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"Riverine Transport of Organic Matter & Nutrients"

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Riverine transport of organic matter and nutrients

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Subiects in my talk

- Anthropogenic pressure and increased pollutant levels
- Riverine fingerprint of "industrial" rivers
- The Po-Adriatic system as a case study
- Transport of organic carbon and nutrients in the Po river
- Algal POC
- Factors affecting riverine transport
- Calculation of fluxes and export rates
- Estuarine behaviour
- Role of riverine OM and nutrient discharge on carbon cycling in coastal waters
- DOM accumulation in NA coastal waters

Why we need to study riverine transport of pollutants?

1)to manage river water quality through:
- the evaluation of pollutant sources;
- the reduction of pollution levels with the control of both pollutant sources and water withdrawals from the river;
- the evaluation of chemical and ecological quality with respect to background reference and water quality objectives (EEC directive on this matter is going to become in force in the new year);
- the evaluation of time trends in concentrations and pollution.

2)to manage coastal water quality through:
- the evaluation of riverine discharges into the sea;
- the evaluation of the modes of transport of pollutant;
- the evaluation of mixing processes which may affect the real discharge to the sea.

3)to improve our knowledge of the behaviour of pollutants by investigating:
- their partitioning;
- their decaying;
- their transformations;
- the factors which control their interactions with biota.

"Civilization" has markedly altered concentrations of pollutants and the biogeochemistry of rivers.

Intensive agricultural and industrial activity have mobilized large quantity of pollutants which have produced effects on the oxygen balance, the concentrations of toxic compounds, the presence and diversity of biological species, the levels of pollutants in the food chain.

The socalled "industrial revolution" and the increase in population have dramatically changed in some areas the population density and its pressure on river systems. Population density in European rivers is one of the highest of all continents.

This external forcing has changed the concentrations of many elements and also the biogeochemistry of rivers. The case of concentration changes of nutrients in the Po river is emblematic.

Marchetti, 1990.

Size of population in large European river basins

River basin name	Inhabitants (10^6 people)	Population density (people/km^2)
Rhine	41.4	184
Rhone	8.1	84
Danube	80.8	99
Po	15.5	232
Tiber	4.5	265

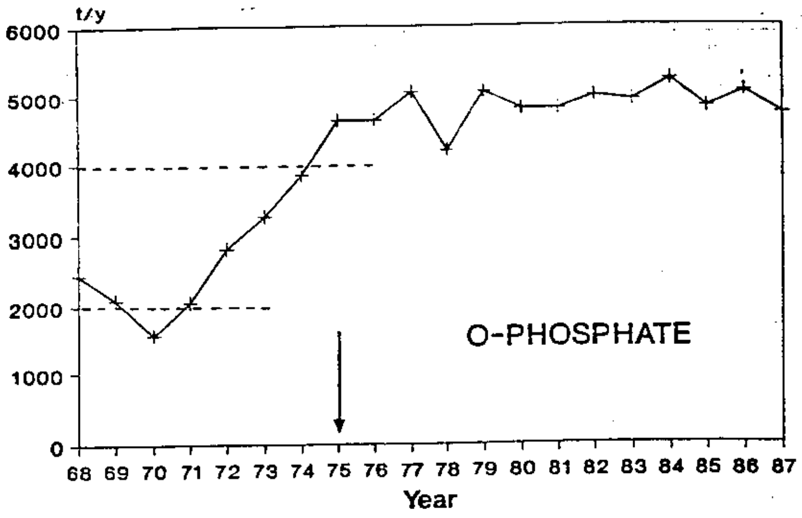


Figure 4: Orthophosphate phosphorus load increase observed in the estuary section of the Po river basin from 1968 to 1987.

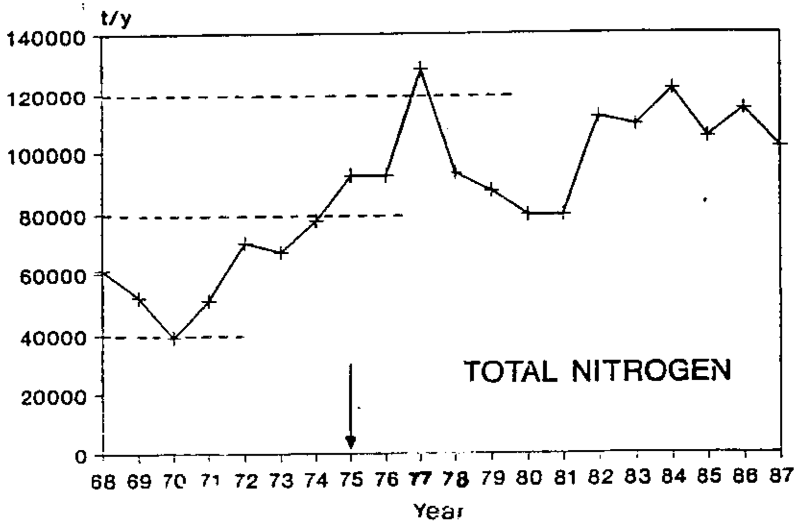


Figure 5: Total mineral nitrogen load increase observed in the estuary section of the Po river from 1968 to 1987.

Riverine fingerprint of “industrial” rivers.

The CO_2 pressure (p-CO_2) of water is a suitable indicator of the dominance of either respiration or photosynthesys in an aquatic ecosystem. It can be calculated from standard hydrochemical parameters, i.e. pH, temperature and alkalinity ($HCO_3^- + 2CO_3^{2-}$).

Values of p-CO_2 >340 ppmv (i.e. the atmospheric pressure) indicate a surplus of CO_2 in the river. This surplus is caused by respiration of organic matter (selfpurification capacity of rivers): in this case rivers are a source of CO_2 to the atmosphere.
Values of p-CO_2 <340 ppmv are indicative of sink for atmospheric CO_2 in rivers. In this case CO_2 consumption by ongoing photosynthesis in the water body is prevailing.

Respiration is accompanied by an O_2 consumption leading to an at least equivalent deficit in dissolved oxygen. If p-CO_2 is higher than what expected by the deficit of oxygen, another source (probably dissolved nitrate) must be available to fuel respiration in the river.

If nitrate would act as a nutrient, i.e. fueling photosynthesis, the nitrate concentration should be positively correlated with the pCO_2 but negatively with the O_2 concentrations. Thus the riverine fingerprint of an industrial river includes the inversion of the interdependence of p-CO_2, pO_2 and NO_3^- concentration.

Relationships between the respiration of organic matter, p-CO_2 and pH.

Organic matter discharged into the rivers tends to increase p-CO_2 and because of the evolution of free CO_2 in the river to decrease pH. As a consequence, “industrial” rivers tend to become more acid from source to estuary. An example is given by the behaviour of pH and O_2 in the Tiber river.

This is in contrast to what happens in lacustrine environments where photosynthesis tend to prevail leading to a depletion of CO_2 and hence to an increase in pH. Increasing in pH and hence in CO_3^{2-} leads to an increase in the supersaturation of carbonate mineral which is responsible for autochthonously precipitated calcite (Lake Pusiano in northern Italy is an example of intensive $CaCO_3$ precipitation). While a strong undersaturation is established almost year-round in fluvial regime.

Millero et al, 1981

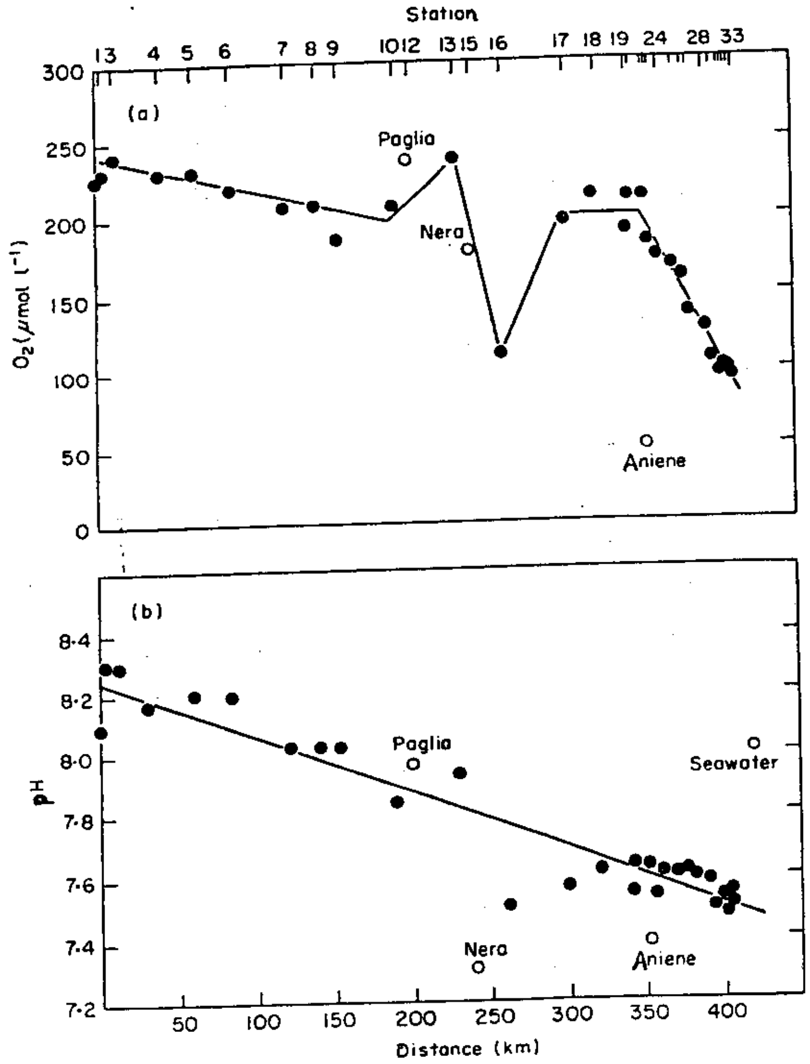


Figure 2. (a) The dissolved oxygen (μmol l^{-1}) and (b) pH for Tiber river waters at various stations and distances from the source.

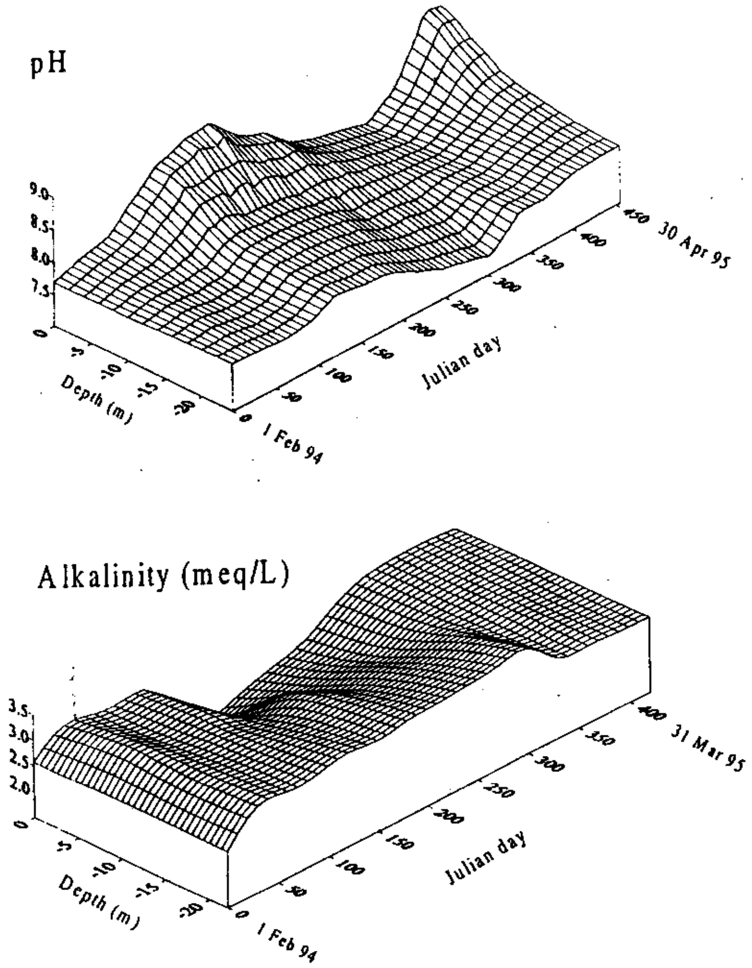


FIGURE 1 - 3-d plot of pH and alkalinity values as a function of depth and sampling time in lake Pusiano.

THURMAN, 1985

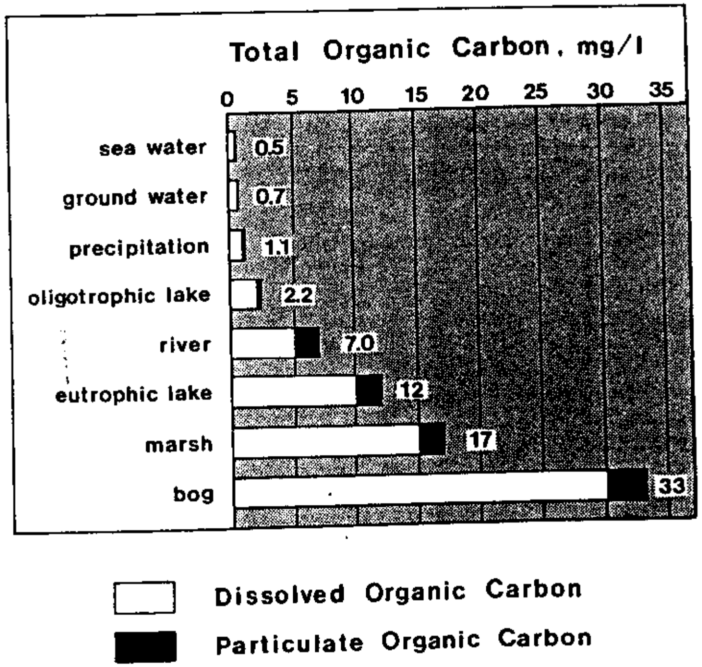


Figure 1.1 Approximate concentrations of dissolved and particulate organic carbon in natural waters.

THURMAN, 1985

e **1.1** Acronyms of commonly used terms for organic matter in water.

Acronym	Meaning
DOC	Dissolved organic carbon
SOC	Suspended organic carbon
POC	Particulate organic carbon
FPOC	Fine particulate organic carbon
CPOC	Coarse particulate organic carbon
TOC	Total organic carbon
VOC	Volatile organic carbon
DOM	Dissolved organic matter
POM	Particulate organic matter
TOM	Total organic matter
COM	Colloidal organic matter
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand

THURMAN, 1985

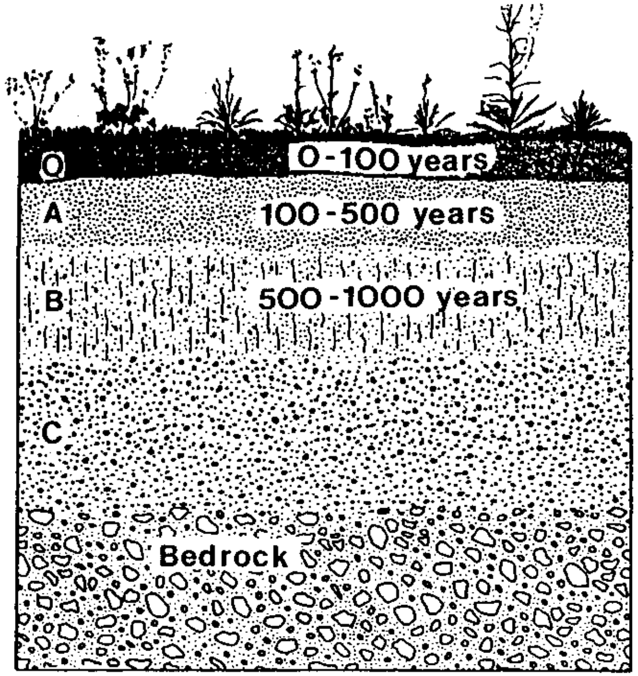


Figure 2.3 Age of organic carbon in various soil horizons, compiled from the data of O'Brien and others (1981).

THURMAN, 1985

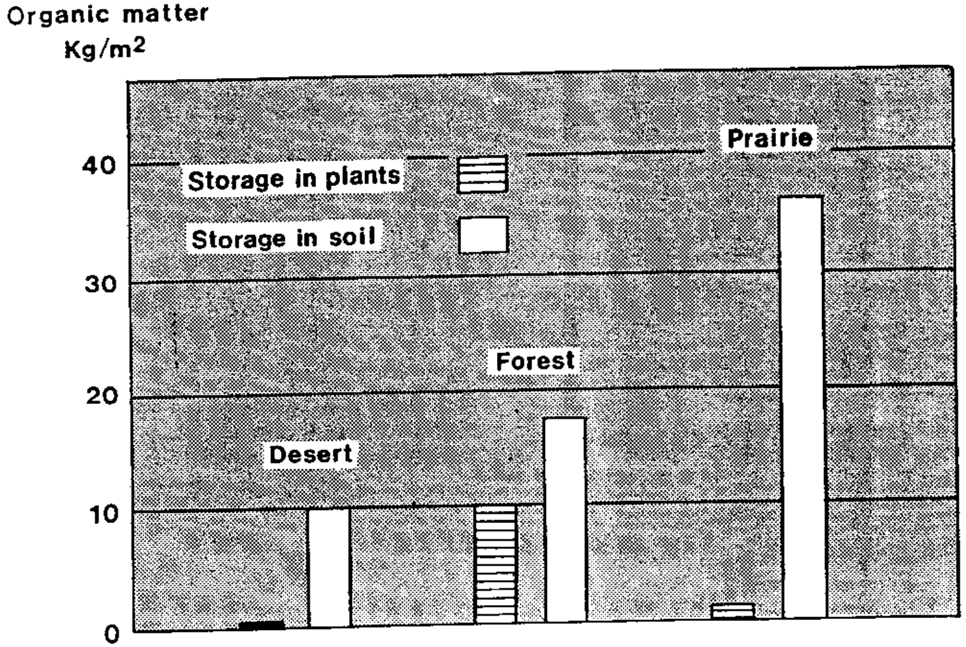


Figure 2.2 Storage of organic matter in soil and plants from different regions.

The Po River

The Po River is, by far, the largest Italian river and its discharge (46 km^3/year) accounts for 11%, 28% and over 50 % of the total freshwater flow into the Mediterranean, the entire Adriatic basin and its northern part, respectively.

The Po River receives inputs from 22 tributaries equally distributed on the left and right banks which drain region from the Alps to the Apennines.

The hydrological regime in the Po is strongly dependent on the flow variations of its tributaries which strongly influence pollutant transport and export to the northern Adriatic.

The Po valley is one of the most productive agricultural areas in Italy. 15.5 million inhabitants live in its watershed giving rise to one of the highest population density in Europe (232 people/km^2).

mean depth 35 m
counterclockwise circulation pattern
strong stratification in the summer

The northern Adriatic basin

It is a shallow small basin which accounts for < 14% and < 3% of the total Adriatic surface area and volume, respectively.

This basin receives significant freshwater inputs which markedly increase its productivity over the oligotrophic features of the Mediterranean Sea. It experiments large trophic gradients from coastal eutrophic to offshore oligotrophic waters.

External annual contributions of nutrients in this basin have been estimated to be of the same order of magnitude as the regeneration rate, thus giving similar contributions to primary production from new and regenerated material (Degobbis & Gilmartin, 1990).

Two major environmental problems affecting this basin concern with the occurrence of anoxia in bottom coastal waters and mucillaginous macroaggregates in the water column: both these problems are related to the cycling of organic carbon.

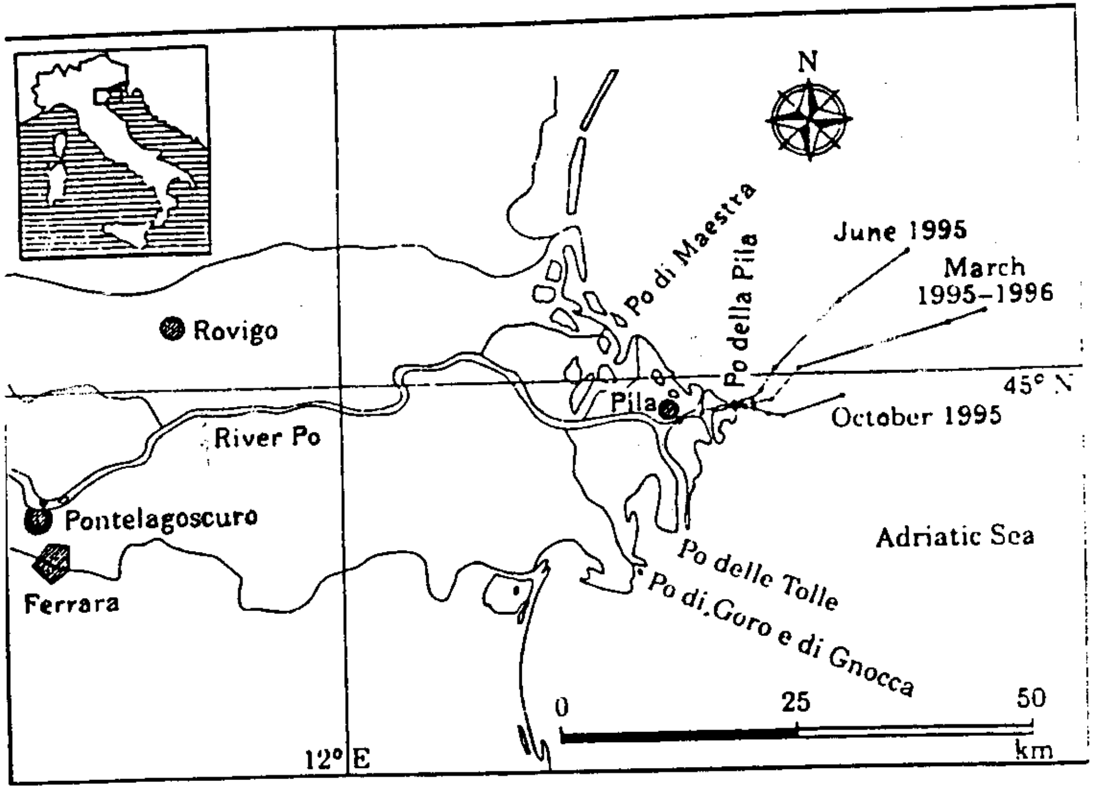
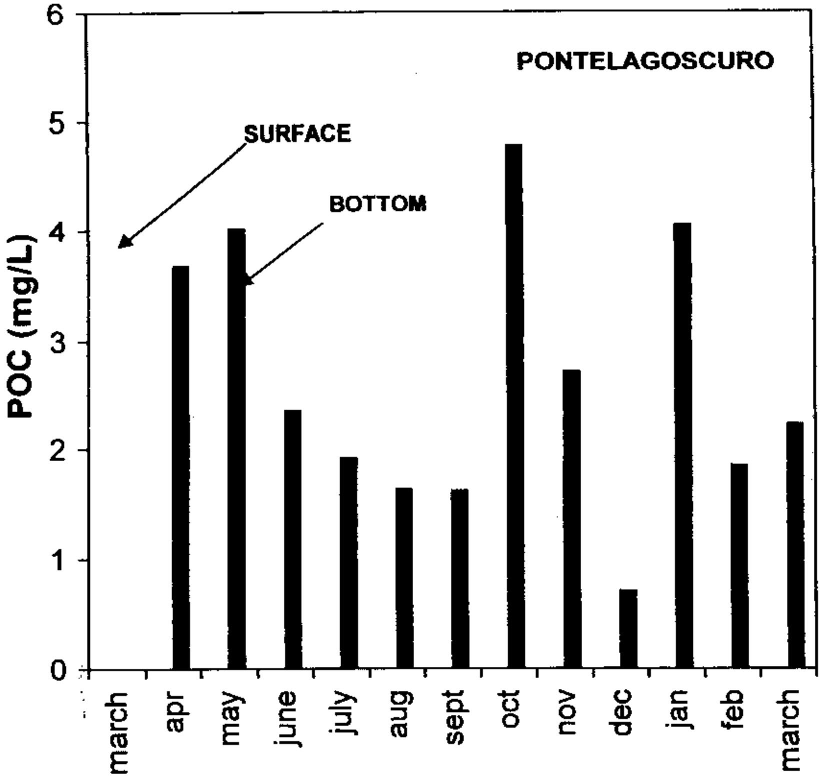
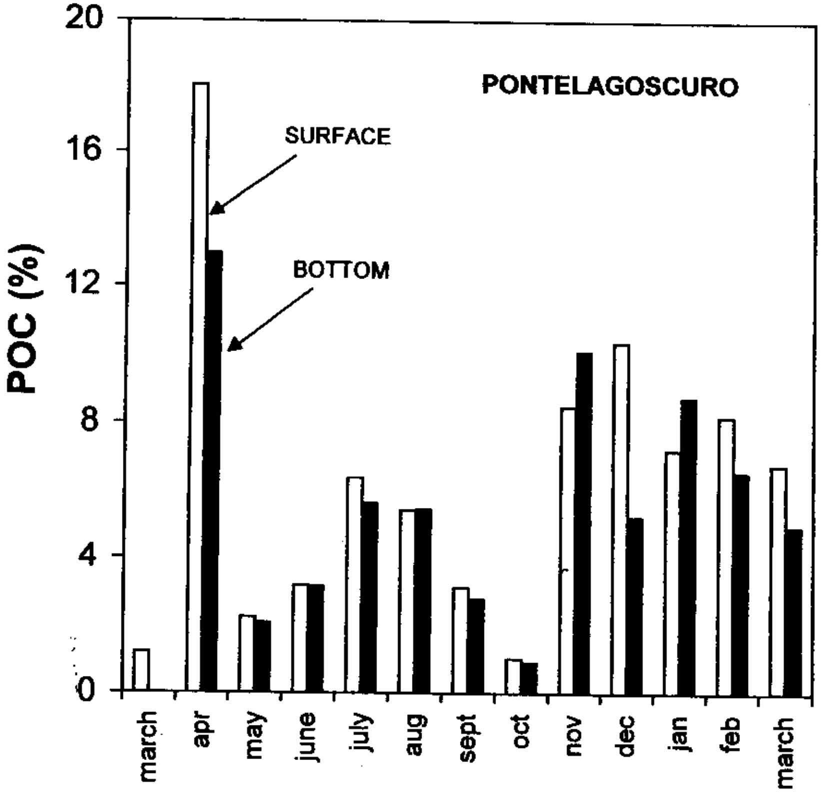
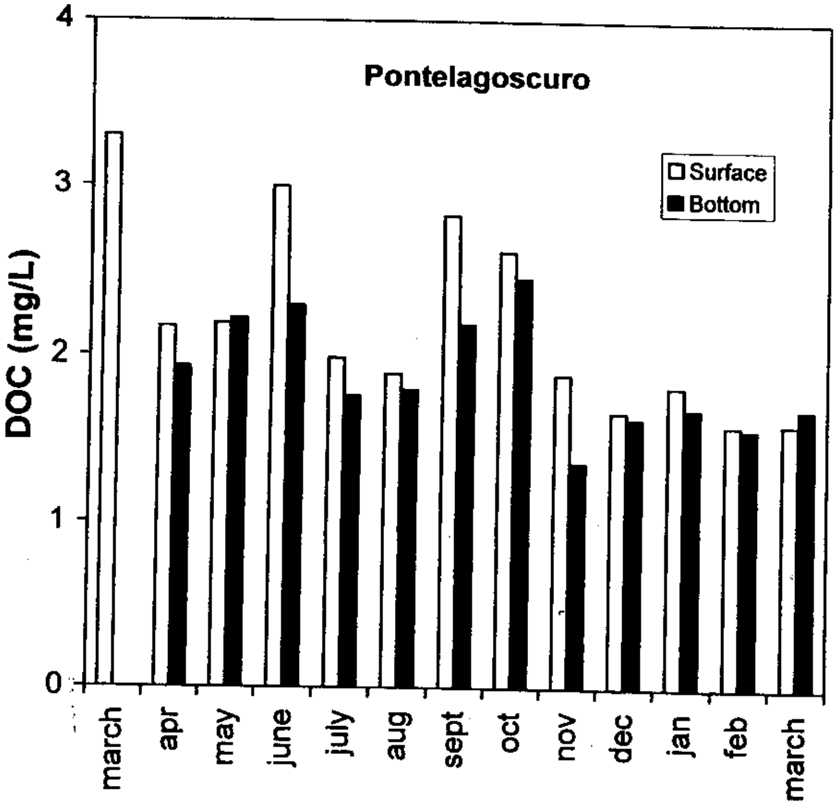
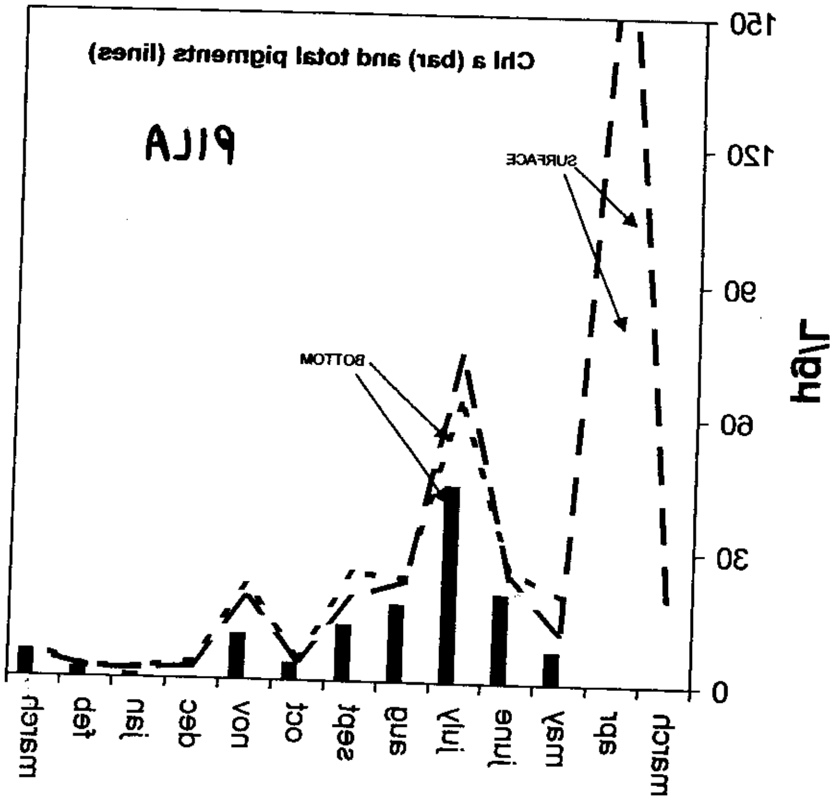


FIGURE 1. Location of the sampling stations.




PONTELAGOSCURO
SURFACE
BOTTOM
POC (%)
20
16
12
8
4
0
march
apr
may
june
july
aug
sept
oct
nov
dec
jan
feb
march


Pontelagoscuro
□ Surface
■ Bottom
DOC (mg/L)
4
3
2
1
0
march
apr
may
june
july
aug
sept
oct
nov
dec
jan
feb
march


Chl a (bar) and total pigments (lines)
PILA
SURFACE
BOTTOM
µg/L
0
30
60
90
120
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march
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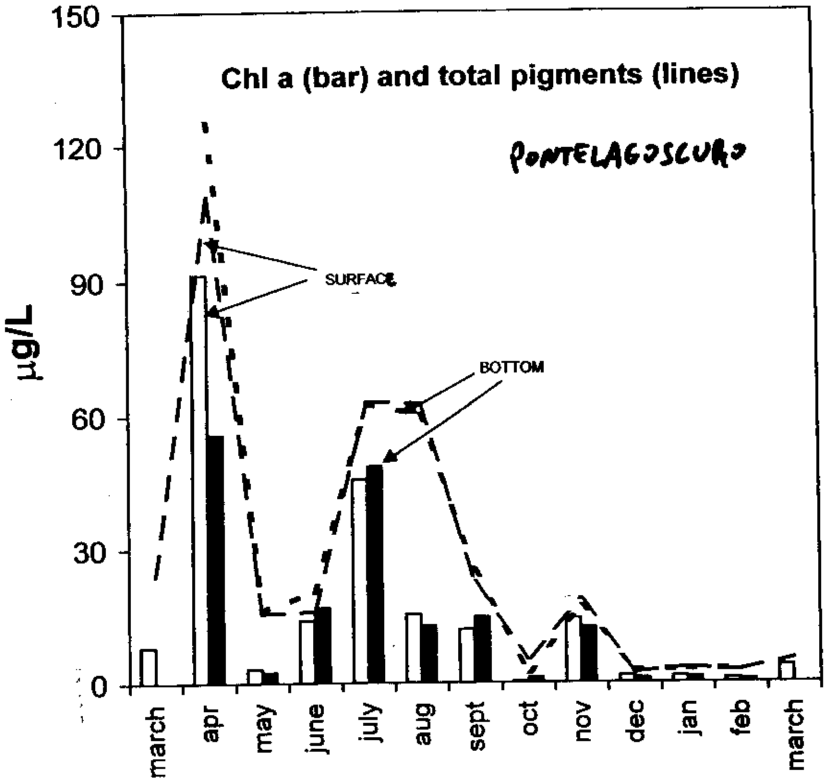
may
apr
march


Chl a (bar) and total pigments (lines)
PONTELAGOSCURO
SURFACE
BOTTOM
µg/L
150
120
90
60
30
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march
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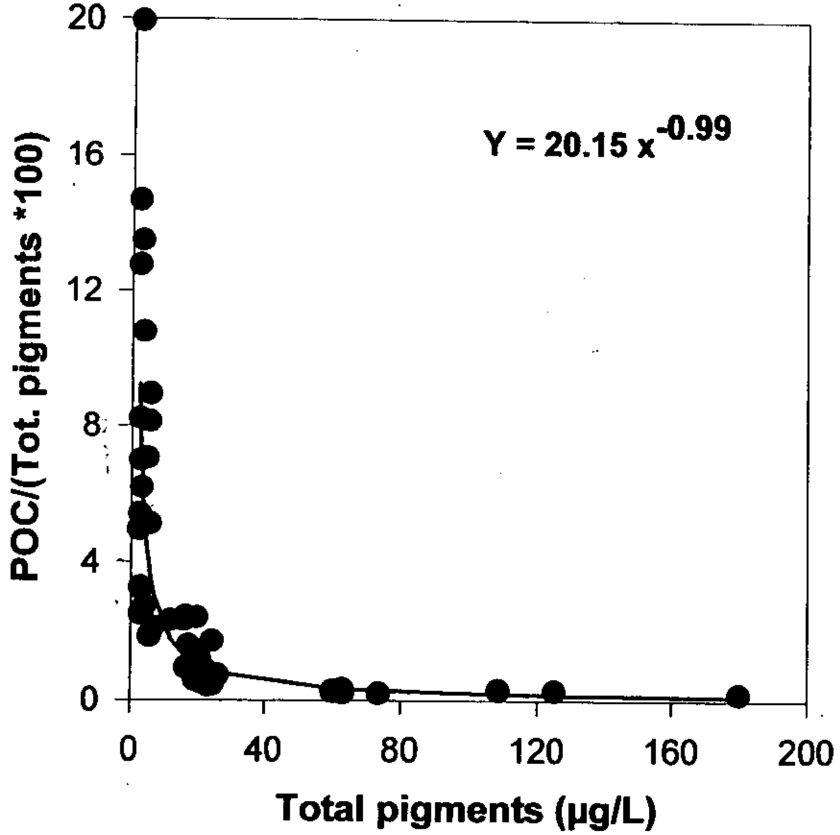
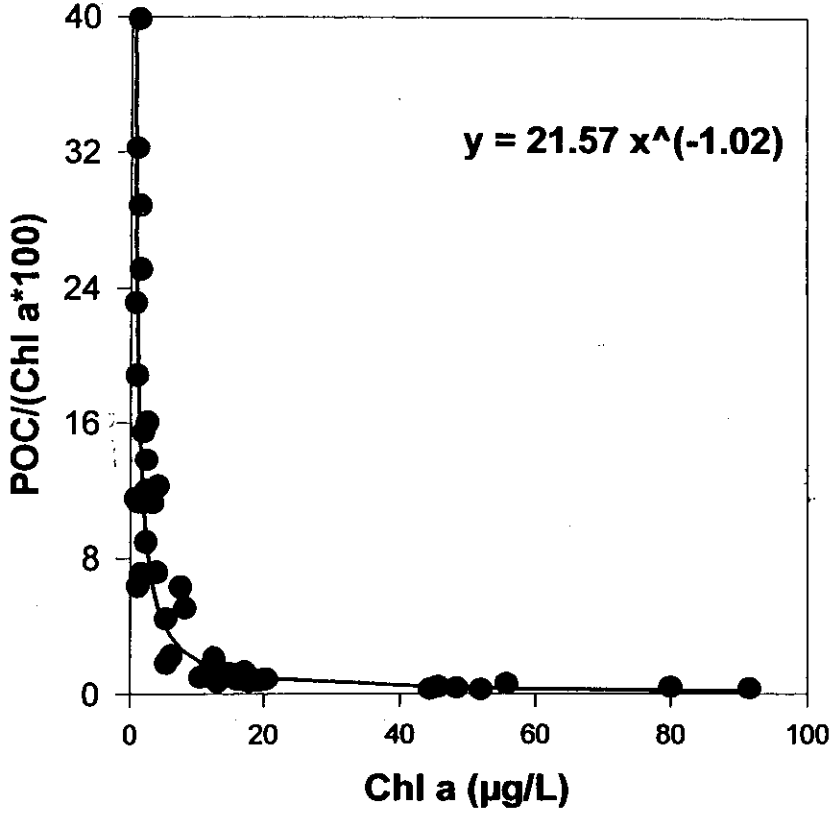
march

Evaluation of algal POC
from total pigments



Evaluation of algal POC



The analysis of the relationships of POC/Chl a and POC/total pigments ratios as a function of Chl a and total pigments, respectively, gives a good estimation of the conversion factors to be used to calculate algal POC These were found to be 20 and 30 for total pigments and Chl a, respectively. Similar values have been applied to other rivers. Admiraal et al. (1992) found a POC/Chl a value of 25 in the lower Rhine; Relexan et al. (1988) found a POC/total pigments ratio of 30; SCOR – UNESCO equations applied to French rivers used a POC/Chl a factor of 35.

Algal POC calculated from Chl a data wich represent fresh phytoplankton biomass ranged from 0.01 to 2.75 mg l^{-1} with a mean of 0.45±0.62 mg l^{-1} compared to the mean value for total POC of 2.39±1.20 mg l^{-1}. These algal POC values indicate a contribution to total carbon transport that is in the range 0.2 – 100 %. The highest contribution were recorded in April, June and July.

Transport of organic carbon in the Po River

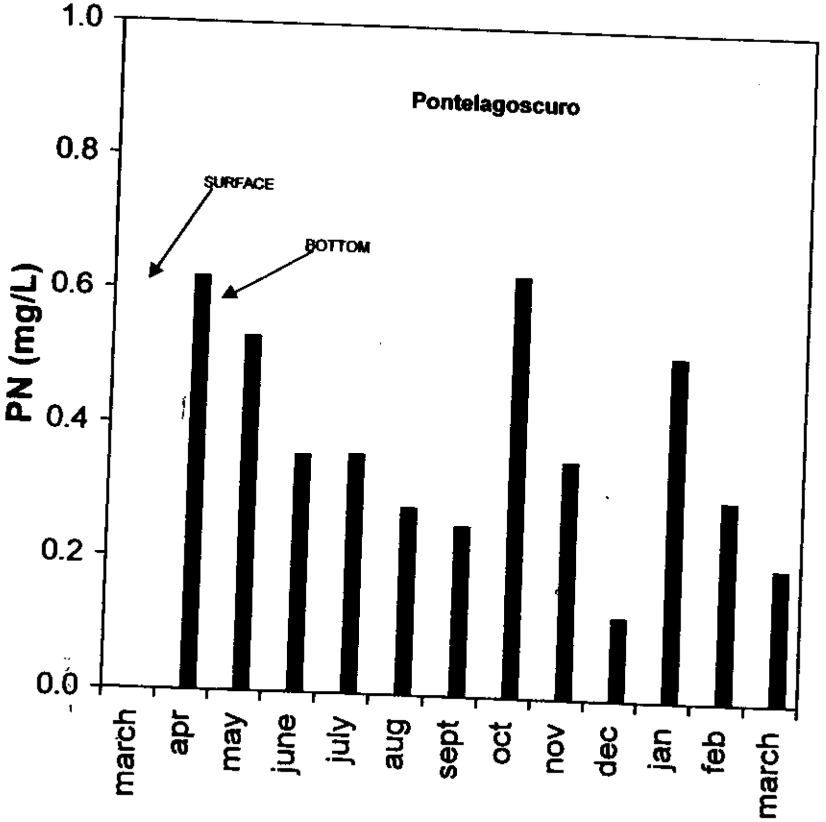
DOC concentrations measured at monthly intervals over one year study ranged from 1.3 to 3.7 mg/l giving an average value of 2.1±0.6 mg/l and a very close median of 2.0 mg/l.

The percentage values of POC in the particulate matter of the Po River varied in the range 0.9-18 % over the study period. The mean value and related standard deviation was 6.4±4.4 %.
The average particulate concentration per unit volume of water was 2.4±1.2 mg/l.

The average DOC and POC values calculated for the lower Po give export rates of 1.65 and 1.91 tonnes km^{-2} $year^{-1}$ which are respectively lower and higher than those proposed for temperate rivers.

Carbon seems to be preferentially transported in the particulate phase in the Po compared to other major temperate world rivers, probably due to:

- a high autochthonous contribution to POC;
- a high weathering rate in the European continent (DOC/TOC ratios in the range 0.30-0.67 are characteristic of highly erosive environments).



Transport of particulate nitrogen

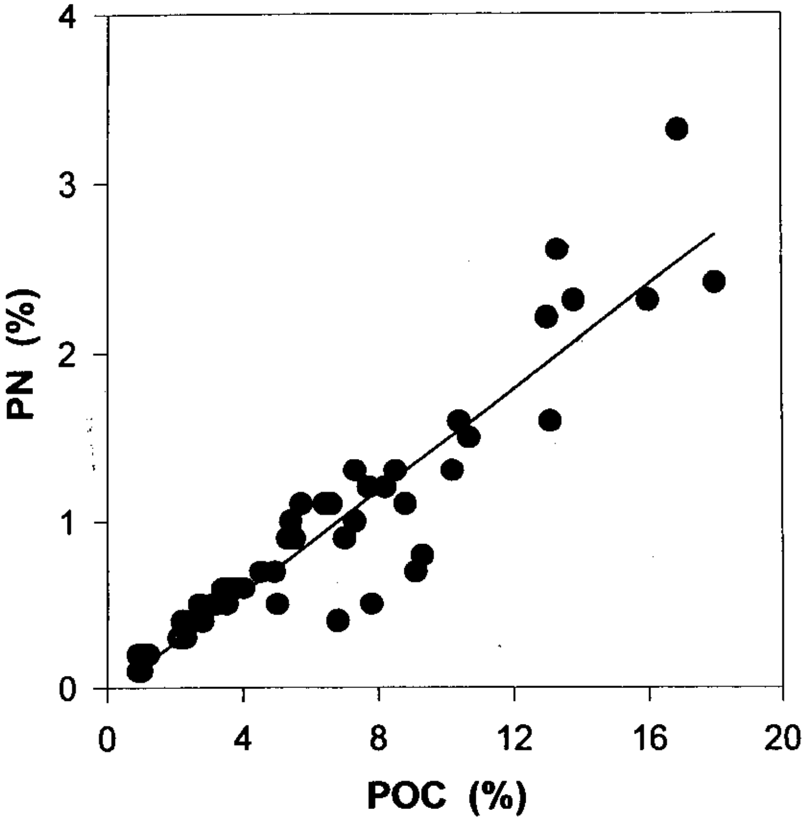
The percentage values of PN in the particulate matter of the Po River varied in the range 0.12–3.31% over the study period. The mean value and related standard deviation was 0.94±0.72%.

The average particulate concentration per unit volume of water was 0.35±0.18 mg l^{-1}.

PN values showed a strong positive correlation with POC values suggesting that organically bound nitrogen was dominant in suspended matter from the lower Po. The inverse of the slope of the equation fitting PN% vs POC% gives an average POC/PN weight ratio of 6.7±0.4 which is close to the value of 7.1 resulting from the average POC/PN ratio.

Such a value for POC/PN in the lower Po is lower than the value of 8.5 (range 8-10) reported by Meybeck for world rivers and found to be insensitive to environmental factors and suggests a high contribution of aquatic plant sources to the particulate matter. This autochthonous contribution is important all year round since only 8 out of 50 samples show POC/PN ratios higher than 8.

Relationship between particulate nitrogen and organic carbon



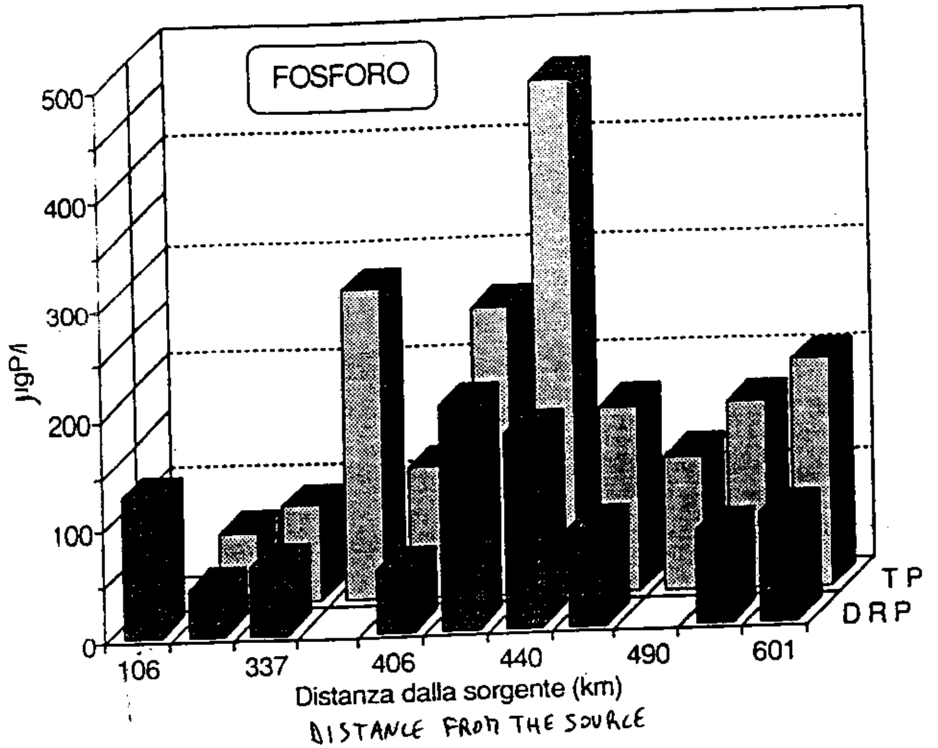


Fig. 6.3 - Concentrazioni medie di fosforo reattivo e totale misurate nel periodo 1989-1990 lungo l'asta fluviale

AVERAGE CONCENTRATIONS MEASURED OVER THE PERIOD 1989-1990 AT DIFFENT DISTANCES FROM THE SOURCE.

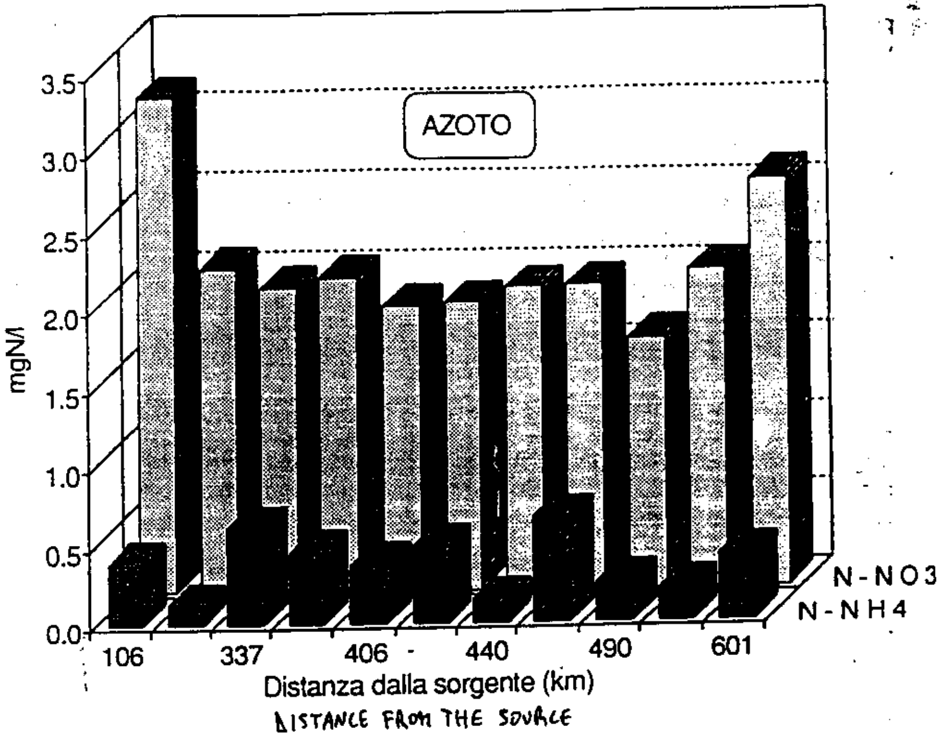


Fig. 6.2 - Concentrazioni medie di azoto nitrico ed ammoniacale misurate nel periodo 1989-1990 lungo l'asta fluviale

AVERAGE CONCENTRATIONS MEASURED OVER THE PERIOD 1989-1990 AT DIFFERENT DISTANCES FROM THE SOURCE

Factors affecting variations in the transport

Temporal variations of DOC, POC and PN appear to reflect variations in the solid transport, phytoplanktonic biomass and flow.

The percentage values of POC and PN appear to vary inversely with riverine suspended matter load; this is the case for most rivers (Meybeck, 1982). The ~~[illegible]~~ lowest values of POC% and PN% were observed on the occasion of peaks in the solid transport.

POC and PN data from both surface and bottom samples were fitted to the equations

$$\text{POC }\% = 60.20 \times SM^{-0.67}$$
$$\text{PN }\% = 8.52 \times SM^{-0.66}$$

These significant relationships suggest that autochthonous particulate organic matter in the lower Po is diluted by land-derived particles which are poor in organic matter.

Influence of flow variations

The dependence of organic matter concentrations on flow shows two opposing effects: dilution and run-off. All the investigated variables, DOC – POC and PN, showed a decreasing behaviour with increasing flow in low to medium discharge conditions because of prevalence of the dilution effect, increase at medium to high flows where the run-off effect predominates and level off or even decrease during flood periods.

As a consequence of these findings, the POC, ~~and~~ PN and DOC data were fitted to polynomial functions which include a positive term directly proportional to flow and two other terms describing the decrease of the dependent variable at low and very high flow conditions:

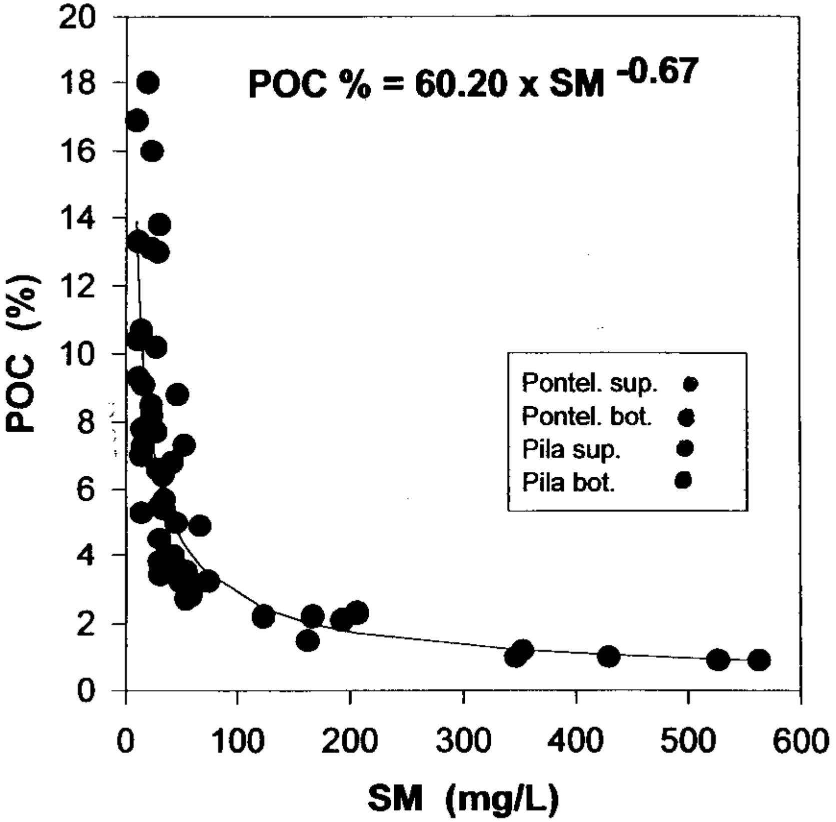
$$\mathrm{POC(mg/L)} = -21.6 + 11776/Q + 0.0135 \times Q - 2 \times 10^{-6} \times Q^2 \quad r=0.92$$

$$\mathrm{PN\ (mg/L)} = -4.1 + 2234/Q + 0.0025 \times Q - 4 \times 10^{-7} \times Q^2 \quad r=0.94$$

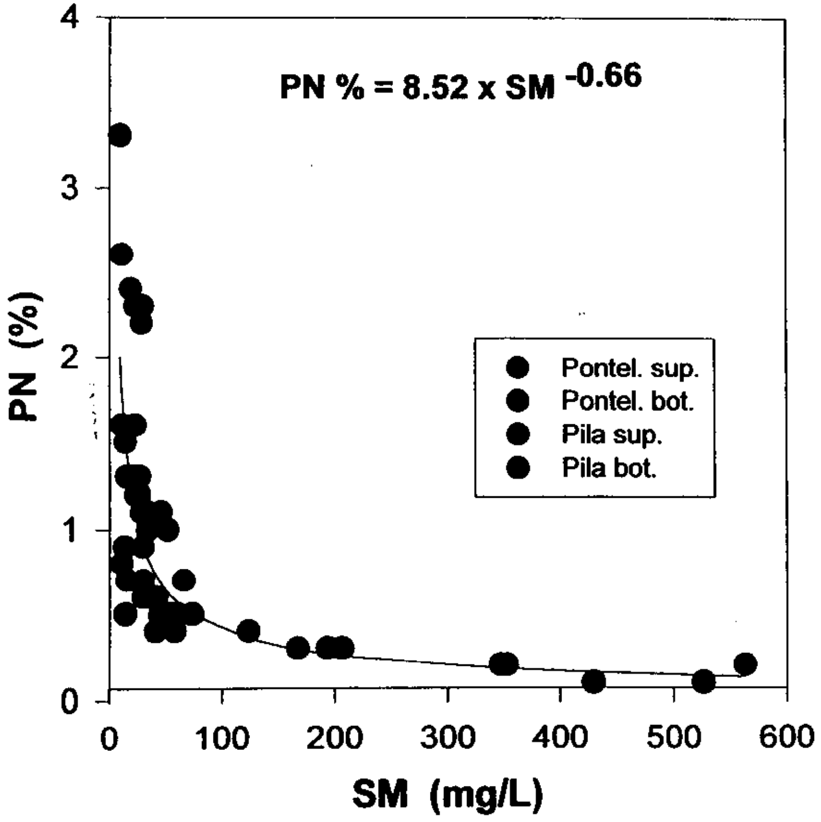
$$\mathrm{DOC(mg/L)} = -8.4 + 4835/Q + 0.0064 \times Q - 10^{-6} \times Q^2 \quad r=0.91$$

Particulate matter shows a quasi-linear relationship with flow in the lower Po although some peaks in the solid transport may occasionally occur at relatively low flow. This is due to some tributaries from the Apennines (Trebbia, Taro, Panaro, secchia, Crostolo) which drain clayey-marly soils making a major contribution to solid transport in the Po without producing a marked increase in water flow.

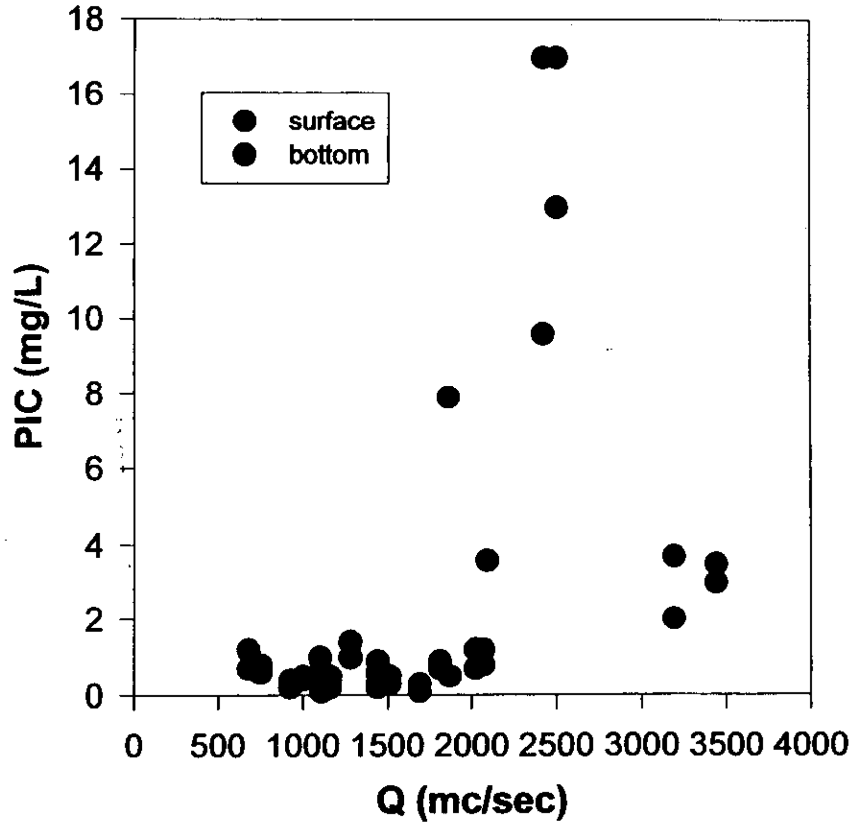
Influence of suspended matter (SM) on the content of particulate carbon

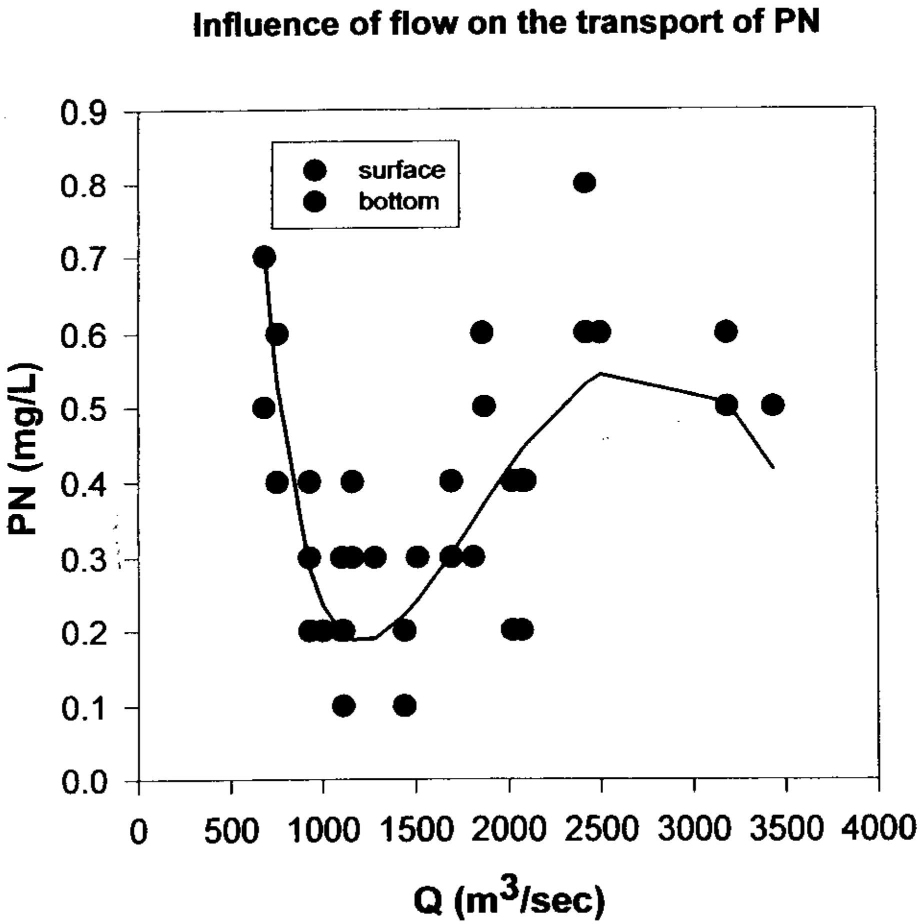


Influence of suspended matter on the content of particulate nitrogen

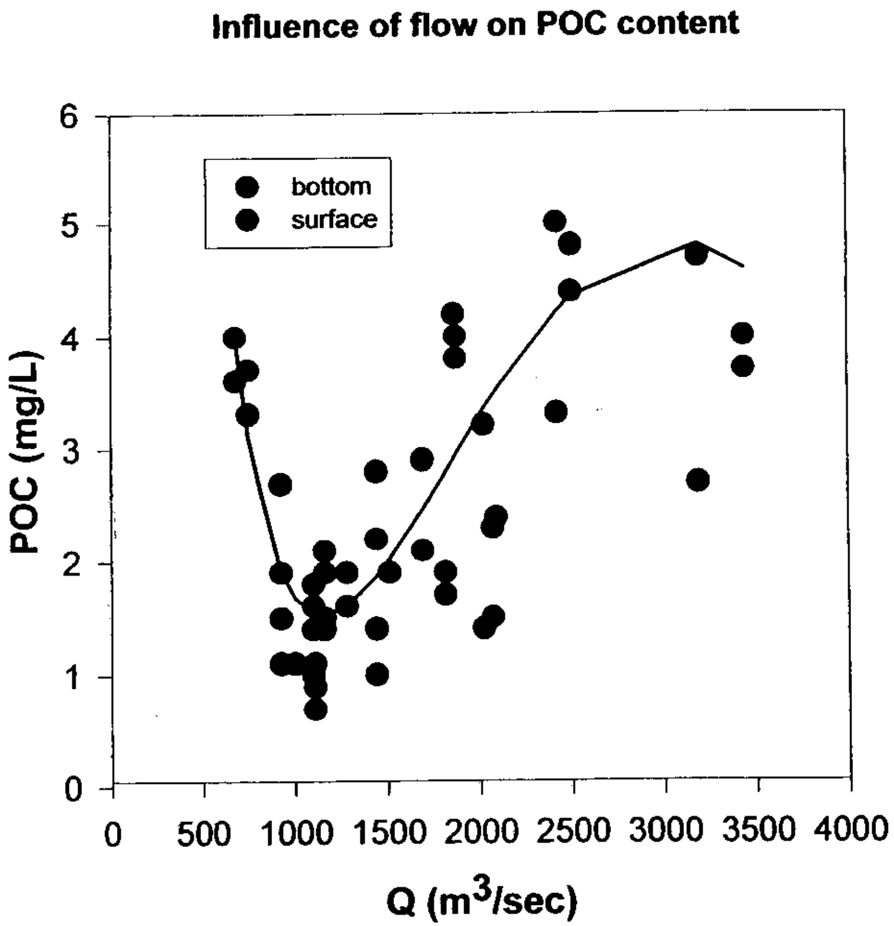


Influence of flow on the transport of PIC

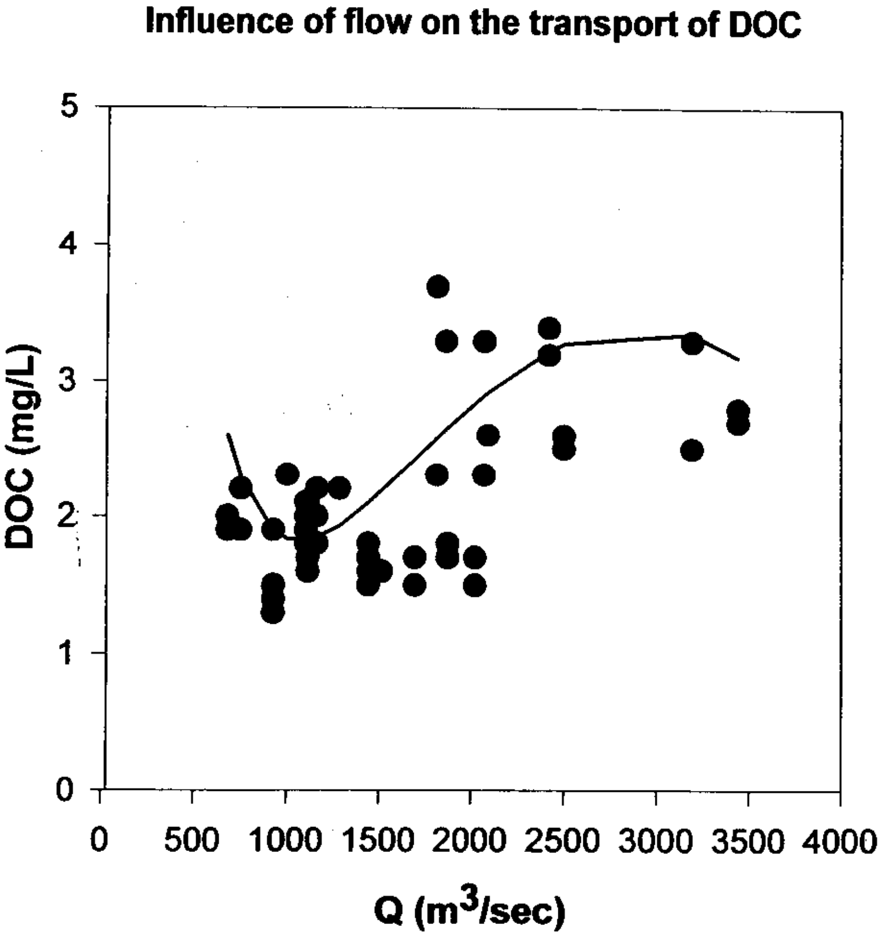




Influence of flow on the transport of PN



Influence of flow on POC content



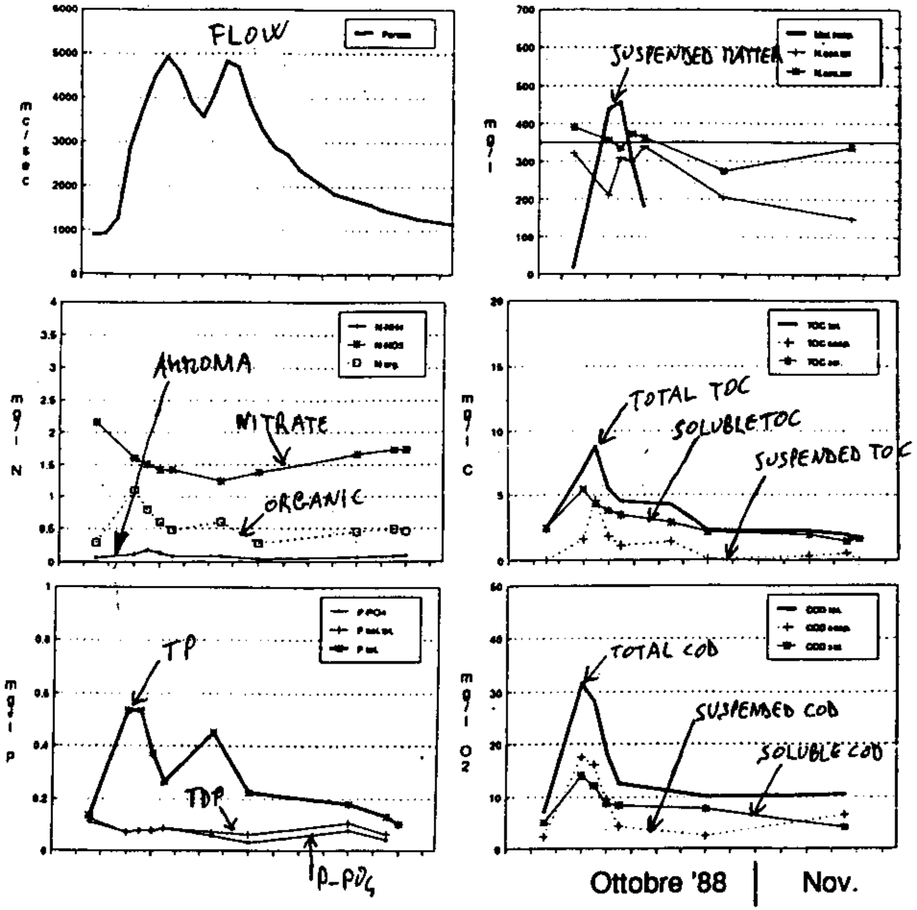


Fig. 7.2 - Andamenti temporali dettagliati dei parametri durante i transitori idrologici

SHORT TERM VARIATIONS OF CHEMICALS IN PERIODS OF MARKED CHANGES IN FLOW

Calculations of annual loads

Mass fluxes of particulate inorganic and organic carbon, particulate nitrogen and dissolved organic carbon to the northern Adriatic basin were calculated by four different methods. They were based on:

(a) the mean of products of the instantaneous concentrations and the mean daily discharge for the sampling day:
$[(\sum_{i=1}^{n}(Ci \times Qi) / n] \times 31.536.$

(b) the product of the arithmetic means of the concentrations and discharges:
$[(\sum_{i=1}^{n}(Ci) \times (\Sigma Qi)/n] \times 31.536.$

(c) the product of discharge-weighted concentrations and the mean annual discharge:
$[(\sum_{i=1}^{n}(Ci \times Qi) / (\sum_{i=1}^{n}Qi)] \times Qy \times 10^{-6}.$

(d) the sum of the product of daily discharge and concentration extended to a whole year by converting mean daily flow to concentrations by means of equations describing the distribution of concentrations vs flow:
$[(\sum_{i=1}^{365}Cti \times Qi)] \times 0.0864$

Riverine transport

Calculating riverine transport is not a straightforward task because a number of variables may affect the results:

- the representativeness of analyzed samples;
- the analytical quality of data;
- the short- and long term variability of measurements;
- the lack, in many cases, of contemporaneous measurements of flow and concentrations;
- the difficulty in evaluating pollutant transport in high flow conditions.

Water discharge is mostly derived from daily readings of a gauge: thus, runoff is the best known mass transport in rivers if a gauge is available in the studied site. Other physical and chemical parameters are, however, mostly monitored in relatively large intervals.

Using arithmetic means gives an equal weight to each of the measurements. The concentration measured at low discharge has the same importance as the concentration measured at peak discharge. This introduces a serious bias in favour of low discharge concentrations in the transportation calculations.

It is therefore much better to use discharge (Q) weighted means for the calculation of total transport:

$$F_x = \sum_{i=1}^{i=n}(X_i * Q_i) / \sum_{i=1}^{i=n} Q_i$$

In order to take into account irregular sampling intervals, the weighting should also be introduced for time (expressed as number of days in a year, D_i). An annual time-weighted concentration can be calculated from a set of measurements beginning not with the first day in the year and ending not with the last day in the year by (Kempe et al., 1991):

$$[X_1 (D_1 + (D_2 - D_1)/2) + X_n (365 - D_n + (D_n - D_{n-1})/2) +$$

$$\sum_{i=2}^{i=n-1} (X_i ((D_i - D_{i-1})/2 + (D_{i+1} - D_i)/2))]/365$$

Another method to calculate total mass transport can be used if the parameter in question shows a significant correlation with discharge. In such a case, the total discharge curve can be used to calculate fluxes simply by converting the individual gauge readings with the regression equation to concentrations.

The most simple way to obtain an estimate of the average transport (F_x) is to use the arithmetic mean (M_x) of the parameter and to multiply it with the arithmetic mean of the discharge measured (M_Q) during the sampling days:

$$F_x = M_Q \times M_x$$

where the arithmetic mean is defined as

$$M_x = (1/n) \times \sum_{i=1}^{i=n} X_i$$

(n = number of measurements, X_i individual measurement of parameter).

If no simultaneous discharge measurement is available, the otherwise available annual discharge is also often used. Annual or long-term arithmetic mean concentrations are used.

However, when the samples are not equally spaced in time, the method becomes unreliable. Also, the widely spaced measurements may then miss a major flooding event, which perhaps could mobilize 50 % of the total annual load.

Table 6 Comparison of loading estimates (t y^{-1} , method A) between four study periods

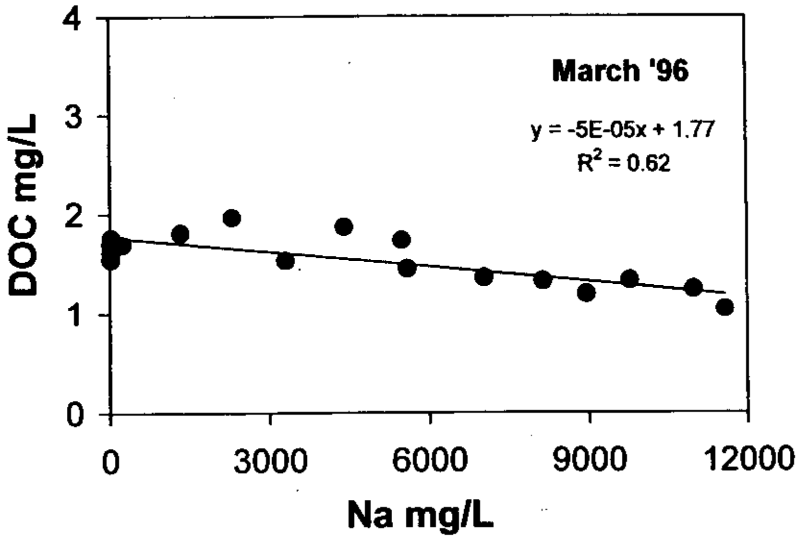
period	n	Q m^3 s^{-1}	TSS x 10^3 t y^{-1}	TDP t y^{-1}	TP t y^{-1}	TDN t y^{-1}	TN t y^{-1}
1982-87 (a)	73	1394		5 319 [d]	12 221	95 000 [e]	106562 [g]
1988-90 (b)	37	1362	2425	3 978	7 300	118 990	144175
1990-93 (c)	92	1495	9009	3 650 [d]	9 855	117 165 [f]	163885
1995-96	12	1596	4042	3 310	5 770	136 100	147200

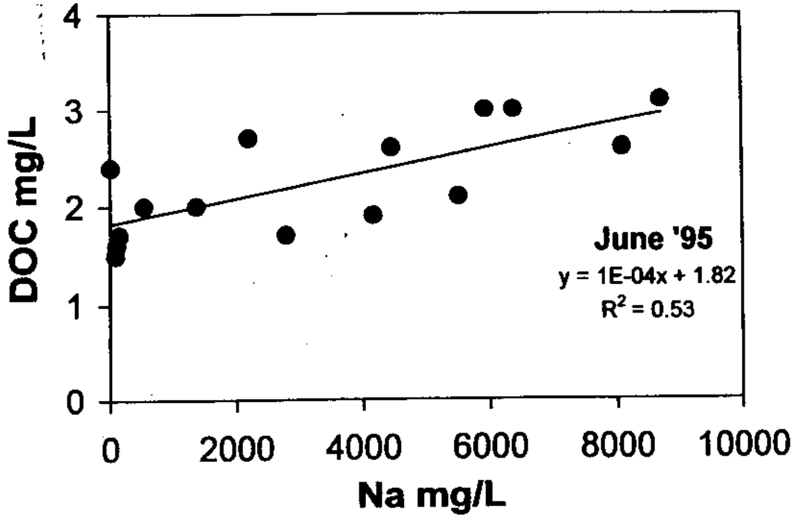
Annual loads (tonnes year^{-1})

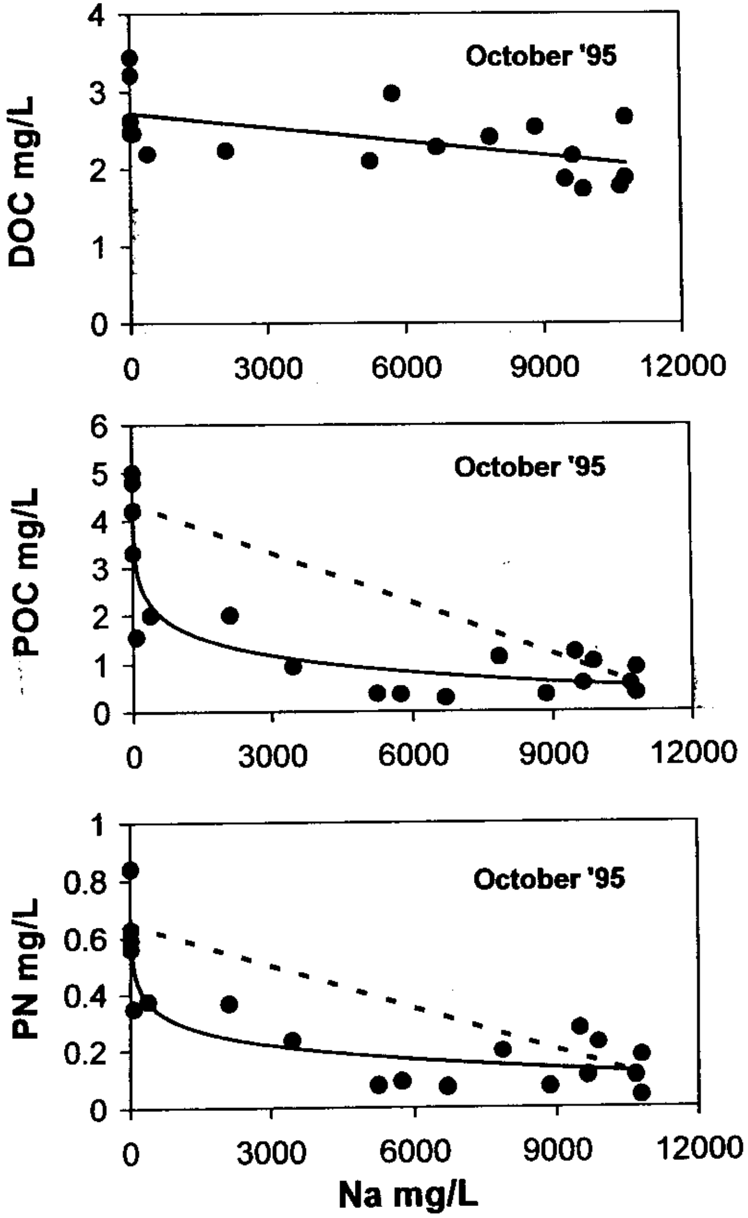
Method	**POC**	**DOC**	**PN**	**PIC**
a)	$13.4\text{x}10^4$	$11.2\text{x}10^4$	$19.4\text{x}10^3$	$14.6\text{x}10^4$
b)	$12.0\text{x}10^4$	$10.6\text{x}10^4$	$17.5\text{x}10^3$	$10.2\text{x}10^4$
→ c)	$13.4\text{x}10^4$	$12.1\text{x}10^4$	$19.4\text{x}10^3$	$14.6\text{x}10^4$
d)	$14.9\text{x}10^4$	$12.5\text{x}10^4$	$17.2\text{x}10^3$	$7.5\text{x}10^4$

(a) istantaneous concentrations and mean daily discharge
(b) arithmetic means of concentrations and discharges
(c) discharge-weighted concentrations and mean annual discharge
(d) concentrations converted by concentrations vs flow equation per each day in the year and daily discharge.

ESTUARINE BEHAVIOUR







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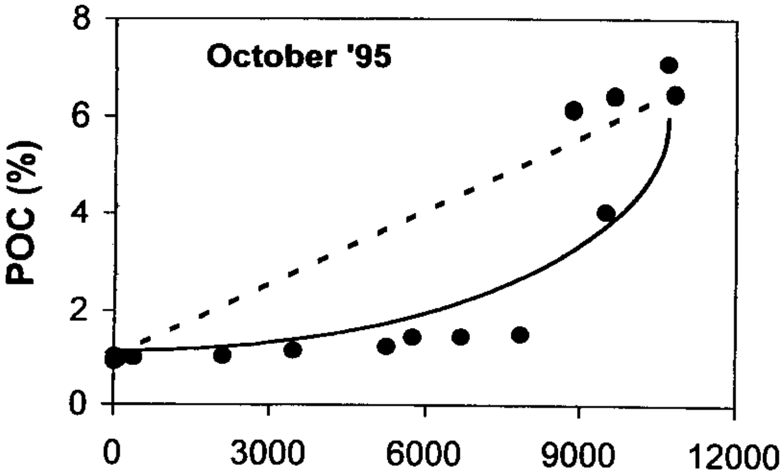
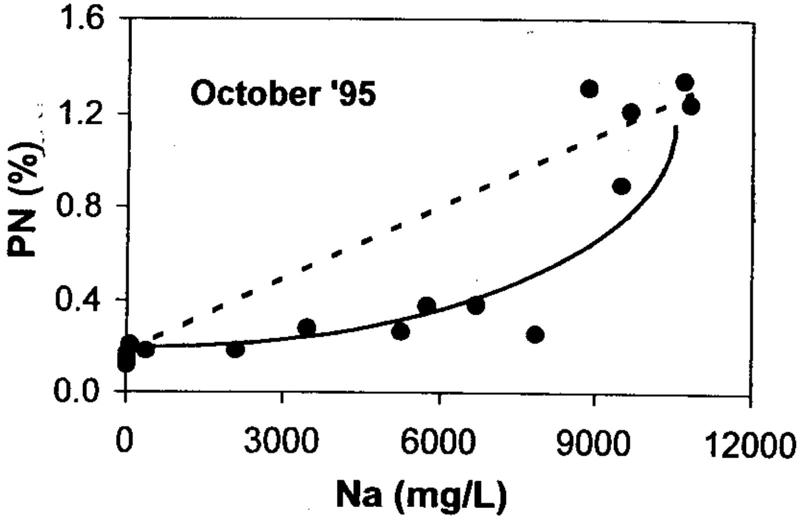




Comparison between the Po and the Rhone rivers.

After the building in 1970 of the imposing dike of Assuan on the Nile and the nearly complete exploitation of its waters for irrigation, the Po and the Rhone are the two largest fresh water inputs to the Mediterranean.

Both these rivers originate from the Alps and drain large catchment areas (Rhone 96000 km^2, and the Po 70091 km^2). The Po shows a slight higher solid transport compared to the Rhone ($5.5x10^6$ vs $4.6x10^6$ tonnes $year^{-1}$) while a slight lower water discharge rate (47 vs 55 km^3 $year^{-1}$). However, these rivers show some marked differences:

- population densities in their watershed differ greatly, 232 and 84 inhabitants km^{-2} for the Po and Rhone, respectively;
- the modes of transport of organic carbon are quite different.

TOC discharge from the Rhone has been estimated at $15x10^4$ tonnes $year^{-1}$, one third of which is POC (Kempe et al., 1991); on the contrary, the Po export rate of TOC was estimated at $25.5x10^4$ tonnes $year^{-1}$, with more than half given by POC.

The average TOC concentration in the lower Po (4.5±1.5 mg/L) and the TOC export rate (3.57 tonnes km^{-2} $year^{-1}$) are slightly lower than the median TOC and the average export rate estimated for major temperate rivers (5 mg/L and 4 tonnes km^{-2} year^{-1}, respectively; Meybeck, 1982). Therefore, the total level of organic carbon in the Po does not seem to be significantly altered by anthropic activity, due to the self-purification capacity of the river. TOC levels in some major temperate rivers (Rhine, Ems and Danube) that are polluted, have been reported to reach four to five times higher than those in the Po (Meybeck, 1982).

The TOC export rate from the Po is about 1.7 times higher than that of the Rhone, making the former river the largest contributor of organic matter to the Mediterranean.

The load of total nitrogen (TN) has been estimated as 15.5x10^4 tonnes year^{-1}, 12 % of which is particulate while about 65 % is due to nitrate. This TN load is about double that reported for the Rhone (7.4x10^4 tonnes year^{-1}; El-Habr & Golterman, 1987), while the NO_3^- load of the Po is similar to that the Loire discharges in to the Atlantic ocean which is about 9x10^4 tonnes year^{-1} (Meybeck et al., 1988).

The average PIC value found in the lower Po (1.9±0.7 %) is about double that of major world rivers (0.9 %; Meybeck, 1982), while the average PN value (0.94±0.72 %) falls in the upper part of the range (0.1-1.3 %) that includes most rivers in the world, as also noted above for POC.

External vs internal organic carbon sources.

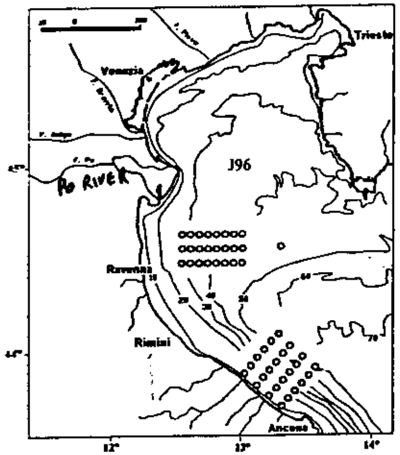
The Po River provides over 50 % of the freshwater input to the northern Adriatic basin and about 50 % of the total nitrogen input (Degobbis and Gilmartin, 1990); hence, as a first guess, we can assume that the total organic carbon load roughly doubles that of the Po, amounting to 50×10^4 tonnes year^{-1}.

This external input may account for about 30 % of the overall annual productivity given by the average value of 89.6 g m^{-2} yr^{-1} of carbon fixed by phytoplankton (Degobbis et al., 1980) and the surface extension of 18,900 km^2 for the northern Adriatic basin. External matter provides additional energy to the system and significantly influences its productivity and trophic dynamics.

In winter, biological and physical processes make organic matter at a low level; bacterial carbon demand largely exceeds the quantity of organic carbon which is exudated or fixed by phytoplankton and riverine discharges are transported in the southward direction escaping the northern basin.

On the contrary, in summer cyclonic circulation and strong stratification make organic matter confined in the northen basin, producing recurrent hypoxia and anoxia in bottom waters and at sediment and mucilaginous aggregates in the water column.

JUNE 1996



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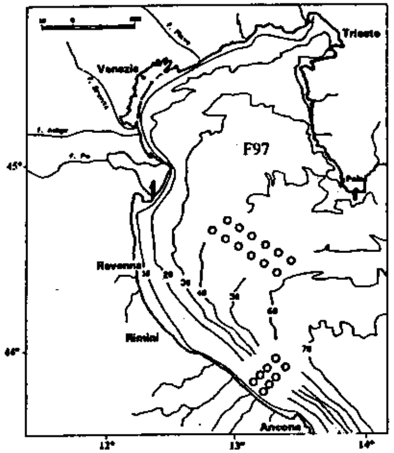

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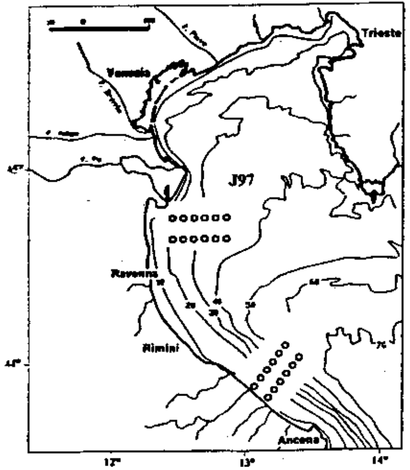

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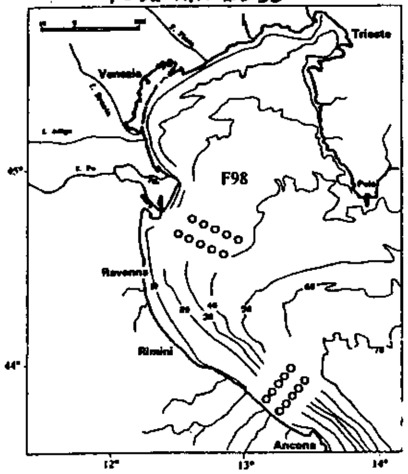
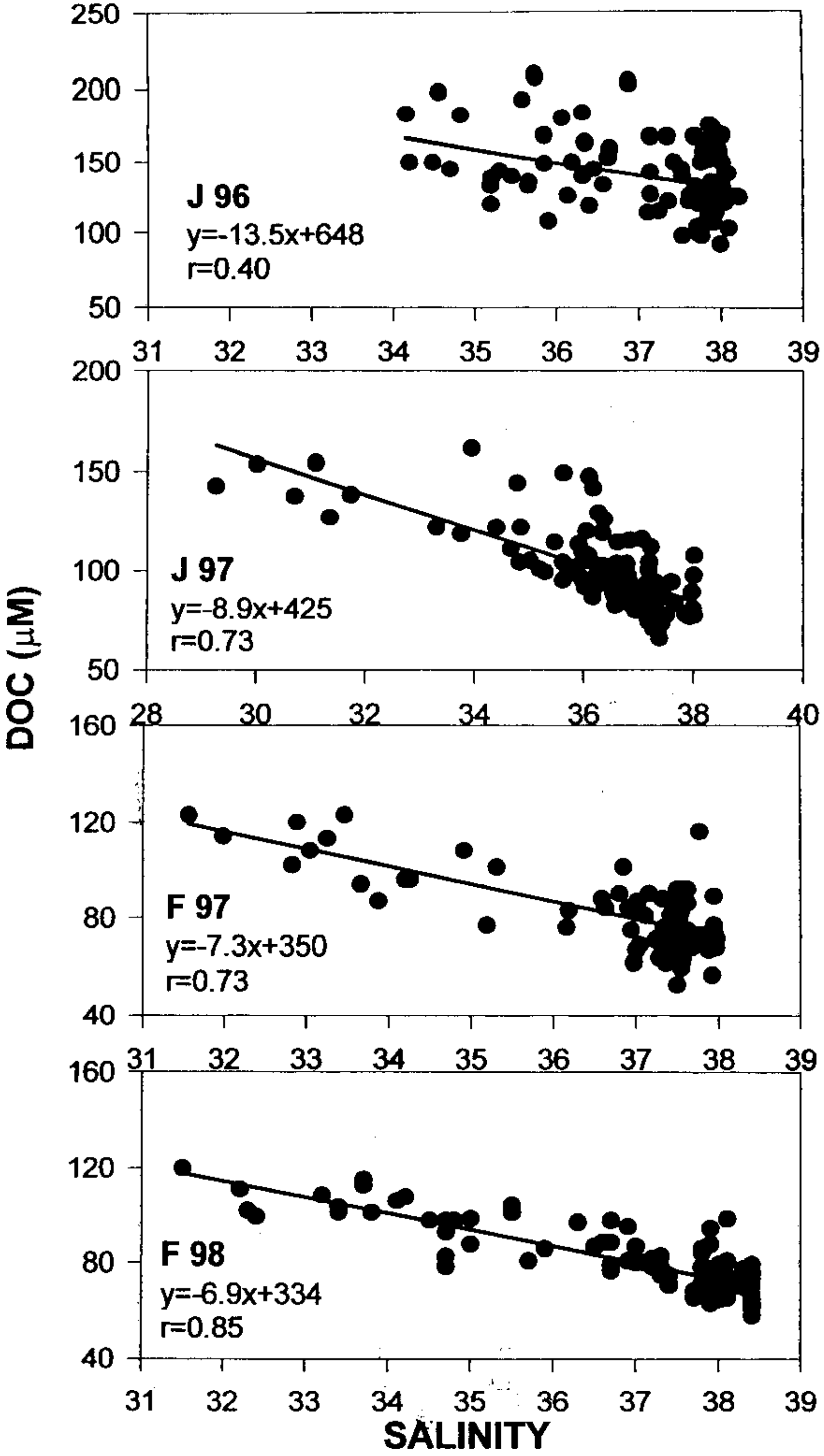
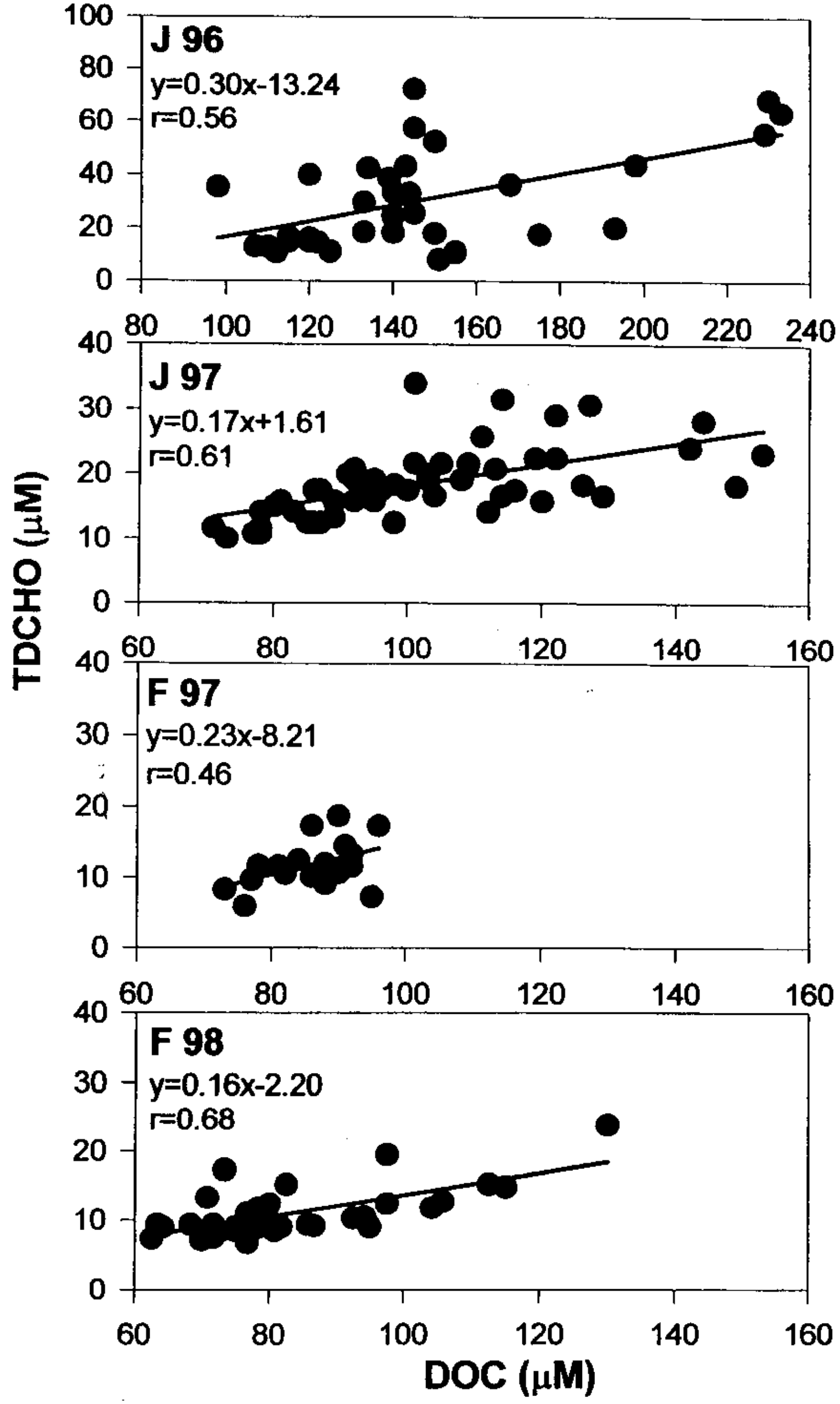
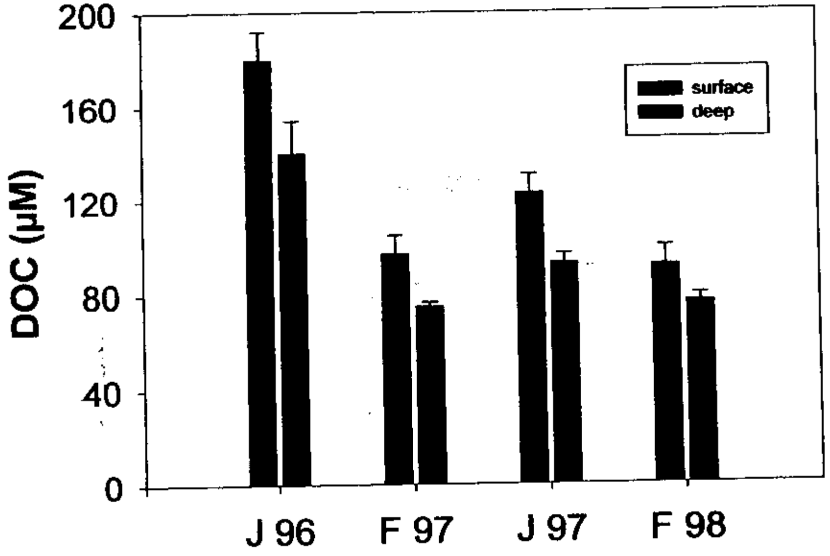




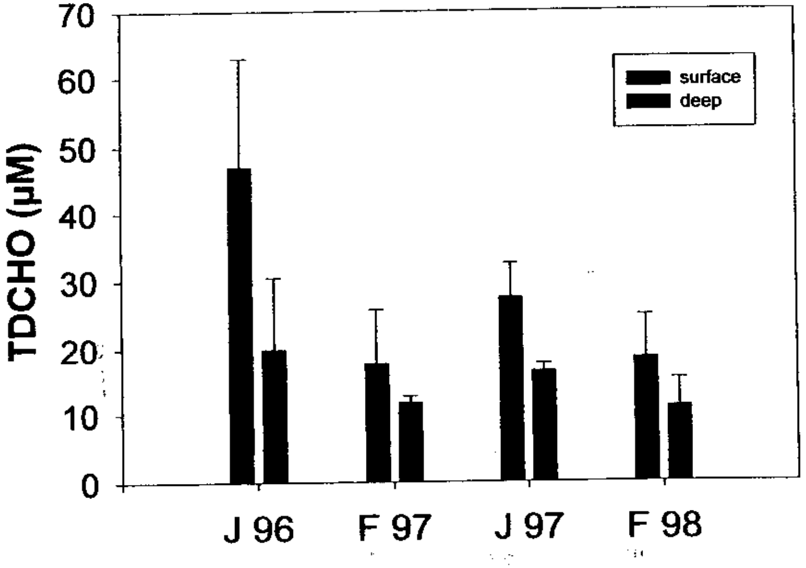


AVERAGE DOC LEVELS IN SURFACE AND DEEP WATERS IN THE FOUR CRUISES

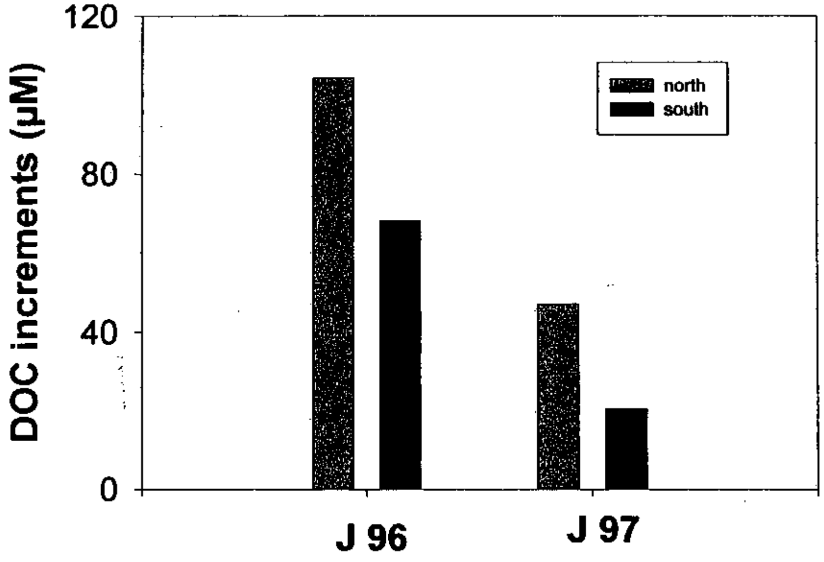
NORTHERN REGION

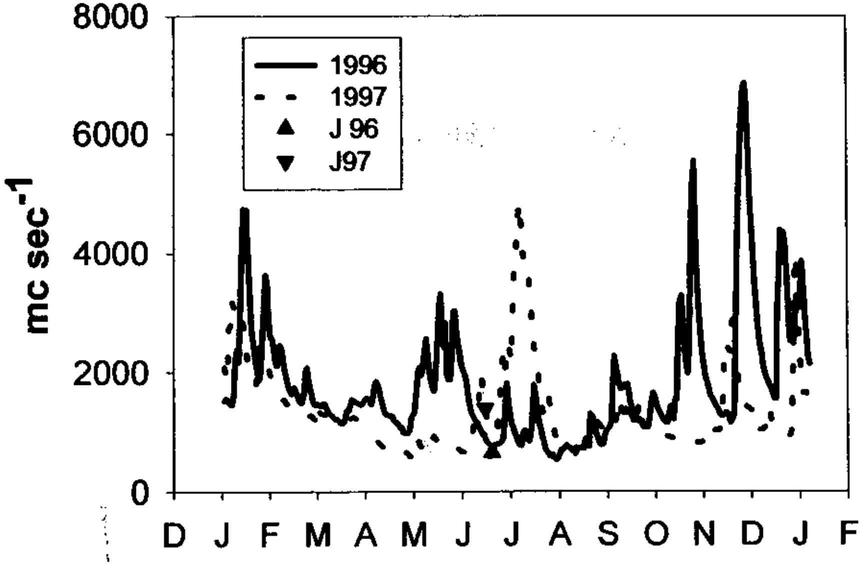


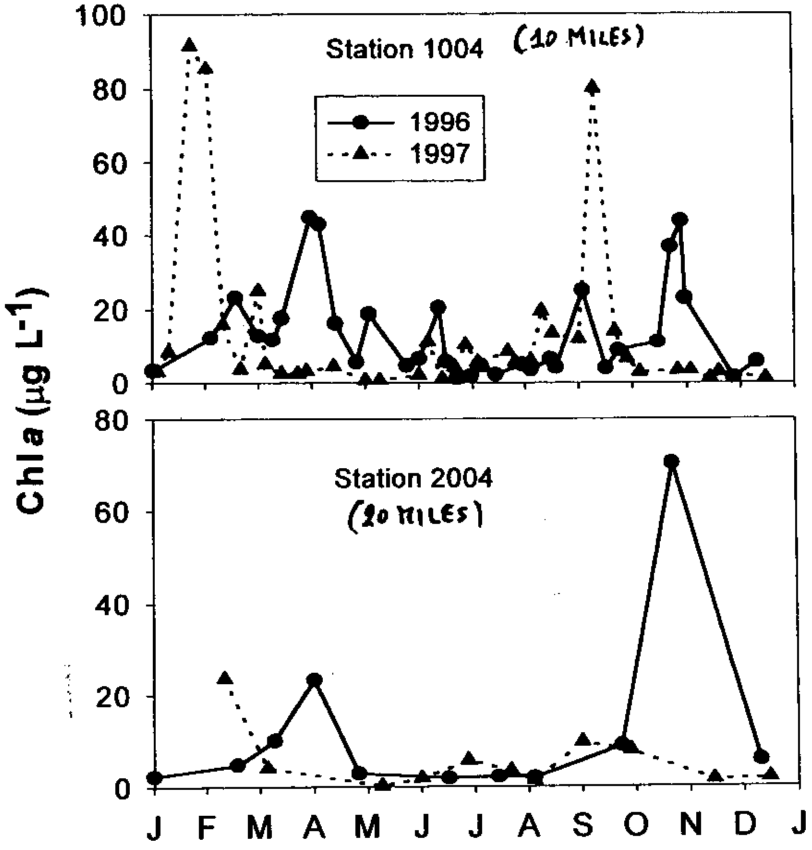
AVERAGE TOTAL DISSOLVED CARBOHYDRATES
IN SURFACE AND DEEP WATERS



DOC increments over the background
winter value of 76 µM




8000
6000
4000
2000
0
mc sec-1
1996
1997
J 96
J97
D J F M A M J J A S O N D J F


Station 1004 (10 MILES)
1996
1997
100
80
60
40
20
0
Chl a (µg L-1)
Station 2004 (20 MILES)
80
60
40
20
0
J F M A M J J A S O N D J

WHY DOC MAY ACCUMULATE IN SURFACE WATERS ?

-<u>part of DOC is refractory</u>: this may either originate from particular non-degradable components of biological material or there may be abiotic processes converting fresh labile DOC into chemically refractory forms. Abiotic processes may presumably be more important in areas receiving large quantity of terrestrial organic matter;

-<u>"malfunctioning" microbial loop</u>: bacterial carbon consumption is unable to match DOC release because is restricted due to mechanisms controlling both growth and biomass of the bacteria. Growth rate and biomass may be kept low by bacteria-phytoplankton competition for mineral nutrients and bacterial predators, respectively (Thingstad et al., 1997);

-<u>water mass circulation</u>: changing from counterclockwise circulation affecting the Adriatic during most part of the year to eddy circulation setting up in summer in the northern basin causes an increased residence time for freshwater and as consequence an increase in organic matter levels, due to direct and indirect sources.

MICROBIAL LOOP (AZAM et al. 1983)

CONSORTIUM OF MECHANISMS WHEREBY ORGANIC CARBON IS DIVERTED AS DOC FROM THE UPWARD FLUX OF PARTICULATE ORGANIC CARBON TOWARD HIGHER TROPHIC LEVELS AND RECYCLED TO THE BOTTOM OF THE FOOD CHAIN.

- OM CONCENTRATIONS IN AQUATIC SYSTEMS RESULTS FROM ALLOCHTHONOUS AND AUTOCHTHONOUS SOURCES.

  ALLOCHTHONOUS SOURCES INCLUDE ANTHROPOGENIC DISCHARGES AND NATURAL LEACHING FROM SOIL AND TERRESTRIAL PLANTS.

  AUTOCHTHONOUS SOURCES ARE RELATED TO PHOTOSYNTHETIC PROCESSES WHICH MAY BE FUELED BY NEW AND REGENERATED NUTRIENTS.

- ANTHROPOGENIC DISHARGES ARE OFTEN RESPONSIBLE FOR A DOMINANCE OF RESPIRATION PROCESSES IN RIVERS, PRODUCING O_2 DEFICIT, [redacted] ACIDIFICATION. AT LOW O_2 LEVELS (BOTTOM WATER SEDIMENT) NO_3 MAY BE USED AS ELECTRON ACCEPTOR FOR RESPIRATION OF ORGANIC MATTER. IN THIS CASE THERE IS AN INVERSION OF THE INTERDEPENDENCE OF $p\text{-}CO_2$, pO_2 AND NO_3 WHICH IS A TYPICAL FINGERPRINT OF ANTHROPOGENICALLY ALTERED RIVERS.
- OM IS A COMPLEX POOL OF COMPOUNDS (LARGELY UNKNOWN) WITH DIFFERENT AGE, BIOAVAILABILITY, MOLECULAR SIZE.
- THE COMBINED DICHARGE OF OM AND NUTRIENTS MAY HAVE SERIOUS CONSEQUENCES ON C CYCLING IN COASTAL WATERS BY DIRECTLY AND INDIRECTLY INCREASING DOC LEVELS.