Year-to-year changes in meteorological features of the French coast area during the last half-century. Examples of two biological responses

Meteorological series
Biological series
Trends
Cycles
Changes

Séries météorologiques
Séries biologiques
Tendances
Cycles
Changements

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ABSTRACT

Chronological series (1949 to 1992) of air temperature, precipitation, atmospheric pressure and wind in different parts of the French coast show evidence of important year-to-year changes, trends and cycles: seven-eight years for temperature, and around three years for precipitation and atmospheric pressure. On the scale of France, it appears that spatial heterogeneity of meteorological factors is smaller than temporal heterogeneity. New methods, such as the cumulative sums method or the envelopes of a variable reveal the interest for ecologists of essaying different numerical approaches. A comparison between climatic series and biological series of a benthic and a pelagic species is described for this purpose.

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RÉSUMÉ

Variabilité interannuelle des facteurs météorologiques sur les côtes françaises de 1949 à 1992. Réponses de deux indicateurs biologiques

Le traitement de séries temporelles (1949-1992) de température de l'air, précipitations, pression atmosphérique et vent, provenant de différents sites des côtes françaises, met en évidence d'importantes variations interannuelles, ainsi que des tendances et des cycles. Des périodes de sept à huit ans se dégagent des données de température, et de trois ans des données de précipitations et de pression atmosphérique. Les résultats tendent également à montrer qu'à l'échelle de la France, l'hétérogénéité spatiale des variables météorologiques est plus faible que l'hétérogénéité temporelle. Des méthodes, telles que les sommes cumulées, les enveloppes supérieures et inférieures d'une série se révèlent d'un grand intérêt en écologie, pour comparer l'évolution des séries biologiques et climatiques. Ceci est illustré avec deux espèces: *Acartia bifilosa* et *Abra alba*.

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INTRODUCTION

Climatic variability is one of the main causes of the natural changes that occur in marine ecosystems. Fluctuations of the European fisheries in the Northeast Atlantic are among the more convincing examples of this (Southward *et al.*, 1988; Binet, 1986). Most of the time, these changes are difficult to correlate with environmental factors, such as sea temperature or wind stress, because the relation is often complex. One part of the problem relates to the choice of the best time scale that the ecologist must take into account. Previous studies in the North Atlantic and in the English Channel showed the importance that the warming process up to 1950, which was followed by a recent cooling, had on the fluctuations of marine populations (Russell *et al.*, 1971; Cushing and Dickson 1976; Southward, 1984). Dickson *et al.* (1988) linked the general decline of the phytoplankton and zooplankton between 1950 and 1980 to a long-term increase in the northerly wind component. These large-scale variations of biological variables are well known under the name of "Russell cycles". Others (Glémarec, 1979; Gray and Christie, 1983; Glémarec *et al.*, 1986) showed the importance of cycles of the environmental variables, such as the pole tide, the sunspot cycle or the secular cycle. Furthermore, account should be taken of the cumulative effects of small changes in the meteorological factors that may also cause an alteration of the ecosystem (Cushing and Dickson, 1976). Yet another problem is the synchronicity between climatic events and the life cycle of marine populations.

In response to these questions concerning the biological response to climatic stress, we collected several biological time series (in the frame of the national programme PNOC: Programme National d'Océanographie Côtière), in an attempt to understand the main causes of the natural variability, and the part of the fluctuations induced by the meteorological changes. This paper concentrates on the nature and the intensity of the climatic variability encountered in different parts of the French coast. To highlight the importance of the time scale in trying to relate biological and meteorological changes, we describe the relation between two coastal species: a pelagic one (*Acartia bifilosa*, Crustacea-Copepoda) and a benthic one (*Abra alba*, Mollusca-Bivalvia); and climatic factors.

DATA

Meteorological records were obtained from the french meteorological centre: Météo-France, SCEM, Toulouse. Six sites corresponding to the setting of the biological time series were selected, from North to South, as follows: Dunkerque (North Sea), La Hève (Eastern English Channel), Batz island (Western English Channel), Bordeaux (Atlantic), Cap Béar and Cap Ferrat (Mediterranean Sea). We used monthly mean values dating from 1949 (date of the first records) to 1992 for the temperature, precipitation, and atmospheric pressure; and daily values for the wind corresponding to the length of the biological time series (from 1977 to 1992 for Dunkerque, La Hève, and Batz, and from 1965 or 1962 to 1990 for Cap Béar and Cap Ferrat). Meteorological records from Genova (Mediterranean Sea) were provided by the *Consiglio Nazionale delle Ricerche*, Italy (Flocchini *et al.*, 1983). These monthly series of temperature, precipitation, and atmospheric pressure data began in 1833 and were complete up to 1985.

Biological time series concern two species: *Acartia bifilosa*, a pelagic copepod collected each month (except in December and January) from 1978 until 1990 in the Gironde estuary by Castel (*see* Castel, 1993); and *Abra alba* collected five to six times every year from 1977 to 1991 in the North Sea (near Dunkerque) by Dewarumez (*see* Dauvin *et al.*, 1993).

METHODS

Two methods were applied to detect changes and to extract the general trend in the series:

- The cumulative sums method involves subtracting a reference value (here the mean of the series) from the data, and successive cumulation of the residuals (Ibanez *et al.*, 1993 *b*). Successive negative residuals produce a decreasing slope, whereas successive positive residuals create an increasing slope (the value of the slope is proportional to the mean deviation). Values not very different from the mean show no slope.

- The eigen-vector filtering is equivalent to a filtering by weighted moving average. This treatment, using Principal Component Analysis, consists in taking as the general trend the first principal component extracted from the autocovariance matrix of the series (Colebrook, 1978; Ibanez and Étienne, 1992).

To extract the periodicity from the meteorological variables (except wind) we used:

- First the Census 2 method in order to remove the seasonality (Shiskin and Eisenpress, 1957; I.N.S., 1965; Phlips and Blomme, 1973; Béthoux *et al.*, 1980). This method, using successive moving averages, displays a series of three components: the general trend, the annual cycle, and the random component.

- Spectral analysis (Platt, 1972; Denman and Platt, 1975; Colebrook and Taylor, 1984) was performed on the stationary part of the cyclic trend extracted from the Census 2 method to detect long-term periodicity (*see* Annex).

We also used harmonic analysis (Legendre and Legendre, 1984), to compare periodicities of biological and meteorological series.
Other treatments were also applied:

- Series of two successive months: January-February, March-April, May-June, July-August, September-October, and November-December, to detect the seasonal evolution of the meteorological variables. We selected series of two, rather than three months, because we noted a greater homogeneity between two than between three successive months. Two-month series have already been used by different authors, such as Glémarec (1979) in considering the relation between sunspot activity and average air temperatures during September and October, and Goy *et al.* (1989) for a forecasting model of *Pelagia noctiluca*.

- Connection of the extremes of a variable, or "envelopes". Lower and upper envelopes were constructed by linking respectively the maxima and minima of the variable (Ibanez *et al.*, 1993 *a*; Gaines and Denny, 1993). The line of the median points corresponds to the medium line between these two envelopes (Ibanez, 1984).

- Deviations between upper and lower envelopes were calculated for temperature. We term this: the "seasonal deviation" of the temperature.

RESULTS

As it is impossible to present results from all six sites, we decided to show those from Bordeaux which is an intermediate situation between the Northern and the Mediterranean sites. The results from all the sites are summarized in Table 1.

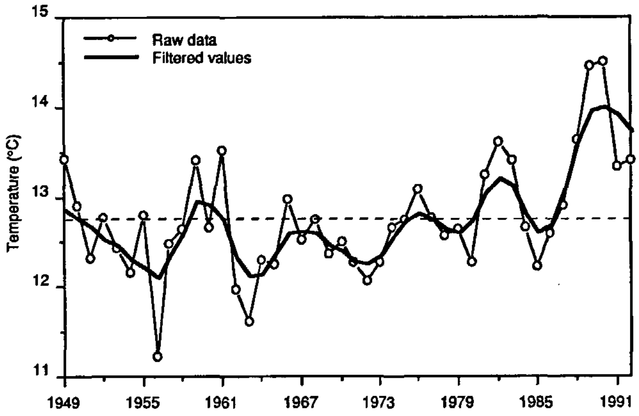

Figure 1

Annual air temperature at Bordeaux from 1949 to 1992 (44 years). A general trend was extracted by the eigen-vector filtering method. Dotted straight line corresponds to the mean value of this series.

Température annuelle de l'air à Bordeaux de 1949 à 1992 (44 années). La tendance générale est obtenue après filtrage par la méthode des vecteurs propres. La droite pointillée correspond à la valeur moyenne de la série.

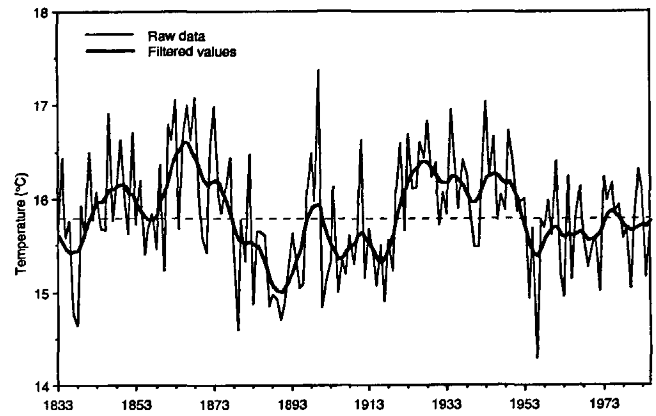

Figure 3

Annual air temperature at Genova from 1833 to 1985 (153 years). General trend was extracted by the eigen-vector filtering method. Dotted straight line corresponds to the mean value of this series.

Température annuelle de l'air à Gênes de 1833 à 1985 (153 années). La tendance générale est obtenue après filtrage par la méthode des vecteurs propres. La droite pointillée correspond à la valeur moyenne de la série.

Air temperature

General trend

Annual air temperatures in Bordeaux (Fig. 1) show year-to-year differences: about 3 °C between the colder year 1956 and the warmer one in 1990. Cyclic variations of around six to eight years, 1956-1962, 1963-1971, 1972-1979, 1980-1985, may be easily detected from the smoothed line (eigen-vector filtering). The early years of the series, except for 1959-1961, are colder than the mean (dotted straight line), and the last years are warmer. This increasing trend is confirmed by calculation of the Spearman rank correlation between the values of the trend and the line numbers (Tab. 1). The cumulative sums series (Fig. 2) points out the main changes: a decreasing slope from 1949 to 1973 which characterizes a group of values lower than the mean; a plateau from 1974 to 1980 characteristic of mean values; and an increasing slope from the 1980s that characterizes some warm years compared to the whole series. This trend is found in all sites, except at Batz island where no trend and no large changes could be detected, and at Cap Ferrat which presents a longer cold period (1954-1986) than the other sites (Tab. 1).

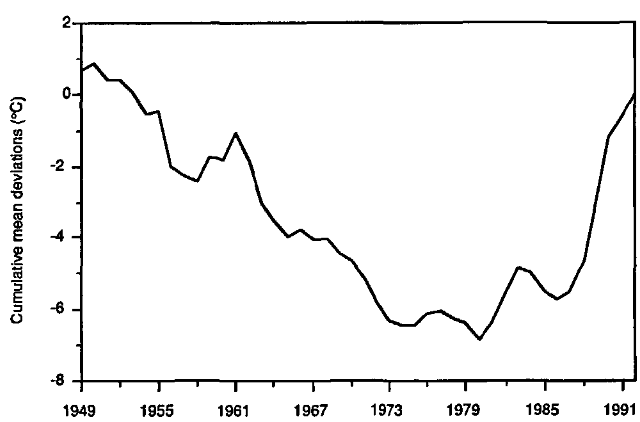

Figure 2

Cumulative sum series of the annual air temperature at Bordeaux from 1949 to 1992. Decreasing slope indicates successive values lower than the mean, whereas increasing slope indicates successive values higher than the mean.

Sommes cumulées de la série de température annuelle de l'air à Bordeaux de 1949 à 1992. La pente décroissante révèle la présence de valeurs successives inférieures à la moyenne, alors qu'une pente croissante révèle la présence de valeurs successives supérieures à la moyenne.

We also analysed records from Genova to place the results obtained with the series of fourty-four years within a larger scale of 153 years (1833-1985). The annual temperatures of this series (Fig. 3) could be roughly divided into four parts: two warm periods, 1840-1875 and 1915-1950 and two cold periods, 1875-1915 (including a short warm period around 1896) and 1950-1985. These results confirm the presence of a cooling from the mid-century up to 1980-1985, as seen in Figures 1 and 2 and in Table 1. The cumulative sums series (Fig. 4) shows that the recent cooling is

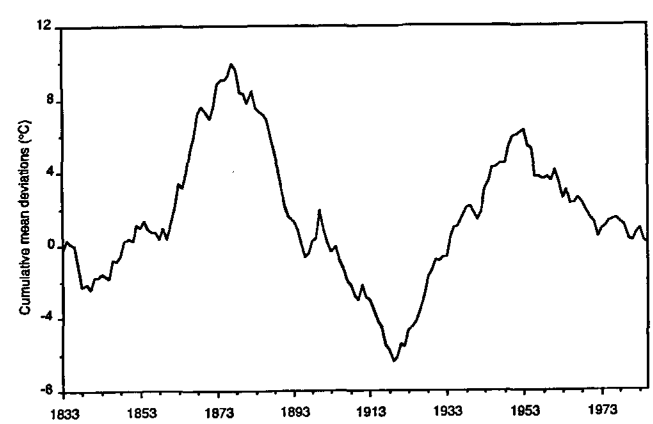

Figure 4

Cumulative sum series of the annual air temperature at Genova from 1833 to 1985.

Sommes cumulées de la série de température annuelle de l'air à Gênes de 1833 à 1985.

	Dunkerque	La Hève	Batz	Bordeaux	Cap Béar	Cap Ferrat
TEMPERATURE						
$\overline{T_c}$; S_T Mini ; Maxi	10.5 0.6 8.9 12	10.7 0.6 9.1 12	11.5 0.4 8.9 12.2	12.8 0.6 11.2 14.5	15.3 0.5 14.1 16.4	15.9 0.5 14.9 16.9
Trend; r_s	+ 0.67	+ 0.37	o 0.15	+ 0.55	+ 0.42	o -0.12
Cycles	90 30 13.8	96 13.8	96 27.4	90 25.7	90 25.7	90 **27.4**
Main Changes	49-66 - 67-87 o 88-92 +	49-73 - 74-87 o 88-92 +	49-92 o	49-73 - 74-80 o 81-92 +	49-80 - 81-92 +	49-53 + 54-86 - 87-92 +
PRECIPITATION						
$\overline{P}$; S_P Mini ; Maxi	661 108 426 866	689 133 429 989	834 145 402 1140	937 175 494 1288	579 203 261 992	709 176 366 1111
Trend: r_s	+ 0.56	+ 0.38	+ 0.53	o 0.09	o 0.15	o 0.24
Cycles	90 30 13.7	90 30 13.8	90 30 14.7	96 32 14.7	64 32	96 32 19.2
Main Changes	49-57 - 58-78 o 79-87 + 88-92 -	49-57 - 58-77 o 78-88 + 89-92 -	49-57 - 58-67 + 68-76 - 77-92 +76-83	49-57 - 58-69 + 70-75 - + 84-92	49-56 - 57-71 + 72-76 - 77-92 o	49-57 - 58-62 + 63-72 o 73-80 + 81-92 -
ATMOSPHERIC PRESSURE						
$\overline{A.P.}$; $S_{A.P.}$ Mini ; Maxi	10153 14 10128 10180	10164 13 10136 10190	10157 15 10128 10188	10164 12 10137 10188	10161 13 10133 10188	10142 12 10124 10167
Trend; r_s	o - 0.25	+ 0.45	o 0.21	o 0.25	o 0.05	o 0.26
Cycles	∞ 32 13.8	36 13.8	36 15	32 15	36 13.8	96 38.4
Main Changes	52-63 + 64-86 - 87-92 +	49-80 - 81-88 o 89-92 +	49-57 o 58-86 - 87-92 +	49-57 o 58-80 - 81-88 o	49-57 o 58-88 - 89-92 +	49-63 o 64-80 - 81-92 +

Table 1

Temperature, precipitations, and atmospheric pressure are respectively in: °C, mm, Hpa. $\overline{T_c}$, $\overline{P}$, $\overline{A.P.}$ corresponds to the annual means, S_T, S_P, $S_{A.P.}$ to the standard deviations. Trends are extracted from the eigen-vector filtering, r_s is the Spearman correlation coefficient calculated between trend and linear sequence of X-axis values. +: r_s is positive and significant at the level of 5 %, there is an increasing trend. o: r_s is not significant at 5 %, there is no trend. Results of cycles are in months. Main changes are given by the cumulative sum curves. Only changes over five years were retained. -: values of this interval are smaller than the mean of the series. o: values are equal to the mean. +: values are greater than the mean of the series.

Température, précipitation et pression atmosphérique sont exprimées respectivement en : °C, mm, Hpa, $\overline{T_c}$, $\overline{P}$, $\overline{A.P.}$ et S_T, S_P, $S_{A.P.}$ correspondent aux moyennes annuelles et aux écarts-types. Les tendances ont été obtenues après filtrage par la méthode des vecteurs propres, r_s est le coefficient de corrélation de Spearman calculé entre la tendance et les valeurs des abscisses. + : r_s est positif et significatif au seuil de 5 %, révélant une tendance croissante. o : r_s n'est pas significatif au seuil de 5 %, il n'y a pas de tendance. Les cycles sont exprimés en mois. Les principaux changements sont repérés à l'aide des séries de sommes cumulées. Seuls les changements de plus de cinq années ont été retenus. - : les valeurs de cet intervalle sont inférieures à la moyenne de la série. o : les valeurs sont égales à la moyenne. + : les valeurs sont supérieures à la moyenne de la série.

less important than the earlier one. An apparent periodicity of around eighty years appears, which may correspond to the secular trend mentioned by other authors (Leroy-Ladurie, 1983; Gray and Christie, 1983).

Cycles

The previous results suggest the presence of periodicities in air temperature over different time scales. Spectra of the cyclic trend extracted by Census 2 method from the different French sites (Fig. 5) invariably show, except for Cap Ferrat, a peak of maximum variance between 90 and 96 months (7.5 to 8 years). This result corresponds to the apparent cycle of the filtered values in Figure 1. A second and smaller periodicity may be detected, especially in Bordeaux (Atlantic) and Cap Bear at around 25 months. On the other hand, for Cap Ferrat the main period is around 25 months, and the second one at around 90 months. Besides these minor differences, there is a great deal of similarity between different spectra from each site on the French coast. The spectrum of the Genova series (Fig. 6) gives a main peak at around eighty years (confirming the result of Fig. 4, and the presence of a secular cycle), and a second one around eight years that is also significant. This second period fits the main period detected on the series of fourty-four years. We shall discuss below different hypotheses we propose for this cycle of seven-eight years.

Two-month series

All these results were obtained from the year-to-year changes, without considering the seasonal fluctuations. Biological cycles of marine populations are seasonal, so meteorological stress could be more important during certain periods. For instance, large changes in temperature or in wind stress during the spring bloom of plankton or during the recruitment of a benthic species can have drastic consequences, whereas the same events in autumn will not

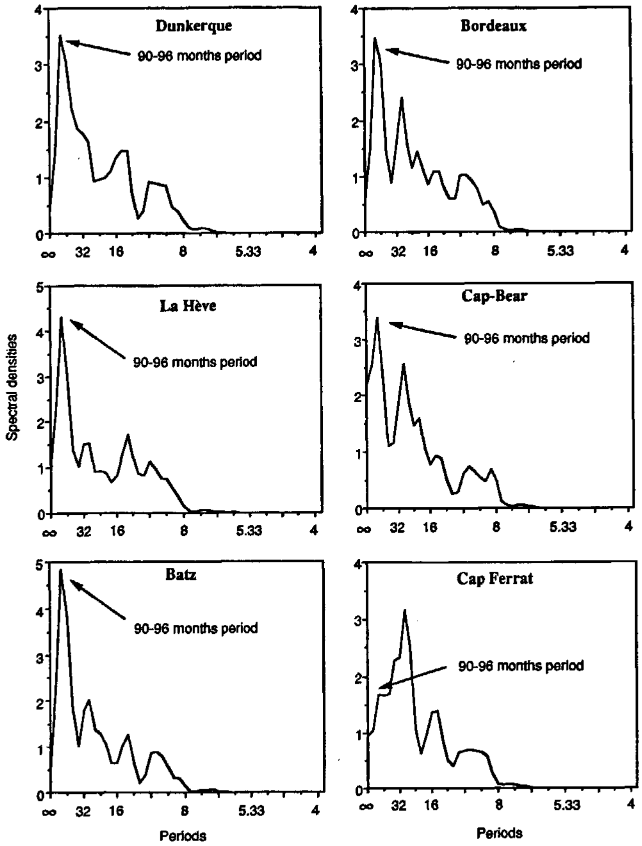

Figure 5

Spectral analysis of the cyclic trend of temperature monthly data from six sites on the French coast. X axis represents monthly periods (logarithm scale), and Y axis the power spectral density (linear scale).

Analyse spectrale sur les tendances cycliques des températures mensuelles des six sites des côtes françaises. L'axe des abscicsses représente les périodes en mois (échelle logarithmique), l'axe des ordonnées la densité spectrale.

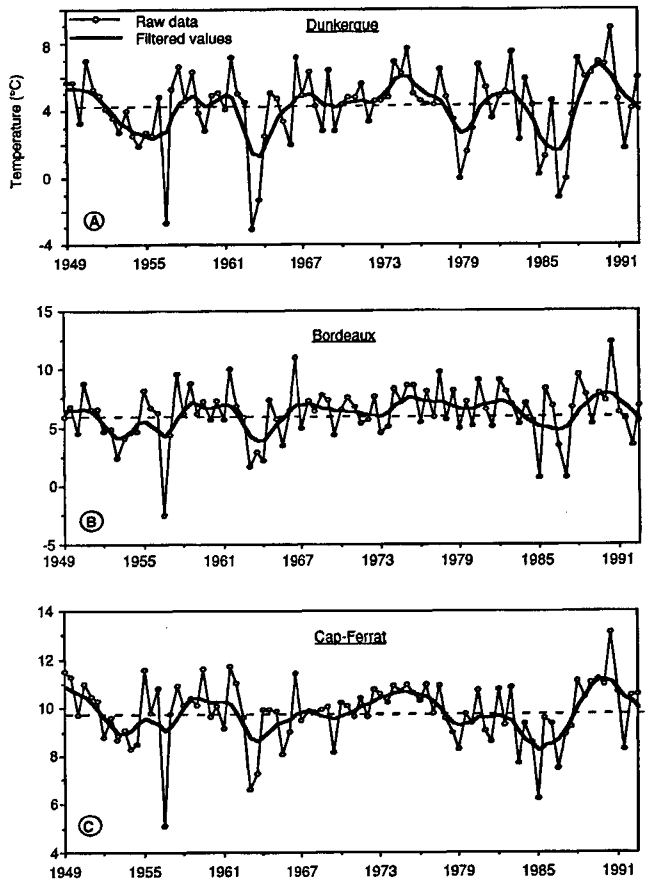

Figure 7

January and February temperatures at: Dunkerque (A), Bordeaux (B), Cap-Ferrat (C), from 1949 to 1992. Dotted straight line corresponds to the mean value of these series.

Températures de janvier-février à : Dunkerque (A), Bordeaux (B), Cap-Ferrat (C), de 1949 à 1992. La droite pointillée correspond à la valeur moyenne de ces séries.

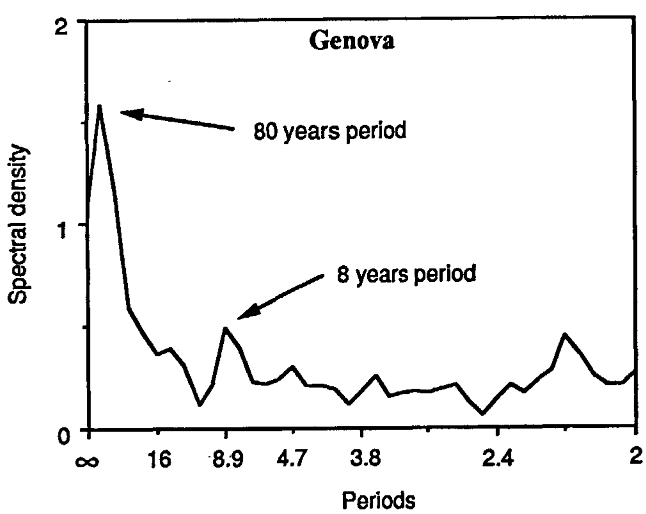

Figure 6

Spectral analysis on the cyclic trend of temperature annual data at Genova. X axis represents annual periods (logarithm scale), and Y axis the power spectral density (linear scale).

Analyse spectrale sur la tendance cyclique des températures annuelles de Gênes. L'axe des abscisses représente les périodes en mois (échelle logarithmique), l'axe des ordonnées la densité spectrale (échelle linéaire).

have any effects. Figures 7 and 8 present the temporal evolution of the winters (January and February), and summers (July and August) from three sites on the French coast [Dunkerque (North Sea), Bordeaux (Atlantic), and Cap Ferrat (Mediterranean Sea)]. There is a large difference in the same site between the winter and summer months. Summers from 1953 to 1973 in Dunkerque and Bordeaux are colder than the mean, whereas winters, except for the years around 1956 and 1963, are warmer than the mean. At both of these sites, the early 1980s see some warm summers, when the winters are not very different from the mean. At Cap Ferrat we can also detect some differences between the summer and the winter seasons, during the 1957-1961 and 1977-1981 periods. These figures show a greater similarity between the different sites at the same season than between the different seasons within the same site. So, on the scale of the French coast, we may say that spatial heterogeneity is smaller than temporal heterogeneity.

Seasonal deviation

Another point rarely taken into account in marine ecology is the difference between the upper and the envelopes of

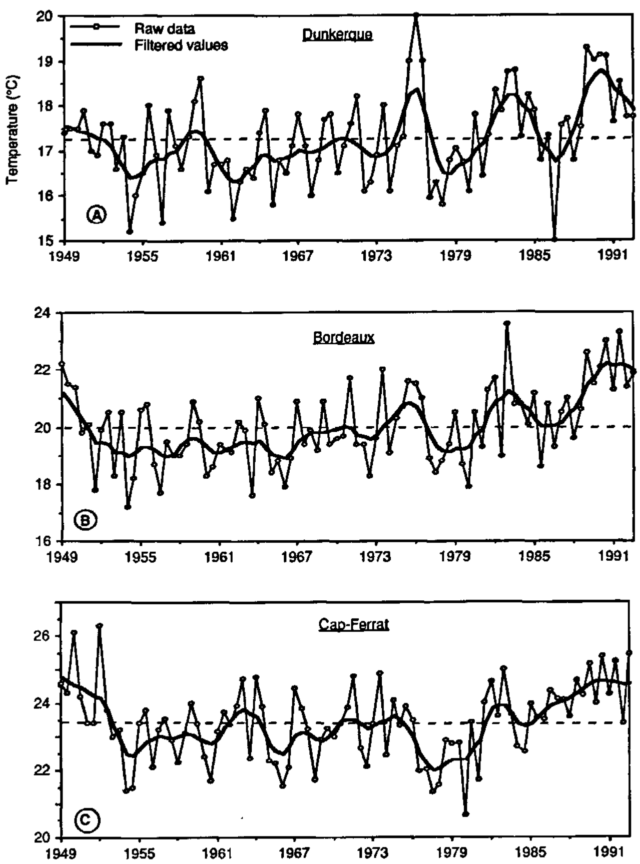

Figure 8

July and August temperatures at: Dunkerque (A), Bordeaux (B), Cap-Ferrat (C), from 1949 to 1992. Dotted straight line corresponds to the mean value of these series.

Températures de juillet-août à : Dunkerque (A), Bordeaux (B), Cap-Ferrat (C), de 1949 à 1992. La droite pointillée correspond à la valeur moyenne de ces séries.

temperature (the "seasonal deviation"). For instance, the speed of the seasonal warming of seawater and its stratification is somewhat dependent on this variation. This "seasonal deviation" is highly variable (Fig. 9): about 10 °C between years with high amplitude (1956, 1976, 1984, 1990, characterized by cold winters or warm summers), and years with small amplitude (1955, 1966, 1978, 1988, characterized by mild winters and average summers).

Precipitation and atmospheric pressure

Changes in precipitation and atmospheric pressure may also have important effects on marine populations. The long-term fluctuations of the jellyfish *Pelagia noctiluca* (Goy *et al.*, 1990) is a good example of this. So, same treatments were performed with these two factors in each site. Annual precipitation at Bordeaux (Fig. 10) show large changes from year-to-year, with an alternation of wet and dry periods. This succession is dominant in Southern sites but not in Northern sites where an increasing trend is detected (Tab. 1). Important differences may be noticed between this annual series and the winter or the summer series (Fig. 11), as between winters and summers themselves (years around 1979 are opposite). No periodicity is obvious from the trend of the annual series (as in Fig. 1), but spectral analysis (Fig. 12) produces a main peak around 32 months, which seems to be an harmonic of a larger periodicity of 96 months. This cycle is found in each site of the french coast (Tab. 1) without exception, with small fluctuations from 30 to 36 months.

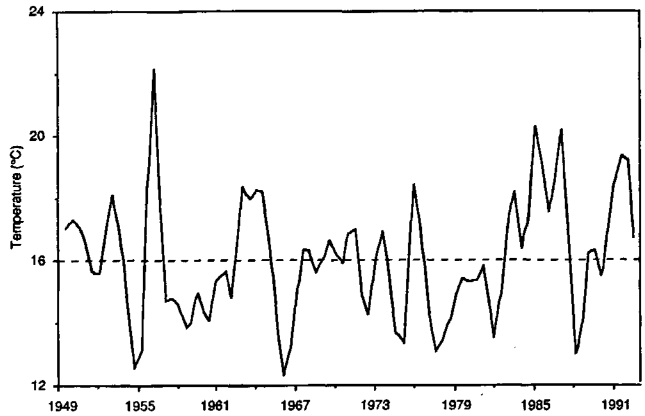

Figure 9

Differences between upper (summers) and the lower (winters) envelopes of the air temperature at Bordeaux from 1949 to 1992. Dotted straight line corresponds to the mean value of this series.

Différences entre l'enveloppe supérieure (étés) et inférieure (hivers) de la température de l'air à Bordeaux de 1949 à 1992. La droite pointillée correspond à la valeur moyenne de la série.

Similar trends are present in the annual atmospheric pressures (Fig. 13) and the winter and the summer series (Fig. 14) at Bordeaux. There is also an alternation of high and low pressures (generally years of high pressure correspond to dry periods: 1953-1958, 1987-1992, and *vice versa*); and winter pressures around 1979 are also opposite to the summer ones. No trend is detected for this variable, except at La Hève, because of the presence of high or mean pressures at the beginning and at the end of the series (Tab. 1). Spectral analysis indicates a period of 32 months, which is also found in all the sites with small fluctuations (Fig. 15). This could be an harmonic of a larger periodicity, as Dunkerque and Cap Ferrat data seem to show it (Tab. 1). This periodicity is very close to the cycle of precipitation.

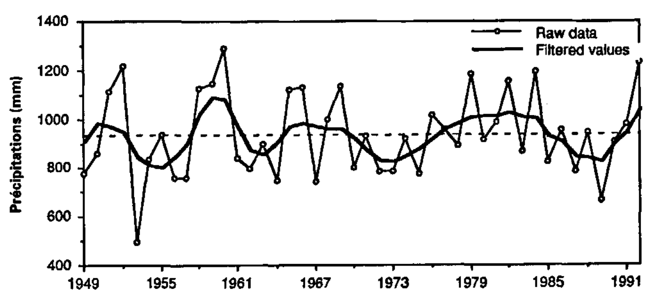

Figure 10

Annual precipitations (mm) at Bordeaux from 1949 to 1992 (44 years). General trend was extracted by the eigen-vector filtering method. Dotted straight line corresponds to the mean value of this series.

Précipitations annuelles à Bordeaux de 1949 à 1992 (44 années). La tendance générale est obtenue après filtrage par la méthode des vecteurs propres. La droite pointillée correspond à la valeur moyenne de la série.

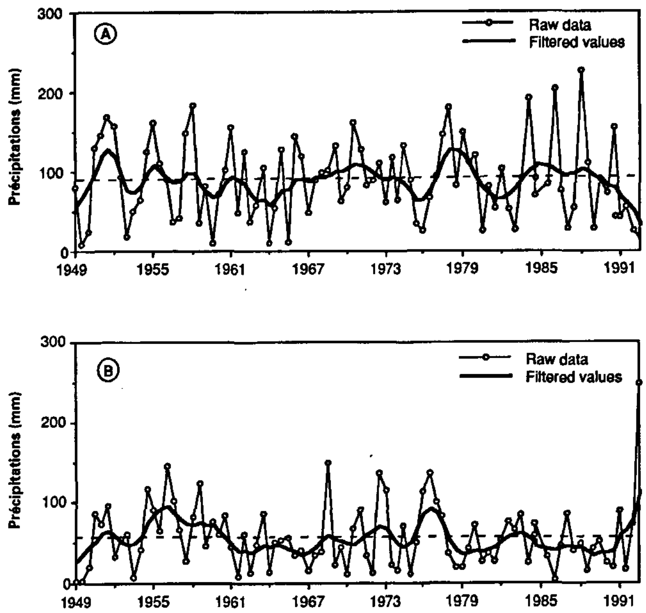

Figure 11

January and February (A), and July and August (B) precipitations at Bordeaux, from 1949 to 1992. Dotted straight line corresponds to the mean value of these series.

Précipitations de janvier-février (A) et de juillet-août (B) à Bordeaux de 1949 à 1992. La ligne pointillée correspond à la valeur moyenne de la série.

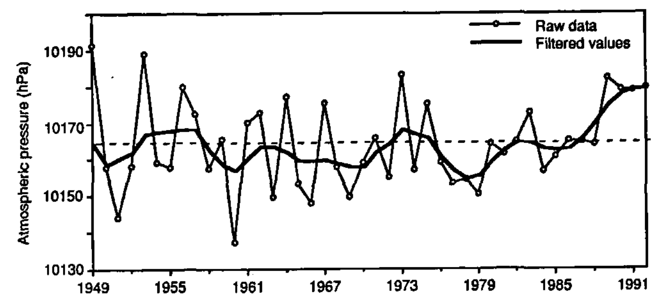

Figure 13

Annual atmospheric pressure (mbar) at Bordeaux from 1949 to 1992 (44 years). General trend was extracted by the eigen-vector filtering method. Dotted straight line corresponds to the mean value of this series.

Pressions atmosphériques annuelles à Bordeaux de 1949 à 1992 (44 années). La tendance générale est obtenue après filtrage par la méthode des vecteurs propres. La droite pointillée correspond à la valeur moyenne de la série.

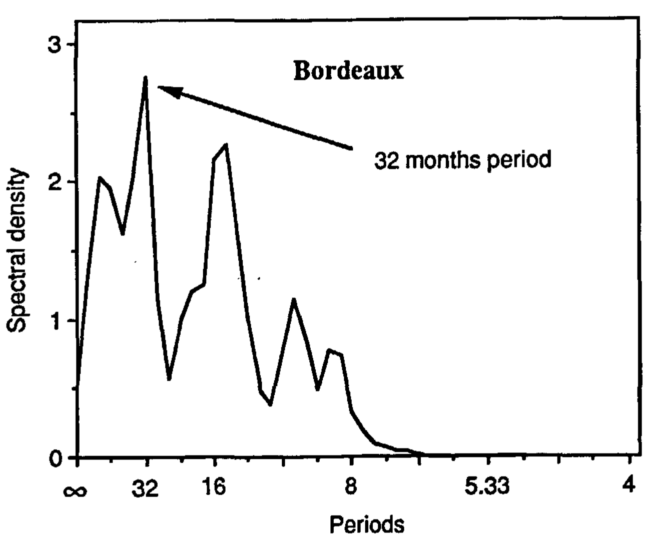

Figure 12

Spectral analysis of the cyclic trend of monthly precipitation data at Bordeaux. X-axis represents monthly periods (loghrithm scale), and Y-axis the power spectral density (linear scale).

Analyse spectrale sur la tendance cyclique des précipitations mensuelles à Bordeaux. L'axe des abscisses représente les périodes en mois (échelle logarithmique), l'axe des ordonnées la densité spectrale (échelle linéaire).

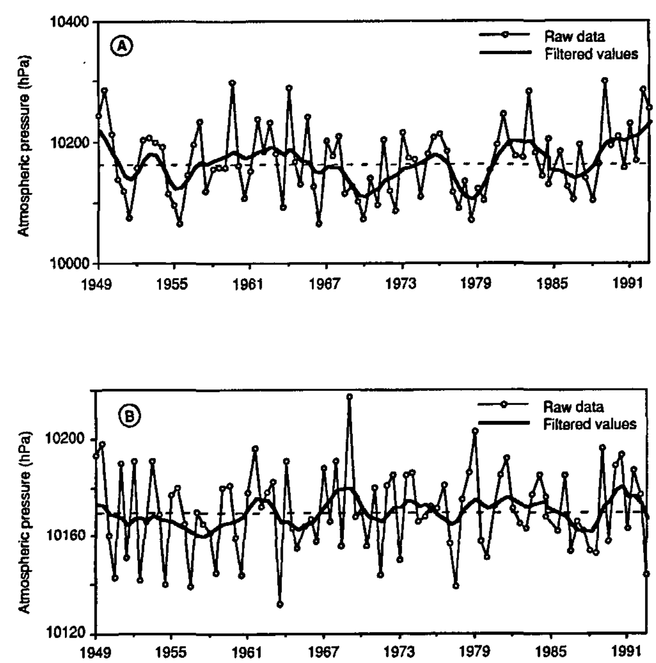

Figure 14

January and February (A), and July and August (B) atmospheric pressures at Bordeaux, from 1949 to 1992. Dotted straight line corresponds to the mean value of these series.

Pressions atmosphériques de janvier-février (A) et de juillet-août (B) à Bordeaux de 1949 à 1992. La ligne pointillée correspond à la valeur moyenne de ces séries.

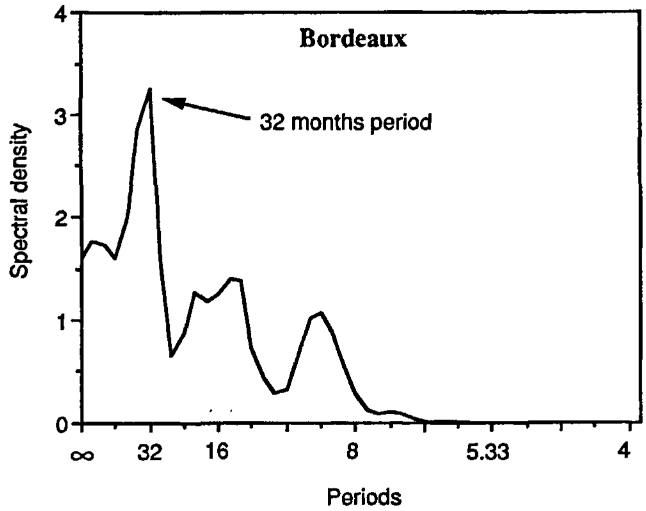

Figure 15

Spectral analysis of the cyclic trend of the atmospheric pressure monthly data from Bordeaux. X-axis represents monthly periods (logarithm scale), and Y-axis the power spectral density (linear scale).

Analyse spectrale sur la tendance cyclique des pressions atmosphériques mensuelles à Bordeaux. L'axe des abscisses représente les périodes en mois (échelle logarithmique), l'axe des ordonnées la densité spectrale (échelle linéaire).

Wind

Wind stress may induce important changes in marine populations by modifying the physical structure of the water column (Dickson *et al.*, 1988; Binet, 1988). Unlike temperature or precipitation, this factor does not involve cumulative effects, and its short-term effects may be as important as the long-term ones. We decided to focus on the strong events, wind in excess of 7 m/s for Batz (threshold given by Lagadeuc (1992) concerning the larval transport in the English Channel), and in excess of 6 m/s for Cap Ferrat (minimum wind intensity that can change the Ligurian current in the surface layer: Charmasson, 1982). The annual variability of the daily observations of strong wind, considering four directions (fig. 16) show important year-to-year fluctuations (see differences between 1980 and 1977 or 1989 at Batz). More interesting is the presence of years with uncommon distribution, in a region usually dominated by westerlies. In 1987 and 1989 there are as many easterlies as westerlies. Futhermore, northerly winds are more numerous at the beginning of the series, while southerlies are more frequent at the end. The Cap Ferrat series may be displayed in two parts: from 1962 to 1975 with many easterlies; and 1975 to 1990 with fewer easterlies and an equal distribution with the westerlies. One other noteworthy point is the irruption of the northerlies from 1973 to 1975, and between 1984 and 1986, which constitutes an unusual event in this region. These results, briefly described, show that the temporal variability of the wind stress is not randomly distributed, and that these trends or isolated events may have an important impact on the biological cycles of the organisms.

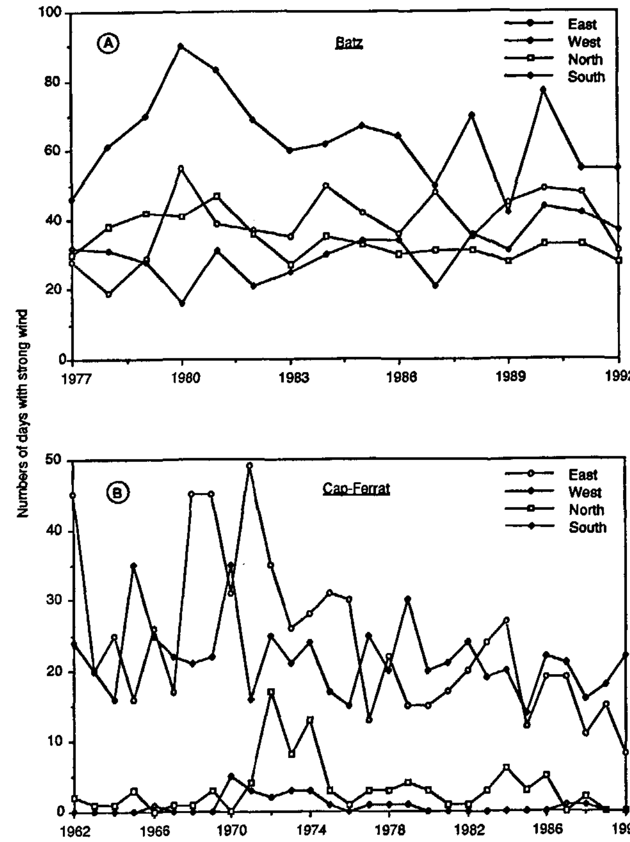

Figure 16

Numbers of days with strong wind/year, from Batz (A) and Cap-Ferrat (B). The four main directions were separated.

Nombre de jours de vent fort par an à Batz (A) et au Cap-Ferrat (B) en fonction des quatre principales directions.

Biological responses

Example of Acartia bifilosa

Acartia bifilosa is a pelagic copepod living in estuaries. Ibanez *et al.* (1993 *b*) showed that the year-to-year fluctuations of this species are correlated to the year-to-year variation of salinity. This species prefers more saline waters, and has its maximum density during the summer. The salinity of an estuary is dependent on the river flow, and so on the precipitations of the river basin. A comparison between the cumulative sums of *Acartia bifilosa* and the cumulative sums of the precipitations (Fig. 17) shows an obvious relation between these two variables. The trends are always opposite, except in 1980, and changes occur in the same years: 1981, 1984, 1987, and 1989. Strong precipitations (1981-1984) coincide with low abundance of *Acartia bifilosa*, and *vice versa.* The Spearman correlation coefficient is about - 0,82 between these two series. This coefficient, tested by Monte-Carlo simulations, is significant at the level of 1 %. These results confirm that precipitation controls the densities of *Acartia bifilosa* in the Gironde estuary. Harmonic analysis were performed on raw data, and on the line of the median points, and on the envelopes of the *Acartia bifilosa* series. No significant periodicity

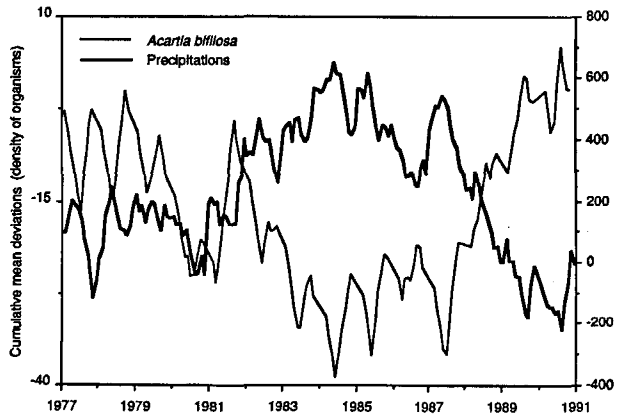

Figure 17

Cumulative sum series of Acartia bifilosa *and of precipitation at Bordeaux from 1977 to 1990. Previously the monthly means were calculated and taken off the data, to eliminate seasonal variability.*

Sommes cumulées de la série d'*Acartia bifilosa* et des précipitations à Bordeaux de 1977 à 1990. Les moyennes mensuelles ont été au préalable retranchées des données afin d'éliminer la variabilité saisonnière.

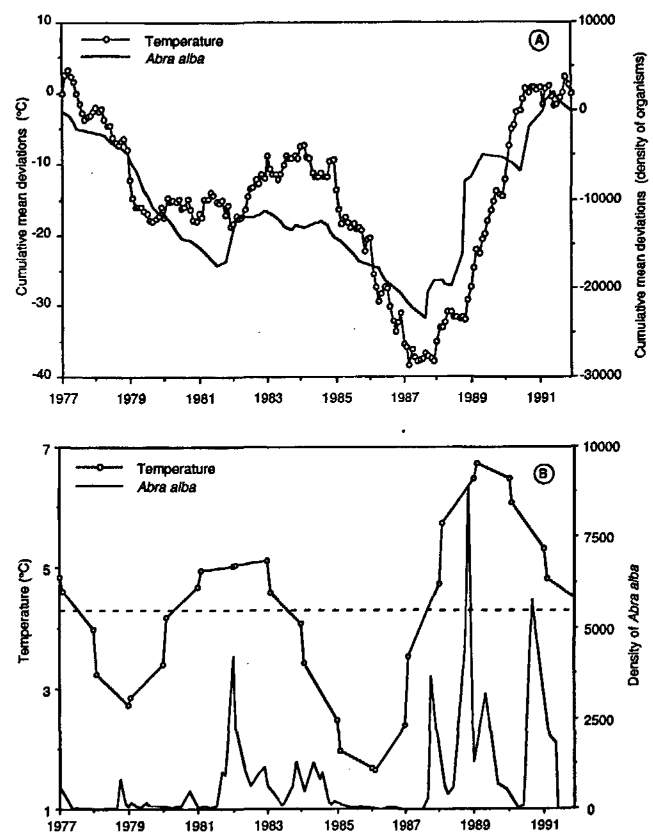

Figure 18

A) Cumulative sum series of Abra alba *and of the temperature at Dunkerque from 1977 to 1991. Previously the monthly means were calculated and taken off the data, to eliminate seasonal variability. B) Raw data of* Abra alba *densities and of the January and February temperatures at Dunkerque from 1977 to 1991.*

A) Sommes cumulées de la série d'*Abra alba* et des températures à Dunkerque de 1977 à 1991. Les moyennes mensuelles ont été au préalable retranchées des données afin d'éliminer la variabilité saisonnière. B) Données brutes d'*Abra alba* et températures de janvier-février à Dunkerque de 1977 à 1991.

was detected other than twelve months (the annual variation).

Example of Abra alba

This bivalve, considered as an opportunistic species and as a biological indicator of disturbance, shows drastic variations in densities over the fifteen years. Comparison between the cumulative sums of abundance of *Abra alba* and air temperature (Fig. 18A, from Dauvin *et al.*, 1993) show that the synchronism between the two curves is not always true; for instance between 1979 and 1983. If we compare raw data of *Abra alba* and the filtered values of the January and February months of the air temperature at Dunkerque, the relation is much more obvious (Fig. 18B). Maxima of density always occur with mild winters (1981-1983, 1988-1991), whereas cold winters are always characterized by very low densities of *Abra alba* (sometimes none as in 1986). The Spearman correlation coefficient is about 0.5, and is significant at the level of 1%. Harmonic analysis on the line of median points and the upper envelope of the series of *Abra alba* reveal a main periodicity about ninety months (7.5 years), but not on raw data. All these results confirm the relation between air temperature and this species: the cycle of 7.5 years is common to air temperature and *Abra alba*. The relation between the winter season and densities of *Abra alba* shows the importance of the overwintering in the temporal variability of this species.

DISCUSSION

The comparison between the different sites of the French coast shows a certain homogeneity between the climatic series. Important meteorological events (cold winters, hot summers, *etc.*), like main changes, trends and periodicities, are very similar from one site to another. Climatic factors show important year-to-year variations, and different periodicities were detected: about three years for precipitations and atmospheric pressure, and seven-eight years for temperature. Many different works have already mentioned a cycle of about three years, these include: Muller and Siedler (1992) who described changes in currents in the North Atlantic, Colebrook and Taylor (1984) who studied the surface heat exchange phenomena, and Owens *et al.* (1989) who followed the variability of phytoplankton species in the North Sea. On the other hand, the period of seven-eight years for temperature has never been described before. In fact, most of the previous studies mentioned a periodicity of around 11 years, corresponding to the sun spot activity (Southward *et al.*, 1975; Southward, 1991; Colebrook, 1976; Glémarec, 1979), that did not emerge from our analyses. We propose two hypothesis in explanation of this seven-eight year cycle: 1) it is an harmonic of a larger period (the secular period), which is revealed from the results of the Genova spectrum (Fig. 6); 2) it is in relation with the pole tide which has a period of seven years (Gray and Christie, 1983). We cannot decide between these different hypothesis in the context of the present study. A similar period of seven-eight years was detected by Quin *et al.* (1978) in respect of the main frequency of the strong El-Niño events (whereas the weak to strong El-Niño events occur every three-four years).

A cycle of five to seven years was mentioned by Glémarec (1993) with regard to the interannual variability of benthic communities. Our results have also mentioned a larger periodicity, recently illustrated by the warming up to 1950, and followed by a cooling. This secular cycle is also detected in the sea-surface temperature with a short delay (Metaxas *et al.*, 1991; UNESCO, 1992). Such a variation on a hundred scale seems to be more or less regular (Leroy-Ladurie, 1983): about eighty years with the Genova series, and around ninety years for Gray and Christie (1983). The relative weakness of the recent cooling (Fig. 4) might be related to the greenhouse effect, but it might also be a consequence of this irregularity. So, meteorological variability is distributed in different time scales which seem to fit one into the other like Russian dolls: the daily variability into the weekly one, into the seasonal one, into the year-to-year one, into the secular one and into the geological one.

Different numerical approaches have to be developed to suit ecological problems. Concerning wind for instance, it may sometimes be useful to study the relaxation of wind as an explanation of the decline in sardine catches (Littaye-Mariette, 1991); in other cases it may be wiser to look at the variability of the direction of strong wind (Lagadeuc, 1992). Long-term variability (as in Fig. 16) may also explain changes in the ecosystem (Dickson *et al.*, 1988). For the other meteorological variables, we used classical methods (extraction of trend and detection of cycles), and more original ones like the "seasonal deviation" of the temperature, the cumulative sums method (Ibanez *et al.*, 1993 *b*), the two month series, and the envelopes (Ibanez *et al.*, 1993 *a*; Gaines and Denny, 1993). Without the cumulative sums method it would not be easy to demonstrate the synchronism between the trend of *Acartia bifilosa* and the precipitations. Even so, comparison between densities of *Abra alba* and the two winter-month series of temperature shows the importance of the overwintering for this species. The effect of winter sea temperatures on marine populations was discussed by Colebrook (1982 and 1985) for zooplankton, and by Winters *et al.* (1993) for fish. Classical treatments could not show this phenomenon. This last example, and the differences noticed above between the annual and two-month series of meteorological factors underline the problem of the time scale. For *Acartia bifilosa*, it is appropriate to compare the biological series with the global meteorological series; but for *Abra alba* it is more interesting to take the season into account.

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Annex

The Census 2 method uses successive moving averages in order to display a series of three components:

X(t) = CT(t) * SC(t) * RC(t)
X(t) : raw data
CT(t) : Cyclic Trend
SC(t) : Seasonal Component
RC(t) : Random Component.

CT results from both the general trend and the long-term cycles. It does not always respect stationarity; however the observed trend is very low, and close to the mean of the series, except at the end of the series, which contains the warmest years (Fig. A1).

To perform spectral analysis, the series must be both long enough (which is the case), and stationary. We tested the stationarity of the first level, which assumes that the mean is the same along the series. Following Kendall (1976), we calculated Spearman correlation coefficients between CT and linear sequences of X axis values in order to detect he presence of a linear trend. Results are presented in Table A1.

Three series of both temperature and precipitation and one series of atmospheric pressure show significant trends. In this case, we remove the four last years of the temperature and atmospheric pressure series, and the final fifteen years of the precipitation series. So no more significant trend can be detected (Tab. A1).

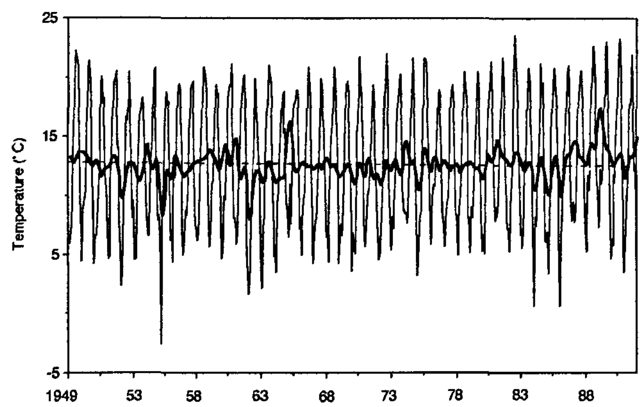

Figure A1

Monthly air temperature at Bordeaux from 1949 to 1992 (solid line) and cyclic trend extracted by the Census 2 method (bold line). Dotted straight line corresponds to the mean value of this series.

Température mensuelle de l'air à Bordeaux de 1949 à 1992 (ligne continue) et tendance cyclique obtenue par la méthode Census 2 (ligne en gras). La droite pointillée correspond à la valeur moyenne de la série.

Spectral analyses were performed on the part of CT which shows no significant trend. The lag window used in these analyses was about 96 months (18 % of the total amout of data). The spectral window corresponded to three successive terms smoothed by the Tuckey Hanning filter.

Table A1

Standard numbers: Spearman correlation coefficients calculated between cyclic trends of the whole series and linear sequences of X axis values for the six sites. Coefficients over 0.09 are significant at the level of 5%.
Bold numbers: Spearman correlation coefficients calculated between cyclic trends of the truncated series and linear sequences of X axis values. Coefficients over 0.09 are significant at the level of 5% for temperature and atmospheric pressure series; and over 0.105 for the precipitation series (348 data).

Chiffres sans caractère particulier : coefficients de corrélation de Sperman calculés entre les tendances cycliques des séries entières et les valeurs des abcisses pour les six sites. Les coefficients supérieurs à 0,09 sont significatifs au seuil de 5 %.
Chiffres en caractère gras : coefficients de corrélation de Sperman calculés entre les tendances cycliques des séries tronquées et les valeurs des abcisses. Les coefficients supérieurs à 0,09 sont significatifs au seuil de 5 % pour les séries de température et de pression atmosphérique, ceux supérieurs à 0,105 sont significatifs (au seuil de 5 %) pour les séries de précipitation (348 valeurs).

	Dunkerque	La Hève	Batz	Bordeaux	C. Béar	C. Ferrat
TEMPERATURE	0.174 * **0.087**	0.112 * **- 0.011**	- 0.049	0.197 * **0.060**	0.076	- 0.043
PRECIPITATION	0.174 * **0.100**	0.169 * **0.063**	0.179 * **0.066**	0.062	0.052	- 0.040
ATMOSPHERIC PRESSURE	0.006	0.132 * **- 0.00**	0.060	0.085	0.051	0.076

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