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Long-term distribution of zooplankton in the Gironde estuary and its relation with river flow and suspended matter.

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Abstract : Mesozooplankton changes taking place in the Gironde estuary (South West France) were investigated during 14 years (1978-1991). The dominant autochthonous species, i.e. the Copepods *Eurytemora affinis, Acartia bifilosa* and the Mysids *Neomysis integer* and *Mesopodopsis slabberi* were taken into account and their long-term distribution was related to river flow, salinity, current velocity and suspended matter.

There was a great decrease of the river flow during the period of investigation, due to a general deficit in pluviosity. On the contrary, the general trend for salinity was an increase from 1978 to 1991. For the suspended matter, a general increase was observed between 1978 and 1981-1982, then a very sharp decrease occurred from 1984 onwards. The same trend was observed for the current velocity and was related to modifications of the morphology of the channels in the study area.

E. affinis was inversely correlated with salinity and positively correlated with the river flow. An inverse correlation between *A. bifilosa* trend of abundance and river flow was observed mainly during the first ten years. Despite high salinities during the last three years, the average abundance of *A. bifilosa* was not regularly increased probably because of the poor exchanges of water during this period (decrease of the current velocity). The distribution of *N. integer* was slightly correlated with environmental factors, probably because the species is capable of displacement in the water and has benthic affinities. On the contrary, *M. slabberi* which is more pelagic, displayed the same distributional trend as *Acartia.*

It is concluded that in the Gironde estuary, the degree of human alteration is weak and that the long-term distribution of the zooplankton can be explained by the natural environmental variability. The dominant factor is the river flow which governs the movements of the populations along the estuary. Emphasis is given to the fact that, in zooplankton research, time series must be long enough (> 10 years) to allow any convincing interpretation of long term changes.

Résumé : La distribution à long terme du mésozooplancton a été étudiée dans l'estuaire de la Gironde (sud-ouest de la France) au cours d'une période de 14 années (1978-1991). Seules les espèces autochtones dominantes ont été prises en considération : les Copépodes *Eurytemora affinis, Acartia bifilosa* et les Mysidacés *Neomysis integer, Mesopodopsis slabberi* et leur distribution temporelle a été reliée au débit fluvial, à la salinité, à la vitesse du courant et à la quantité de matières en suspension.

On constate une décroissance générale des débits au cours de la période d'étude, à cause d'un déficit pluviométrique. Au contraire, la tendance générale pour la salinité est une augmentation de 1978 à 1991. En ce qui concerne les matières en suspension, on observe une augmentation entre 1978 et 1981-1982, puis une diminution très prononcée à partir de 1984. La même évolution est notée pour la vitesse de courant dont la diminution semble liée aux modifications de la morphologie des chenaux dans la zone d'étude.

E. affinis est inversement corrélé avec la salinité et positivement avec le débit fluvial. L'évolution des effectifs suit assez bien celle des matières en suspension ; la corrélation n'est pas significative car il existe un léger décalage temporel entre les deux variables. Une corrélation inverse entre l'abondance d'A. *bifilosa* et le débit fluvial est observée, surtout pendant les dix premières années. Malgré de fortes salinités, l'abondance moyenne en *A. bifilosa* n'est pas régulièrement augmentée au cours des trois dernières années probablement à cause de la faiblesse des échanges d'eaux pendant cette période (décroissance des vitesses moyennes de courant). La distribution de *N. integer* est peu corrélée avec les facteurs de l'environnement probablement parce que cette espèce est capable de mouvements autonomes dans la masse d'eau et parce qu'elle a des affinités benthiques. Au contraire, *M. slabberi,* qui est plus pélagique, montre une distribution ayant la même tendance que celle d'*A. bifilosa.*

Il semble bien que l'estuaire de la Gironde soit peu affecté par les activités humaines et que l'évolution à long terme du zooplancton puisse être expliquée par la variabilité naturelle de l'environnement. Le facteur dominant est le débit fluvial qui gouverne le mouvement des populations le long de l'estuaire. L'étude met en évidence que dans le domaine de la recherche en plancton, les séries temporelles doivent être suffisamment longues (> 10 ans) pour permettre des interprétations convaincantes sur les modifications à long terme.

INTRODUCTION

Although estuaries are intensively studied in the perspective of management, long-term series are not so numerous, especially for zooplankton. Continuous zooplankton data for a period of greater than 3-4 years are limited in number.

Haertel *et al.* (1969) reported on a 5 years study from the Columbia River estuary (Oregon, USA). Their study was related to the possibility of reduction of the water flow due to the construction of dams, as well as to the increase of human population and industrial growth in the drainage basin. They found *Eurytemora affinis* to be the major zooplankter. Regression analysis indicated a close correlation between phosphate levels and *Eurytemora* abundance. They also showed that high temperature may be responsible for the late summer-early autumn depression in *Eurytemora* abundance. However, their work was not made in the perspective of studying long-term evolution of zooplankton and the authors did not conclude about the long-term trend of zooplankton populations.

A study of year-to-year variation of abundance and seasonal cycle over 7 years was made by Frolander *et al.* (1973) in the lower Yaquina Bay (Oregon). They showed that the annual cycle of coastal currents controls the annual cycle of zooplankton species composition but there were no persistent trends in zooplankton abundance over the sampling period.

In the Sacramento-San Joaquin Delta (California), Orsi & Mecum (1986) observed a long-term decline of all freshwater zooplankton groups over a 7 year period. In the cases of Rotifers and Copepods the decline was significantly correlated with a decline in chlorophyll *a*. A reduction in the organic waste loading to the delta as a result of improved waste treatment was mentioned as a possible cause of the phytoplankton decline. The brackishwater Copepod *Eurytemora affinis* was excluded from the analysis.

In Europe, long-term (9 years) dynamics of mesozooplankton densities was studied at Seili (Northern Baltic) by Vuorinen & Ranta (1987). Zooplankton was dominated by Rotifers and the Copepods *Acartia* spp. and *Eurytemora affinis hirundoides*. There was a considerable year-to-year variation in the relative abundance of zooplankton species. The mesozooplankton responded to salinity changes due to changing hydrography occurring in the Baltic Sea ; 1/3 of the taxa increased in numbers, while most of the taxa (2/3) decreased in numbers. However, in most cases these changes were not distinguishable from random fluctuations.

At the same sampling site, and during 9 subsequent years, Viitasalo *et al.* (1990) monitored the abundance of crustacean mesozooplankton in relation to changes in salinity (decrease) and eutrophication. The most important species, *Acartia bifilosa*, increased with time while the other dominant species, *Eurytemora affinis*, showed no obvious trend. These unexpected results could not be attributed to any single environmental factor.

In general the conclusions from these long-term series are rather disappointing. Several hypotheses can explain this lack of consistent conclusion.

- In the above examples, sampling was made once at each sampling date (except in the Columbia River where samples were taken at low and high tide). Thus the shifting of the populations upstream and downstream with the tide was not considered. It is clear that this shifting is the principal source of short-term variability in the abundance estimates, increasing the variance associated with each data point. However this does not apply to the Baltic where the tidal amplitude is very low.
- The other possibility is that the time-series may be too short to detect any long-term change in zooplankton populations.
- Finally, the natural variability of the estuarine populations may be too large to allow the detection of any long-term change.

This paper report on the mesozooplankton changes taking place in the Gironde estuary (South West France) in 1978-1991. Only the dominant autochthonous species, i.e. the Copepods *Eurytemora affinis* (Poppe), *Acartia bifilosa* (Giesbrecht) and the Mysids *Neomysis integer* (Leach), *Mesopodopsis slabberi* (Van Beneden) are taken into account. As compared with other studies, the representativeness of the data is improved by i/ sampling during a whole tidal cycle at each sampling date, ii/ providing a longer time-series (14 years). The main explicative factors considered here are river flow, salinity, current velocity and suspended matter concentration which are thought to represent the general hydrology of the estuary.

STUDY AREA

The Gironde estuary (Lat. 45°20'N, Long. 0°45'W) is the largest French estuary and covers an area of 625 km^2 at high water (Fig. 1). The freshwater inflow to the estuary is brought by the rivers Garonne and Dordogne, the total drainage of which covers approximately 71 000 km^2. The two rivers join 70 km from the inlet. In the middle and lower estuary, two main channel systems are separated by a network of bars, shoals, islands and secondary channels. The mean yearly combined discharge of the Garonne and the Dordogne varies between 800 and 1 000 m^3 s^{-1}. The discharge varies seasonally, usually reaching a maximum in January-February (mean 1 500 m^3 s^{-1}) and a minimum in August-September (mean 250 m^3 s^{-1}). During average tidal conditions, the period of freshwater flushing is 20 days at flood tide, 86 days at low water. Tidal current velocities vary considerably and can reach 2 m s^{-1}. According to the terminology of Pritchard (1955), the Gironde is a "Type B" estuary (intrusion of a salt wedge with tides) during high river flow and a "Type C" (partially mixed) during low river flow.

The mean upstream limit of the saline intrusion (0.5 ppt) is located about 75 km from the inlet during low river flow and 40 km from the inlet during high river flow. The density gradient, i.e. the salinity gradients, result in a residual circulation system. The higher the fluvial discharge in the main channel of the lower estuary, the stronger the upstream residual circulation on the bottom.

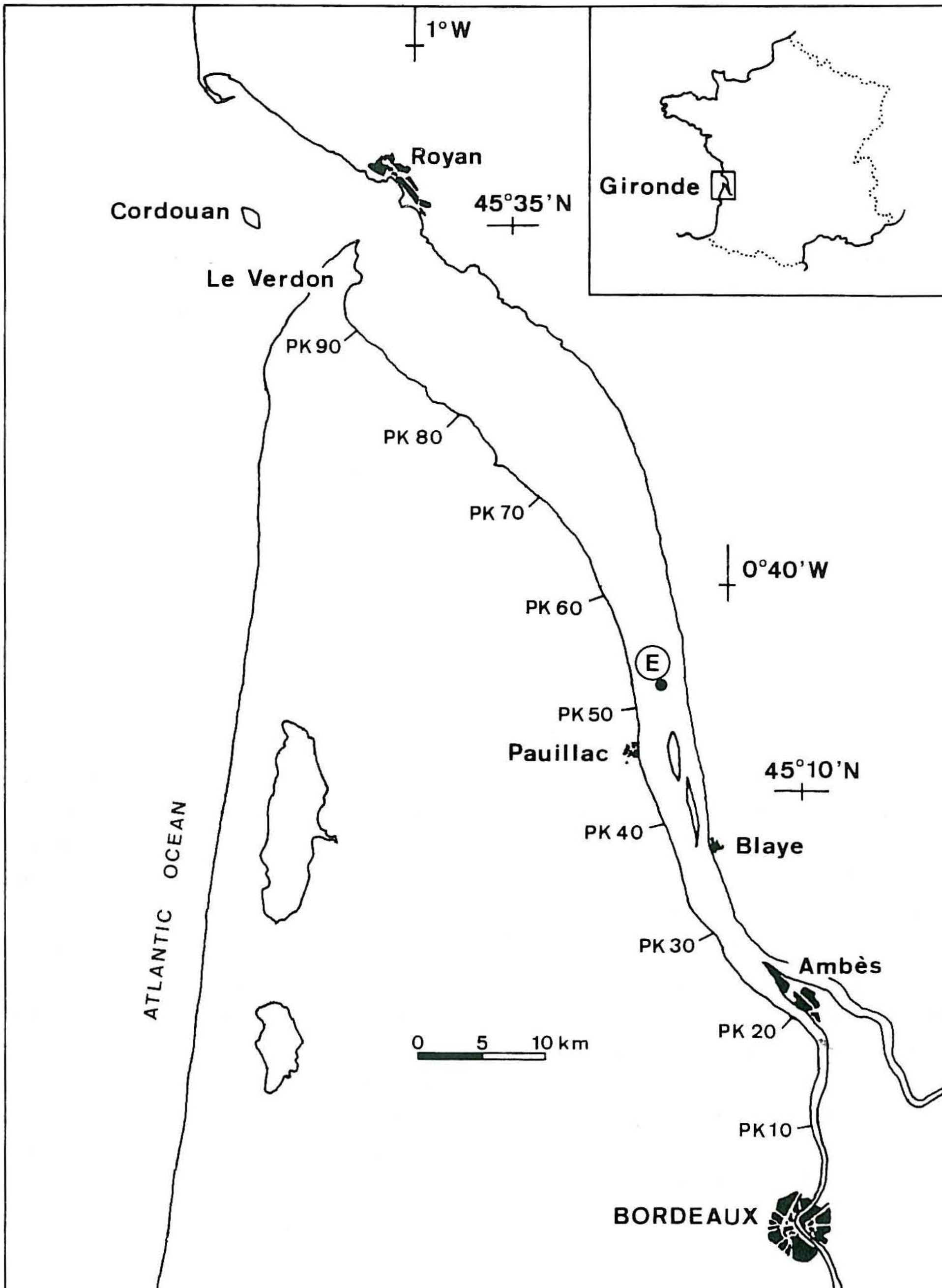


Fig. 1 : Map of the Gironde estuary showing the sampling station E (52 km downstream the city of Bordeaux).

One of the main feature of the Gironde estuary is the high turbidity of the water, with particulate concentrations that may exceed 1 g l^{-1} in a large part of the estuary. All the silt and clay in suspension in the Gironde estuary originates from the Garonne and Dordogne rivers. These two river systems supply between 1.5 and 3 10^6 t of suspended sediment annually, with a mean of about 2.2 10^6 t. A well developed turbidity maximum forms at the upstream limit of the salinity intrusion, in the zone of convergence of bottom residual currents. This maximum migrates to the lower estuary during the winter and spring high river flow, and to the upper estuary during summer and fall low river flow. During low river flow, the mass of turbid water stretches downstream at ebb and upstream at flood, thus covering a zone of more than 70 km in length. Conversely, during high river discharge, the turbidity maximum zone is much more restricted in space, leading to very high suspended matter concentrations (several g/l). The accumulation and migration of the turbidity maximum seems to be a purely dynamic phenomenon, with little relationship to variations in salinity (Jouanneau & Latouche, 1981). Because of the circulation and transportation patterns, a particle entering the estuary may remain in the maximum turbidity zone for one year or more before being expelled to the sea.

MATERIAL & METHODS

One sampling station (Station E, 52 km from the city of Bordeaux) was selected in the oligo-mesohaline zone of the estuary (Fig. 1). This station is considered as representative of the autochthonous zooplankton community (Castel & Feurtet, 1992).

The zooplankton data were collected from May 1978 to November 1991. Samples were taken monthly in winter and fortnightly in summer. Sampling was generally done from February to November during the years 1978-1984. From 1985 onwards, sampling was performed between March and November and duplicate campaigns were made only in July (Tabl. I). The sampling ranged over 163 months and the number of samples totalled 1 484. Zooplankton was collected with a standard WP2 net. One tow was made just below the surface and another near the bottom. Each tow was 1 to 2 min long. Samples were obtained at appox 2 h intervals during a tidal cycle and were made against the current. The volume of water filtered through the net was monitored with a TSK mechanical flowmeter or with a Hydrobios digital flowmeter. During the first 2 year the filtration coefficient was calculated by comparison with the values recorded by a flowmeter placed outside the net's mouth. The volumes filtered and the filtration coefficients were usually 4 to 25 m^3 and 75 to 95 % respectively. The catch was preserved in 4 % seawater/formalin.

At the same time and with the same periodicity the following variables were measured : temperature, salinity, current velocity, suspended matter concentration (dry weight after filtration on GF/C).

For the numerical analyses surface and bottom samples and measurements were averaged. When two sampling campaigns were made during the same month, the values obtained were averaged. Missing values were interpolated by computing the mean between the preceding value and the following one. Two subsequent missing values were not interpolated and the file was compressed.

The first step in the analysis was to graph the original data against time. To investigate long-term trends in the zooplankton numbers, the abundance estimates were adjusted by removing the seasonal effect. In order to remove the seasonal variation in plankton abundances and environmental parameters, residuals were calculated by substracting the corresponding monthly average of the forteen-year period from each observation (Chatfield, 1984). The residuals were log-transformed except for temperature and salinity. Linear correlation was used to evaluate the covariance of changes in zooplankton abundances and environmental factors ; Pearson correlations were calculated between time and zooplankton abundance residuals and environmental residuals.

TABLE I

Number of sampling campaigns undertaken in the Gironde estuary according to months during the study period (1978-1991). N° Sl. : number of zooplankton samples taken each year. * Refers to campaigns during which only environmental variables could be measured.

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Sum
J	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
F	*1	1	1	1	1	*1	0	0	0	0	0	0	0	0	6
M	0	1	1	1	1	1	1	1	1	0	1	1	1	1	12
A	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13
M	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
J	2	2	2	2	2	2	1	1	1	1	1	1	1	1	20
J	2	2	2	2	2	2	2	2	2	2	2	2	2	2	28
A	2	2	2	2	2	2	1	1	1	1	1	0	0	0	17
S	0	1	0	0	0	1	1	1	1	1	0	1	1	1	9
O	1	0	1	1	1	0	0	0	0	1	1	1	1	1	9
N	1	1	0	0	0	1	1	1	1	1	1	1	1	1	11
D	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3
Sum	10	12	12	12	12	12	10	9	9	9	9	9	9	9	143
N° Sl	108	144	126	140	138	126	80	90	90	90	90	90	90	82	1 484

RESULTS

Hydrography

Water temperature correlated positively with time (r = 0.493, p<0.01). This trend is illustrated by the evolution of the maximum temperatures. For instance a maximum value of 22 °C was recorded on 29 August 1978 and a value as high as 26.5 °C was noted on 23 July 1991. However, the temperature data show that the year 1984, winter 1985 and winter-spring 1986 have been colder than the long-term average for the whole period (Fig. 2).

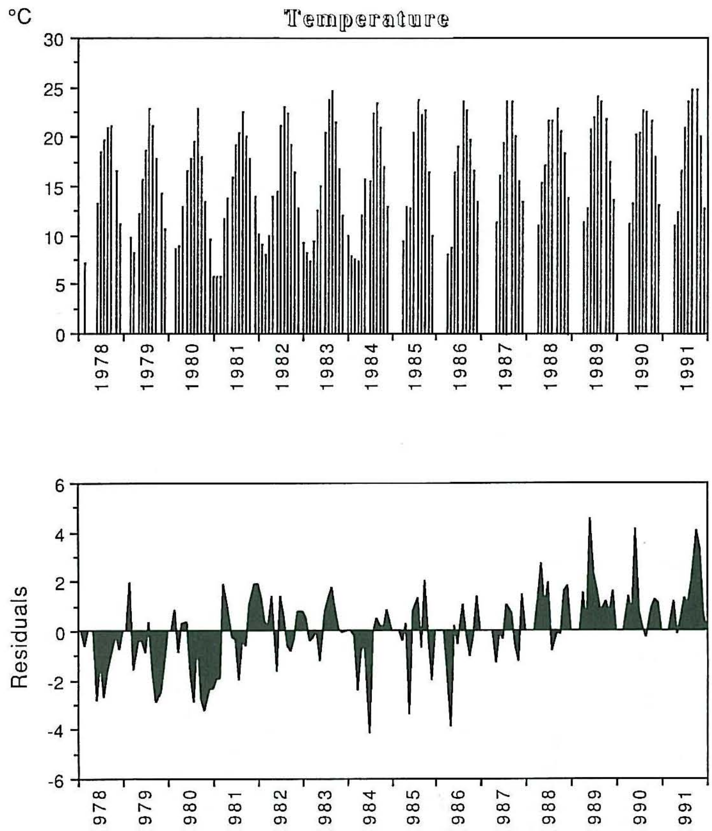


Fig. 2 : Averaged surface and bottom water temperatures in the Gironde estuary. The upper panel gives the original data (n = 138) and the lower graph displays deviations from the long-term monthly averages.

On average, the river flow is the lowest in August-September and the highest in February (Tabl. II). There was a general decrease of the river flow during the period of investigation, except in 1988 when a significant increase was observed (Fig. 3). The observation of the residuals clearly shows the general decrease trend of the river flow with the exception of 1988. The overal correlation with time was - 0.417 ($p<0.01$). The general decrease of the river flow was mainly due to a deficit in pluviosity occurring in 1986, 1987 and from 1989 onwards. The most striking feature is a protraction of the low water period.

The salinity regime at the sampling station falls in the oligo-mesohaline range. Contrary to the river flow, the general trend for salinity was an increase from 1978 to 1991 (correlation with time, $r = 0.541$, $p<0.01$). The same exception was found in 1988 (Fig. 4). Salinity is normally inversely correlated to the river flow. The general trend of the salinity evolution is inverted compared with that of the river flow but the correlation is not absolute (Tabl. III). This is especially clear when comparing the amplitude of the variations which

TABLE II

Average monthly values (1978-1991) of environmental variables and zooplankton densities in the middle Gironde estuary.

	F	M	A	M	J	J	A	S	O	N
Temperature (°C)	7.77	9.76	12.63	16.17	19.62	22.45	22.84	20.70	16.73	12.02
Salinity (ppt)	1.24	1.74	2.09	2.14	2.65	4.78	7.41	8.71	7.60	4.83
River flow (m^3/s)	1 593	1 379	1 406	1 250	758	447	304	312	509	740
SPM conc. (mg/l)	1 353	1 463	1 315	1 199	1 090	865	749	867	1 167	1 624
E. affinis (N/m^3)	5 232	11 386	11 430	15 108	7 129	3 777	1 678	1 103	1 377	2 671
A. bifilosa (N/m^3)	0	6	53	144	67	689	695	304	209	39
N. integer (N/m^3)	0	3	17	58	81	104	52	23	14	6
M. slabberi (N/m^3)	0	2	17	46	132	476	485	273	145	31

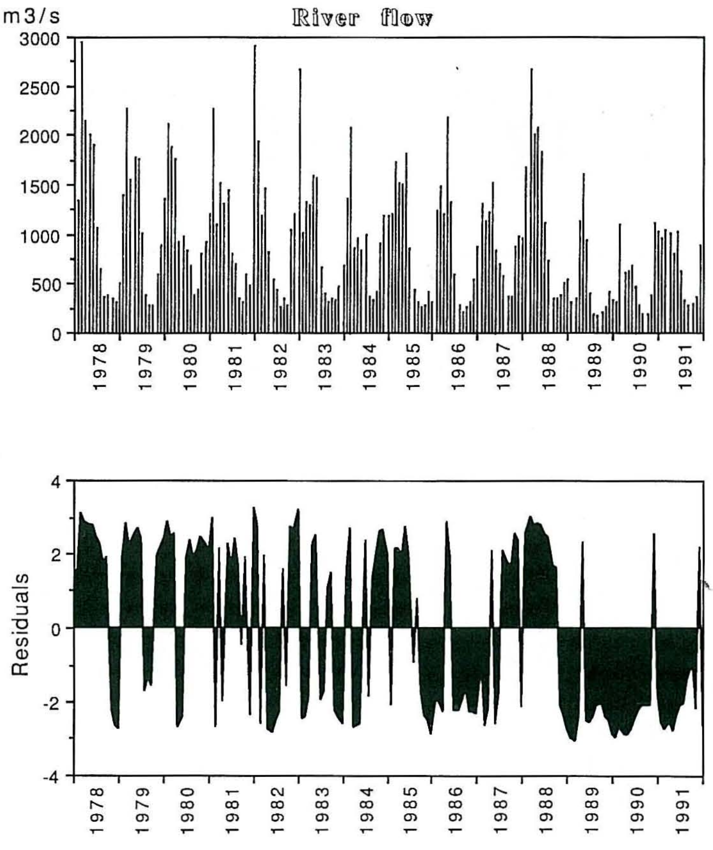


Fig. 3 : River flow (Garonne + Dordogne) in the Gironde estuary. The upper panel gives the original data (n = 168) and the lower graph displays deviations from the long-term monthly averages.

TABLE III

Correlation coefficients between environmental variables and between factors and zooplankton population densities (the seasonal effect removed from all data sets). The level of significance is indicated by * $p<0.05$, ** $p<0.01$.

	Temperature	Salinity	River flow	SPM conc.
Temperature (°C)		0.417**	- 0.293**	No meaning
Salinity (ppt)			- 0.619**	- 0.207*
River flow (m^3/s)				0.063
E. affinis (N/m^3)	- 0.241*	- 0.333**	0.311**	0.032
A. bifilosa (N/m^3)	0.063	0.274**	- 0.288**	0.130
N. *integer* (N/m^3)	0.061	0.001	- 0.071	0.105
M. *slabberi* (N/m^3)	0.062	0.292**	- 0.346**	0.152

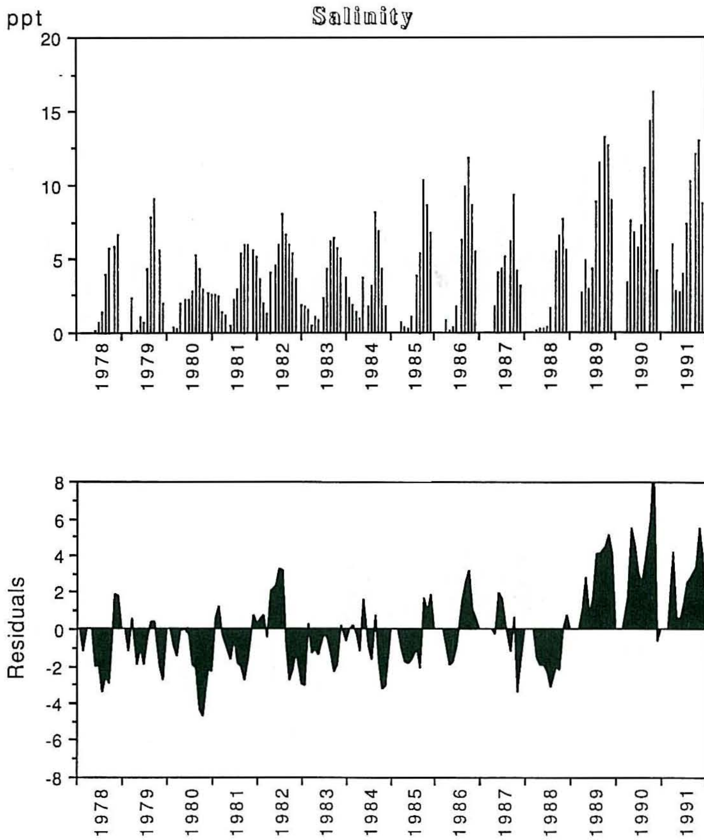


Fig. 4 : Averaged surface and bottom salinities in the Gironde estuary. The upper panel gives the original data (n = 138) and the lower graph displays deviations from the long-term monthly averages.

are not the same for both variables. Besides these long-term changes there were the normal annual fluctuations in salinity (the highest values in late summer-early spring and lowest values in winter ; Tabl. II). There was a good correlation between salinity and temperatures (seasonally adjusted).

On average net velocity was negatively correlated with time ($r = -0.255$, $p<0.05$). However, two distinct phases could be distinguished : a phase of increase from 1978 to 1982 and a decreasing phase from 1983 onwards (Fig. 5).

For the suspended matter, the trend was slightly different, although the general tendency was a decrease with time ($r = -0.341$, $p<0.01$). In a first phase a general increase was observed between 1978 and 1981-1982. Values were higher than the mean in 1982-1984, and then from 1984 onwards, a very sharp decrease occurred (Fig. 6).

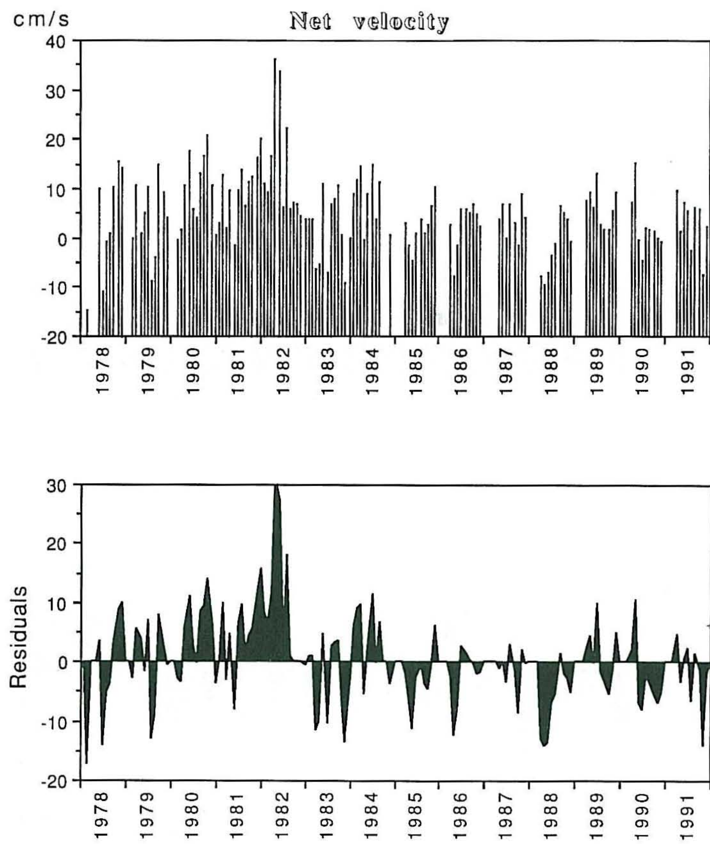


Fig. 5 : Averaged surface and bottom net velocities in the Gironde estuary. The upper panel gives the original data ($n = 136$) and the lower graph displays deviations from the long-term monthly averages. Positive values indicate an upstream direction of the net velocity, negative values indicate downstream net velocities.

The suspended matter concentration depends on the river flow and resuspension. In the present study, the correlation between SPM and river flow was non significant. Conversely, a good correlation ($r = 0.543$, $p<0.01$) was found between SPM concentration (in mg/l) and net velocity (m/s) computed from the current velocity measurements made during each tidal cycle.

Zooplankton populations

The autochthonous zooplankton community is dominated by two copepod species : *Eurytemora affinis* (Poppe) and *Acartia bifilosa* (Giesbrecht). High numbers of *Acartia tonsa* Dana can be recorded in summer but during a short period of time, thus the species is not included in the analysis. The Mysids *Neomysis integer* (Leach) and *Mesopodopsis slabberi* (Van Beneden) are not true planktonic forms but young individuals are found in significant number in most samples. They are taken into account in the present study.

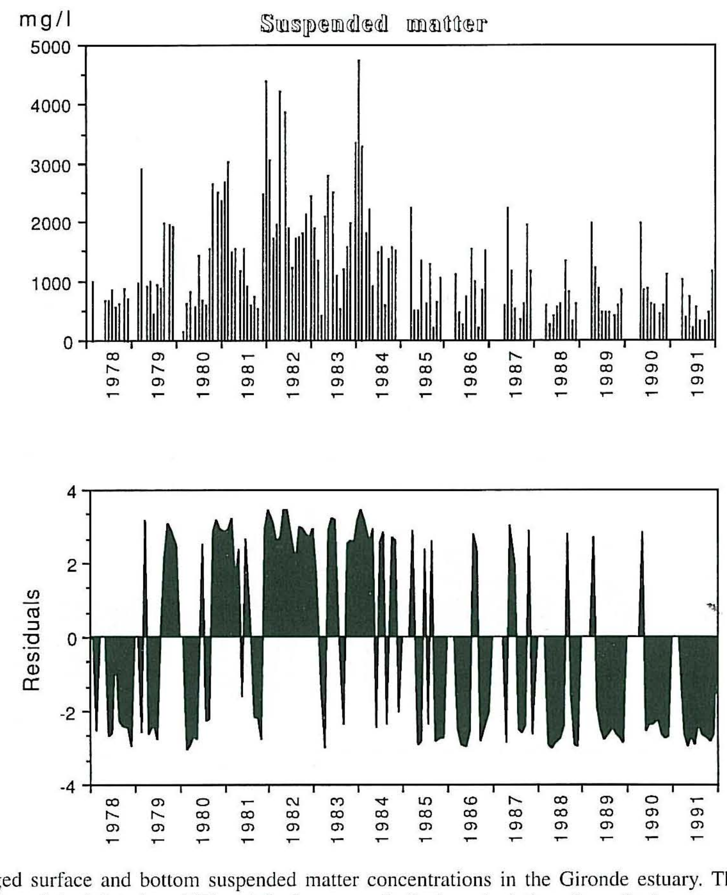


Fig. 6 : Averaged surface and bottom suspended matter concentrations in the Gironde estuary. The upper panel gives the original data (n = 137) and the lower graph displays deviations from the long-term monthly averages.

Eurytemora affinis is clearly the most dominant species in the oligo-haline zone of the Gironde estuary (Castel & Veiga, 1990), as it is the case in most estuaries. It is mostly abundant in spring, with a maximum in May (Tabl. II). Lowest densities are observed in September when temperature and salinity are high. During the study period *Eurytemora* showed an oscillatory behaviour, especially when considering the peaks of abundance, with a maximum in 1984 and in 1991 (Fig. 7). However, the trend for the mean abundance (residuals) was not the same as the trend for maximum abundance. During the first part of the study, the trend for *Eurytemora* was inversely related to that of the suspended matter (compare Fig. 7 and 6). However, the correlation was non existent over the whole sampling period.

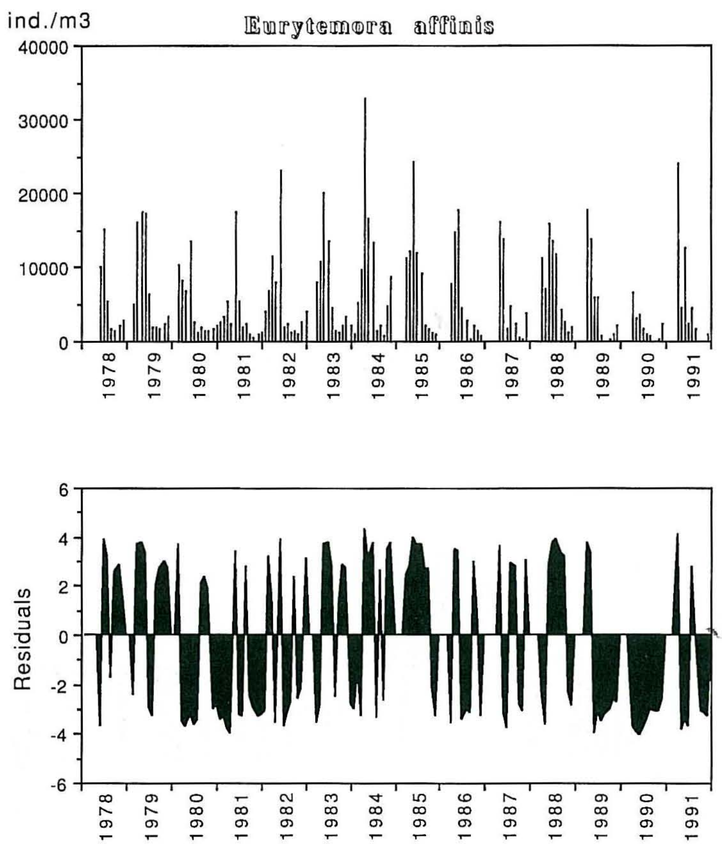


Fig. 7 : Averaged surface and bottom densities of the Copepod *Eurytemora affinis* in the Gironde estuary. The upper panel gives the original data (n = 135) and the lower graph displays deviations from the long-term monthly averages.

During the second phase (1984 onwards), *Eurytemora* abundances followed the general trend observed for the river flow. During this period, the river flow decreased significantly. Furthermore, the current velocity decreased, especially the flood current. This can explain that, during this period, *Eurytemora* became more sensitive to the river flow variation in the study area. Consequently, the population was also affected by high salinity. Over the whole sampling period, *Eurytemora* was inversely correlated with temperature and salinity and positively correlated with the river flow (Tabl. III).

Acartia bifilosa is much less abundant than *Eurytemora*. Its maximum abundance is observed in late July-August (Tabl. II). *Acartia* lives more seaward than *Eurytemora* and prefers higher salinity (Castel, 1981). The general trend of increase observed for the salinity was found in *Acartia* population but the correlation was not very high (r = 0.274). *Acartia* was mainly correlated to salinity till 1988. Similarly, an inverse correlation between *Acartia* trend of abundance and the river flow was observed mainly during this first period

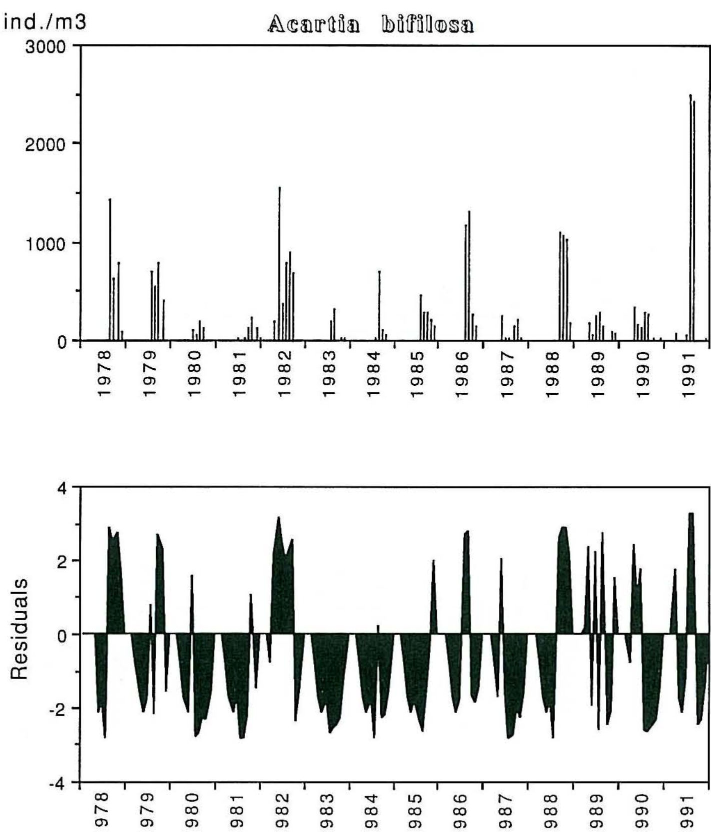


Fig. 8 : Averaged surface and bottom densities of the Copepod *Acartia bifilosa* in the Gironde estuary. The upper panel gives the original data (n = 135) and the lower graph displays deviations from the long-term monthly averages.

of ten years. Thereafter, the correlation was quite nonexistent. Despite high salinities during the last three years, the average abundance of *Acartia* was not regularly increased (Fig. 8).

Neomysis integer is a typical inhabitant of the oligo-mesohaline zone of the estuary. It is most abundant in July (Tabl. II). The peaks of abundance tended to increase from 1978 to 1987 (Fig. 9). However, after extraction of the seasonal effect, no trend was evidenced (correlation with time, r = - 0.110), except low values from 1989 to early 1991 probably due to the high salinities. *N. integer* lives preferentially near the bottom (pers. obs., Sorbe, pers. comm.). This together with its capacity of swimming make it more independent of the water mass displacement, which can explain the lack of correlation between *N. integer* and the environmental variables.

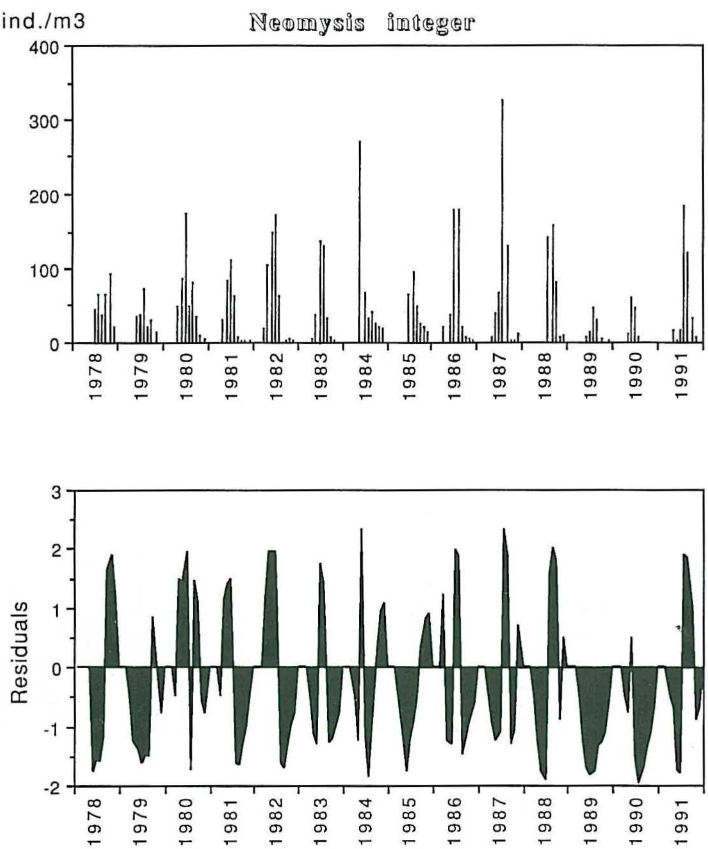


Fig. 9 : Averaged surface and bottom densities of the Mysid *Neomysis integer* in the Gironde estuary. The upper panel gives the original data (n = 135) and the lower graph displays deviations from the long-term monthly averages.

Mesopodopsis slabberi lives more downstream than *N. integer*. It colonizes the polyhaline zone. At the sampling station, maximum abundance is recorded in late July-August (Tabl. II). Like *A. bifilosa, M. slabberi* did not show a clear trend of abundance during the study period (Fig. 10). Both species had a very similar trend of evolution (correlation between residual, $r = 0.718$, $p<0.01$). Contrary to *N. integer, M. slabberi* is more pelagic and colonizes the whole water mass (pers. obs., Sorbe, pers. comm.). This can explain the better correlation found between *M. slabberi* and environmental factors (i.e. salinity). Although *Mesopodopsis* was correlated with salinity and inversely correlated with river flow, the increase in salinity during the years 1989-1991 was not followed by a clear increase in the abundance.

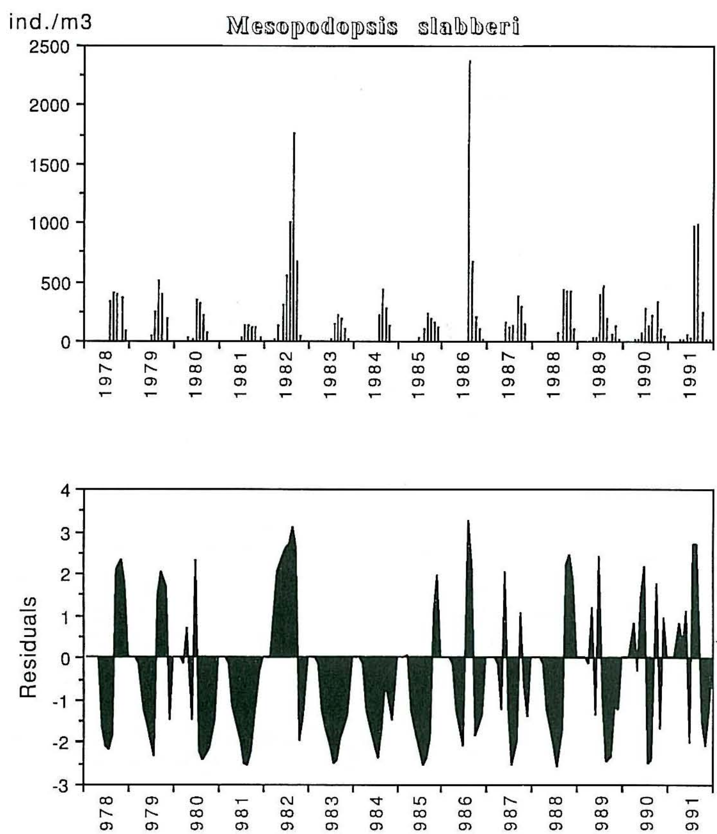
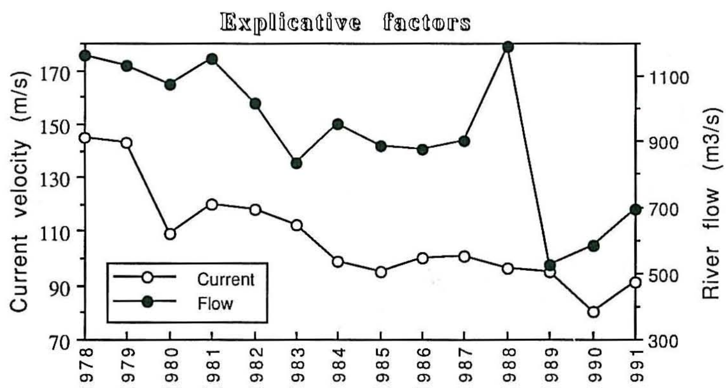


Fig. 10 : Averaged surface and bottom densities of the Mysid *Mesopodopsis slabberi* in the Gironde estuary. The upper panel gives the original data ($n = 135$) and the lower graph displays deviations from the long-term monthly averages.

DISCUSSION

Two main factors can explain the long-terrn trend of zooplankton population densities in the Gironde estuary during the period 1978-1991. There was a clear decrease of the river flow (except in 1988) probably caused by the general evolution of the climatological conditions (deficit in pluviosity). The impact of the construction of dams on the rivers of the drainage basin cannot be neglected but information is lacking. The second factor is the modification of the morpho-sedimentology of the study area due to the natural migrations of the banks (maps provided by P. Castaing, pers. comm.). To this hydro-morphological modification is associated a decrease of the current velocity (Fig. 11).

The decreasing trend of evolution of river flow and current velocity has consequences on ecological factors such as salinity and suspended matter concentration. The mean salinity normally increased in correlation with the reduction of river flow. The suspended matter



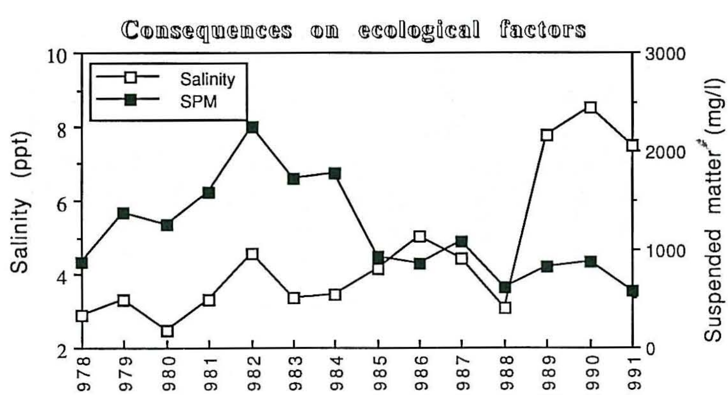


Fig. 11 : Summary of the long-term trend of the most important environmental factors influencing zooplankton populations in the Gironde estuary. Current velocity is the mean maximum velocity.

concentration depends on the river flow and the resuspension. During the first phase of the study (1978-1981), the river flow was extremely high. The turbidity maximum was pushed downstream the study area. Maximum SPM concentrations were recorded 15 km downstream the sampling area (P. Castaing & J.-M. Jouanneau, pers. comm.). Then, with the decrease of the river flow, the turbidity zone moved upstream and was situated exactly at the sampling station in 1982-1984. This is corroborated by the fact that, during this period, the net velocity increased and was oriented upstream. The last phase, with very low SPM concentrations, can be explained by two hypotheses :

- As the river flow continued to decrease, the turbidity zone continued to move upstream. In fact, the turbidity zone was often observed near Bordeaux.
- The second explanation is that due to the decrease of the current velocity, the resuspension was low. It is probably why the increase in river flow observed in 1988 was not followed by an increase in suspensed matter concentration.

All these trends in the hydrodynamics probably explain the evolution of the zooplankton populations. *Eurytemora affinis* lives preferentially in the upper part of the estuary. Its downstream distribution is limited by both salinity and the maximum turbidity zone. The maximum of the population is found just upstream the maximum of SPM concentration or in the turbidity cloud if the SPM concentration is not too high (Castel, 1984 ; Castel & Feurtet, 1989). This distribution is the result of transport processes (Castel & Veiga, 1990) leading to a kind of "amassment" in the zone of high turbidity (Soltanpour-Gargari & Wellershaus, 1984). Thus the long-term trend of evolution of *E. affinis* can be explained by the relative position of the population and of the turbidity maximum. At the beginning of the study, high abundance of *Eurytemora* was recorded, as the turbidity maximum was situated downstream the sampling station. With the upstream migration of the turbidity maximum, the abundance of *Eurytemora* decreased at the sampling point, the population being pushed upstream. Samples taken in 1989-1991 showed that the abundance was significantly higher 20 km upstream the station E (unpublished data). Furthermore, the decrease in abundance was probably accentuated by the high salinities occurring at the end of the sampling period.

Acartia bifilosa, which is a polyhaline species, has a maximum abundance downstream the sampling station. Its abundance in the middle estuary is greatly influenced by the salinity and by the river flow. This influence has been demonstrated recently (Ibanez *et al.*, in press). However, the strong increase in salinity observed in 1989-1991 did not result to such an extent to an increase of *Acartia* abundance. A possible explanation is that the colonisation of the sampling area was restricted due to the reduction of water circulation : it is likely that the decrease of the flood current velocity has reduced the flux of water in the study area. The same occurred for the Mysid *Mesopodopsis slabberi*, a species with the same spatial and temporal distribution as *Acartia*.

In summary, during the period 1978-1991, the hydrology of the middle estuary was characterized by two phases corresponding to i/ a fluvial dominated estuarine system (1978-1984) and ii/ to a mixed system with low water exchanges (1984-1991). During the first phase, *Eurytemora* was favoured by low salinity but was affected by high SPM concentrations, and *Acartia* did not colonize very well the area due to low salinity. During the second phase, *Eurytemora* was transported upstream and was affected by high salinities at the sampling point ; *Acartia* was theoretically favoured by high salinity but was affected by low exchanges of water.

From all the data, it seems clear that the long-term evolution of zooplankton in the Gironde estuary can be explained in great part by the general hydrology. The dominant factor is the river flow which governs the movements of the populations along the estuary. The SPM concentrations also affect the populations (Sellner & Bundy, 1987 ; Castel & Feurtet, 1987) but the variations of SPM concentration depend on both the river flow and the morphology of the bottom.

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