103	3000	4114	15875	1864	4138	1154	278	83	379

Appendix 3.2.2. Abundance of adult copepods and cladocera (n/m3) during cruise of May 1994.

Station	Depth	Acartia	Para.	Pseudo.	Oithona	Centro.	Clauso.	Temora	Oncaea	Corycae.	Euter.	Total CVI	Evadne	Podon	Penilia	TotalClado
13	0-5	3595	652	0	2519	0	0	18	0	0	0	6784	0	881	0	881
13	0-15	2775	1559	0	3850	70	0	35	0	0	18	8335	9	449	0	458
14	0-5	1480	423	18	1481	53	0	35	0	0	0	3489	0	2079	0	2079
15	0-5	740	159	0	775	18	0	0	0	0	0	1692	0	18	352	370
15	0-15	335	441	26	1198	44	0	79	18	0	0	2141	0	62	0	62
16	0-5	511	282	18	741	0	0	18	0	0	0	1568	53	529	0	581
16	0-15	220	141	18	837	26	0	44	35	0	0	1885	26	53	0	79
17	0-2	70	35	0	159	0	0	0	0	0	0	264	0	176	0	176
17	0-8	2438	59	0	1498	0	0	0	0	0	0	3994	0	352	0	396
18	0-2	2247	88	0	1278	0	0	0	0	0	0	3612	44	1630	0	1674
18	0-8	1821	529	0	2115	0	0	0	0	0	0	4493	0	675	0	675
19-A	0-2	1233	308	0	3656	0	0	0	0	0	0	5286	0	2467	0	2467
19-A	0-4	0	132	0	1057	0	0	0	0	0	0	1189	0	264	0	264
19-B	0-2	88	44	0	572	0	0	0	0	0	0	705	0	1189	0	1189
19-B	0-5	925	88	0	969	0	0	0	0	0	0	1982	0	529	0	529
20	0-2	11278	0	0	0	0	0	0	0	0	0	11278	0	881	0	881
21	0-2	1145	0	0	881	0	0	0	0	0	0	2026	88	352	0	441
22	0-2	7401	441	0	617	0	0	0	0	88	0	8546	0	2026	0	2026
22	0-10	11454	2819	969	14801	176	0	1146	176	0	0	31542	352	441	0	793
23	0-2	10881	793	176	4317	176	0	441	44	0	0	16872	44	705	44	793
23	0-10	405	229	35	265	0	0	18	0	0	0	969	985	1269	0	1286
24	0-2	1233	352	0	1982	0	0	44	0	0	0	3612	3656	1233	0	1278
24	0-10	727	154	0	859	22	0	22	11	0	0	1795	11	154	0	165
24	0-15	493	952	0	2704	53	0	88	0	0	18	4308	0	53	0	53
25-A	0-2	10749	0	0	352	0	0	0	0	0	0	11101	220	6872	0	7093
25-A	0-10	5485	33	0	793	22	0	0	0	0	0	6333	0	859	0	859
25-B	0-2	10617	220	0	88	0	0	0	0	0	0	10925	0	7137	0	7137
25-B	0-10	29075	837	0	4096	0	0	0	0	0	0	34009	0	4978	0	4978
25-B2	0-2	5463	176	88	793	176	0	5595	0	0	0	6652	44	3480	0	3524
26	0-2	1366	88	0	572	0	0	0	0	0	0	2070	2114	4361	0	4405
26	0-8	2188	176	0	499	0	0	0	15	0	0	2878	0	852	0	852
27	0-2	1013	88	0	352	0	0	0	0	0	0	1454	1498	3568	0	3612
27	0-8	5125	235	0	1131	0	0	0	29	0	29	6549	6578	852	0	881
36	0-2	5683	264	0	176	0	0	0	0	0	0	6123	0	8811	0	8811
36	0-8	3289	250	0	705	0	0	15	0	0	0	4302	59	367	0	426
Mean :		4101	373	39	1677	24	0	217	9	3	2	6308	451	1732	11	1776

Appendix 3.2.3 Abundance of adult copepods and cladocera (n/m3) during cruise of June 1994

Station	Depth	Acartia	Para.	Pseudo.	Oithona	Centro.	Clauso.	Temora	Oncaea	Corycae.	Euter.	Total CVI	Evadne	Podon	Penilia	TotalClado.
1	4	1586	2203	0	88	0	0	0	0	0	0	3877	0	110	264	374
1	10	2305	1401	0	221	44	0	0	44	0	0	4009	59	162	338	558
2	2	14890	4493	88	2996	485	0	0	44	0	0	22996	88	396	705	1189
3-A	2	617	3260	0	44	220	0	0	0	0	44	4229	176	0	529	705
3-A	10	11	760	0	66	33	0	0	0	0	22	914	99	0	363	463
3-B	2-10	11	903	0	88	0	0	0	0	0	0	1013	77	0	639	716
4	2	0	7753	0	132	220	0	0	0	0	0	8106	484	0	44	529
4	10	44	826	0	55	11	11	0	55	0	0	1013	198	0	22	220
5-A	2	0	0	0	44	44	0	0	0	0	0	132	661	0	0	661
5-A	10	33	374	11	77	55	0	0	0	0	11	573	198	0	0	396
6	2	3568	10132	0	881	132	0	0	44	0	0	14802	176	0	220	396
6	10	187	1222	0	160	0	0	0	22	0	11	1669	44	0	55	99
6	20	106	1057	9	484	18	0	0	44	0	0	1727	9	9	132	150
6	28	264	1248	0	1013	29	0	15	73	15	0	2966	0	0	29	29
7	2	3084	6828	0	352	44	0	0	44	0	0	10441	44	661	925	1630
7	10	782	2566	0	286	33	0	0	0	0	11	3756	286	297	0	583
8	4	1189	132	0	66	0	0	0	0	0	0	1388	0	793	0	2181
9	7-10	2115	8253	0	58	29	0	0	0	0	0	10954	0	29	147	11131
10	4-10	529	2878	0	250	44	0	0	44	0	0	3818	646	323	822	1791
11	4	749	3018	0	220	44	0	0	22	0	0	4053	749	176	6454	7379
11	10	191	925	0	353	29	0	0	15	0	0	1512	117	132	822	1072
12	10	88	1744	0	97	44	0	9	0	0	0	2018	141	18	1533	1692
13A	4	463	2048	0	264	264	0	0	0	0	0	3040	44	0	3678	3722
13A	10	59	294	0	162	0	0	0	88	0	0	646	161	0	3686	3847
13B	2	88	6960	0	396	705	0	0	0	0	0	8150	749	0	661	1410
13B	10-15	229	670	0	441	70	0	53	264	0	0	1762	123	18	3137	3278
14	39	122	346	32	185	7	0	18	36	0	0	757	27	0	700	727
Mean :		1234	2678	5	351	96	0	4	31	1	4	4456	198	116	959	1738

Appendix 3.2.6. Polynomial curve fitting between the abundance of frequently appearing species zoooplankton (ind m^{-3}) and the average salinity within the mixed layer during May 1994. A : adult, C: copepodites and N: naupliar stages. Number of data N = 35.

Zooplankton genera	Stages	Model	r
Acartia clausi	A	$y = 448.8+597.3x-43.3x^2+1.6x^3$	0.42
	C	$y = 7603.3-1127.4x+103.1x^2-2.3x^3$	0.16
	N	$y = 14796-4318.4x+796.5x^2-20.83x^3$	0.35
Paracalanus parvus	A	$y = 531-52.5x+1.8x^2-0.01x^3$	0.48
	C	$y = 45.8-8x+0.6x^2-0.01x^3$	0.26
Para/Clausocalanus	N	$y = 346.5-245.5+34.4x^2-0.9x^3$	0.52
Oithona spp.	A	$y = 2474.4-130.4x-1.6x^2+0.2x^3$	0.41
	C	$y = 150.4-11.4x+1.0x^2-0.02x^3$	0.09
	N	$y = -0.11+684.7x-20.7x^2+0.04x^3$	0.27
Temora spp.	A	$y = -234.3+112.9x-6.9x^2+0.13x^3$	0.12
	C	$y = 25.1-3.2x+0.2x^2-0.002x^3$	0.33
	N	$y = -1.3-17.7x+3.5x^2-0.1x^3$	0.46
Centropages spp.	A	$y = -9.9+11.12x-1.0x^2+0.02x^3$	0.37
	C	$y = -2.6+9.5x-0.7x^2+0.2x^3$	0.47
	N	$y = -2.9-2.5x+0.7x^2-0.02x^3$	0.38
Oncaea spp.	A&C	$y = -494+2.6x-0.3x^2-0.006x^3$	0.51
	N	$y = 12.8+10.1x+1.2x^2-0.03x^3$	0.25
Calanus spp.	N	$y = 21.4+3.6x+0.4x^2-0.002x^3$	0.23
Total copepods	A	$y = 3421.2+459.8x-47.4x^2+1.3x^3$	0.45
	C	$y = 5906.8-657.73x+75.8x^2-1.83x^3$	0.16
	N	$y = 14042-3888.2x+814.5x^2-21.8x^3$	0.39
Podon spp.		$y = -929.1+874.6x-37x^2-0.4x^3$	0.42
Evadne spp.		$y = -129.9+62.8x-5.4x^2+0.1x^3$	0.74
Penilia avirostris		$y = -16.2+11.2x-1.2x^2+0.04x^3$	0.47

Appendix 3.2.4. Abundance of copepodites, nauplii and other mesozooplankton during cruise on May 1994.
Cop = copepodites, Nau= nauplii

Station	Depth	OitCop	TemCop	CenCop	CalaCop	TotalCop.	Ciriped.	Mysid	NauAcar	NauPara	NauOit	NauTem	NauCen	NauCala	NauOnca	TotalNaup.	Ciriped	Bivalve
13	0-5	106	35	0	0	6361	70	0	21357	4617	9833	388	211	0	0	36405	634	705
14	0-5	176	18	18	0	14203	88	70	31084	3595	3877	493	106	35	18	39207	106	5181
15	0-5	18	18	18	0	2079	18	18	15507	4229	8070	247	35	0	0	28088	141	2819
16	0-5	35	0	35	0	3630	18	0	7648	1093	1022	88	0	0	0	9850	18	1463
17	0-2	18	0	0	0	916	159	0	273833	529	0	0	0	0	0	274361	4934	12775
18	0-2	53	0	18	0	3084	70	0	50000	1013	1850	132	44	0	0	53040	573	4537
19-A	0-2	264	0	22	0	2709	264	0	44317	0	0	0	0	0	0	44317	176	88
19-B	0-2	264	0	44	0	1938	485	44	70044	132	0	0	0	0	0	70176	88	44
20	0-2	529	0	0	0	8282	1233	0										
22	0-2	264	0	44	0	6784	0	0	70837	1586	1189	705	220	0	0	74537	44	5947
23	0-2	220	0	88	0	9648	44	88	16630	507	705	286	22	0	0	18150	44	1344
24	0-2	396	0	44	0	10661	0	0	74097	4405	6696	617	176	0	0	85991	0	8811
25-A	0-2	0	0	44	0	3656	132	0	79163	1233	1013	44	44	0	0	81498	0	2511
25-B	0-2	0	0	44	0	2070	132	0	164890	529	0	0	0	0	0	165463	0	4626
25-B2	0-2	0	0	0	0	1542	0	44	226167	0	0	0	0	0	0	226167	44	14405
26	0-2	44	0	44	0	2115	132	88	0	0	0	0	0	0	0	0	0	0
27	0-2	0	44	44	0	4581	352	0	84846	0	176	132	0	0	0	85154	529	352
36	0-2	0	0	88	0	35991	88	88	126564	44	0	0	0	0	0	126608	44	17269
Mean :		133	6	33	0	6681	183	24	79823	1383	2025	184	50	2	1	83471	434	4875

Appendix 3.2.5. Abundance of copepodites, nauplii and other zooplankton during cruise of June 94.

Station	Depth	CopAcar	ParaCop	OitCop	TemCop	CenCop	CalaCop	TotalCop	NauAcar	NauPara	NauOit	NauTem	NauCen	NauCala	NauOnca	NauTot	Ciriped	Bivalve
1	0-4	3304	198	0	0	0	22	3524	3943	132	352	154	396	0	0	5000	77	77
2	0-2	21189	661	0	0	0	661	22511	0	0	0	0	0	0	0	0	0	881
3-A	0-2	661	1189	88	0	0	132	2070	154	66	22	22	154	0	0	441	0	2643
3-B	2-10	165	441	11	0	11	77	705	154	66	22	22	154	0	0	441	0	2643
4	0-2	0	661	0	0	0	44	705	1762	441	154	6608	0	0	0	9097	0	220
5-A	0-2	44	132	0	0	0	0	176	1013	88	352	1718	0	0	0	3260	0	88
6	0-2	11145	969	220	0	0	617	12952	4934	9097	7247	110	2004	0	0	23392	0	242
7	0-2	7709	4229	44	44	0	881	12907	38040	242	5022	352	1630	0	0	45286	88	4978
8	0-4	9824	132	22	0	0	0	9978	101079	22	220	22	88	0	0	1E+05	264	9648
9	0-7	9824	132	22	0	0	0	9978	6671	101	13	0	76	0	0	6860	101	3593
10	4-10	308	543	0	0	0	15	866	4229	6784	13458	110	881	0	0	25463	0	925
11	0-4	308	264	44	0	0	0	749	1733	910	7181	294	132	0	0	10250	0	3054
12	0-10																	
13A	0-4	264	206	0	0	0	103	573	485	66	0	0	0	0	0	551	0	352
13B	0-2	0	1938	0	0	132	441	2511	1256	6278	3458	3744	2115	0	0	16916	0	793
14	0-39	172	154	0	2	0	2	332	727	2533	2093	1740	507	0	110	7709	22	419
Mean		4328	790	30	3	10	200	5369	11079	1788	2640	993	542	0	7	17407	37	2037

Appendix 3.3.1. Physical, chemical and biological parameteres (Seasonal cruises 1994-1996)

Stations, date&time	Position	Depth [m]	Salinity [psu]	Temp. [°C]	Chl-a [µg/l]	Prim.Prod.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Ammonia [µM]
1	44 31.8'N	0	37.6	8.9	51.3		0.31	4.29	6.34	0.70
21.1.95	12 30.9'E	0.5	37.6	9.19						
08:50		1	37.6	9.19						
Secchi:6		2	37.6	9.19						
		5	37.6	9.19	36.1		0.01	3.85	5.81	0.98
		12	36.9	9.19	34.3		0.00	3.74	5.81	0.81
		17	36.9	9.3	35.7		0.01	3.74	5.91	0.04
		22	36.9	9.3	47.7		0.05	2.07	6.34	1.22
2	44 40.0'N	0	38	10.5			0.02	1.76	3.70	0.57
21.1.95	13 06.0'E	0.5	38	10.5						
12:00		1	38	10.5						
Secchi:9		2	38	10.5						
		3	38	10.5	18.9					
		4	38	10.5				1.65		
		5	38	10.5			0.02		3.17	0.39
		8	38	10.5	22					
		9	38	10.5						
		10	38	10.5			0.03		3.17	0.19
		14	38	10.5				1.65		
		18	38	10.5	25.2					
		19	38	10.5						
		20	38	10.5				1.76	3.70	0.31
1	44°29.0N	0	35.7	8.7	20.5	195.5	0.09	2.29	8.44	0.44
02.3.95	12°32.0E	0.5	35.7	8.7						
10:00		1	35.7	8.7						
		2	35.7	8.7	7.44	261	0.06	2.18	7.78	0.49
		6	36.1	8.8	7.26	207	0.09	2.24	6.49	0.64
		7	36.2	8.8						
		8	36.3	8.8	7.74					
2	44°35.1'N									
02.3.95	12°50.8E	0	37	9.4	12.24		0.17	0.44	33.02	4.01
11:25		0.5		9.4						
		1		9.4						
		2		9.4	10.56		0.19	0.32	34.61	0.17
		9		9.1	5.3		0.21	0.47	4.12	0.10
		14		9.2	2.15		0.19	1.34	4.02	0.10
		21		9.9	11.52		5.70	2.09	2.19	0.20
		22								
3	44°43.0N	0	37.2	9.1	0.918	222.7	0.08	5.00	14.93	0.70
2.03.95	12°32.0'E	0.5	37.2	9.1						
12:00		1	37.2	9.1						
		5	37.4	9.1	1.53	258.9	0.06	3.53	8.44	0.41
		10	37.6	9	2.55	207	0.04	2.48	4.48	0.49
4	44°45.0'N	0	36	9	3.54	71.4	0.03	2.69	10.52	0.58
02.3.97	12°31.5'E	0.5	36	9						
12.4		1	36	9						
Secchi:3		2	36	9						
		5	36.5	9.1	4.62	50.3	0.02	2.63	3.30	0.27

Appendix 3.3.1. Continued

Stations, date&time	Position	Depth [m]	Salinity [psu]	Temp. [°C]	Chl-a [µg/l]	Prim.Prod.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Ammonia [µM]
5	44°35.7'N									
02.3.95	12°46.5'E	0	37.6	9.6	2.8		0.23	0.47	2.08	0.52
15 30		0.5	37.6	9.6						
Secchi 5		1	37.6	9.6						
		2	37.6	9.6	2.6		0.15	0.41	2.08	0.90
		12	37.8	9.6	2.5		0.16	0.92	1.89	0.17
		24	9.8	9.8	1.6		0.12	0.52	1.75	4.58
1	44°27.3E	1		13.7	7.92		0.23	0.92	2.34	0.65
18.04.96	12°31.1'E	5		10.1	3.18		0.10	0.37	1.41	0.25
10:00		10		8.6	1.83		0.07	0.28	0.14	0.19
Secchi:2.5		20		9.8	2.6		0.04	0.25	0.05	0.41
2	44°35.1N	1		14.6	1.64		0.07	0.27	0.25	0.26
18.04.96	12°50.7'E	5		13	1.06		0.04	0.52	0.13	0.27
14:00		10		12.9	0.96		0.02	0.11	0.30	0.18
Secchi:5		20		9.7	0.77		0.02	0.16	0.04	0.32
		30		9.7	0.58		0.03	0.17	0.04	0.45
3	44°43.0N	1		14.5	0.48		0.02	0.08	0.07	0.25
18.04.96	12°32.5E	35		12.1	1.25		0.03	0.75	3.02	0.56
Secchi:15										
1	44°40.4	1	33.1	16.2	6.91		0.24	1.28	0.47	0.44
23.04.96	12°39.5'	5	36	14.3	6.1		0.17	0.93	1.67	0.38
		10	38.4	9	2.22		0.08	2.08	0.87	0.68
		20	39.3	9.5	1.83		0.09	4.28	0.48	0.69
		26	39.3	9.5	0.48		0.06	5.27	0.17	0.78
2	44°17.11'N	1	35.5	16.4	5.58		0.15	0.71	0.14	0.35
23.04.96	12°32.4'E	5	36.7	14.7	3.53		0.15	0.68	0.14	0.32
		10	39.3	13	0.96		0.02	0.21	0.08	0.30
		20	39.3	13	1.16		0.04	0.37	0.02	0.17
		30	39.3	13	1.35		0.05	0.99	0.04	0.05
1	44°32.0'	0	36.9	11.5	52.6	37.2	0.27	32.20	127.10	14.96
11.04.95	12°30.6'	1	37	11.4	42.6	19.77				11.22
10:00		2	37.6	10.8	30.3	14.98	1.80	72.52	99.82	12.07
Secchi:8		3	37.7	11.3	24.5	8.25	0.09	76.16	71.92	17.68
1-5 See: Station : 36, 23, 5 ,14&15.										
19-26.05.94										
1		ẋ	23	22.4	23.5		0.28	23.30	20.80	1.38
19.06.95		15	37	16.5	12.9		0.03	2.15	2.85	0.76
11:10										
Secchi:1.8										
2	44° 38 N	0	28.1	23.4	12.2		0.14	13.80	31.80	0.76
19.06.95	12° 34.05 E	4	36.3	17.7	1.36		0.07	6.27	21.70	1.20
12:50		15	37.8	12.2	25.58		0.02	7.40	1.18	1.52
Secchi:4.8										
3	44° 46.0'N	0	30.8	23.3	8.84		0.06	0.75	11.40	0.52
19.06.95	13° 34.0'E	15	38.2	16.2	6.8		0.01	0.81	0.69	0.40
15:30										
Secchi:5										
4		0	30.7	24.9						
19.06.95		10	38	18.7						

Appendix 3.3.1. Continued.

Stations, date&time	Position	Depth [m]	Salinity [psu]	Temp. [°C]	Chl-a [µg/l]	Prim.Prod.	Phospate [µM]	Silicate [µM]	Nitrate [µM]	Ammonia [µM]
17.11.94	12°41.3'E	5	30.2	17.4	5.19	2.46	0.04	0.49	4.56	0.30
15:10		10	33.9	18.6	6.45	3.34	0.04	0.58	5.01	0.36
		15	35	19.1	6.96	5.83	0.05	0.54	4.02	0.40
4	44°32.7'N	0	20.9	14.8	5.58		0.21	9.67	15.90	0.66
17.11.94	12°46.5'E	5	33	17.7	0.1		0.10	2.63	7.90	0.36
16:10		10	34.3	18.2						
Secchi:2.2		15	34.6	18.3	0.08		0.08	5.37	8.80	0.48
5	7nm-SE of	0	24.6	14.9	14.43		0.18	11.44	13.72	0.43
17.11.94	St.4	10	34.3	17.7	24.39		0.23	7.79	10.64	0.39
17:10		20	35.3	18	9.57		0.05	0.26	7.01	0.30
1	44°31'N	0	16.4		29.9		0.55	20.13	128.80	1.21
13.12.94	12°27.8'E	2	24.9		22.8		0.14	33.70	26.00	0.47
9:50										
Secchi:1										
2	44°41'N	0	18.8		23.8		0.44	35.30	128.00	0.60
13.12.94	12°34'E	5	27.8		26.64		0.16	7.04	26.00	0.32
12:10		10	29		28.32		0.20	4.40	18.70	0.24
Secchi:1.2										
3										
13.12.94	44°36'N	0	26		24.12		0.18	14.85	70.00	0.89
12:45	12°41'E	5	28.5		11.76		0.08	11.00	39.18	0.15
Secchi:2		10	30		9.45		0.05	10.45	25.22	0.37
4	44°32'N	0	26.3		16.56		10.83	3.30	43.50	0.26
13.12.94	12°46'E	5	31.2		10.65		4.37	12.32	12.88	0.37
14:20		10	32.3		9.27		6.50	9.35	18.78	0.52
Secchi:3.5										
5	44°32'N	0	33.9		8.01		0.06	5.39	6.44	0.48
13.12.94	12°46'E	5	34.4		0.39		0.05	6.60	10.73	0.38
15:06		10	34.6		5.25		0.04	7.70	11.80	0.18

Appendix 3.3.1. Continued

Stations, date&time	Position	Depth [m]	Salinity [psu]	Temp. [°C]	Chl-a [μg/l]	Prim.Prod.	Phospate [μM]	Silicate [μM]	Nitrate [μM]	Ammonia [μM]
1	44° 32.1' N	2	27.9	23.3	15.3			3.43	22.17	0.77
22.06.95	13° 28'.4 N	9	35.3	21.2	3.12			1.63	1.53	0.47
11.15		15	37.4	14.1	1.77			1.28	0.40	0.54
Secchi:1.8										
2	44°41.5'N	3	31.7	24.5	1.56		0.05	1.77	11.83	0.71
22.06.95	12°34.7'E	9	38	18	1.77		0.05	0.90	0.80	0.46
16.45		15	38	15.8	1.21		0.04	0.76	0.72	0.40
Secchi:6										
1	44°46.8'N	1	33.2	26.3	0.26		0.09	3.81	4.38	0.05
13.07.97	12°27.4'E	5	34.4	23.1	0.22		0.04	4.80	3.35	0.05
10:07		15	38.2	18.1	0.2		0.04	2.10	0.72	0.06
Secchi: 6		30	38.5	11.9	0.21					
2	44°41.5'N	0	33.8	26.4						
13.07.97	12°47.7'E	5	36.1	24.3				0.99	2.68	0.06
11:00		10	36.9	22.1						
Secchi: 10										
3	44°36.4'N	0	35.5	27.7			0.03	1.64	2.91	0.07
13.07.97	12°41.3'E	5	37.2	24.2						
12:07		10	37.5	22.1						
Secchi: 22		30	38	18.9			0.04	0.84	2.91	0.07
1	44°31.8'N	0	35.2	21.8	0.63					
15.09.95	12°28.4'E	5	35.6	21.8						
10:00		10	35.9	21.7	0.29					
Secchi:7		30	37.5	16.5	0.48					
2	44°41.5'N	0	34	21.6	2.84					
15.09.95	12°54.7'E	5	34.1	31.5						
12:00		15	35.4	21.4	0.43					
Secchi:3.5		30	38	15.3	0.14					
3	44°36.4'N	0	34.8	21.6	1.98					
15.09.95	12°31.3'E	5	34.8	21.2						
15:00		15	36.7	20.1	0.77					
Secchi:3.5		30	38.2	13.8	0.19					
1	44°33.8'N	0	13.2	14.2	5.48	3.36	0.63	10.38	9.35	1.64
17.11.94	12°29.4'E	5	34	18						
10:00		10	34	18.3	0.46	0.52	0.09	3.03	6.16	0.85
Secchi:0.5										
2	44°41.5'N	0	13	13	2.11	0.52	0.63	10.38	9.35	1.64
17.11.94	12°34.7'E	5	15.8	16.5	4.05	1.64	0.09	3.03	6.16	0.85
12:00		10	35	17.5	3.45	7.88	0.09	11.10	10.18	0.91
Secchi:2.2		15	36	18.1	2.77	3.62	0.04	0.82	4.98	0.43

Appendix 3.3.2. Continued

Oithona nana	18	0	18	0	0	0	0	0	0
Oithona plumifera	0	0	0	35	0	35	0	0	0
Acartia clausi	0	0	0	229	0	229	2009	0	2009
Temora longicornis	1744	0	1744	388	0	388	0	0	0
Temora stylifera	0	0	0	0	0	0	564	0	564
Oncaea subtilis	0	0	0	0	0	0	0	0	0
Oncaea media	0	0	0	0	0	0	247	0	247
Corycaeus spp.	35	0	35	53	0	53	0	0	0
Calonalanus pavo	0	0	0	18	0	18	317	0	317
Microsetela rosea	35	0	35	0	0	0	0	0	0
Euterpina acutifrons	0	0	0	35	0	35	247	0	247
Clytemnestra	0	0	0	0	0	0	0	0	0
Pontella mediteranea	35	0	35	0	0	0	0	0	0
Anomalocera	0	0	0	0	0	0	0	0	0
		total	2396		total	1286	0	0	0
Evadne tergestina	0	0	0	0	0	0	352	0	352
Evadne spinifera	0	0	0	317	0	317	0	0	0
Evadne nordmanni	564	0	564	282	0	282	388	0	388
Podon polypomoides	18	0	18	0	0	0	0	0	0
Podon intermedius	0	0	0	0	0	0	17621	0	17621
Penilia avirostris	1480	0	1480	7524	0	7524	70	0	70
Oikopleura	0	0	0	0	0	0	0	0	0
Fritilaria	0	0	0	0	0	0	0	0	0
Mussel	35	0	35	35	0	35	141	0	141
Polychaeta	0	0	0	0	0	0	106	0	106
Sagita	0	0	0	18	0	18	23753	35	23789
Total	4458	35	6890	9445	18	10749			

Date : 17.11.94
Depth : 0-12
Station : 1

Date : 17.11.94
Depth : 0-12
Station : 2

Date : 17.11.94
Depth : 0-12
Station : 3

Date : 17.11.94
Depth : 0-12
Station : 4

Species	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Paracalanus parvus	1101	147	1248	2344	317	2661	4793	599	5392	1322	529	1850
Calanus helgolandicus	0	0	0	0	0	0	0	0	0	0	0	0
Eucalanus elongatus	0	0	0	0	0	0	0	0	0	0	0	0
Clausocalanus spp.	125	125	250	106	335	441	599	599	1198	0	0	0
Pseudo. elongatus	0	0	0	0	0	0	0	0	0	0	0	0
Centropages kröyeri	0	0	0	0	0	0	0	0	0	0	0	0
Centropages typicus	15	0	15	0	70	70	106	0	106	0	0	0
Oithona similis	213	0	213	264	0	264	352	0	352	264	0	264
Oithona nana	51	0	51	106	0	106	211	0	211	0	0	0
Oithona plumifera	0	0	0	18	0	18	106	0	106	0	0	0
Acartia clausi	477	580	1057	1674	1797	3471	3630	5956	9586	2291	1013	3304
Temora longicornis	7	7	15	18	18	35	0	0	0	0	0	0
Temora stylifera	0	0	0	0	0	0	0	0	0	308	0	308
Oncaea subtilis	0	0	0	0	0	0	0	0	0	0	0	0
Oncaea media	308	0	308	1093	0	1093	3348	0	3348	1101	0	1101
Corycaeus spp.	15	0	15	35	0	35	0	0	0	0	0	0
Calonalanus pavo	0	0	0	141	0	141	0	0	0	0	0	0
Microsetela rosea	0	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	125	0	125	0	0	0	70	0	70	0	0	0
Clytemnestra	0	0	0	0	0	0	0	0	0	0	0	0
Pontella mediteranea	0	0	0	0	0	0	0	0	0	0	0	0
Scelethricidae	0	37	37	0	0	0	0	0	0	0	0	0
Total Copepods	2438	896	3333	5797	2537	8335	13216	7154	20370	5286	1542	6828

Appendix 3.3.2. Continued

Date 13 07.95 Date 13.07.95

Depth 0-5 Depth : 0-5

Station : 1 Station :3

Species	Female {ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Calanus helgolandicus						
Eucalanus elongatus	536	148	684	1233	141	1374
Clausocalanus spp.	11	0	11	0	0	0
Pseudo. elongatus	11	0	11	0	0	0
Centropages kröyeri	236	113	349	0	0	0
Centropages typicus	4	0	4	0	0	0
Oithona similis	0	0	0	0	0	0
Orthona nana	7	0	7	141	0	141
Oithona plumifera	190	14	204	1974	247	2220
Acartia clausi	7	0	7	388	0	388
Temora longicornis	4	0	4	0	0	0
Temora stylifera	32	4	35	211	0	211
Oncaea subtilis	7	0	7	0	0	0
Oncaea media	0	0	0	0	0	0
Corycaeus spp.	0	0	0	0	0	0
Calonalanus pavo	229	0	229	176	0	176
Microsetela rosea	7	0	7	0	0	0
Euterpina acutifrons	0	0	0	0	0	0
Clytemnestra	0	0	0	211	0	211
Pontella mediteranea	18	0	18	2256	0	2256
Anomalocera	0	0	0	35	0	35
Evadne tergestina	0	0	0	0	0	0
Evadne spinifera	0	0	0	0	0	0
Evadne nordmanni	0	0	0		total	7013
Podon polypomoides	0	0	0	35	0	35
Podon intermedius	0	0	0	0	0	0
Penilia avirostris	0	0	0	0	0	0
Oikopleura	0	0	0	0	0	0
Fritilaria	0	0	0	423	0	423
Mussel	0	0	0	8352	0	8352
Polychaeta	0	0	0	388	0	388
Sagita	18	0	18	0	0	0
Total	14	0	14	0	0	0
	21	0	21	106	0	106
	1350	278	1628	0	0	0
				15930	388	23330

Date :15.09.95

Depth : 0-5 Date :15.09.95 Date :15.09.95

Station : 1 Depth 0-5 Depth5-10

Station :2 Station :3

Species	Female {ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Paracalanus parvus	476	35	511	370	18	388	1374	35	1410
Calanus helgolandicus	0	0	0	0	0	0	0	0	0
Eucalanus elongatus	0	0	0	18	0	18	0	0	0
Clausocalanus spp.	0	0	0	0	0	0	106	0	106
Pseudo. elongatus	0	0	0	0	0	0	0	0	0
Centropages kröyeri	0	0	0	0	0	0	0	0	0
Centropages typicus	0	0	0	35	0	35	35	0	35
Oithona similis	18	0	18	88	0	88	176	0	176

Appendix 3.3.2. Continued

Centropages typicus	0	0	0	0	0	0	0	0	0
Oithona similis	449	9	458	0	0	0	0	0	0
Oithona nana	35	0	35	26	0	26	26	0	26
Orthona plumifera	0	0	0	0	0	0	0	0	0
Acartia clausi	0	0	0	2	0	2	2	0	2
Temora longicornis	0	0	0	2	0	2	2	0	2
Temora stylifera	0	0	0	2	0	2	2	0	2
Oncaea subulis	0	0	0	0	0	0	0	0	0
Oncaea media	0	0	0	2	0	2	2	0	2
Corycaeus spp.	0	0	0	2	0	2	2	0	2
Calonalanus pavo	0	0	0	0	0	0	0	0	0
Microsetela rosea	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	0	0	0	4	0	4	4	0	4
Candacia armata	79	0	79	5	0	5	5	0	5
Pontella mediteranea	0	0	0	0	0	0	0	0	0
Anomalocera	0	0	0	0	0	0	0	0	0
		total	1278	0	0	0	0	0	0
Evadne tergestina	0	0	0	0	0	0	0	0	0
Evadne spinifera	0	0	0	70	0	70	70	0	70
Evadne nordmanni	115	0	115	4	0	4	4	0	4
Podon polypomoides	0	0	0	0	0	0	0	0	0
Podon intermedius	0	0	0	0	0	0	0	0	0
Penilia avirostris	0	0	0	0	0	0	0	0	0
Oikopleura	0	0	0	21	0	21	21	0	21
Fritilaria	0	0	0	9	0	9	9	0	9
Mussel	53	0	53	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0	0	0	0
Sagita	0	0	0	731	25	756	731	25	756
Total	1410	35	2722						

Date : 24.05.94	Date : 24.05.94	Date : 24.05.94
Depth : 0-5	Depth : 0-5	Depth : 0-5
Station : 1	Station : 2	Station : 3

Species	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Eucalanus elongatus	264	44	264	661	132	793	106	53	159
Clausocalanus spp.	0	0	0	0	0	0	0	0	0
Pseudocalanus elongatus	0	0	0	0	0	0	0	0	0
Centropages kröyeri	0	0	0	132	44	176	0	0	0
Centropages typicus	0	0	0	0	0	0	0	0	0
Oithona similis	0	0	0	176	0	176	0	18	18
Oithona nana	176	0	176	1894	132	2026	687	18	705
Oithona plumifera	0	0	0	88	0	88	0	0	0
Acartia clausi	0	0	0	2203	0	2203	70	0	70
Temora longicornis	5683	485	5683	4934	5947	10881	705	35	740
Temora stylifera	0	0	0	0	0	0	0	0	0
Oncaea media	0	0	0	441	0	441	0	0	0
Coryaceus	0	0	0	44	0	44	0	0	0
Microsetella rosea	0	0	0	0	0	0	0	0	0
Candacia armata	0	0	0	0	0	0	0	0	0
Euterpina acutrifrons	0	0	0	0	44	44	0	0	0
Pontella	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
Total Copepods:				0	0				
Evadne tergestina	6123	0	6123	0	0	16872			1692

Appendix 3.3.2. Continued

Evadne spinifera	0	0	0	0	0	0	0	0	0
Evadne nordmanni	0	0	0	0	0	0	0	0	0
Podon polyphomoides	0	0	0	44	0	44	18	0	18
Penilia avirostris	8811	0	8811	705	0	705	352	0	352
Total Cladocera:	0	0	0	44	0	44	0	0	0
Oikopleura	8811	0	8811	0	0	793			370
Fritilaria	0	0	0	220	0	220	1022	0	1022
Mussel	0	0	0	44	0	44	35	0	35
Polychaeta	132	0	132	176	0	176	53	0	53
Sagita	88	0	88	308	0	308	35	0	35
	0	0	0	0	0	0	18	0	18

Date : 19.06.95 Date : 19.06.95 Date : 19.06.95
Depth : 0-5 Depth : 0-5 Depth : 0-5
Station : 1 Station : 2 Station : 3

Species	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Calanus helgolandicus									
Eucalanus elongatus	194	0	194	1013	26	1040	338	4	342
Clausocalanus spp.	0	0	0	0	0	0	11	0	11
Pseudo. elongatus	0	0	0	0	0	0	7	0	7
Centropages kröyeri	0	0	0	0	0	0	21	4	25
Centropages typicus	0	0	0	0	0	0	0	0	0
Oithona similis	0	0	0	0	.0	0	0	0	0
Oithona nana	9	0	9	0	0	0	14	0	14
Oithona plumifera	194	9	203	106	18	123	106	11	116
Acartia clausi	115	0	115	35	0	35	14	0	14
Temora longicornis	0	0	0	0	0	0	7	0	7
Temora stylifera	581	70	652	564	26	590	733	0	733
Oncaea subtilis	0	0	0	0	0	0	0	0	0
Oncaea media	0	0	0	0	0	0	0	0	0
Corycaeus spp.	0	0	0	0	0	0	0	0	0
Calonalanus pavo	9	0	9	0	0	0	46	0	46
Microsetela rosea	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	0	0	0	0	0	0	0	0	0
Candacia armata	0	0	0	0	0	0	0	0	0
Pontella mediteranea	0	0	0	18	0	18	11	0	11
Anomalocera	35	0	35	97	0	97	14	0	14
Evadne tergestina	0	0	0	0	0	0	0	0	0
Evadne spinifera	0	0	0	0	0	0	4	0	4
Evadne nordmanni	0	0	0	0	0	0	60	0	60
Podon polypomoides	0	0	0	62	0	62	0	0	0
Podon intermedius	44	0	44	0	0	0	0	0	0
Penilia avirostris	1040	0	1040	308	0	308	39	0	39
Oikopleura	0	0	0	0	0	0	0	0	0
Fritilaria	35	0	35	79	0	79	367	0	367
Mussel	0	0	0	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0	7	0	7
Sagita	53	0	53	9	0	9	14	0	14
Total	9	0	9	0	0	0	4	0	4
	0	0	0	0	0	0	0	0	0
	2317	79	2396	2291	70	2361	1815	18	1833

Appendix 3.3.2. Continued

Abundance of COPEPODS (Adult)

Date 02 03 95
Depth 0-5
Station 1

Date : 02.03.95
Depth : 0-5
Station : 1

Date : 02.03.95
Depth : 0-5
Station : 2

Date : 02.03.95
Depth : 0-5
Station : 3

Species	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]
Paracalanus parvus	70	0	70	35	18	53	1128	0	1128	53	35	88
Calanus helgolandicus	0	0	0	0	0	0	0	0	0	53	0	53
Eucalanus elongatus	0	0	0	0	0	0	0	0	0	0	0	0
Clausocalanus spp.	18	0	18	0	0	0	35	18	53	211	0	211
Pseudo. elongatus	0	0	0	0	0	0	18	0	18	88	0	88
Centropages krôyeri	0	0	0	0	0	0	0	0	0	0	0	0
Centropages typicus	0	0	0	0	0	0	0	0	0	35	0	35
Oithona similis	405	35	441	546	106	652	2837	194	3031	0	0	0
Oithona nana	35	0	35	18	0	18	159	0	159	0	0	0
Oithona plumifera	53	0	53	53	0	53	106	0	106	2590	35	2626
Acartia clausi	0	0	0	0	0	0	687	35	722	2185	370	2555
Temora longicornis	0	0	0	0	0	0	0	0	0	53	0	53
Temora stylifera	0	0	0	0	0	0	53	0	53	0	0	0
Oncaea subtilis	0	0	0	0	0	0	0	0	0	0	0	0
Oncaea media	0	0	0	0	0	0	0	0	0	18	0	18
Corycaeus spp.	0	0	0	0	0	0	0	0	0	35	0	35
Calonalanus pavo	0	0	0	0	0	0	0	0	0	0	0	0
Microsetela rosea	0	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	0	0	0	0	0	0	0	0	0	0	0	0
Clytemnestra	0	0	0	0	0	0	0	0	0	0	0	0
Pontella mediteranea	0	0	0	35	0	35	0	0	0	0	0	0
Anomalocera	0	0	0	0	0	0	0	0	0	0	0	0
					total	811		total	5269		total	5762
Evadne tergestina	0	0	0	0	0	0	0	0	0	0	0	0
Evadne spinifera	0	0	0	0	0	0	0	0	0	0	0	0
Evadne nordmanni	0	0	0	0	0	0	0	0	0	0	0	0
Podon polypomoides	0	0	0	0	0	0	0	0	0	0	0	0
Podon intermedius	0	0	0	0	0	0	0	0	0	0	0	0
Penilia avirostris	0	0	0	18	0	18	0	0	0	0	0	0
Oikopleura	0	0	0	0	0	0	0	0	0	0	0	0
Fritilaria	106	0	106	176	0	176	0	0	0	18	0	18
Mussel	53	0	53	35	0	35	0	0	0	0	0	0
Polychaeta	0	0	0	18	0	18	0	0	0	0	0	0
Sagita	18	0	18	0	0	0	0	0	0	70	0	70
Total	758	35	793	934	123	1868	5022	247	10537	5410	441	11612

Date : 18.04.95
Depth : 0-5
Station : 1

Date : 18.04.95
Depth : 0-5
Station : 2

Date : 18.04.95
Depth : 0-5
Station : 3

Species	Female	Male	Total	Female	Male	Total	Female	Male	Total
	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]
Paracalanus parvus	564	26	590	303	9	312	303	9	312
Calanus helgolandicus	35	0	35	0	0	0	0	0	0
Eucalanus elongatus	0	0	0	0	0	0	0	0	0
Clausocalanus spp.	53	0	53	2	0	2	2	0	2
Pseudo. elongatus	26	0	26	0	0	0	0	0	0
Centropages krôyeri	0	0	0	278	16	294	278	16	294

Appendix 3.3.2. Mesozooplankton abundance (seasonal cruises 1994-1996)

Abundance of COPEPODS (Adult)

Date 21.01.95	Date : 21.01.95	Date : 21.01.95	Date : 21.01.95
Depth 0-5	Depth 0-25	Depth : 0-5	Depth : 0-25
Station : 1	Station : 1	Station 2	Station 2

Species	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]	Female [ind.m-3]	Male [ind.m-3]	Total [ind.m-3]
Paracalanus parvus	198	44	242	352	92	444	617	110	727	134	39	173
Calanus helgolandicus	0	0	0	4	7	11	0	0	0	7	0	7
Eucalanus elongatus	0	0	0	0	0	0	0	0	0	0	0	0
Clausocalanus spp.	0	0	0	247	88	335	0	0	0	194	14	208
Pseudo. elongatus	22	0	22	25	0	25	0	0	0	4	0	4
Centropages kröyeri	0	0	0	7	0	7	0	0	0	0	0	0
Centropages typicus	0	0	0	0	0	0	0	0	0	7	7	14
Oithona similis	286	0	286	141	18	159	1740	88	1828	81	11	92
Oithona nana	22	0	22	4	0	4	0	0	0	0	0	0
Oithona plumifera	22	0	22	7	0	7	44	0	44	11	0	11
Acartia clausi	0	0	0	32	4	35	1233	286	1520	11	0	11
Temora longicornis	0	0	0	11	0	11	0	0	0	0	0	0
Temora stylifera	0	0	0	7	0	7	0	0	0	7	0	7
Oncaea subtilis	0	0	0	0	0	0	0	0	0	0	0	0
Oncaea media	66	0	66	127	0	127	22	22	44	53	0	53
Corycaeus spp.	44	0	44	4	0	4	0	0	0	0	0	0
Calonalanus pavo	0	0	0	2	0	2	0	0	0	0	0	0
Microsetela rosea	0	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	22	0	22	21	0	21	22	0	22	32	0	32
Clytemnestra	66	0	66	14	0	14	176	0	176	0	0	0
Pontella mediteranea	0	0	0	0	0	0	0	0	0	0	0	0
Anomalocera	0	0	0	0	0	0	0	0	0	0	0	0
Total copepods			793	0	0	0		total	4361	0	0	0
Evadne tergestina	0	0	0	0	0	0	0	0	0	0	0	0
Evadne spinifera	0	0	0	0	0	0	0	0	0	0	0	0
Evadne nordmanni	0	0	0	11	0	11	0	0	0	7	0	7
Podon polypomoides	0	0	0	0	0	0	0	0	0	0	0	0
Podon intermedius	0	0	0	0	0	0	0	0	0	4	0	4
Penilia avirostris	44	0	44	0	0	0	22	0	22	7	0	7
Oikopleura	0	0	0	0	0	0	66	0	66	4	0	4
Fritilaria	0	0	0	28	0	28	22	0	22	0	0	0
Mussel	22	0	22	0	0	0	22	0	22	11	0	11
Polychaeta	0	0	0	21	0	21	22	0	22	7	0	7
Sagita	0	0	0	1063	208	1270	22	0	22	578	70	648
Total	815	44	1652				4031	507	8899	4031	507	8899

Appendix 3.3.2. Continued

Evadne tergestina	0	0	0	0	0	0	0	0	0	88	0	88
Evadne spinifera	0	0	0	0	0	0	0	0	0	0	0	0
Evadne nordmanni	15	0	15	0	0	0	35	0	35	0	0	0
Podon polypomoides	0	0	0	18	0	18	0	0	0	88	0	88
Podon intermedius	0	0	0	0	0	0	0	0	0	0	0	0
Penilia avirostris	954	0	954	3700	0	3700	5040	0	5040	0	0	0
Total Cladocera	969		969	3718	0	3718	5075	0	5075	176	0	176
Oikopleura	22	0	22	0	0	0	35	0	35	44	0	44
Fritilaria	0	0	0	0	0	0	35	0	35	0	0	0
Mussel	0	0	0	35	0	35	35	0	35	0	0	0
Polychaeta	15	0	15	35	0	35	106	0	106	0	0	0
Sagita	59	0	59	18	0	18	106	0	106	132	0	132
	3407	896	4302	9515	2537	12053	18291	7154	25445	5463	1542	7004

Date : 13.12.94	**Date : 13.12.94**	**Date : 13.12.94**
Depth : 0-5m	**Depth : 0-5m**	**Depth : 0-5m**
Station : 1	**Station : 2**	**Station : 3**

Species	**Female**	**Male**	**Total**	**Female**	**Male**	**Total**	**Female**	**Male**	**Total**	**Female**	**Male**	**Total**
	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]	[ind.m-3]
Paracalanus parvus	150	35	185	9	9	18	159	18	176	229	44	273
Calanus helgolandicus	0	0	0	0	0	0	0	0	0	0	0	0
Eucalanus elongatus	9	0	9	0	0	0	0	0	0	0	0	0
Clausocalanus spp.	0	0	0	0	0	0	0	0	0	0	0	0
Pseudo. elongatus	26	0	26	0	0	0	9	0	9	0	0	0
Centropages kröyeri	0	0	0	0	0	0	0	0	0	0	0	0
Centropages typicus	0	0	0	18	0	18	9	0	9	9	0	9
Oithona similis	53	0	53	26	0	26	123	0	123	159	0	159
Oithona nana	79	0	79	0	0	0	9	0	9	18	0	18
Oithona plumifera	0	0	0	0	0	0	0	0	0	0	0	0
Acartia clausi	344	0	344	872	106	978	194	185	379	229	220	449
Temora longicornis	0	0	0	0	0	0	0	0	0	0	0	0
Temora stylifera	0	0	0	0	0	0	0	0	0	0	0	0
Oncaea subtilis	0	0	0	0	0	0	0	0	0	0	0	0
Oncaea media	167	0	167	18	0	18	185	0	185	62	0	62
Corycaeus spp.	0	0	0	0	0	0	0	0	0	0	0	0
Calonalanus pavo	0	0	0	0	0	0	0	0	0	0	0	0
Microsetela rosea	0	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	26	0	26	18	0	18	9	0	9	9	0	9
Clytemnestra	0	0	0	0	0	0	0	0	0	0	0	0
Pontella mediteranea	0	0	0	0	0	0	0	0	0	0	0	0
Anomalocera	0	0	0	0	0	0	0	0	0	0	0	0
Total Copepods			890			1075			900			978
Evadne tergestina	0	0	0	0	0	0	0	0	0	0	0	0
Evadne spinifera	0	0	0	0	0	0	0	0	0	0	0	0
Evadne nordmanni	0	0	0	0	0	0	0	0	0	0	0	0
Podon polypomoides	0	0	0	0	0	0	0	0	0	0	0	0
Podon intermedius	0	0	0	0	0	0	0	0	0	0	0	0
Penilia avirostris	0	0	0	0	0	0	53	0	53	26	0	26
Total Cladocera						0			53			26
Oikopleura	0	0	0	0	0	0	18	0	18	0	0	0
Fritilaria	0	0	0	0	0	0	0	0	0	0	0	0
Mussel	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0	9	0	9	0	0	0
Sagita	0	0	0	9	0	9	0	0	0	0	0	0
Total	855	35	890	969	115	1084	775	203	978	740	264	1004