Manila clam *Tapes philippinarum* culture: Sediment-clam interactions

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Abstract – Manila clam (*Tapes philippinarum*) culture and sediment interactions were tested by comparing two rearing areas, including an oceanic ('Le-Ferret') and a more estuarine ('Les-Jacquets') sites in the bay of Arcachon (France). The growth of a calibrated clam population (10-mm spat) was monitored in these two areas with a concomitant sediment-water interface survey over a 1.5-year period. Two sites per area, including control and rearing plots, were sampled on a monthly basis. The potential clam farming impacts by bioturbation and interactions were examined at three sediment depths: 0–1, 1–2 and 2–10 cm. Moreover, the main hydrobiological parameters were measured on a weekly basis to establish a relationship between these parameters and sediment-water interface characteristics. The existence of a gradient between the three depths was revealed for most of the parameters examined, with the exception of silt and organic carbon levels, and this regardless of the area examined. Clam growth showed a rate improvement in the oceanic area, which is characterized by a lower silt content. The clam effect was minimal and the activity identified at the 'Ferret' site was in fact due to the presence of a net which acted as a particle trap. No significant relationship was established between water column parameters and those of the sediment-water interface at the two geographical sites examined. These results demonstrate that clam rearing had only a limited effect on the environmental sediment parameters (i.e. water percentage, and phaeopigments and silt levels) from a spatio-temporal point of view. Therefore, a return to environmental conditions existing before the implementation of clam farming is likely to occur upon cessation of this activity. © Ifremer/Elsevier, Paris

Clam culture / bioturbation / sediment-water interface / *Tapes philippinarum* / bay of Arcachon

Résumé – **L'élevage de la palourde japonaise *Tapes philippinarum* : interactions entre le sédiment et les palourdes.** Les interactions entre l'élevage de la palourde japonaise *Tapes philippinarum* et le sédiment ont été testées par une comparaison de deux sites d'élevage, comprenant un secteur océanique (Le-Ferret) et un secteur d'influence estuarienne (Les-Jacquets) dans le bassin d'Arcachon (France). La croissance d'une population de naissain calibré (10 mm de longueur) a été suivie sur ces deux zones avec une étude parallèle de l'interface eau-sédiment pendant une période de 18 mois. Une zone d'élevage et une zone témoin ont été suivies pour chaque site. L'impact potentiel de l'élevage de palourdes a été examiné à trois profondeurs de sédiment : 0–1, 1–2 et 2–10 cm. De plus, les paramètres hydrobiologiques ont été échantillonnés avec une fréquence hebdomadaire afin d'établir une corrélation entre ces derniers paramètres et les caractéristiques de l'interface eau-sédiment. Un gradient de profondeur a été mis en évidence pour la majorité des paramètres hydrobiologiques, à l'exception du contenu en vase fine (« silt ») et des concentrations en carbone organique, et ce, quelle que soit la zone testée. La croissance des palourdes s'est avérée supérieure dans le secteur océanique, caractérisé par un contenu plus faible en vase. L'effet de l'élevage de palourdes sur les caractéristiques sédimentaires fut minime, avec un effet significatif sur le site du Ferret résultant de la présence d'un filet d'élevage agissant comme un piège à particule. Aucune corrélation n'a pu être mise en évidence entre les paramètres de la colonne d'eau et ceux de l'interface eau-sédiment pour les deux zones géographiques testées. Ces résultats démontrent que l'élevage n'a eu qu'un impact limité sur les paramètres sédimentaires (tels que la teneur en eau, en phaeopigments et le pourcentage de vase) d'un point de vue spatio-temporel. Par conséquent, un retour aux conditions environnementales initiales du début de l'élevage est très probable, dès l'arrêt de cette activité. © Ifremer/Elsevier, Paris

Vénériculture / bioturbation / interface eau-sédiment / *Tapes philippinarum* / bassin d'Arcachon

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1. INTRODUCTION

From the middle of the 20th century until today, the French oyster farming industry has had numerous upheavals [20–22]. Severe oyster mortalities led to crises during the early 70s and eventually to the Portuguese oyster *C. angulata*'s disappearance, which prompted managers to massively import the Pacific cupped oyster *C. gigas* [21]. Moreover, since then, the oyster culture's impact on the environment was demonstrated with the siltation process resulting from both oyster biodeposits and rearing structures (i.e. tables), as well as increased organic carbon level, which elevates oxygen demand and, therefore, leads occasionally to anoxic conditions [8, 43]. Both aspects revealed the critical need to diversify shellfish-farming through the rearing of additional and/or substitute commercially attractive species, including the Manila clam *Tapes philippinarum*.

In 1974, the know-how of hatcheries and nurseries in terms of spat mass production allowed the first clam rearing facilities to be set up in Brittany [13, 27, 28]. By 1980, the rearing cycle feasibility was tested at other sites along the Atlantic coast [2, 3, 14, 17, 38, 48]. The setting-up and the development of this new shellfish industry in France was followed by numerous studies (for a review, see [16]) dealing primarily with the issues of predation [36, 39], physiology [4, 9–11, 15, 18, 40] as well as pathology [33–35]. Since the recent development and spread of natural populations of *T. philippinarum* along the Atlantic coast, additional studies have been carried out on population dynamics [1] and recruitment processes [10]. Although a large number of studies have examined mollusc-environment relationships (e.g. [19]), few were carried out in vitro [9, 30] or considered in situ clam-sediment interactions [15, 24, 32, 37, 45–47, 50]. Although several studies have examined clam farming impact on meiofauna, few considered concomitantly direct physical-trophic interactions at the sediment level [7, 25]. This study aims to examine the clam-sediment interactions within the intertidal zone of the Arcachon Bay during a rearing cycle.

2. MATERIALS AND METHODS

2.1. Site distribution

In order to determine sediment-clams interactions, experimental Manila clam *Tapes philippinarum* rearings were carried out in two areas of the bay of Arcachon using traditional techniques. The first rearing plot was set up in the 'Jacquets' site which is a relatively protected area where numerous clam farms have been inventoried. In contrast, the second rearing station was set up in a more oceanic area, 'Le-Ferret' (*figure 1*). A calibrated hatchery-produced spat population (mean length $\approx$ 10 mm) was sown at densities of 250 individuals·m^{-2} on 100-m^2 rearing plots. The clam
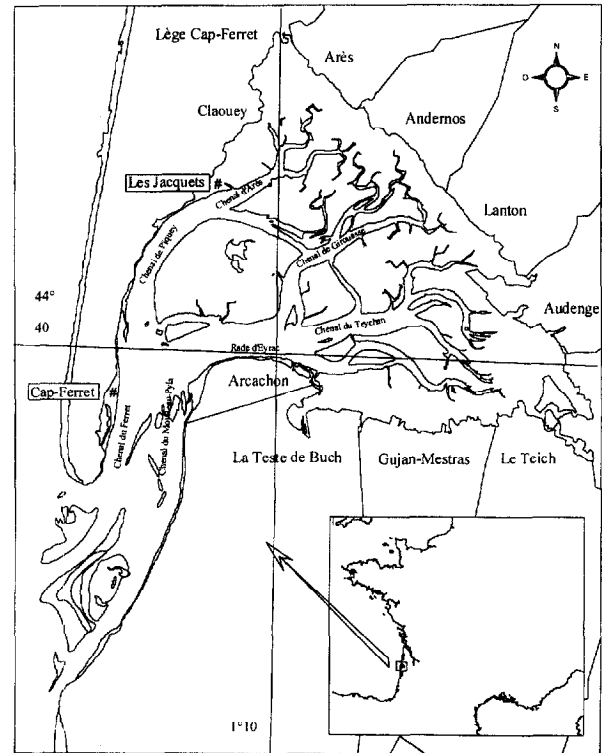

Figure 1. Location of the experimental area (bay of Arcachon) showing clam sampling stations 'Le-Ferret' and 'Les-Jacquets'.

beds were equipped with nets installed temporarily at the 'Jacquets' site (during the summer) and permanently at the 'Ferret' site to limit predation by the common shore crab *Carcinus maenas* [36], the gray triggerfish *Balistes capriscus* and the gilthead bream *Sparus aurata* [39].

2.2. Clam and sediment monitorings

Sampling of both clams and sediment was performed from March 1989 to June 1990 on a monthly basis. With regard to clams, shell length and live weight of 30 individuals randomly sampled were measured. For the sediment, seawater and silt (i.e. mineral particles < 63 µm) percentages, chlorophyll a, phaeopigments and particulate organic carbon concentrations were determined at the 'Jacquets' and 'Ferret' sites on a monthly and quarterly basis, respectively. At each site, two areas were sampled: the actual rearing plot and a control plot without clams located in the near vicinity of the former area. In each area, three sediment depths were considered from a core sample: the fraction between 0 and 1 cm, termed the '0' fraction; the fraction between 1 and 2 cm referred to as fraction '1'; and finally, the 2 to 10 cm fraction referred to as fraction '10'. Pre-calibrated 60-mL syringes were used to obtain sediment cores. Ten random cores were obtained for each area. The sediment

layers obtained in this way were then homogenized in situ using a battery-operated mixer (Black and Decker, model H 223) and divided up into glass vials. All samples were maintained in the dark in an icebox. On return to the laboratory, samples were either immediately analyzed or stored. Water percentage was calculated by double weighing on a precision balance (Mettler AE 163) both before and after drying at 60 °C for 48 h. Only the sediment fraction below 300 μm in size was used to evaluate the other sediment parameters. The silt percentage was determined by a double weighing of the dry matter (drying at 60 °C for 48 h) before and after sifting at 63 μm. The chlorophyll *a* and phaeophytin concentrations were determined based on the technique described by Lorenzen [29] after pigment extraction with 90 % acetone from sediment samples frozen beforehand. Finally, the particulate organic carbon levels were assessed after filtration of sediment samples on a Whatman GF/C filter, oxidation using a sulfo-chromic mixture and quantitative analysis of the oxidant using ferrous sulfate ammonia [12]. The differences in sediment water and silt percentage in chlorophyll *a*, phaeopigments and organic carbon levels existing among the three depths (0, 1 and 10 cm) and between the two study areas (rearing station and control area) were evaluated using two-way analysis of variance for the totality of the data recorded.

2.3. Hydrobiology monitoring

In addition, the main hydrobiological parameters were recorded on a weekly basis to detect any possible correlation between these parameters and their sediment counterparts. Sampling at the water bottom was performed at midday in the vicinity of the experimental clam beds either at high tide during spring tides or at low tide during neap tides. Temperature was measured using a field thermo-salinometer probe (YSI model 33). After seawater pre-filtration on a 300-μm filter, the particulate material was retrieved on a 0.45-μm Whatman GF/C filter. The total and organic seston concentrations were determined by double weighing before and after combustion at 450 °C in a muffle furnace whereas chlorophyll *a* and phaeopigment concentrations were measured using the fluorometric method [51].

3. RESULTS

3.1. *Tapes philippinarum* growth

Shell length and especially live weight of *Tapes philippinarum* were higher at the 'Le-Ferret' rearing area than at the 'Les-Jacquets' site (*figure 2*). At both stations, development was poor during the first two months after sowing. Thereafter, growth rates increased sharply with clam sizes doubling within 3 to 4 months after the initial 2 months. Growth rates varied according to season (lower in autumn and winter)
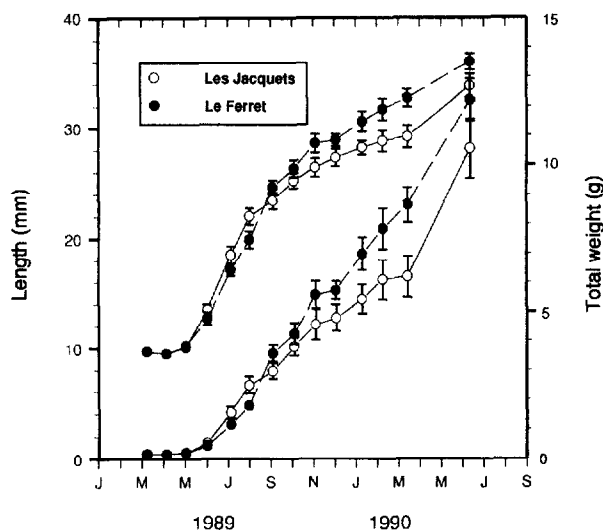
Figure 2. *Tapes philippinarum* growth in shell length and live weight (means ± 95 % confidence intervals) reared in an oceanic station 'Le-Ferret' and in an inner station 'Les-Jacquets' (bay of Arcachon) from March 1989 to June 1990.

and study area (lower in 'Les-Jacquets'). Nevertheless, the growth rate was satisfactory: during the 16 month culture period, the clams grew from 10 to 34–36 mm in length (*figure 2*). Increases in live weight were more constant; at the end of the study, clams weighed between 10 and 12 g (*figure 2*).

3.2. Sediment characteristics

3.2.1. Water percentage

At the 'Jacquets' rearing area, water percentage changes over time revealed the presence of significant differences between both control and clam farming sites, and among the three sediment depths examined (*figure 3*). Within the control area, the water percentage at the 0 and 1 cm depth varied from 25 to 45 % with slightly higher values at the surface. At the 10 cm depth, water percentage showed limited variability over time, ranging from 20 to 25 %. At this last depth, a similar water percentage trend was observed for all rearing sites whereas the water percentage profiles at the 0 and 1 cm depth showed large variability over time with values ranging from 30 to 40 % at 1 cm and the surface, respectively. However, a two-way analysis of variance revealed the highly significant effect of the 'depth' factor and the non-significant 'site' effect on water percentage, although an inversed trend was noted over time between the control and rearing plots (*table I*). Moreover, a Fisher PLSD multiple comparison test revealed that these differences were highly significant among the three depth levels (0, 1, 10 cm, *table I*).

A different profile was observed at the 'Ferret' rearing area. At the control site, values ranged from 15 to 20 % and this regardless of depth. At the rearing site, a

Table I. Two-way ANOVA: combined effects of depth (cm) and site (with or without clams) on sediment water percentage for both rearing areas (ns, not significant; *, significant; **, very significant; ***, highly significant). Fisher's PLSD multiple comparison tests the depth effect. Depth fraction: '0', 0–1 cm; '1', 1–2 cm; '10', 2–10 cm.

Rearing area	Variable	Degree of freedom	Mean square	F-ratio	P-value
'Les-Jacquets'	Main effects				
	Depth	2	1273.513	55.833	0.000***
	Site	1	0.688	0.029	0.8647 [ns]
	Interaction	2	13.552	0.594	0.5553 [ns]
	Residual	66	22.810		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	5.501	2.880	0.0003*	
	0–10	15.037	2.880	0.0000***	
	1–10	9.536	2.880	0.0000***	
'Le-Ferret'	Main effects	Degree of freedom	Mean square	F-ratio	P-value
	Depth	2	116.717	5.258	0.011*
	Site	1	292.410	1.311	0.001***
	Interaction	2	61.609	2.776	0.0783 [ns]
	Residual	30	22.196		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	3.532	3.928	0.0763 [ns]	
	0–10	6.218	3.928	0.030**	
	1–10	2.687	3.928	0.1727 [ns]	

Table II. Two-way ANOVA: combined effects of depth (cm) and site (with or without clams) on silt percentage for both rearing sediment areas (ns, not significant; *, significant; **, very significant; ***, highly significant). Fisher's PLSD multiple comparison tests the depth effect. Depth fraction: '0', 0–1 cm; '1', 1–2 cm; '10', 2–10 cm.

Rearing area	Variable	Degree of freedom	Mean square	F-ratio	P-value
'Les-Jacquets'	Main effects				
	Depth	2	1151.111	18.691	0.000***
	Site	1	17.228	0.0280	0.5986 [ns]
	Interaction	2	34.030	0.553	0.5781 [ns]
	Residual	66	61.588		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	3.379	4.523	0.1406 [ns]	
	0–10	13.323	4.523	0.0000***	
	1–10	9.943	4.523	0.0000***	
'Le-Ferret'	Main effects	Degree of freedom	Mean square	F-ratio	P-value
	Depth	2	74.908	0.896	0.4187 [ns]
	Site	1	603.767	7.225	0.0116*
	Interaction	2	26.758	0.320	0.7285 [ns]
	Residual	30	83.568		

similar trend was observed at the 10-cm depth whereas values rose from 15 to 30 % and 20 to 40 % at 1 and 0 cm, respectively (figure 3). A two-way analysis of variance revealed the significant effect of study site on water percentage (table I). However, a Fisher PLSD multiple comparison test for the 'depth' effect, revealed that these differences were only significant between the extremes (0 and 10 cm, table I).

3.2.2. Silt content

At the 'Jacquets' rearing area, silt levels ranged from 30 to 60 % at the 0- and 1-cm depths in the control site

with minimum values recorded in September 1989 (figure 3). At 10 cm, lower percentages ranging between 10 and 40 % were observed, although the profile remained the same, as did the September 1989 minimum value. In clam rearing site, a completely different profile was observed with a less distinct differentiation among the three depths and values ranging between 20 and 50 % (figure 3). A two-way analysis of variance revealed the highly significant depth effect and the non-significant effect of study site on silt content (table II). A Fisher's PLSD multiple comparison test, however, showed that these differences were
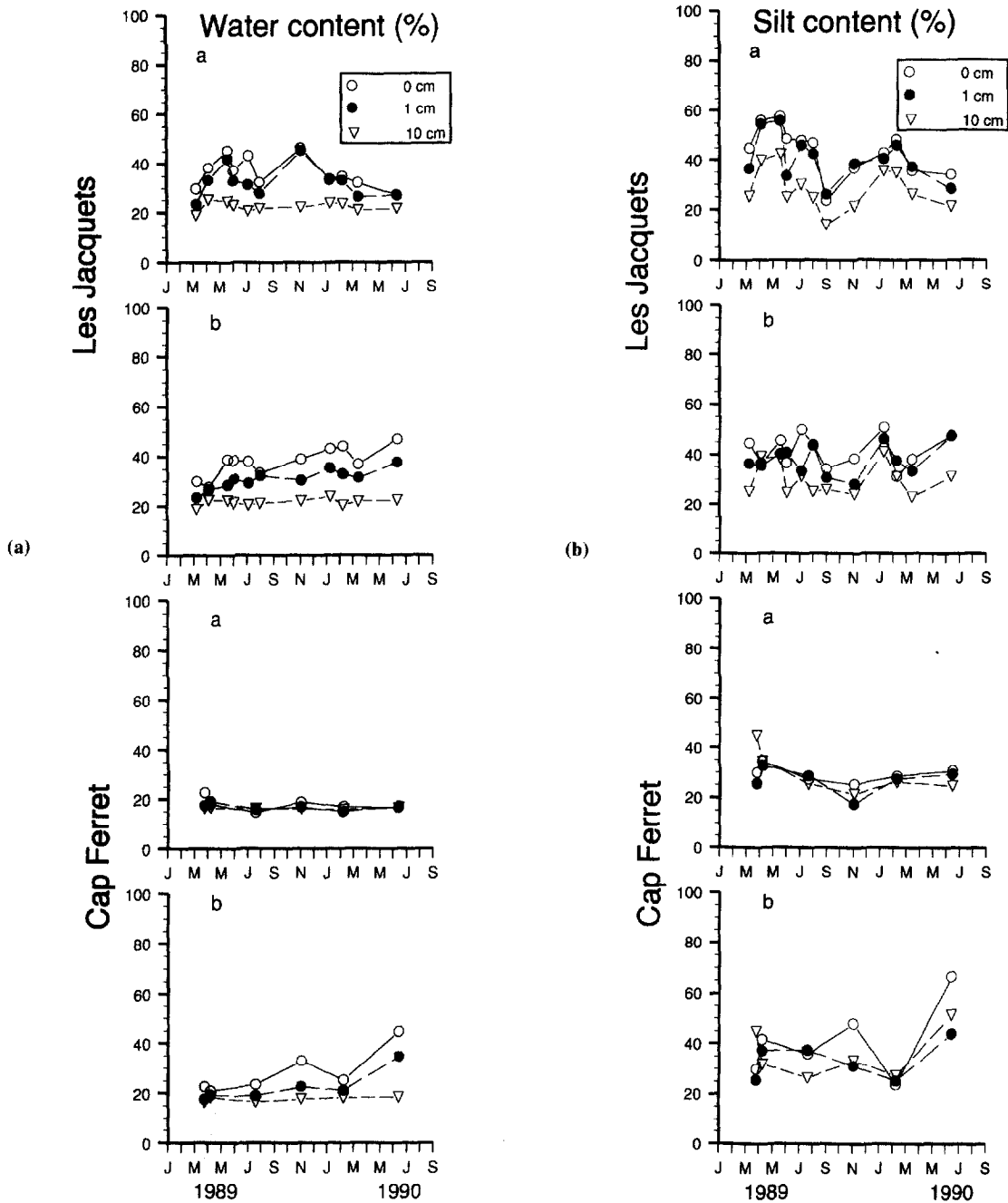
Figure 3. Seasonal variations of sediment water (a) and silt (b) contents at depth layers of 0–1, 1–2 and 2–10 cm in 'Le-Ferret' and 'Les-Jacquets' sites (bay of Arcachon) in control and rearing sites.

all significant but at the 0- to 1-cm depth fractions (*table II*).

At the 'Ferret' rearing area, a different silt content evolution was observed. Silt content levels remained low with values ranging from 20 to 40 %. In addition, levels remained fairly constant both over time and among the different depths in the control site (*figure 3*). Based on this last figure, it appears that only the surface layer in the rearing site was noticeably dif-

ferent with silt levels between 30 and 60 % (*figure 3*). A two-way analysis of variance confirmed the non-significant depth effect and the significant effect of study site (at $P = 0.05$) on silt content (*table II*).

3.2.3. Chlorophyll a and phaeopigment levels

At the 'Jacquets' rearing area, the chlorophyll *a* concentration trend in the control site revealed the presence of a gradient among the three recorded depths
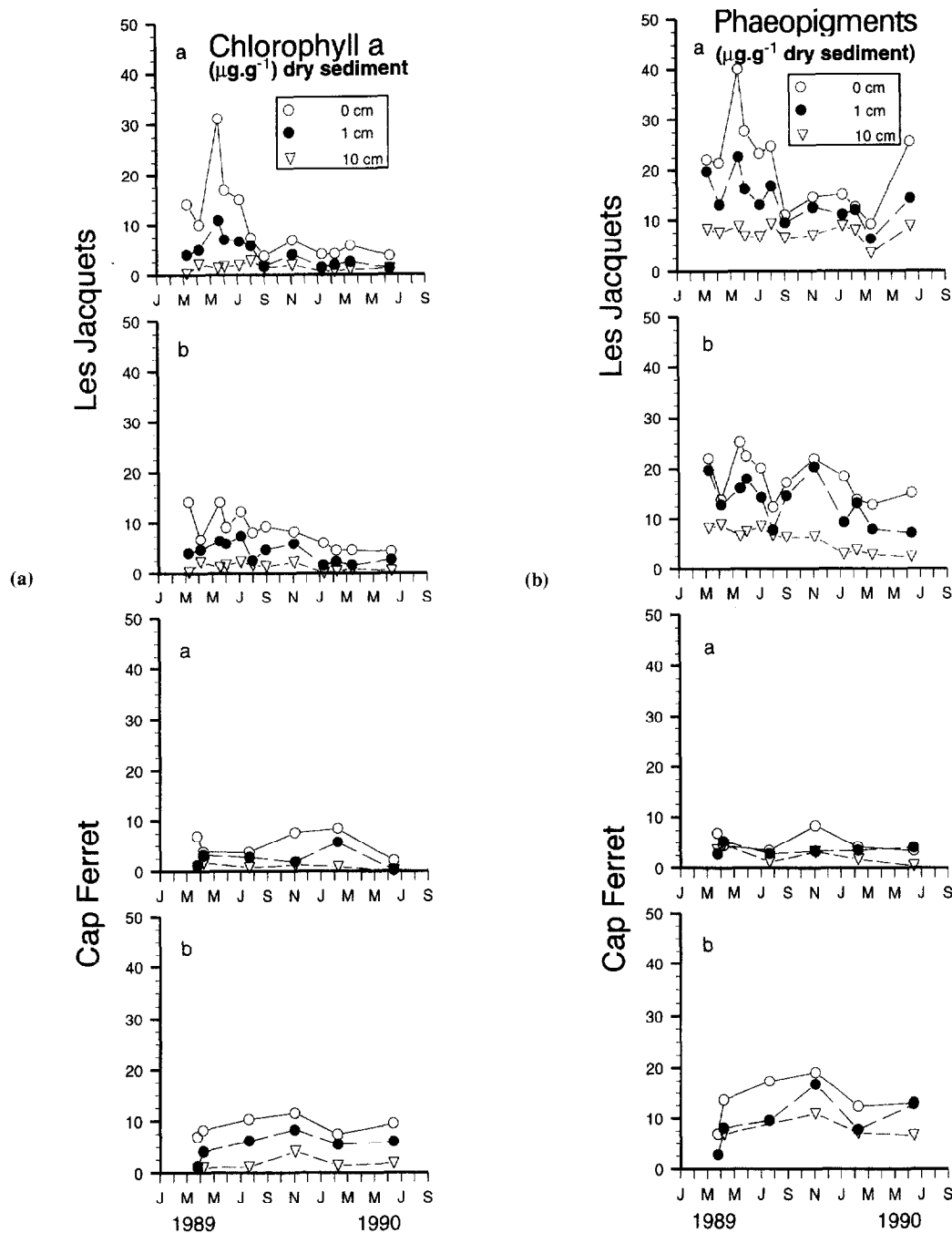
Figure 4. Seasonal variations of sediment chlorophyll *a* (a) and phaeopigments (b) concentrations at depth layers of 0–1, 1–2 and 2–10 cm in 'Le-Ferret' and 'Les-Jacquets' sites (bay of Arcachon) in control and rearing sites.

(*figure 4*). At the surface (0 cm), concentrations greater than 8 μg·g⁻¹ dry sediment were observed from March to August 1989 with a particularly important benthic bloom in May 1989 (31.18 μg·g⁻¹). Earlier values remained well below, ranging from 4 to 8 μg·g⁻¹. At 1-cm depth, the chlorophyll *a* concentrations were approximately the same but with lower levels ranging from 0 to 2 μg·g⁻¹. At this last depth, the evolution of chlorophyll *a* concentrations in the rearing site was

similar to that described for the control site, therefore demonstrating the absence of effect due to clam presence (e.g. biodeposits) (*figure 4*). Moreover, few differences were observed at 1 cm between these two sites. Conversely, from March to August 1989, surface values (0 cm) were distinctly lower than those recorded in the control site as they did not exceed 14 μg·g⁻¹. A two-way analysis of variance revealed the highly significant depth effect and the non-significant

Table III. Two-way ANOVA: combined effects of depth (cm) and site (with or without clams) on chlorophyll a concentration for both rearing sediment areas. Fisher's PLSD multiple comparison tests the depth effect. Depth fraction: '0', 0–1 cm; '1', 1–2 cm; '10', 2–10 cm.

Rearing area	Variable	Degree of freedom	Mean square	F-ratio	P-value
'Les-Jacquets'	Main effects				
	Depth	2	398.745	26.029	0.000***
	Site	1	9.017	0.589	0.4457 [ns]
	Interaction	2	4.873	0.318	0.7287 [ns]
	Residual	66	15.319		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	5.114	2.256	0.0000***	
	0–10	8.055	2.256	0.0000***	
	1–10	2.941	2.256	0.0114*	
'Le-Ferret'	Main effects	Degree of freedom	Mean square	F-ratio	P-value
	Depth	2	105.819	30.160	0.000***
	Site	1	49.844	14.206	0.0007***
	Interaction	2	5.979	1.704	0.1991 [ns]
	Residual	30	3.509		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	3.381	1.562	0.0000***	
	0–10	5.919	1.562	0.0000***	
	1–10	2.538	1.562	0.0024**	

effect of study site on chlorophyll a concentrations (*table III*). Moreover, a Fisher's PLSD multiple comparison test showed that these differences were significant among the three depths examined (0, 1, 10 cm) and were highly significant between the depth extremes (0 and 10 cm, *table III*).

At the 'Ferret' rearing area, a chlorophyll a gradient among the three depths was also revealed. This gradient was more pronounced in the clam rearing site where levels were generally higher at 0 and 1 cm with values between 5 and 10 $\mu g \cdot g^{-1}$ dry sediment (*figure 4*). A two-way analysis of variance revealed the highly significant depth effect and the highly significant effect of study site on chlorophyll a concentrations (*table III*). Therefore, in contrast to 'Les-Jacquets' area, clam rearing led to a significant increase of chlorophyll a at the sediment level. Moreover, a Fisher's PLSD multiple comparison test showed that these differences were highly significant among the three depths examined (0, 1, 10 cm, *table III*).

At the 'Jacquets' rearing area, phaeopigments concentrations revealed a gradient among the three depths and this regardless of the study site (*figure 4*). From March to August 1989, concentrations at the surface (0 cm) ranged between 20 and 40 $\mu g \cdot g^{-1}$ for the control site but did not exceed 25 $\mu g \cdot g^{-1}$ in the rearing site. The opposite trend was subsequently observed as concentrations in the rearing site were seen to be generally higher than those of the control. At 1 cm, phaeopigment levels were approximately the same as those recorded at the surface with lower values ranging from 10 to 20 $\mu g \cdot g^{-1}$. At 10 cm, phaeopigment levels exhibited low seasonal variations with values ranging from 5 to 10 $\mu g \cdot g^{-1}$ and active chlorophyll levels between 20

and 30 %, and this regardless of the study site concerned. The highly significant depth effect at three levels and the non-significant site effect on phaeopigment concentrations are shown in *table IV*.

At the 'Ferret' rearing area, phaeopigment levels in the control site were particularly low being less than 8 $\mu g \cdot g^{-1}$ and this regardless of depth (*figure 4*). Conversely, levels were higher in the clam rearing site with a pronounced depth gradient (*figure 4*). Indeed, values were between 8 and 20 $\mu g \cdot g^{-1}$ for the 0- and 1-cm depths and between 2 and 10 $\mu g \cdot g^{-1}$ at 10 cm. At this last depth, and for both study sites examined, active chlorophyll rates ranged between 20 and 35 %. At the other depths (0 and 1 cm), these levels ranged from 30 to 50 %. A two-way analysis of variance revealed a significant depth effect (at $P = 0.01$) and the highly significant site effect on phaeopigment concentrations (*table IV*). A Fisher's PLSD multiple comparison test, however, showed that, for depth, these differences were only highly significant between the extremes (0 and 10 cm, *table IV*).

3.3. Particulate organic carbon

Particulate organic carbon concentrations in the control and rearing sites of the 'Jacquets' area were observed to evolve heterogeneously with values ranging from 20 to 60 $\mu g \cdot g^{-1}$ dry sediment (*figure 5*). This heterogeneity was confirmed by a two-way analysis of variance which revealed for both a non-significant depth ($P > 0.36$) and study site ($P > 0.98$) effect on organic carbon concentrations.

At the 'Ferret' area, these levels exhibited a low seasonal variation with distinctly lower values ranging

Table IV. Two-way ANOVA: combined effects of depth (cm) and site (with or without clams) on phaeopigment concentration for both rearing sediment areas. Fisher's PLSD multiple comparison tests the depth effect. Depth fraction: '0', 0–1 cm; '1', 1–2 cm; '10', 2–10 cm.

Rearing area	Variable	Degree of freedom	Mean square	F-ratio	P-value
'Les-Jacquets'	Main effects				
	Depth	2	954.598	39.666	0.000***
	Site	1	41.983	1.745	0.1911 [ns]
	Interaction	2	7.045	0.293	0.7472 [ns]
	Residual	66	24.066		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	5.611	2.827	0.0002***	
	0–10	12.589	2.827	0.0000***	
	1–10	6.978	2.827	0.0000***	
'Le-Ferret'	Main effects	Degree of freedom	Mean square	F-ratio	P-value
	Depth	2	77.406	8.079	0.0016**
	Site	1	339.358	35.417	0.0000***
	Interaction	2	17.326	1.808	0.1814 [ns]
	Residual	30	9.582		
	Depth fraction	Mean diff.	Crit. diff.	P-value	
	0–1	2.805	2.581	0.0341*	
	0–10	5.070	2.581	0.0004***	
	1–10	2.265	2.581	0.0832 [ns]	

from 15 to 30 $\mu g \cdot g^{-1}$ (*figure 5*), and this regardless of study site and depth. A two-way analysis of variance, however, revealed a non-significant site effect but confirmed a significant study site effect ($P = 0.02$ at $P = 0.05$) on organic carbon concentrations.

3.4. Hydrobiological parameters trends

The seston concentrations did not exhibit any discernible cycle with values ranging from 5 to 30 $g \cdot m^{-3}$ at the 'Jacquets' and 'Ferret' rearing areas, with only one observation exceeding this range at the latter site (56 $g \cdot m^{-3}$) in March 1989 (*figure 6a*). Evolution of the organic seston was globally quite similar to that of the total seston with values between 1 and 15 $g \cdot m^{-3}$ in both areas (*figure 6b*).

The lack of a spring bloom influenced the chlorophyll a concentration trends in the 'Jacquets' area. In addition, only one fall bloom of low magnitude (7.5 $mg \cdot m^{-3}$) was recorded (September, *figure 6c*). At this time, chlorophyll a levels in the 'Ferret' area were higher with a maximum of 17.5 $mg \cdot m^{-3}$ (*figure 6c*). The phaeopigment levels in the water column at both the 'Jacquets' and 'Ferret' areas were of the same order of magnitude as chlorophyll a levels with values ranging from 0 to 10 $mg \cdot m^{-3}$ (*figure 6d*). This is contrary to the results obtained at the sediment-water interface.

4. DISCUSSION AND CONCLUSION

The impact of oyster farming on trophic capacity and sedimentation has been extensively studied [5, 8, 23, 41, 43, 44], as well as mussel farming impact [49].

However, the effects of clam rearing in the intertidal zone has received very little attention and the available results are often contradictory [7, 25, 26, 31, 45, 46]. By way of example, Castel [7] demonstrated that the disruptive activity of the Manila clam leads to a decrease in the abundance of nematodes but not of copepods. This result can best be explained by an increase in habitat heterogeneity. This author also reveals the existence of a significant effect of clam farming on the biotic and physical characteristics at the sediment-water interface. However, these results seem to depend on the nature of the sediment present [7]. Conversely, Kaiser et al. [25] observed that clam farming had no significant effect on benthic biodiversity other than a non-significant increase in the benthic fauna. They also failed to demonstrate any significant effect on sediment particle size or on organic carbon and chlorophyll pigment contents. A comparison between a control and a rearing site including rearing nets revealed the occurrence of a significant difference in the benthic community as demonstrated by an increase in the number of deposit feeders. This quantitative difference, which has no effect on the biodiversity, is not due to the presence of clams but rather to nets which increase both the sedimentation levels by a factor of 4 and the sediment homogeneity beneath these structures. The clam activity in the absence or presence of nets tends to increase the proportion of silt in the sediment [45–47] (*figure 3*). Meanwhile, clams may become smothered by sediments that accumulates on nets depending on local sedimentation rates [42]. In the present study, the parameters examined exhibited a greater homogeneity in rearing than in control sites. These differences were further accentuated
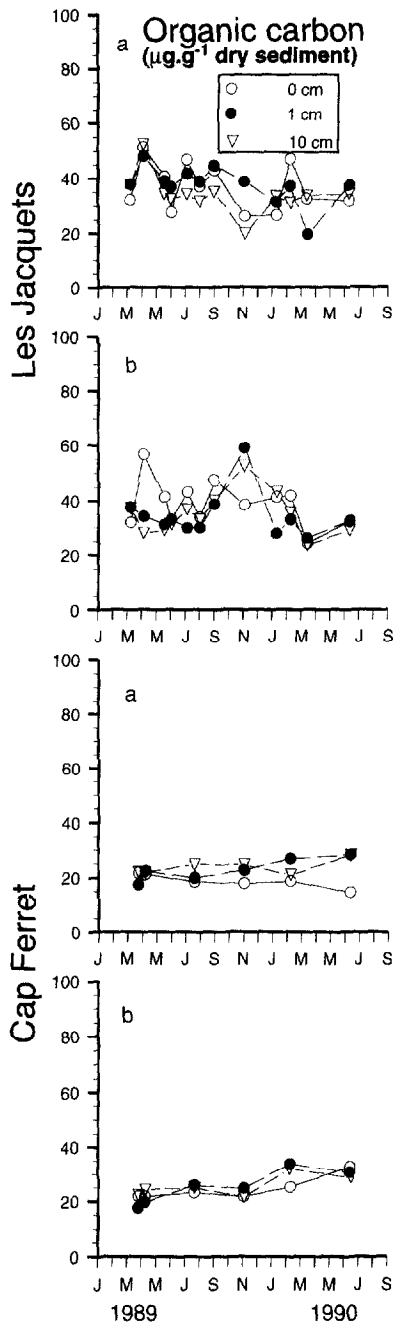
Figure 5. Seasonal variations of sediment carbon organic concentration at depth layers of 0–1, 1–2 and 2–10 cm in 'Le-Ferret' and 'Les-Jacquets' areas in control and rearing sites.

Figure 6. Seasonal variations of suspended matter (a), particulate organic matter (b), chlorophyll a (c) and phaeopigment (d) concentrations in seawater in 'Le-Ferret' and 'Les-Jacquets' stations (bay of Arcachon).

as the clams increased in size. Castel [7] demonstrated that a 20-mm minimal size was necessary to generate significant differences at the sediment-water interface. In the present study, these differences were quite noticeable beginning in the spring of the second year of rearing and corresponded to a resumption of clam growth (30-mm size). For example, the water percentage in the 0–1-cm depth layer was greater in the con-
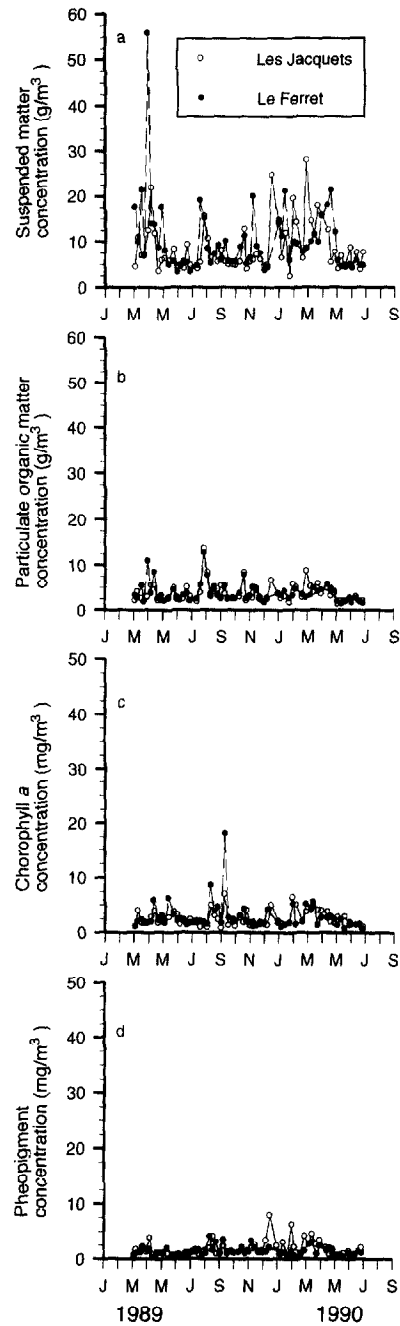
trol than in the rearing site (with a more distinct difference observed in the 'Ferret' area), whereas no significant difference was observed at 10 cm and this regardless of the site examined. The presence of clams only generated a significant increase in silt content in the 'Ferret' area (*table II, figure 3*). This increase is likely due, in part, to the biological clam activity but is mainly attributable to the mechanical action resulting

from the permanent presence of rearing nets [42, 45]. The more oceanic geographical location of this last area probably limited this effect as the difference between study sites (with or without clams) was only significant at the 5 % threshold. Conversely, chlorophyll *a* levels exhibited a distinct gradient among the three depths examined and this in both geographical areas (*table III*), with the highest values occurring at the surface. At 10 cm, these concentrations were particularly low and did not exceed 2 μg·g^{-1} dry sediment. Once again, the clam presence was only felt in the 'Ferret' area, a difference which can be attributed to a mechanical action, as opposed to a biological activity. An analogous observation was made for phaeopigments. Indeed, a gradient was observed among the three depths regardless of study site as was a mechanical action due to the presence of permanent nets in the 'Ferret' area. Similar observations have already been reported and the location of rearing areas in habitats where the water is more or less renewed could help explain the observed variability for this parameter [7, 45]. Conversely, no clearly discernible trend was observed for organic carbon concentrations as the depth effect was not significant in either geographical area examined and as the nets' mechanical action in the 'Ferret' area was only weakly significant ($P < 0.05$).

In both geographical areas examined, it is difficult to establish a relationship between silt levels at the sedi-ment surface and suspended matter concentration trends in the water column (*figures 3, 6*) as the fluctuations of the latter parameter are particularly abrupt. The same is true of organic carbon and particulate organic matter concentrations. As for chlorophyll *a* and phaeopigment levels, no correlation was established between the phytoplankton blooms of the water column and those at the sediment surface.

These results demonstrated that clam rearing has only a limited impact on environmental parameters (i.e. water percentage, silt levels, phaeopigments) from a spatio-temporal point of view. Moreover, clam digging associated with the harvesting process was reported as of limited or beneficial impact on the environment [6]. Actually, digging mixes the substrate leading to oxidation of lower sediment parts. Similarly, following suction-harvesting on a muddy sand clam plot, sediment structure and profile were restored after 3 months [47]. It would thus appear that, by taking into consideration hydrodynamic conditions in the selection of aquaculture sites, this impact should be limited even further and, in all cases, will be lower compared to *C. gigas* culture [8]. In light of the limited impact due to bioturbation, it is suggested that a return to environmental conditions existing before the implementation of clam farming will be obtained upon cessation of this rearing activity.

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