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Ecological observations on plankton of the Loire estuary (France)

Yves Rincé[1], Véronique Martin-Jézéquel[2] & Brigitte Ravail[3]
1. Laboratoire de Biologie marine, Université de Nantes, 2, rue de la Houssinière, 44072 Nantes cedex 03, France.
2. Centre d'Études Océanographiques et de Biologie marine, CNRS, place G. Teissier, 29211 Roscoff, France.
3. Centre de Recherche en Écologie marine et Aquaculture, L'Houmeau, Case 5, 17137 Nieul-sur-mer, France.

Abstract : Hydrological and planktological studies were performed in the Loire estuary in 1981-1982. The hydrological regime of the river produces variations in the seasonal cycle of the plankton, while spring- and neap-tides, through suspended matter and water mixing, cause different patterns of spatial distribution of plankton.

Résumé : Des études ont été réalisées en 1981-1982 dans l'estuaire de la Loire, sur les paramètres hydrologiques et les populations planctoniques. Le cycle saisonnier du plancton varie en fonction du régime hydrologique fluvial, tandis que sa distribution spatiale dans l'estuaire est liée au mélange des masses d'eaux et à la matière en suspension, en relation avec les cycles de marée vive eau-morte eau.

INTRODUCTION

Numerous papers deal with the hydrodynamics, sedimentology and biology of the Loire estuary, for pollution (Fleury, 1974 ; Frenel, 1978 ; Ottmann & Quéré, 1979 ; Port Autonome de Nantes-Saint Nazaire, 1983) or impact of industrial plants (Maillard & Métayer, 1976 ; EDF, 1979). Only two pluridisciplinary works include plankton surveys (Piéri, 1977 & Quéré, 1977). Significant changes in the topography and hydrodynamics of the estuary occurred, which required a re-examination of inputs and biological consequences. Indeed, the Loire estuary is subject to industrial outflows which may have farreaching consequences on this ecosystem.

Within the study area, fresh waters from a 120 000 km^2 watershed face about 250 millions m^3 of sea water. Hydrodynamical effects of tides are noticed up to 95 km upstream. Annual mean riverflow is 825 $m^3\ s^{-1}$, higher flows reach 1 540 $m^3\ s^{-1}$ and lower flows fall to 120 $m^3\ s^{-1}$. Two main urban centers Nantes and St Nazaire, several smaller towns and numerous factories contribute to pollution, especially in terms of DOC (380 000 t yr^{-1}, provided from upstream sources and 13 000 t yr^{-1} directly flowed into the estuary). Loads of suspended matter cause heavy turbidity (up to 2 g l^{-1} in surface water), with mineral and organic particle mass evaluated from 6 to 10 x 10^5 tons which move up and down in relation to tide dynamics and seasonal fluctuations of flow.

Among nutrients, phosphate concentrations reveal a source located in the area of maximum turbidity, comprised between 0.8 and 3.6 µg.at l^{-1} during most of the year. Nitrogen concentrations are subject to a decrease from 45-290 µg.at l^{-1} to 20-200 µg.at l^{-1} between upstream and downstream stations.

Our purpose is to complement the chemical and physical examination of Rincé *et al.* (1985) by looking for relationship between hydrological features and plankton behaviour. Investigations were carried out from September 1981 to July 1982.

MATERIAL AND METHODS

Hydrological and biological samples were collected at three stations in three distinct zones (Fig. 1) of the estuary. Different regimes were investigated during spring-tide and neap-tide at low flow (September 1981, July 1982), mean flow (November 1981, April 1982) and high flow (February 1982). For each station, samples were collected every two hours, during a 12 hours tide cycle. Three supplementary investigations were made in May, June and July (Table 1).

Hauls were made at 1 m below the surface, against the current (current speed ranged between 0.5 and 2.5 m s^{-1}) with a 50 µm mesh net for phytoplankton and a 200 µm (Bongo) net for zooplankton. Owing to turbidity, only surface sampling was performed and filtration efficiency was often less than 50 %. Hauls did not exceed three minutes in time. Filtered volumes estimated from TSK flowmeter measurements were comprised between 10 and 45 m^3. Clogging of the nets led us to use sampling bottles as well (Niskin's bottles of 1litre). Net catches for qualitative observation and bottles samples for counting were preserved in buffered 2 % formaldehyde for zooplankton and 1 % acetic-Lugol's solution for phytoplankton.

Water samples for assessing phytoplanktonic biomass as pigment concentrations were filtered on glassfiber filters (GF/C). Filtered particles were ground with the filter in aqueous aceton (90 %). Chlorophyll-a and phaeopigment contents were measured in a Turner Desigh fluorometer according to Lorenzen's (1966) equations. The fluorometer was calibrated using chlorophyll-a obtained from Sigma Chemical Company. Scor-Unesco (1974) equations were used to calculate the quantity of chlorophyll-a after spectrophotometric checking of its purity.

Counts of algal cells and animals were made in settling chambers using an inverted microscope. Algal species were identified according to Bourrelly (1968, 1970, 1972), Germain (1981) and Hustedt (1930 a-b, 1959, 1961). Animals were identified according to Brauer (1961), Leloup (1952), Rose (1970) and Tattersall & Tattersall (1951). Population densities were expressed as numbers of cells or individuals per litre or per cubic meter.

Dissolved oxygen concentrations were obtained according to Winkler's method. An automatic salinometer (Autosal 8 400) was used for determination of salinity values. Loads of suspended matter were calculated from dry weight of residue after filtration of a known volume of sample (Whatman glassfiber disk, dried at 103°C for 1 hour).

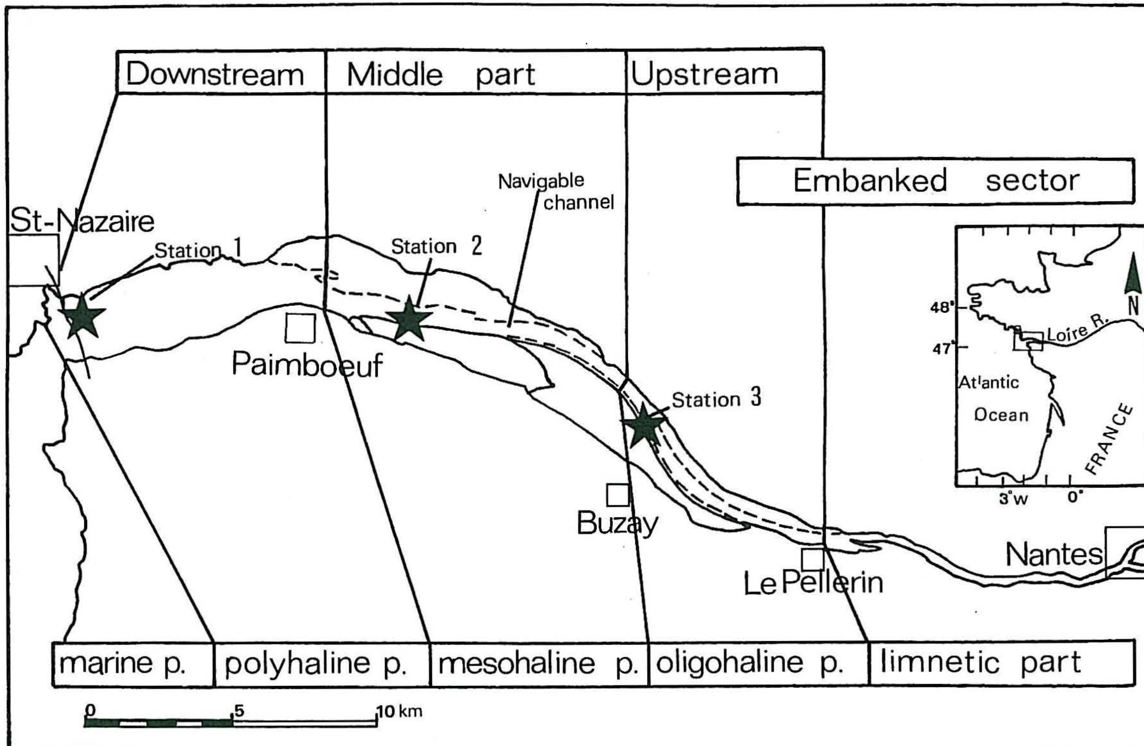

Fig. 1 - Map of the studied area

TABLE 1 - Sampling days and tide coefficients

Sampling date	Tide coefficient
16 September	107
23 September	47
13 November	112
19 November	47
9 February	100
17 February	34
8 April	96
15 April	40
24 May	105
16 June	53
16 July	58

RESULTS

Salinity

Marked differences between stations confirm the partition of the estuary into three parts. According to Caspers's classification (1959) data from station 1 exhibit a polyhaline dominant and a winter mesohaline trend. Station 2 has a mesohaline dominant with a winter oligohaline trend. Station 3 belongs to the oligohaline part of the estuary, with a winter limnetic trend (Fig. 2).

Dissolved oxygen

Two characteristic periods appear in the annual cycle corresponding respectively to low and high saturation numbers (Fig, 3), The first phase in late summer (September) correspond to the lowest concentrations, between 1 and 7 mg l^{-1}. The second phase corresponds to higher flows and lower temperatures, with O_2 concentrations between 3 and 14 mg l^{-1}. The horizontal distribution of dissolved oxygen exhibits minima which are more marked upstream (station 2 & station 3) than downstream and spring maxima (probably related to photosynthetic activity) are higher in station 3 than in the other two stations.

Suspended matter

During late spring, the river regime decreases and suspended matter reach its maximum for the three stations, respectively in April (St. 1), May (St. 2) and June-July (St. 3). A second maximum is observed in autumn (November) for the three stations (Fig. 2).

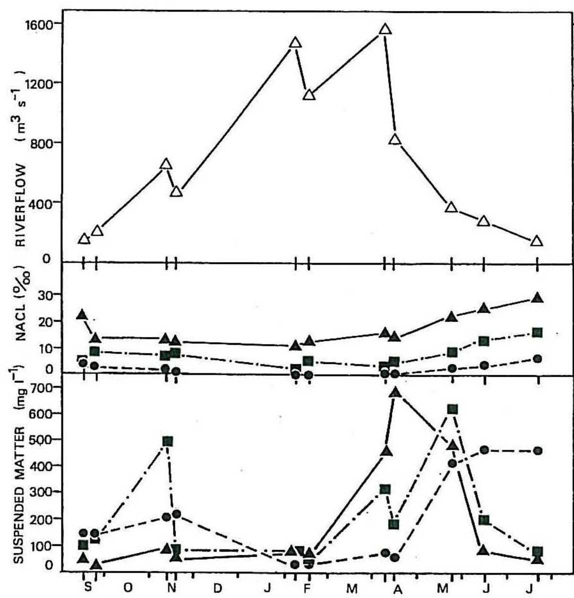

Fig. 2 - Evolution of riverflow, salinity and suspended matter in the Loire estuary (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

Algal pigments and number of cells of phytoplankton

The seasonal distribution of algal pigments shows two distinct periods. All along late summer, fall and partly winter, degraded pigments represented by phaeopigments are more abundant than chlorophyll-a. During a second period, from winter to summer, the chlorophyll-a-/phaeopigment ratio is often inverted. At station 1, spring and summer values do not reach the maximum recorded at station 2 and station 3 (Fig. 4-5).

All year long, estuarine waters carry amounts of phaeopigments which reflect the accumulation of degraded material and, probably, the effect of physical and chemical features upon phytoplankton.

Cell numbers exhibit a sharp contrast between station 1 and the other two. At station 1, densities fluctuate from 1.0 10^7 to 2.0 10^9 cell m^{-3}. Reduced effectives correspond to winter communities. At station 2 densities range between 4.0 10^7 and 5.8 10^9 cells m^{-3}. At station 3, they vary between 9.0 10^7 and 8.0 10^9 cells m^{-3} (Fig. 6).

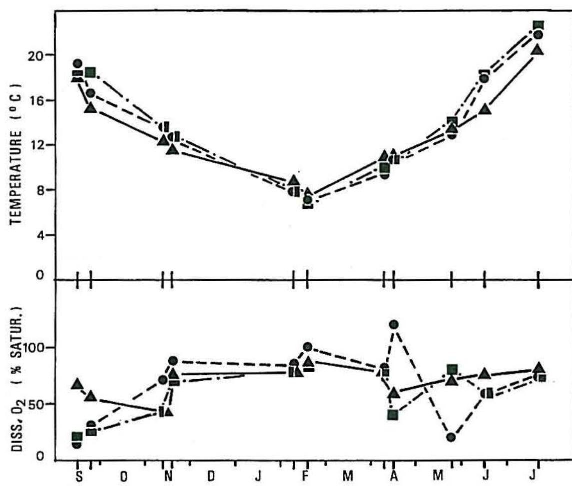

Fig. 3 - Evolution of temperature and dissolved oxygen (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

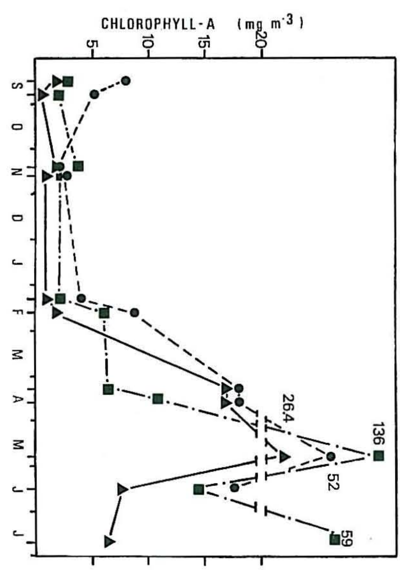

Fig. 4 - Chlorophyll-a in water (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

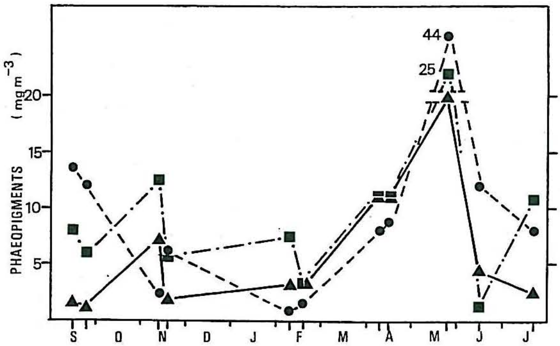

Fig. 5 - Phaeopigments in water (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

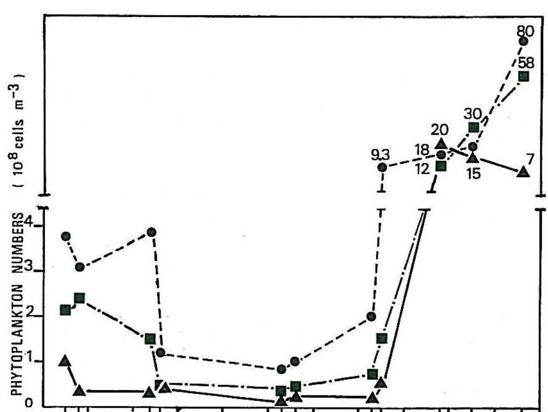

Fig. 6 - Phytoplankton numbers (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

Distribution and seasonality of phytoplankton

The floristic list of taxa is shown in table 2.

• Bacillariophyceae. They are dominant during the whole year at all stations. *Melosira granulata* and its variety *curvata*, *M. sulcata* and *Cyclotella meneghiniana* are the most frequent taxa. Increasing abundance of the neritic species *Skeletonema costatum* and of the oceanic one *Asterionella formosa* takes place in winter. Spring flowering of *Cyclotella stelligera* and *Stephanodiscus hantzschii* (fresh water species) is recorded at every station.

TABLE 2

Floristic list of taxa encountered within the Loire estuary.

CYANOPHYTA
Gomphosphaeria sp.
Lyngbia sp.
Xicrocystis marginata Kützing
Oncillatoria limona Agardh

CHLOROPHYTA
Actinastrum hantzschii Lagerheim
Ankistrodesmus falcatus (Corda) Ralfs
Characlum sp.
Chlamydomonas sp.
Closteriopsis longissimum GM Smith
Closterium venus Kützing
Coelastrum microporum Naegeli
Crucigenia fenestrata Schmidle
Desmidium sp.
Hyaloraphidium contortium Pascher & Korchikoff
Hyaloraphidium sp.
Pediastrum boryanum (Turpin) Meneghini

Pediastrum clathratum (Schroder) Lemmermann
Pediastrum tetran (Corda)Rabenliorat
Scenedesmus falcatus Chodat
Scenedesmus gutvinski Chodat
Scenedesmus javanensen Chodat
Scenedesmus protuberans Fritsch & Rich
Scenedesmus quadricaudatus (Turpin) Brébisnon
Scenedesmus smithii Teiling
Scenedesmus tenuispina Chodat
Selenastrum bibralanum Reinach
Staurastrum furcigerum (Ehrenberg) Drébisson
Staurodesmus dickel (Turner) Cronsdale

DINOPHYTA
Exuviella compresan (Stein) Ostenfeld
Gonyaulax spinifera (Claparède & Lachman) Diesing
Gymnodinium aeruginosum Stein
Noctiluca miliaris Suriray
Peridinium cinctum (Muller) Ehrenberg

CHRYSOPHYTA
Chrysococcus rufescens Klebs
Mallomonas sp.

BACILLARIOPHYTA
Achnanthes brevipes Agardh
Achnantes subsessilia Kützing
Actinoptychus undulatus (Bailey) Ralfs *in* Pritchard
Amphiprora paludosa Wm Smith
Amphora coffeaeformia (Agardh) Kützing
Amphora ovalis Kützing
Amphora ovalis var. pediculus (Kützing) Van Heurck
Asterionella formosa Hassall
Asterionella japonica Cleve
Bacteriastrum varians Lauder
Biddulphia aurita (Lyngbye) Brébisson & Godey
Biddulphia mobiliennis (Bailey) Grunow
Biddulphia rhombus (Ehrenberg) Smith
Campylosira cymbelliformia (Schmidt) Grunow *in* Van Heurck
Chaetoceros debilis Cleve
Chaetoceros socialis Lauder
Chaetoceros sp.
Cocconeis placentula Ehrenberg
Coscinodiscus küteingii Schmidt
Coscinodiscus lineatus latestriata Ehrenberg
Coscinodiscus oculus-iridis Ehrenberg
Coscinodiscus radiatus Ehrenberg
Cyclotella glomerata Bachmann
Cyclotella meneghiniana Kützing
Cyclotella stelligera Cleve & Grunow
Cymatopleura solea (Brébisson) Wm Smith
Cymbella ventricosa Kützing
Diploneis crabro Ehrenberg
Ditylum brightwellii (West) Grunow *ex* Van Heurck
Eunotia faba (Ehrenberg) Grunow
Eunotia pectinalis (Kützing) Rabenhorst
Eunotia tenella (Grunow) Hustedt
Fragilaria construens (Ehrenberg) Grunow
Fragilaria construens var. binodis (Ehrenberg) Grunow
Gomphoneis olivacea (Lyngbye) Dawson
Gomphonema affinae Kützing
Gomphonema constrictum Ehrenberg
Grammatophora oceanica Ehrenberg
Grammatophora serpentina Ehrenberg

Gyrosigma acuminatum (Kützing) Rabenhorst
Gyrosigma attenuatum (Kützing) Cleve
Gyrosigma fasciola (Ehrenberg) Cleve
Gyrosigma spencerii (Wm Smith) Cleve
Hantzschia amphioxys (Ehrenberg) Grunow
Hyalodiscus stelliger Bailey
Melosira ambigua O. Muller
Melosira granulata (Ehrenberg) Ralfs *in* Pritchard
Melosira granulata var. curvata Grunow *in* Van Heurck
Melosira italica Ehrenberg

Melosira jurgensi Agardh
Melosira nummuloides (Dillwyn) Agardh

Melosira sulcata (Ehrenberg) Kützing
Melosira varians Agardh
Navicula ammophila Grunow
Navicula anglica Ralfs
Navicula arenaria Donkin
Navicula biskanteri Hustedt
Nuvicula cryptocephala Kützing
Navicula cuspidata Kützing
Navicula gregaria Donkin
Navicula hungarica var. capitata (Ehrenberg) Cleve

Navicula lanceolata (Agardh) Ehrenberg
Navicula mutica Kützing
Navicula neoventricosa Hustedt
Navicula palpebralis Brébisson *ex* Wm Smith
Navicula pupula Kützing
Navicula viridula Kützing
Nacivula viridula var. rostellata (Kützing) Cleve
Neidium productum (Wm Smith) Cleve
Nitzschia delicatissima Cleve
Nitzschia dissipata (Kützing) Grunow
Nitzschia fruticosa Husted
Nitzschia lanceolata Wm Smith
Nitzschia longissima (Brébisson) Ralfs
Nitzschia microcephala Grunow
Nitzschia palea (Kützing)Wm Smith
Nitzschia parvula Lewis
Nitzschia rostellata Hustedt
Nitzschia sigma (Kützing) Wm Smith
Nitzschia thermalis (Ehrenberg) Auerswald *in* Rabenhorst
Nitzschia thermalis var. minor Hilse
Nitschia tryblionella Hantzsch *in* Rabenhorst
Opephora martyi Héribaud
Pinnularia acuminata Wm Smith
Pinnularia biceps Gregory
Pinnularia lundii Hustedt
Pinnularia microstauron (Ehrenberg) Cleve
Pleurosigma aestuarii (Brébisson *in* Kützing) Wm Smith
Pleurosigma angulatum (Quekett) Wm Smith
Pleurosigma angulatum var. strigosum (Wm Smith) Van Heurck
Pleurosigma obscurum Wm Smith
Raphoneis amphiceros Ehrenberg
Rhizosolenia delicatula Cleve
Rhizosolenia fragilissima Bergon
Rhizosolenia pungens Cleve-Euler
Rhizosolenia setigera Brightwell
Rhizosolenia shrubsolei Cleve
Schroderella delicatula (Peragallo) Pavillard
Skeletonema costatum (Greville) Cleve
Stauroneis salina Wm Smith
Stephanodiscus astrea (Ehrenberg) Grunow
Stephanodiscus astrea var. minutula (Kützing) Grunow
Stephanodiscus dubius (Fricke) Hustedt
Stephanodiscus hantzschii Grunow
Streptotheca tamesis Shrubsole
Surirella angustata Kützing
Surirella ovata Kützing
Synedra acus Kützing
Synedra pulchella Kützing
Synedra ulna (Nitzsche) Ehrenberg
Thalassionema nitzschioides Hustedt
Thalassiosira eccentrica (Ehrenberg) Cleve

EUGLENOPHYTA
Euglena viridis Ehrenberg
Peranemaceae (undetermined)
Phacus longicauda Dujardin

PROTOZOA (CILIOPHORA)
Strombidium viride Stein

At station 1, Coscinodiscales with mainly freshwater species represent 15 to 90 % of the biomass (expressed as numbers of cells). Naviculales comprising 4.7 to 40 % of the cells collected at station 1 are more frequent during winter and spring. Most are fresh water species typical of periphyton and littoral epipelon. The occurrence of neritic and oceanic species reflects the influence of sea water at station 1. *Chaetoceros* sp., *Biddulphia* sp., *Asterionella japonica, Rhizosolenia* sp. and *Ditylum brightwelli* constitute a typical association. They are often damaged and their abundance maxima occur in spring and fall..

At station 2, the relative abundance of Coscinodiscales ranges from 40 % in February to 80 % in September. This group consists of neritic (e.g. *Coscinodiscus* sp.), estuarine (e.g, *Melosira nummuloïdes*) and freshwater species (e.g. *Cyclotella stelligera*). Naviculales, dominated by *Nitzschia* sp. do not present any clear seasonality at this station.

At station 3, most of the diatoms occurring in polyhaline and mesohaline stations seem to be damaged, especially Coscinodiscales. Two genera exhibit seasonal abundance : *Cyclotella* sp. represents 50 to 60 % of the cells encountered in summer ; *Stephanodiscus* sp. forms 4 to 23 % of cells encountered in spring.

• Chlorophyceae. They constitute the second major group as regards number of species and relative abundance. Their seasonality shows a maximum in September, at every station. Major species are the freshwater taxa *Scenedesmus* sp., *Actinastrum hantzschii* and

Pediastrum sp. Due to salinity, they are recorded all year long only in the oligohaline station where they represent up to 15 % of the total numbers.

• Cyanophyceae. Four species, *Gomphosphaeria* sp., *Lyngbia* sp., *Microcystis marginata* and *Oscillatoria limosa* compose this group, They appear during fall at the three stations, where they may represent 1.3 to 12 % of the total numbers.

• Cryptophyceae. This taxonomic unit gathers several forms unidentified in this study. According to their dimensions (lesser than 10 µm) they belong to the nannoplankton. At Station 1, they appear in winter only. Their relative abundance is more marked in winter at Station 3 (7.6 to 64 %) than at Station 2 (6 to 36 %).

• Euglenophyceae. This group only contains two identified froms : *Euglena viridis*, *Phacus longicauda*, plus unidentified Peranemaceae. All are freshwater organisms, which is consistent with their relative abundance (2 % at station 2, 2 to 4% at station 3).

Influence of tide regime

In the polyhaline sector of the estuary, samples collected during springtides include neritic and estuarine species (e.g. *Actinoptychus undulatus* :1.4 10^6 cells l^{-1}, *Melosira nummuloïdes* : 2 10^5 cells l^{-1}) associated with freshwater species originating from benthos and submersed substrates. Neap-tides samples contain predominantly fresh water forms (in September *Cyclotella meneghiniana* : 1 to 3 10^4 cells l^{-1} ; in November Chlorococcales :2-3 10^4 cells l^{-1}) while neritic species are missing.

In the mesohaline sector, the contrast between spring-tides and neap-tides is noticeable only during fall and winter. In November, spring-tide samples contain neritic, estuarine and fresh water forms (*Cyanophyceae* and *Melosira granulata*).

The oligohaline part of the estuary is almost free of marine inputs, but benthic and epiphytic species (*Navicula* sp., *Nitzschia* sp. and *Amphora ovalis*) occur in spring-tide samples, while neap-tide ones mostly contain true planktonic ones.

Distribution and .seasonality of zooplancton

The faunistic list of taxa is shown in table 3.

The Loire estuary zooplankton is an assemblage of estuarine typical species (e.g. *Nemopsis bachei, Neomysis integer, Mesopodopsis slabberi*, Copepoda -3 species among 13), seasonal communities (larvae of neritic benthic Crustaceans and Gastropods), neritic populations brought by floods (e,g, *Sagitta bipunctata*, Cladocera - 2 species among 9, Copepoda - 6 species among 13) and freshwater species associated with waters (e.g. *Cypris pubera*, Cladocera -7 species among 9, Copepoda - 4 species among 13). Densities range from 2 10^2 to 3 10^5 individuals m^{-3} (Fig. 7). Copepoda form the major group (55 to 99 %), followed by Mysidaceae (2 to 35 %). Non planktonic Amphipoda (Gammaridae) occur in the samples at the rate of 0,2 to 12 % of the total. At the more saline stations Cladocera and Ostracoda reach 0.5 to 10 % of the total.

• Copepoda. At station 1, Copepods are dominant. Temorideae and Centropagideae are recorded all year long. During winter, in addition Cyclopideae (*Eucyclops* sp. and *Macrocyclops* sp.) appear. Numbers reach 45 10^3 per m^3. During spring, copepods remain dominant (97 % of all individuals with 8 to 13 10^4 ind.m^{-3}). The Copepods decrease slightly in late spring (70 %) and remain near 80 % in June.

At station 2, the winter community includes four families with almost equal numbers of neritic, estuarine and freshwater forms (Temorideae, Centropagideae, Cyclopideae and Acartiideae). Total numbers reach 8 10^4 individuals m^{-3}. The abundance maximum (2.8 10^5 individuals m^{-3}) is in February. During spring, the Copepod ratio remains above 90 % but decreases in June (71 %). In fall, Copepods are abundant (8 10^4 ind.m^{-3}), and Cyclopideae constitute 99 % of their numbers.

At station 3, Cyclopideae and Diaptomideae are major constituents of the communities. Winter communities are mainly composed of estuarine (*Eurytemora hirundoides*) and freswater forms (*Diaptomus castor*). The winter maximum occurs in February (5.6 10^4 ind.m^{-3}). Spring populations drop severely (6.8 10^2 ind.m^{-3}). Three families contribute to the Copepod fauna (62-86 % of the total) : Cyclopideae, Temorideae and Diaptomideae. Their number reaches 4 10^3 ind.m^{-3} in May. Fall communities are dominated by Copepods (90 %) in lower number (8 10^2 ind.m^{-3}).

Mysidaceae. Two species were identified : *Neomysis integer* and *Mesopodopsis slabberi*. At station 1, the incoming ovigerous females and larvae with 1 300 individuals m^{-3} in November leads to 10^2 sexed adults m^{-3} next February. During spring, they form 18 % of the total individuals, and 32 % in July. At station 2, *Neomysis integer* reaches 2.3 10^3 ind.m^{-3} in April.. It is replaced by *Mesopodopsis slabberi* in summer (10^3 ind.m^{-3}).

At Station 3, Mysidaceae are recorded, in winter, in small numbers (10^2 ind.m^{-3}, 1 %).

Cladocera. Two species (*Evadne nordmanni* and *Podon polyphemoides*) are of marine origin, while seven species belong to freshwater.

At station 1, the neritic species occur during spring in low numbers (less than 1 %). Fresh water species (*Daphnia pulex, Daphnia* sp. and *Bosmina* sp.) are recorded in November but are rare too.

In the mesohaline zone, Cladocera represent a small part of the zooplankton. A freshwater species (*Bosmina* sp.) occurs during late winter and spring, while neritic species are recorded during fall.

At station 3, Cladocera from 10 % of the total individuals in spring, They all belong to freshwater species (*Alona costata, Bosmina* sp., *Daphnia* sp. : 2-3 10^2 ind.m^{-3}).

Other groups. Several other groups, among which many meroplanktonic forms, characterize one station or another. Larvae of Annelids, Gastropods, Bivalves, are collected in fair proportions in May, June and July, in the polyhaline estuary. Besides, from the neritic zone, larvae of Cirripedia, Caridea, Anomura and Brachyura with eggs, and larvae of fishes are imported.

In the mesohaline zone, spring and summer communities are less varied. Cnidarians, Ctenophora, and Chaetognatha are found here.

TABLE 3

Faunistic list of taxa encountered within the Loire estuary.
E : estuarine species ; F : freshwater species ; M : marine species.

COELENTERATA (ANTHOMEDUSAE)
E Nemopsis bachei Agassiz

CTENOPHORA
M Bolinopsis infudibulum Müller
M Pleurobrachia pileus (Müller) Vanhoffen

ANNELIDA
E Boccardia sp.

CHAETOGNATHA
M Sagitta bipunctata Quoy & Gaimard

CLADOCERA
F Alona costata Sars
F Bosmina coregoni Baird
F Bosmina longirostris Müller
F Daphnia longispina Müller
F Daphnia pulex Leydig
F Daphnia similis Claus
M Evadne nordmanni Loven
F Iliocryptus acutifrons Sars
M Podon polyphemoides (Leuckart)

OSTRACODA
F Cypris pubera Müller

COPEPODA
F Acanthocyclops americanus (Marsh)
M Acartia clausi Giesbrecht
M Acartia discaudata (Giesbrecht)
M Centropages hamatus (Lilljeborg)
F Diaptomus castor (Jurine)
F Eucyclops sp.
M Euterpina acutifrons (Dana)
E Eurytemora hirundoides (Nordquist)
M Longipedia coronata Claus
F Macrocyclops sp.
M Oncaea media Giesbrecht
E Pseudocalanus elongatus Boeck
E Temora longicornis (Müller)

MYSIDACEA
E Mesopodopsis slabberi (Van Beneden)
E Neomysis integer (Leach)

AMPHIPODA
M Gammarus zaddachi Sexton
M Marinogammarus marinus (Leach)

Larvae of Annelida
Larvae of Gastropoda and Lamellibranch
Larvae of Cirripedia, Caridea, Anomura and Brachyura
Eggs and Larvae of Fishes

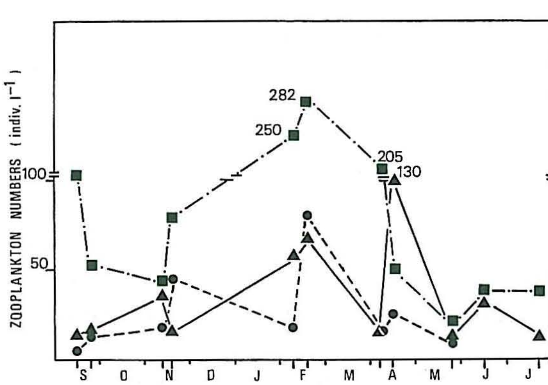

Fig. 7 - Zooplankton numbers (▲, Station 1 ; ■, Station 2 ; ●, Station 3).

The oligohaline estuary is the only location where Ostracoda were collected. *Cypris pubera* (6 10^3 individuals m^{-3} forming 10 % of the biocoenosis) is noticeable in April.

Influence of tide regime

During late summer and fall, zooplankton numbers at station 1 are higher during spring-tides than during neap-tides, with a dominance of neritic Copepods at mean river regime.

At high river flows, zooplankton numbers in the polyhaline estuary are lower at spring-tides than at neap-tides, reflecting a dominance of limnetic species (Cyclopideae).

In the mesohaline zone, the freshwater species may still dominate in numbers. This is true at mean flows in November (numbers higher at neap-tides). During spring, zooplankton is more abundant at spring-tide, and mainly composed of Mysidaceae and neritic and estuarine Copepods.

In the inner part of the estuary, low species numbers always coincide with spring-tides. During mean and high river regime zooplankton numbers are higher at neap-tide, illustrating the importance of freshwater inputs.

DISCUSSION-CONCLUSION

In the lower zone of the Loire estuary, sea water brings marine plankton (about 60 species except meroplanktonic forms), while freshwater provides limnetic forms to the inner zone (about 100 species). The impact of salinity on the number of species per station is subject to river regime and tidal cycles. Neritic plankton reach the mesohaline part of the estuary during spring tides and at low river regimes.

At meso- and oligohaline stations the algal biomass shows a seasonal trend where increasing rivers flow, by increasing phytoplanktonic numbers and chlorophyll-a contents.

The zooplankton biomass at station 2 is also affected by river flow. Numbers increase during high waters and decrease during mean and low waters.

Maximum concentrations of photosynthetic pigments occur when turbidity increases. This seems to be inconsistent with the lack of light penetration and photosynthetic activity. However, such a correlation between pigment and suspended matter is well known in estuaries (e.g, in the Gironde, Castel, 1981). This suggests that light limitation is decreased due to turbulence which gathers photosynthetic organisms in the euphotic layer, and due to nutrients described as non-limiting (Rincé *et al.*, 1985). In a recent study, primary production was evaluated in the Loire estuary (Billen *et al.*, 1986). Longitudinal profiles of algal production are consistent with our observations on spatial and temporal distribution of taxonomic composition. Upstream, a first winter peak of primary production occurs when river flow increases (1 000 m^3 $sec.^{-1}$) ; at Station 3, it coincides with Bacillariophyceae and Cryptophyceae abundance. A second maximum occurs in summer and fall. Bacillariophyceae and Chlorophyceae are the major constituents of phytoplankton at station 3. In the area of maximum turbidity primary production remains lower than 0.2 g C m^{-2} j^{-1}, except in September, This is in agreement with population densities observed at station 2. They attain their maximum in September with numerous diatoms, Chlorophyceae and Cyanophyceae. Downstream, primary production shows a spring maximum which corresponds with increasing populations of neritic and oceanic diatom species.

For many planktonic animals, the organic part of suspended matter constitutes a sufficient nutritive input. This aspect of plankton life in estuaries was extensively reported by Poulet (1973), Heinle & Flemer (1975) and Lenz (1977). This is illustrated at station 1 (neap-tide samples in April), but at station 2 high loads of suspended matter coincide with scarce zooplanktonic populations (as observed in May 1982) ; on the other hand, low turbidity values coincide with maximum abundance of zooplankton (as observed during high waters in February 1982). In every station, counts of zooplanktonic individuals show no relation to phytoplanktonic cell numbers, which is in agreement with the previous idea of "energy" flow in estuaries : the trophic requirements of the main zooplanktonic groups are fulfilled upon organic detrital material and the bacterial assemblages (Castel, 1981). According to Cairns (1972 ; *in* : Angeli, 1976) faint zooplankton, in spite of large amounts of detrital material, would be the consequence of fast gut transit and insufficient digestion.

Dealing with water oxygenation, several authors point out that in many localities among estuaries, Copepods may endure extremely low concentrations (Bakker *et al.*, 1977 ; Davis, 1975). This unusual feature among animal communities could explain the prominence of this group in the Loire estuary even in the later summer under-oxygenated waters. In return *Neomysis integer* populations grow less with decreasing oxygen concentrations as shown by its scarceness from May to November in station 1 and station 2 while *Mesopodopsis slabberi* forms 22 % of the total counts. Such a distribution of the same species was already stated in the Gironde estuary (Sorbe, 1981).

On the whole, communities sampled in the Loire estuary show densities in the same range as biocoenosis living in similar estuaries (Gabriel *et al.*, 1975 ; Eriksson *et al.*, 1977 ; Malone, 1977 ; Castel, 1981). In addition, except the occurrence of a few nitrophile or pollution-tolerant diatoms, phytoplanktonic and zooplanktonic communities do not exhibit any dramatic changes as compared to previous studies in the same estuary (Des Cilleuls, 1930, 1932 ; Denayer, 1970 ; Prat, 1977). Related studies of zoobenthos and demersal fish (Marchand, 1983) give support that the Loire estuary remains a balanced ecosystem in which species commercially interesting can find suitable conditions for their development. Thus we assume that the phyto- and zooplanktonic communities, though disturbed because of industrial plants, have until now been preserved sufficiently for their efficiency in the trophic chain.

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