Suspended and Sedimented Matter at a Fixed Station Near Gascons, Baie des Chaleurs, Québec

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SUSPENDED AND SEDIMENTED MATTER AT A FIXED STATION NEAR GASCONS, BAIE DES CHALEURS, QUÉBEC

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L. Godbout, D. Dobson, G. Moreault, and L. Devine. 1995. Suspended and sedimented matter at a fixed station near Gascons, baie des Chaleurs, Québec. Can. Tech. Rep. Fish. Aquat. Sci. 2058: vii+42 p.

Water column constituents and sedimentation rates of C, N, and pigments were measured at a fixed station near Gascons (26 m) in baie des Chaleurs, Québec, at 1-4 day intervals between 16 June and 20 August 1992. Water column constituents were chlorophyll *a* and phaeopigments (<5 µm, 5-153 µm, 0.7-153 µm) and particulate organic carbon and nitrogen. Constituents in the water column and in the sedimentation varied little throughout the sampling period (CV <50%) except for water column chlorophyll *a* >5 µm and phaeopigments >5 µm (CV >117%) and sedimented chlorophyll *a* (CV=92%). The standing stock of chlorophyll *a* in the size class >5 µm was positively related to the standing stock of total chlorophyll *a*. This log-log model had a slope of 2.25 and explained 86.5% of the variation. Empirical models describing the sedimentation rate of pigments (R^2=41.0-46.4%) had higher predictive power than those predicting the sedimentation rates of either C (R^2=11.5%-14.6%) or N (R^2=20.2%-24.2%). The best predictor of the sedimentation rate of pigments was the standing stock of pigment in the size class >5 µm (R^2=46.4%). The slope of this log-log relationship (0.41) implied that the sedimentation rate did not increase linearly with the standing stock of pigment >5 µm. Inferences from these models and their implications on the monitoring of baie des Chaleurs are discussed.

RÉSUMÉ

L. Godbout, D. Dobson, G. Moreault, and L. Devine. 1995. Suspended and sedimented matter at a fixed station near Gascons, baie des Chaleurs, Québec. Can. Tech. Rep. Fish. Aquat. Sci. 2058: vii+42 p.

Les composantes de la matière en suspension ainsi que le taux de sédimentation du C, N et des pigments ont été mesurées à une station fixe près de Gascons (26 m), baie des Chaleurs, Québec, à des intervalles de 1 à 4 jours, entre le 16 juin et le 20 août 1992. La chlorophylle *a* et les phéopigments (<5 µm, 5-153 µm, >0.7-153 µm) ainsi que le carbone et l'azote organique ont été mesurés dans la colonne d'eau. Sauf pour la chlorophylle *a* >5µm et les phaéopigments >5µm (CV > 117%), la concentration des particules en suspension a peu varié au cours de la saison (CV <50%). Le taux de sédimentation des diverses composantes varia peu (CV <50%) sauf pour celui de la chlorophylle *a* (CV=92%). Le stock de chlorophylle *a* >5 µm peut être prédit à partir du stock de chlorophylle *a* totale. Cette relation log-log a une pente de 2.25 et explique 86.5% de la variation. Les modèles empiriques décrivant le taux de sédimentation des pigments ont une plus grande capacité de prédiction (R^2=41.0-46.4%) que ceux du C (R^2=11.5%-14.6%) ou de l'N (R^2=20.2%-24.2%). Le stock de pigments >5 µm (R^2=46.4%) est le meilleur prédicteur du taux de sédimentation des pigments. La pente (0.41) de ce modèle log-log indique que le taux sédimentation des pigments augmente de façon non linéaire avec une augmentation du stock de pigments >5 µm. Les inférences de ces modèles et leurs implications sur le monitorage de la baie des Chaleurs sont discutées.

1.0 INTRODUCTION

One priority of the Department of Fisheries and Oceans (DFO) is to better understand coastal marine ecosystems in order to make predictions about their condition. The coastal ocean is important not only because it is the most biologically productive area of the world's oceans, but also because it is the most affected by human activities. Land- and ocean-based activities contribute to nutrient loads and pollutant input and therefore have the potential of affecting the food web structure and productivity (Messieh *et al.* 1991; ICES 1992; Caddy 1993). In addition, the global increase of atmospheric CO_2 will also have the greatest consequences on coastal waters. Beside direct physiological and behavioral effects, an increase in temperature and river runoff, hence in stratification, may result in less organic material reaching the bottom, which would further modify the food web structure of coastal oceans (Frank *et al.* 1988).

The relative contribution of any particular human activity to alterations in coastal waters and the identification of appropriate methods for mitigation require a good knowledge of the functioning of coastal oceans. To that end, DFO's oceanographic support program has initiated the collection of basic data on patterns of physical, chemical, and biological structures. The St. Lawrence Estuary and gulf have been the subject of numerous studies (see El-Sabh and Silverberg 1990 and Therriault 1991 for reviews), but shallow coastal waters, including baie des Chaleurs, which is exposed to multiple human activities (pulp and paper industries, pollutants in river runoff, sediment dredging, aquaculture), have received little attention. Previous work in baie des Chaleurs was performed mostly at depths greater than 70 m. Existing data are for primary production (Legendre 1971; 1973) and for the composition and distribution of phytoplankton and zooplankton (Brunel 1959, 1970; Lacroix and Filteau 1970, 1971). Data on contaminants in sediments are very sparse (Loring 1988) while data on spatial and temporal variability of suspended particulate concentrations and sedimentation rates are lacking. Suspended matter is important because it represents the amount of energy available for production while the magnitude of sedimentation relative to other fates determines the response of coastal waters to changes in nutrient loads, pollutant input, and food web structure. In particular, data from sites representing a gradient of perturbations and a measure of the variability are needed for the establishment of reference levels for the assessment of human activities and environmental monitoring. Unfortunately, such a data set is nonexistent, but could be obtained by combining our field measurements at a fixed station with others as they become available. New data could also be acquired from the calibration of satellite imagery of baie des Chaleurs using our field observations.

In this study, measurements will be used to assess 1) the variability of suspended particulate concentrations and sedimentation rates at a fixed station in baie des Chaleurs throughout the summer, 2) the interrelationships between water column attributes, and 3) the relationships of sedimentation rates with standing stocks of particulate matter and water density stratification (D_s).

Constituents of particulate matter, such as chlorophyll *a*, carbon, and nitrogen, are appealing because they represent holistic measures and are therefore potentially useful for comparing and ranking coastal habitats. For instance, total algal biomass as reflected by chlorophyll *a* and the contribution from various algal size classes has been used as an index of trophy or productivity. The pattern that emerges when using data pooled from all oceanic areas is that the total amount of algal biomass increases as nutrients increase, but the relative contribution of smaller cells to the standing crop decreases (Raimbault *et al.* 1988; Chisholm 1992). Thus, beyond certain thresholds, algal biomass can only increase by the addition of larger size classes of cells. Sedimentation is also a holistic measure of trophy and food web structure because it depends partly on particle settling velocity and therefore on particle size. One would expect a greater proportion of the water column's supply of pigments or of C to be sedimenting in a more productive system (Harris 1986; Bishop 1989; Wassmann 1990) because a greater proportion of algal biomass is in a larger form, with higher potential sinking rates.

In this report, we used the coefficient of variation and time plots to describe the summer variation of suspended particulate matter concentrations (depth-integrated, 0-17 m) and the sedimentation rate of various constituents. Ratios of C to N and chlorophyll *a* to pigments served as a basis to compare the composition of suspended and sedimented matter. Estimated daily loss rate (percentage of sedimenting suspended matter) helped to quantify the contribution from the water column to sedimentation. Interrelationships between suspended particulate concentrations were examined to gain insight on the functioning of coastal waters. The relationships of the sedimentation rates with suspended particulate concentrations and D_S aimed at describing the response of the coastal water in terms of changes in sedimentation rate to changes in water column attributes. Our goal was merely to explore potential relationships, since time series data from a single site may not provide the necessary data structure.

2.0 METHODOLOGY

2.1 STUDY SITE

Baie des Chaleurs (Figure 1) extends from the Restigouche River in the west to a point between Grande Rivière and northern Miscou Island in the east and is approximately 135 km long. The mean width is 32 km and the mean depth 43 m. During the summer, the mean circulation along the north shore is westward and believed to be an extension of the Gaspé Current (Bonardelli *et al.* 1993). Our fixed station, in 26 m of water, was along the north shore of the bay within two kilometers Gascons (48°09' 41" N, 64° 56' 25" W) and is known to have scallop beds. Upwelling and downwelling events were observed at Gascons and shown to be generated in response to alongshore winds with maximum variability occurring at periods of 5-10 d. (Bonardelli *et al.* 1993).

2.2 SAMPLING AND ANALYTICAL METHODS

Water column and sedimentation sampling was made from a 7.6 m boat from 15 June to 20 August 1992. These samples, as well as vertical profiles of salinity, temperature, and fluorescence, were usually obtained at 1-4 day intervals (average 3 days) between 07:30 and 10:30. Summaries of the sampling calendar, types of measurements, and data are given in Appendices 1-4. Two sediment traps (A and B) were deployed between 15 June and 13 July and thereafter only one trap was deployed until 20 August.

A fluorometer (Aquatracka III, Chelsea Instruments) connected to an STD (Applied Microsystems model 12) was used to obtain vertical profiles of temperature, salinity, and *in situ* fluorescence. Two profiles were obtained on each visit, the first upon arrival at the site and the second before departure. Additional profiles were obtained at 2-hour intervals at high tide (22 and 24 June, 10:00 to 19:00 and 9:00 to 19:00, respectively) and low tide (27 and 29 June, 8:20 to 19:30 and 8:00 to 12:00, respectively). All readings were stored using a time step of 1 to 5 seconds.

Water samples were collected with Niskin bottles throughout the sampling period at depths of 1, 5, 9, and 17 m except that sampling at the 1 m depth began on 25 July. The water was first filtered through a 153 μm nitex mesh and a 10 ml subsample was stored in cryovials and preserved in liquid nitrogen for subsequent nutrient analysis. The remaining water was transferred to 4 l dark plastic bottles and kept in a cooler. These samples were split into two fractions [< 5 μm and total (<153 μm)] within three hours. Two replicates of 100 to 200 ml of water from each fraction were filtered on GF/F filters for pigments and on 450°C pre-combusted GF/F for organic carbon and nitrogen. Filters were stored in foil or petri dishes and kept in a freezer at the field laboratory. Upon returning to the main laboratory, all cryovials and filters were transferred to a cryo-freezer.

Measurements of sedimentation rate were obtained using a self-buoyant sediment trap with a collection vessel suspended on a gimbal modified from Broman *et al.* (1990). Two 8-inch trawl floats, mounted opposite each other on a PVC ring, acted as buoyancy. In the ring, a PVC tube was gimbal-mounted to the rods of the floats. A splitter plate and two turbulence-generating 5 mm^2 strips mounted on the PVC tube provided hydrodynamic stability. Seston was collected using a removable cylindrical vessel made of PVC (3.75 l) with an inner diameter of 10 cm and a height of 50 cm. The traps were balanced in a swimming pool by adding weight to the splitter plate; stability was assessed both in the pool and in the field. Broman reported the trap to be hydrodynamically stable under laminar and turbulent water currents with flow rates up to 40 cm s^{-1}. Previous July-August current data at Gascons (Bonardelli *et al.* 1993) and diver's observations on our trap (16 and 23 June 1992) suggested that the traps were stable at Gascons. The traps were installed at 8 m off-bottom to minimize contamination due to resuspension. No preservative was used in the collection cylinder (Smetacek *et al.* 1978). Sedimented material was usually collected every 1-4 days (average 3 days), when the contents were poured into a dark 4 l plastic bottle and kept in a cooler. Within two hours, one or two aliquots of 50 to 100 ml of water were filtered on GF/F filters for measurements of total chlorophyll *a* and phaeopigments or on 450°C pre-combusted GF/F for measurements organic carbon and nitrogen.

Nutrient samples were analyzed for nitrate+nitrite and silicate by colorimetric methods using a Technicon autoanalyzer II (Technicon 1977, 1979). Chlorophyll *a* was extracted at 5°C in 90% acetone for 18 h and then measured fluorometrically (Turner model 112) before and after acidification. Concentrations of chlorophyll *a* and phaeopigments were determined using the equations of Parsons *et al.* (1984). Water sampling at 1 m began only on 25 July; chlorophyll *a* values for earlier dates were estimated using a log-log empirical relationship (R^2=0.68, N=82) obtained by regressing the log of measured chlorophyll *a* at 1, 5, 10, and 17 m against the log of the voltage obtained with the fluorometer *in situ*. Because chlorophyll may be transformed into phaeopigments in sediment traps over time, concentrations of phaeopigments and chlorophyll *a* were summed to produce a variable called "sedimentation rate of pigments" when constructing an empirical relationship. Carbon and nitrogen filters were analyzed on a Perkin Elmer 240 Elemental CHN analyzer. One replicate per sampling date was analyzed for total organic C and N.

2.3 DATA TREATMENT

The sedimentation of a constituent X (S, mg m^{-2} d^{-1}) was calculated according to

$$S= [X]\cdot V\cdot A^{-1}\cdot D^{-1} \qquad (1)$$

assuming a collection volume (V) of 0.475 l, a collection surface (A) equal to the area of the cylinder mouth (0.00785 m^2), and where D is the deployment period in days and [X] is the measured concentrations of either pigments, C, or N in the 475 ml of water.

Areal standing stocks or depth-integrated (0-17 m) concentrations in the water column were obtained by extrapolation between sampling depth , i.e. by adding the products of concentrations at 1, 5, 10, and 17 m with depth intervals (0-3, 3-7.5, 7.5-13.5, and 13.5-17 m).

Average daily loss rates (L_i, %) during a specific collection interval i were calculated as

$$L_i=(S_i\cdot SS_i^{-1})\cdot 100 \qquad (2)$$

where S_i is the sedimentation rate (mg m^{-2} d^{-1}) of constituent X during the i^{th} collection period and SS_i is the time-averaged standing stock (mg m^{-2} d^{-1}), i.e. the average suspended concentration potentially available for deposition from the total water column. SS_i during the i^{th} collection period is the average of the depth-integrated concentration at the beginning and end of the i^{th} collection period.

The index of density stratification (D_s) was calculated as

$$D_s= \Delta \text{ sigma-t} / 16 \text{ m} \qquad (3)$$

where sigma-t is the difference in sigma-t over the 1-17 m layer.

Paired t-tests were used to compare the composition between two groups (suspended and sedimented matter; during and after the declining bloom). C/N and chlorophyll *a* / phaeopigment ratios were arcsine transformed to obtain normality. Equality of variance was tested using the folded Form F statistic; when rejected, the Cochran and Cox (1950) probability level of the t-test was used (Lee and Gurland 1975).

Potential relationships between sedimentation rate and water column attributes were obtained through regression analysis (SAS 1982). Each constituent of the sedimentation (pigments, organic carbon and nitrogen) was regressed against SS_i and D_s to identify the regression that gave the most precise estimate of sedimentation as indicated by a high R^2 value and a low mean square error value. SS_i were the standing stocks of pigments, chlorophyll *a*, and phaeopigments in three size classes (<5 µm, 5-153 µm, <153 µm) along with total organic carbon and nitrogen. Unless otherwise stated, all variables required $\log_{10}$ transformation to stabilize the variance. The best combinations of predictors were determined using a forward stepwise multiple regression. Collinearity between the independent variables was evaluated using the Kendall's tau correlation coefficient and the condition index. If collinearity occurred, each collinear variable was used to build separate models that were compared with all others.

3.0 RESULTS

3.1 PHYSICAL AND CHEMICAL FACTORS

Numerous physical processes acted on the water column. Effects from spring runoff were noted throughout the first half of the summer: salinity down to 18 m was on average 3 psu lower than during the second half of the summer. Frequent upwellings also affected the water column. On three occasions (24-30 June, 8-15 July, and 4-12 August), saline (>27.5 psu), cool (<4°C), and nutrient-rich water (NO_3+NO_2 >2 µmole l^{-1}; SiO_4 >5 µmole l^{-1}) from the bottom was upwelled into the water column (Figures 2a,b; 3a,b). However, bottom water was never upwelled throughout the whole water column, although in early summer it rose to within 12 m of the surface. Following upwelling events, the water pattern was sometimes fully inverted (i.e. high temperature, low salinity, and low nutrients at deeper depth), reflecting downwelling events, while on other occasions the pattern was only partly inverted (i.e. high temperatures, high salinity, and low nutrients), suggesting the presence of a water mass with marked differences. Such a pattern was observed between 15 and 30 July, when in contrast to conditions observed during the upwelling event, water temperature (>10°C) and salinity (>27) were both relatively high while nutrient content was low (NO_3+NO_2 = 0.4-0.8 µmole l^{-1}; SiO_4 =1-2 µmole l^{-1})(Figures 2a,b; 3a,b).

The index of water density stratification (D_s) averaged 0.091, with values ranging from 0.021 to 0.311 (Figure 4). There was a clear tendency for higher stratification during the first half of the summer.

3.2 TEMPORAL VARIATION OF ALGAL PIGMENTS AND ORGANIC CARBON AND NITROGEN IN SUSPENDED AND SEDIMENTED MATTER

Depth-integrated concentrations (0-17 m) of total chlorophyll *a*, phaeopigments, and organic carbon and nitrogen varied only from 25% to 42% of their summer means (Table 1). Nonetheless, depth-integrated concentrations of all constituents measured in early summer (16-21 June) were at least twice those observed during the remainder of the summer (Figures 5a-d; Table 1).

In contrast, both depth-integrated chlorophyll *a* and phaeopigments in the size fraction >5 µm varied by up to nearly 120% of their summer means. The early summer concentration of each fraction was six times that observed during the remainder of the summer (Table 1; Figures 5e,f).

On the other hand, both pigments in the fraction <5 µm only varied within less than 30% of their summer means and showed no temporal trend throughout the summer ($P>0.33$; $P>0.16$) (Table 1; Figures 5e,f).

The dominance of large cells (68% of total algal biomass) and the depletion of nutrients ($NO_3+NO_2 < 0.4$ µmole l^{-1}; $SiO_4 < 2$ µmole l^{-1}) in early summer indicated the decline of the spring bloom. A comparison of the variability during and after the declining bloom revealed that all constituents varied only within 36% of their means during both periods (Table 1). The exception is for both pigments in the size class >5 µm, which tended to be more variable after the declining bloom (52.83% for chlorophyll *a* and 67.35% for phaeopigments; Table 1).

Sedimentation rates of phaeopigments and organic carbon and nitrogen varied from 39.8% to 46.4% of their summer means while the sedimentation rate of chlorophyll *a* varied within 92.3% (Table 2). Temporal patterns in the daily sedimentation rates for all constituents were similar to patterns found in suspension: rates were greater during rather than after the declining bloom ($P>0.0054$ to $P>0.0004$)(Table 2; Figures 6a-d). However, the sedimentation rate of chlorophyll *a* was on average four times higher during rather than after the declining bloom while depth-integrated concentrations of total chlorophyll *a* varied only by a factor of two (Tables 1,2). Another difference is that sedimentation rates tended to be more variable than most constituents in suspension, particularly after the declining bloom (Tables 1,2).

3.3 SUSPENDED AND SEDIMENTED MATTER

Comparisons of the composition of suspended and sedimented matter

Mean summer ratios of both C/N and chlorophyll *a* / pigments were significantly greater in the water column than in the sedimentation (Table 3a). This implies either that on average constituents in suspension were not deposited at equivalent rates or that there were extended and variable time lags before deposition.

Comparisons of the composition during and after the declining bloom revealed that suspended and sedimented matter had similar and low C/N ratios only during the bloom (Table 3b). The similarity in composition and the presence of fresher algal material during the bloom suggests that the bulk of sedimented matter consisted of algal cells from the water column.

Daily loss rates

Among all the constituents of the water column, phaeopigments contributed the most to sedimentation (expressed in terms of %). The daily loss rate for integrated phaeopigment above the depth at which sedimentation was measured varied from 11.8% to 39.9% and averaged 22.0% over the summer. In contrast, summer values of daily loss rate for integrated chlorophyll *a* averaged 2.69% and varied from 0.9 to 6.3%. Average daily loss rates for particulate carbon and nitrogen were 3.22% and 3.63% respectively, with values ranging from 1.6% to 6.42%.

Interrelationships between water column attributes

Prior to building empirical relationships describing sedimentation rates based on standing stocks of particulate matter and D_S, we examined the relationships between these variables to gain some insight on the water column and to identify potential problems of collinearity among the predictors. Correlations among the independent variables were moderate or weak except between C and N (Kendall's tau = 0.86) and between a variable and one of its components (e.g. pigment >5 µm and chlorophyll *a* >5 µm)(Appendix 5). With respect to the interrelations among water column constituents, two observations are worth mentioning. First, the standing stock of chlorophyll *a* in the size class >5 µm was positively related to the standing of total chlorophyll *a* (Figure 7). This log-log model had a slope of 2.25 and explained 86.4% of the variation. A slope greater than 1 implies that the quantity of large algal cells increased with total algal biomass but that the rate of increase was greater at higher algal biomass. Hence, this model supports the expectation that there is a greater contribution of large algal cells at a higher total algal biomass. Second, the ranges of the chlorophyll *a* to carbon ratio (0.002-0.005) and chlorophyll *a* to N ratio (0.015-0.037) were at least ten times smaller than those observed for algae either in batch culture or in the field (Sakshaug *et al.* 1983; Dortch and Packard 1989). This indicates that the bulk of C and of N were not in phytoplankton but in detritus, possibly consisting of fecal pellets from carnivorous zooplankton.

3.4 RELATIONSHIP BETWEEN SEDIMENTATION RATES AND STANDING STOCKS OF PARTICULATE MATTER AND D_S

To avoid collinearity problems, only one from the pair of collinear variables (C-N, pigment >5 µm- chlorophyll *a* >5 µm) was included in the same model predicting sedimentation rate. The standing stock of pigments in the size class >5 µm was the best single predictor of pigment sedimentation rate (Figure 8a). When considering all observations, this model explained 46.4% of the variation in pigment sedimentation and had a slope of 0.41. Exclusion of the low sedimentation rate data points would lead to a model that would explain 75.9% of the variation. The next best single predictive model was based either on chlorophyll *a* >5 µm or phaeopigments >5 µm and explained 44.0% and 41.0% respectively of the variation in pigment sedimentation. These relationships were positive and suggest that an increase in the standing stock of pigments in the size class >5 µm would result in an increase in the amount of pigments exported downward. However, other variables were also important, since 10 of the 36 observations were much lower than predicted. When testing the importance of other variables, phaeopigments in the size class <5 µm explained an additional 8% of the variation. Water density stratification tended to improve the model based on chlorophyll *a* >5 µm but was not significant (P>0.11). Both variables had positive coefficients, but their effect resulted from a small number of extreme observations and hence should be taken with caution. The inclusion of phaeopigments >5 µm and chlorophyll *a* >5 µm in the same model did not produce a better model because of complications from collinearity.

The standing stock of N was the best single predictor of the N sedimentation rate. This relationship had a slope of 0.56 and explained 24.3% of the variation (Figure 8b). The next best single variate model was based on the C/N ratio of the standing stock. This relationship had a slope of -0.07 and explained 20.2% of the variation. Similarly, C sedimentation rates were best predicted by the standing stock of carbon (R^2=14.6%, slope=0.59)(Figure 8c) and to a lesser extent by the C/N ratio (R^2=11.5%, slope=-0.05). None of the other variables explained additional variation in the models predicting either C or N sedimentation.

4.0 DISCUSSION

4.1 RELATIONSHIPS BETWEEN SEDIMENTATION RATES AND STANDING STOCKS

The contribution of large cells to algal biomass as well as our comparisons of the composition of matter supports the hypothesis that a greater proportion of algae sediments at higher algal biomass. However, the slope of this log-log relationship (sedimented pigments - stock of chlorophyll *a* >5 µm) as well as those based on either the stock of phaeopigments >5 µm or pigments >5 µm was less than 1. This implies that pigment sedimentation is not linearly related to the stock of pigments >5 µm. In other words, there is a greater amount of pigment sedimenting at higher standing stocks of pigments >5 µm, but the rate of increase in deposition is smaller at higher pigment standing stocks. For example, a four-fold increase in the stock of pigments >5 µm (2.5-10.0 mg m^{-2}) would lead to only a three-fold increase in the sedimentation rate of pigments >5 µm (0.11- 0.35 mg m^{-2} d^{-1}) .

The stock of chlorophyll *a* >5 µm explained as much variation as the stock of phaeopigments >5 µm in pigment sedimentation rates. However, phaeopigments contributed the more to sedimentation, particularly after the bloom, when the average sedimentation rate of phaeopigments was three times that of chlorophyll *a* (Table 2). If we assumed that grazing was the main process leading to the degradation of chlorophyll *a* to phaeopigments, grazing and/or coprophagy would then be more important than cell sinking in the downward exportation of pigments from the water column.

Relationships describing sedimented C or N were also in agreement with the notion that the contribution of both C and N from the water column is greater at higher standing stocks. However, these relationships explained much less variation than the previous ones, in part because of the small variation in standing stock of C and N: the stock of C (Figure 8b) and N (Figure 8c) varied by less than 1-fold while a 4-fold variation was observed in the pigment stock >5 µm (Figure 8a). These weak relationships may also have resulted because the standing stocks of C and N do not reflect the actual availability of C and N. The very small ratios of chlorophyll *a* to C or to N in both the suspended and sedimented matter suggest that fecal pellets of small carnivorous zooplankton may constitute an important proportion of the sedimenting C and N. Nonetheless, the standing stock of C or N might be weakly correlated with C and N produced by small carnivores zooplankton and hence poorly related to sedimentation rates of C or N.

Finally, although a substantial part of the variation in sedimented pigments was explained by the stock of pigments >5 µm in the water column, further testing is required to determine if the addition of new variables would improve the fit of the model. In this study, phaeopigments <5 µm and D_s were identified as potential predictors. Phaeopigments <5 µm may have contributed to sedimentation by forming aggregates: aggregation is more likely to occur when particle concentration is high (Hahn and Stumm 1970), and we observed that phaeopigments <5 µm contributed the most to sedimentation when concentrations were high. The importance of water density stratification has also been reported in other sites (Hargrave 1980). Vertical differences in current speed as well as current speed at the mouth of the trap should also be considered as potential predictors since they affect scouring and loss of material settled in traps (Hargrave 1980; Smetacek *et al.* 1978; U.S. GOFS 1989). Assessment of the relative importance of these variables would be required for a well-balanced data set, i.e. one that includes observations representing different combinations of the independent variables.

4.2 IMPLICATION OF OUR FINDINGS ON THE MONITORING OF BAIE DES CHALEURS

Our results showed that the contribution of large algal cells increased with total algal biomass and that sedimentation and water column constituents were best related through pigments >5 µm. These findings imply that the monitoring of total algal biomass and algal biomass in the size class >5 µm is likely to be useful in the assessment of the response in the coastal waters to changes in nutrient load and human activities, with the expectation being that eutrophic waters would tend to have higher total algal biomass and a greater contribution of algae >5 µm than oligotrophic waters. Further testing of our model predicting algal biomass >5 µm from total algal biomass as well as the development of new relationships based on nutrient load would be useful in the establishment of such a prognostic tool. With respect to monitoring, a model based on total algal biomass is appealing because such data over a wide spatial scale are becoming available from satellite imagery .

In addition, because pollutants such as heavy metals and chlorinated hydrocarbons are transported with particulate matter (Fowler and Knauer 1986), one would expect a greater proportion of pollutants to be transported downward when a higher quantity of pigments >5 µm is found in the water column. The extent of pollutant transport in relation to total and size-fractionated pigment biomass or production would be worth testing. If a good relationship exists, a sampling program combining extensive pigment measurements (*in situ* measurements or satellite imagery) with less extensive measurements of pollutants (*in situ* measurements) may provide an inexpensive prognostic of downward transport of pollutants.

Finally, an important consideration for a monitoring program is the sampling frequency, which is a function of the desired precision of the estimate and the variability. Based on the 1992 summer mean and variance at Gascons and random sampling theory, nine visits during the summer would be required to obtain a precision of 40% on the summer means of pigments in the size class >5 µm while only four visits would be required for a precision of 60%.

4.3 COMPARISON OF SUSPENDED AND SEDIMENTED MATTER IN VARIOUS COASTAL SITES

The pattern of algal biomass and pigment sedimentation at Gascons during the summer of 1992 was similar to other systems in that high values occurred early in the season and were related to the spring bloom (Hargrave and Taguchi 1978; Smetacek *et al.* 1984; Fowler *et al.* 1991; Wassmann 1991). However, there is a substantial variation in the absolute standing stocks among coastal waters, as illustrated by the mean summer standing stock of chlorophyll *a* and phaeopigments at two sites in Nova Scotia [St. Georges Bay (34 m) and Bedford Basin (70m)] and at Gascons (26 m) (Table 4). To minimize the within-site variation, only data from after the spring bloom were used for this comparison. The sediment traps used at the Nova Scotia sites were of the same design. They consisted of four cylinders (31 cm height and 7.5 cm internal diameter) clamped onto a metal wire that was held in position by an anchor and a subsurface float. As reflected by algal biomass, there was a trophic gradient from St. Georges Bay (oligotrophic) to Bedford Basin (eutrophic). High algal biomass in Bedford Basin has been associated with nutrient input from river runoff (Subba Rao and Smith 1986) while low algal biomass in St. Georges Bay has been attributed to nutrient recycling within the upper mixed layer (Hargrave *et al.* 1985). However, differences in pigment sedimentation rates among sites were not directly related to algal biomass. For example, sedimentation rates of pigments in Bedford Basin were comparable to those of St. Georges Bay even though the standing stocks of chlorophyll *a* and phaeopigments were 6- and 30-fold higher, respectively, in Bedford Basin than in St. Georges Bay. Furthermore, the highest sedimentation rates of pigments were observed at Gascons even though its water column supply was less than half that of Bedford Basin. This suggests that variables other than total algal biomass influenced sedimentation. At Gascons, we showed that high sedimentation rates were found when the stock of pigments >5 μm was high while at Bedford Basin low sedimentation rates have been attributed to advective processes (Hargrave and Taguchi 1978; Wassmann 1990). In addition, differences in sediment trap design and sampling frequency might explain some of the variation in sedimentation rates measured among sites. For instance, a higher collection efficiency would be expected at Gascons because the trap had an aspect ratio (i.e. the ratio of the height to the diameter) of 5 while that at the Nova Scotia sites was 4 (Hargrave and Burns 1979). Finally, more frequent sampling at Gascons (3 days on average) than the other sites (7 days) may have resulted in less degradation and consequently a higher apparent pigment sedimentation rate.

In summary, data from our fixed station indicated that most of the sedimenting matter was composed of detritus having low pigment content (most likely fecal pellets from carnivorous zooplankton). The model describing the pigment sedimentation rate had a greater predictive power (R^2= 46.4%) than those describing the sedimentation rates of C (14.6%) or N (24.2%). Among water column constituents, the stock of pigments >5 μm was the best single predictor of the pigment sedimentation rate; this log-log relationship was not linear. Between-site comparisons suggest that pigment sedimentation also depends on physical factors. Further testing based on a data set including measurements of size-fractionated pigments and current speed would be required to assess their relative importance on pigment sedimentation rate. Nine visits during the summer would be required to obtain a precision of 40% on the summer means of pigments in the size class >5 μm while only four visits would be required for a precision of 60%.

5.0 Acknowledgments

This study was completed with the assistance of several individuals. We thank Edouard St-Onge of Mont-Joli Machinerie for his interest in the construction and assessment of sediments traps, Marie-Lyne Dubé for nutrient analysis, Colette Trickey for her assistance in the laboratory and field, Jean-François Sanfaçon for his help in coupling the STD and fluorometer, and André Ducharme for his skill in providing a computer interface. Special acknowledgment is due to A. Vézina for his criticism of an earlier version, to M. Starr for numerous discussions, and to M. Fréchette and M. Starr for their valuable comments in the revision process. Thanks go to the city of Mont-Joli for allowing the use of their swimming pool to test the stability of our sediment traps. Finally, thanks to all the fishermen of Anse à la Barbe for their conversations and interest, and to all the people of Port Daniel who helped us in so many ways.

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Table 1. Statistics on suspended matter throughout the summer and during and after the declining bloom period. Average ($\overline{X}$), range, and coefficient of variation (CV) for depth-integrated concentrations (0-17 m) of chlorophyll *a* (Chl *a*), phaeopigments (Phaeo), and organic carbon (C) and nitrogen (N). Units are mg m^{-2}; number of samples in parentheses. P is the probability of a greater T when testing for difference between two groups (during and after the declining bloom).

		Summer (n=27)	Declining bloom (n=3)	Post-bloom (n=24)	P>T
Total Chl *a*	$\overline{X}$	21.64	39.21	19.44	0.0001
	Range	5.10-48.49	25.44-48.49	5.10-31.19	
	CV	42.00	31.02	30.47	
Chl *a* 5-153 µm	$\overline{X}$	6.74	26.69	4.25	0.05
	Range	0.65-33.41	15.75-33.41	0.65-10.54	
	CV	117.84	35.82	52.83	
Chl *a* <5 µm	$\overline{X}$	14.89	12.52	15.19	0.33
	Range	4.45-24.43	9.69-15.09	4.45-24.34	
	CV	29.91	21.61	30.14	
Total Phaeo	$\overline{X}$	6.64	13.02	5.84	0.0001
	Range	3.11-15.28	11.21-15.28	3.11-8.05	
	CV	40.7	15.94	23.80	
Phaeo 5-153 µm	$\overline{X}$	1.81	7.24	1.13	0.03
	Range	-0.18-9.47	5.53-9.47	-0.18-2.91	
	CV	119.06	27.92	67.35	
Phaeo <5 µm	$\overline{X}$	4.82	5.77	4.70	0.16
	Range	2.08-7.03	4.47-7.03	2.08-6.61	
	CV	25.9	22.12	25.58	
Total C	$\overline{X}$	6,920.10	11,757.23	6,315.46	0.06
	Range	4631.25-1,3642.95	8,965.00-13,642.95	4,631.25-8,182.75	
	CV	29.2	20.98	14.59	
Total N	$\overline{X}$	848.94	1664.77	746.96	0.0001
	Range	437.25-1,860.55	1,384.75-1,860.55	437.25-1,151.50	
	CV	42.5	14.95	27.11	

Table 2. Statistics on sedimentation throughout the summer and during and after the declining bloom period. Average ($\overline{X}$), range, and coefficient of variation (CV) for sedimentation rates of chlorophyll *a* (Chl *a*), phaeopigments (Phaeo), and organic carbon (C) and nitrogen (N). Units are mg m^{-2} d^{-1}; number of samples in parentheses. P is the probability of a greater T when testing for difference between two groups (during and after the declining bloom).

		Summer (n=28)	Declining bloom (n=5)	Post bloom (n=23)	P>T
Total Chl *a*	$\overline{X}$	0.75	2.03	0.47	0.0054
	Range	0.19-2.90	1.09-2.90	0.19-1.17	
	CV	92.3	32.01	49.17	
Total Phaeo	$\overline{X}$	1.53	2.43	1.33	0.0005
	Range	0.52-2.98	2.23-2.91	0.52-2.98	
	CV	45.6	11.83	44.74	
Total C	$\overline{X}$	235.91	345.04	212.18	0.0024
	Range	88.21-458.37	243.39-458.37	88.21-439.75	
	CV	39.8	22.78	37.83	
Total N	$\overline{X}$	33.12	53.05	28.60	0.0004
	Range	11.58-70.43	35.09-70.43	11.58-64.46	
	CV	46.42	26.24	41.37	

Table 3. Paired t-test comparisons based on the ratios of organic carbon to nitrogen (C/N) and of chlorophyll *a* to pigments (Chl *a*/pig) in suspended and sedimented matter. Minimum and maximum values are in parentheses. Ratios were arcsine transformed. P is the probability of a greater T when testing for difference between A) mean summer ratios in suspended and sedimented matter and B) mean ratios during and after the declining bloom for suspended and sedimented matter.

A) mean summer ratios

	Suspended matter	Sedimented matter	P>T
C/N	8.42 (6.47-10.18)	7.48 (4.6-10.87)	0.005
Chl *a*/pig	0.76 (0.65-0.82)	0.29 (0.16-0.57)	0.0001

B) mean ratios during and after the declining bloom

	Suspended matter			Sedimented matter		
	Declining bloom	Post bloom	P>T	Declining bloom	Post bloom	P>T
C/N	6.90 (6.47-7.28)	8.61 (7.13-10.18)	0.003	6.93 (5.88-6.93)	7.71 (4.6-10.87)	0.02
Chl *a*/pig	0.76 (0.72-0.79)	0.76 (0.65-0.82)	0.94	0.44 (0.29-0.59)	0.24 (0.16-0.77)	0.0001

Table 4. Depth-integrated water column concentrations (mg m^{-2}) and sedimentation rates (mg m^{-2} d^{-1}) of total chlorophyll *a* (Chl *a*) and total phaeopigments (Phaeo) in various coastal waters of the southeast region of the Gulf of St. Lawrence during the summer (June-August). Data from St. Georges Bay, Nova Scotia, (Marine Ecology Laboratory, 1980) and from Bedford Basin (Hargrave et al. 1976, Hargrave and Taguchi 1978). Mean ($\overline{X}$), range, and coefficient of variation (CV); number of samples in parentheses.

		St. Georges Bay	Bedford Basin	Gascons
Water column		0-15 m	0-20 m	0-17 m
Chl *a*	$\overline{X}$	7.08 (9)	48.15 (6)	19.44 (24)
	Range	1.5-13.98	11.1-100.0	5.10-31.19
	CV	71.3	63.1	30.47
Phaeo	$\overline{X}$	3.81 (8)	116.67 (5)	5.84 (24)
	Range	0.64-8.14	75.0-208.3	3.11-8.05
	CV	70.9	46.8	23.80
sedimentation		20 m	20 m	19 m
Chl *a*	$\overline{X}$	0.17 (11)	0.12 (3)	0.47 (23)
	Range	0.009-0.72	0.03-0.18	0.19-1.17
	CV	111.4	68.9	49.17
Phaeo	$\overline{X}$	0.23 (11)	0.16 (3)	1.33 (23)
	Range	0.027-0.48	0.10-0.24	0.52-2.98
	CV	65.9	44.6	44.74

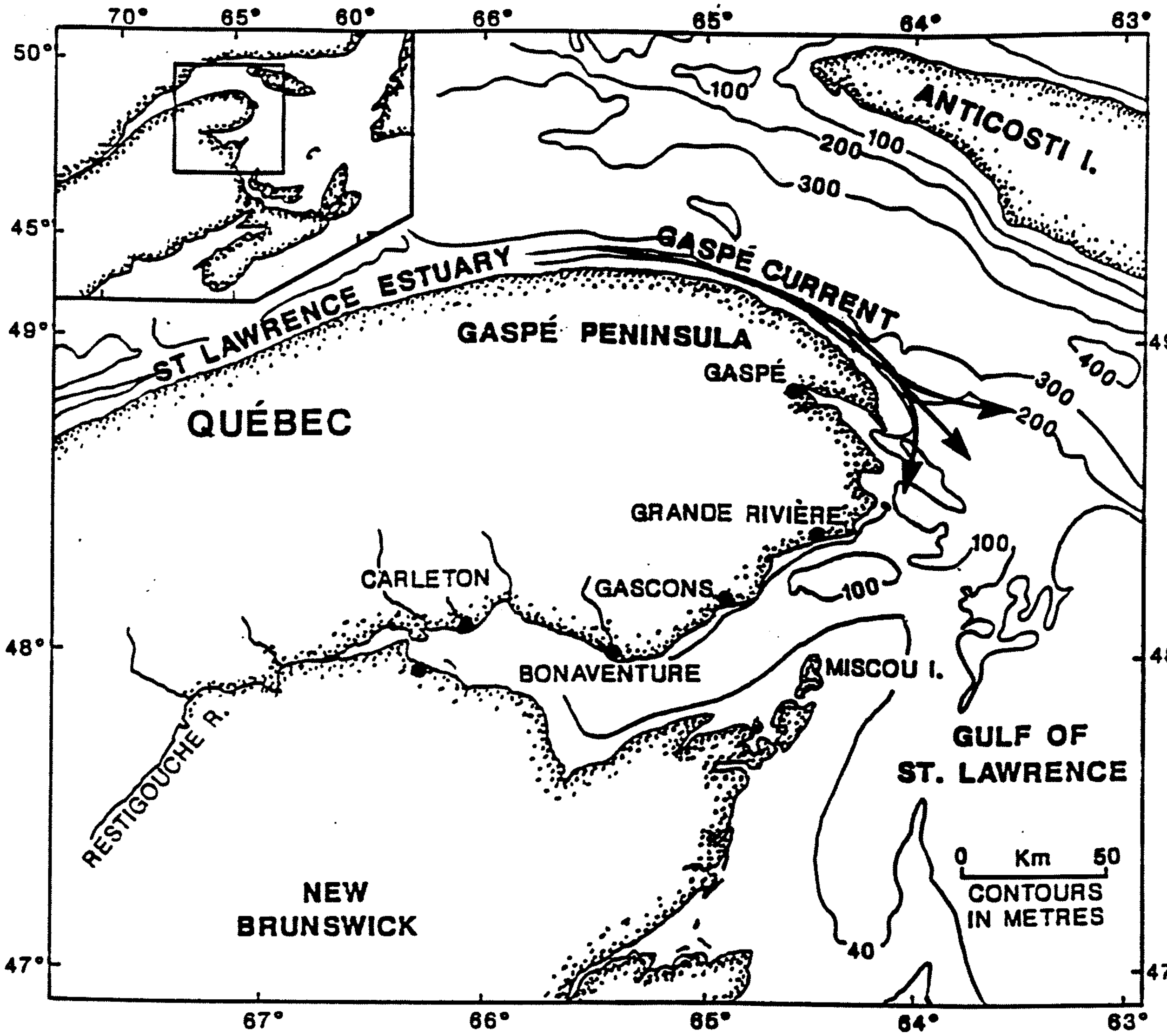

Figure 1. Location of the sampling site near Gascons, baie des Chaleurs, Québec. Reproduced with permission of J. Bonardelli.

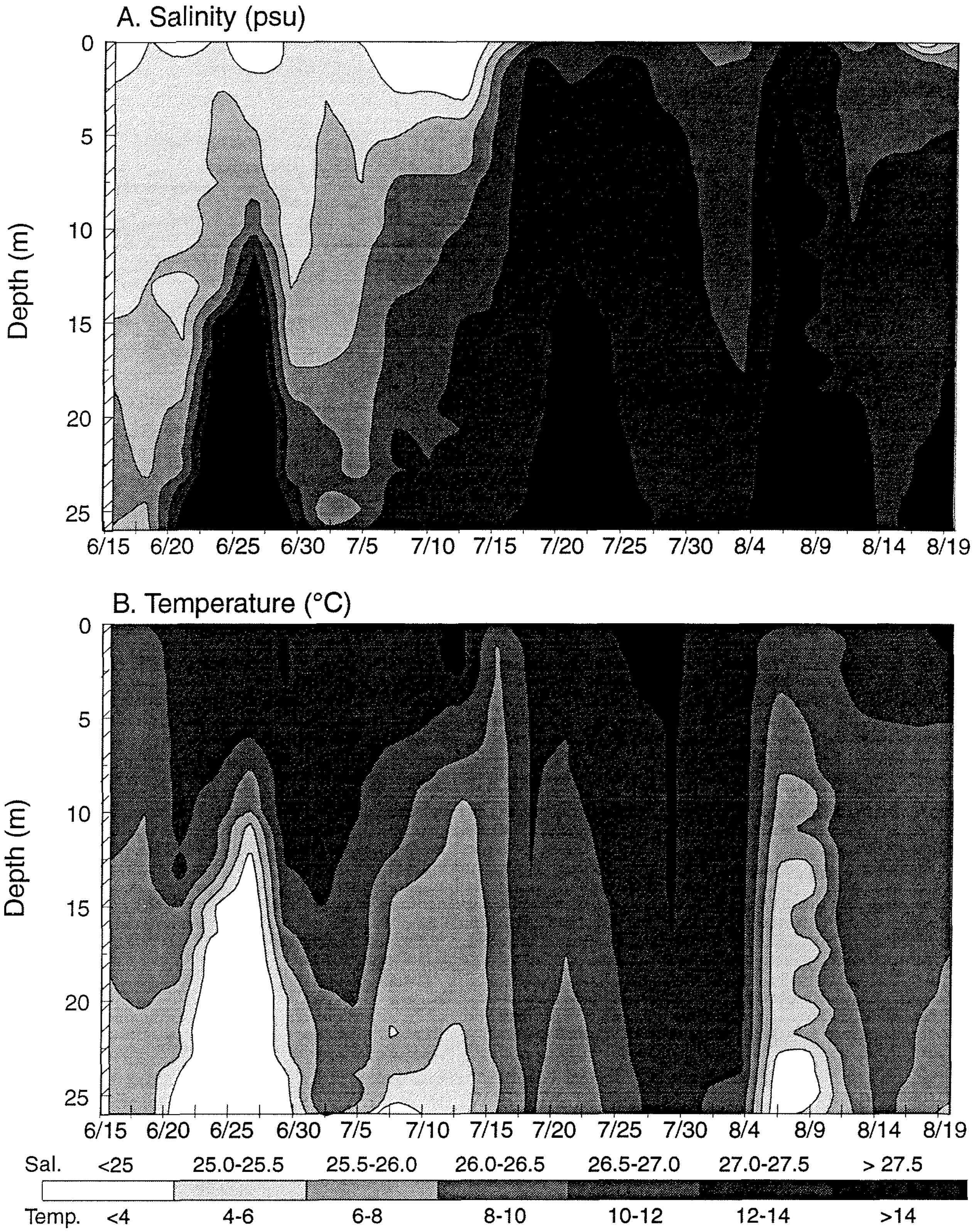

Figure 2. Variation with depth of A) salinity and B) temperature at Gascons from 16 June to 20 August 1992. Hatched area indicates unavailable data.

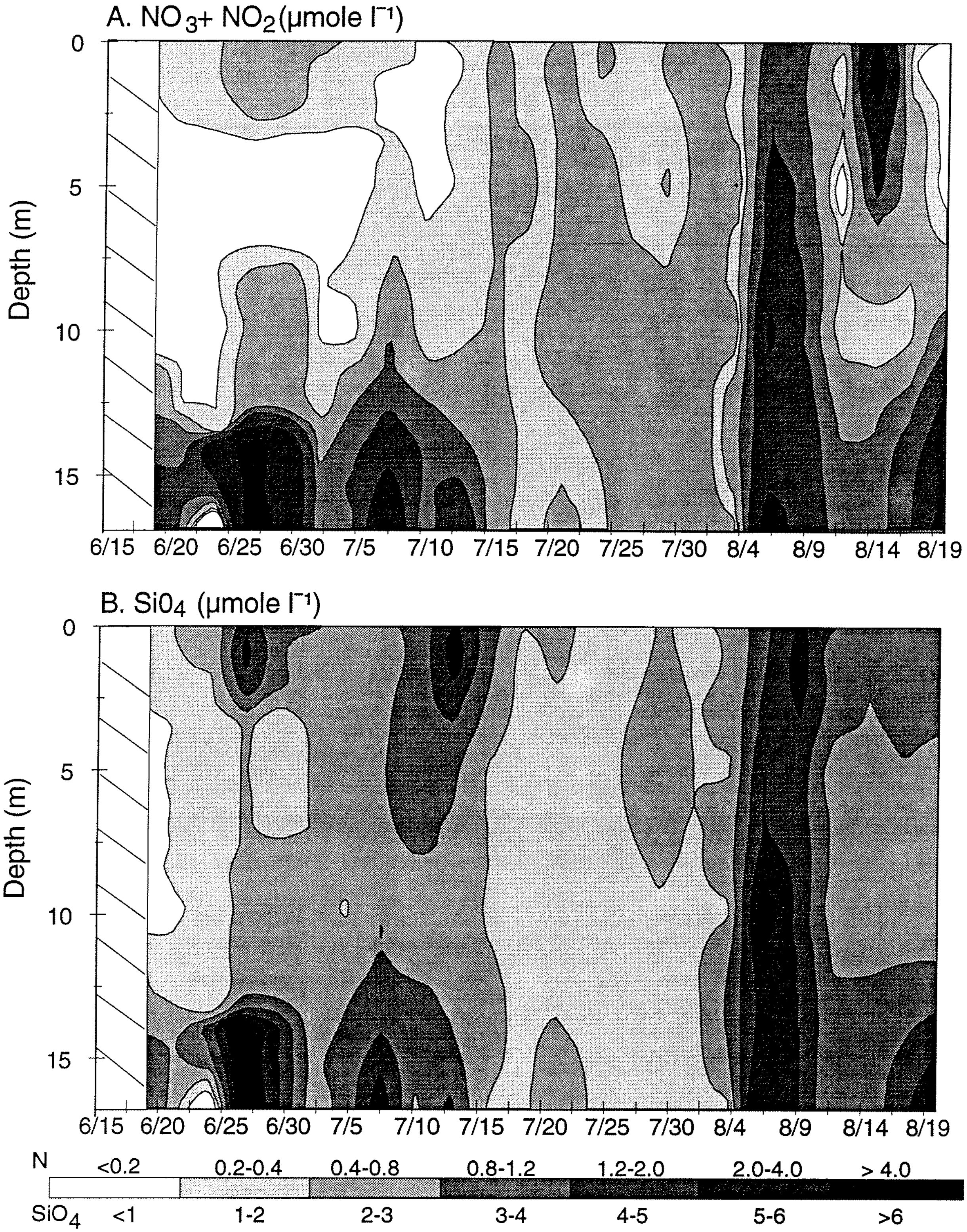

Figure 3. Variation with depth of A) nitrate-nitrite (NO_2+NO_3, µmole l^{-1}) and B) silicate (SiO_4, µmole l^{-1}) at Gascons from 19 June to 20 August 1992. Hatched area indicates unavailable data.

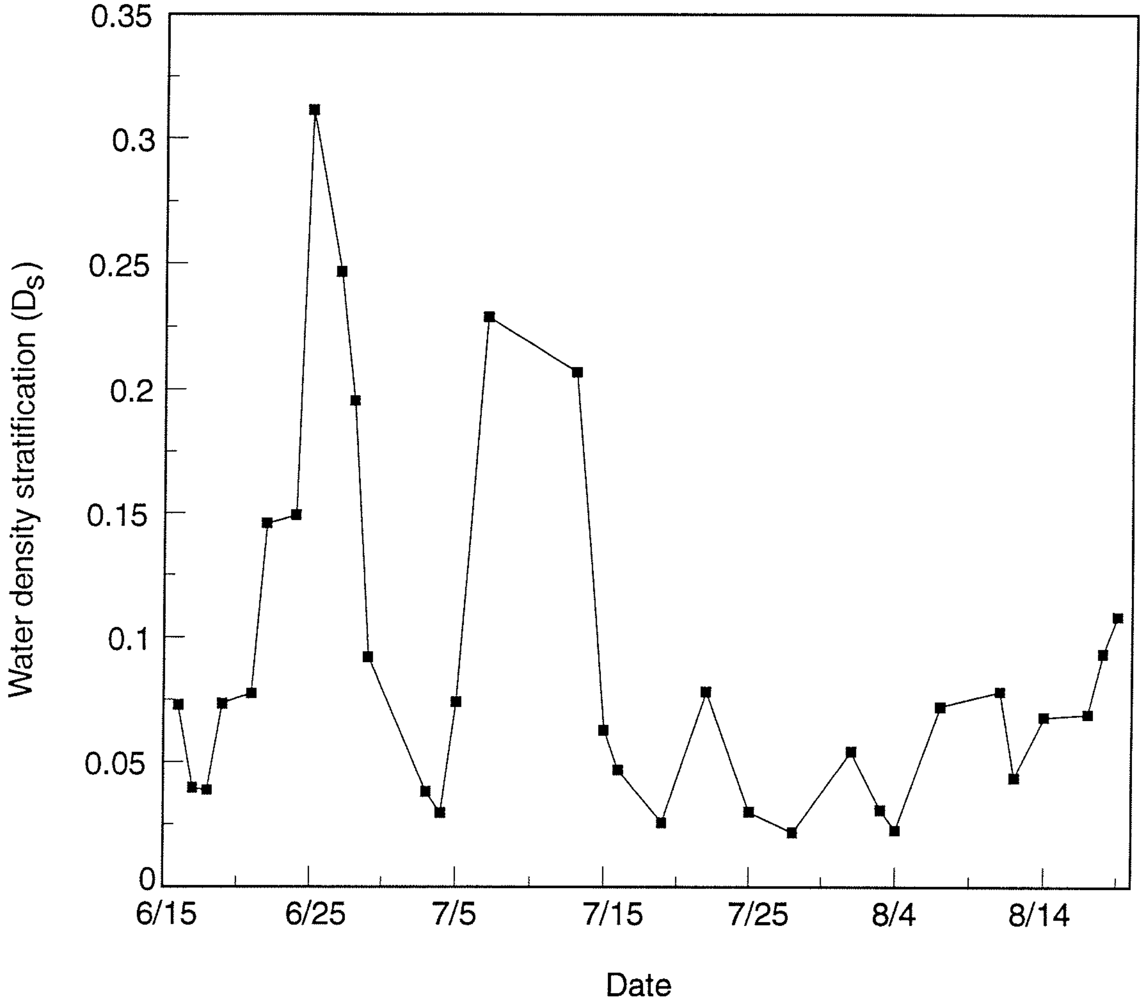

Figure 4. Temporal changes in water density statification (D_S) at Gascons from 16 June to 20 August 1992.

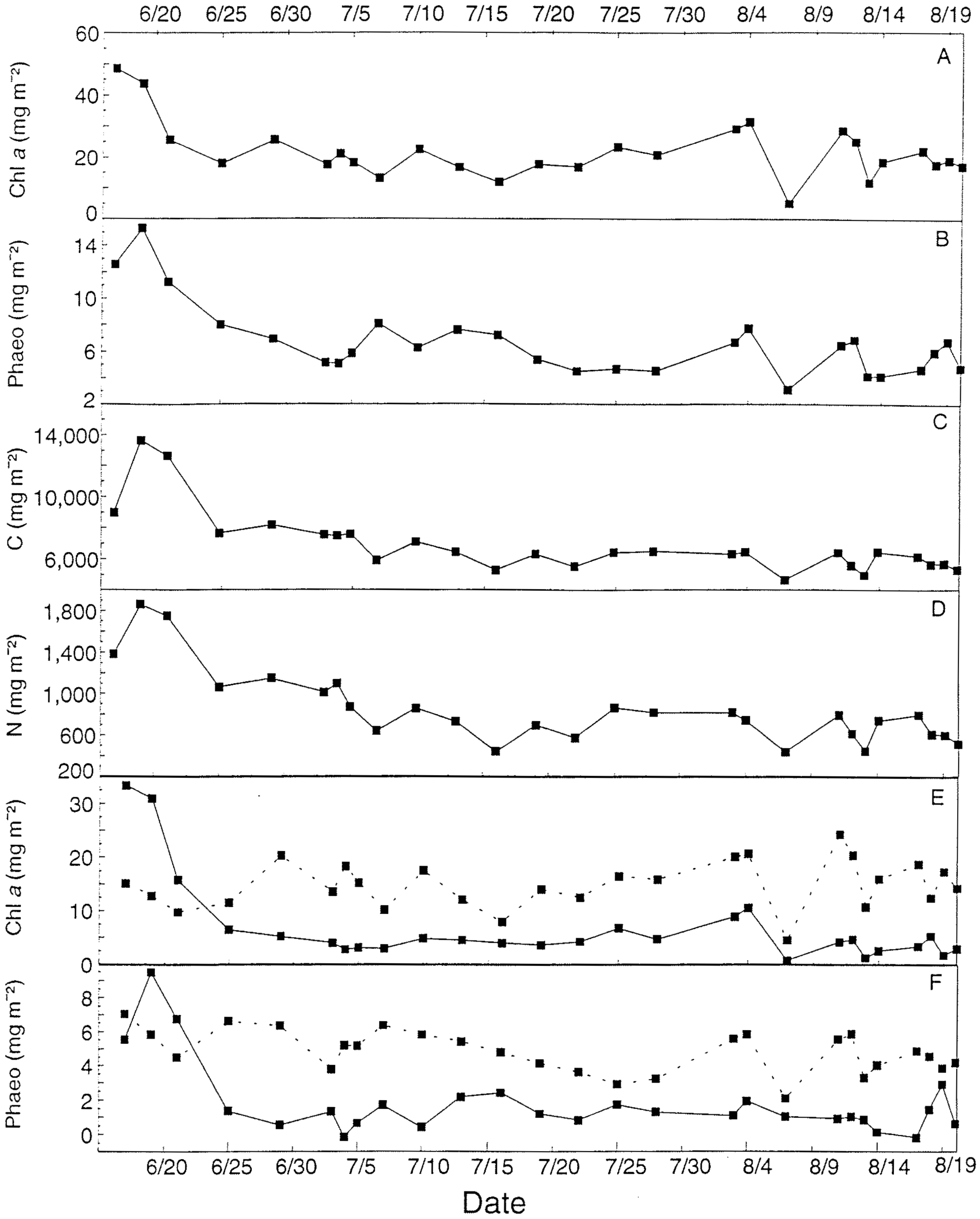

Figure 5. Variation of depth-integrated (0-17 m) A) chlorophyll *a* (Chl *a*), B) phaeopigments (Phaeo), C) organic carbon, and D) organic nitrogen; and of E) chlorophyll *a* and F) phaeopigments in two size classes (<5 μm: dashed line; 5-153 μm: solid line) at Gascons from 16 June to 20 August 1992.

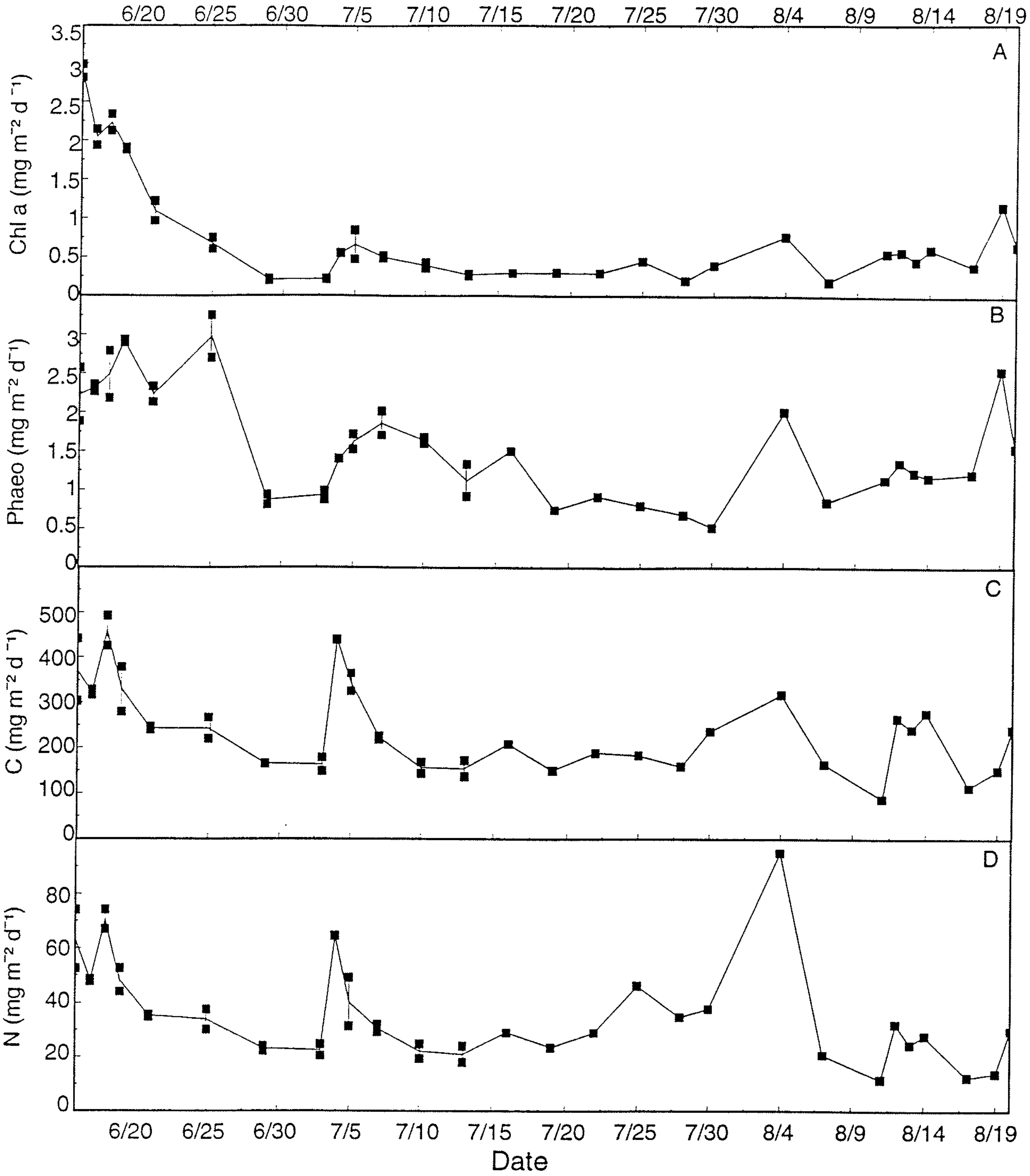

Figure 6. Variation of sedimentation of total A) chlorophyll *a* (Chl *a*), B) phaeopigments (Phaeo), C) organic carbon, and D) organic nitrogen at Gascons from 16 June to 20 August 1992.

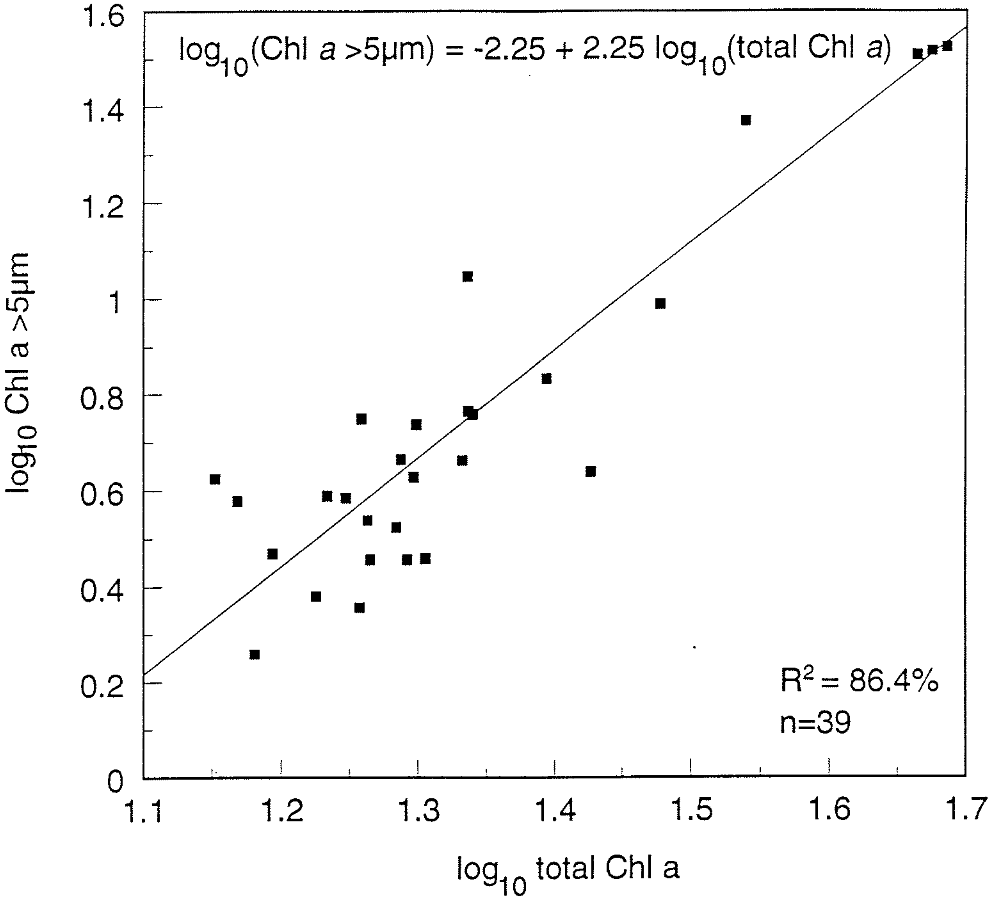

Figure 7. Relationship between chlorophyll *a* in the size class >5 µm and total chlorophyll *a* in the water column.

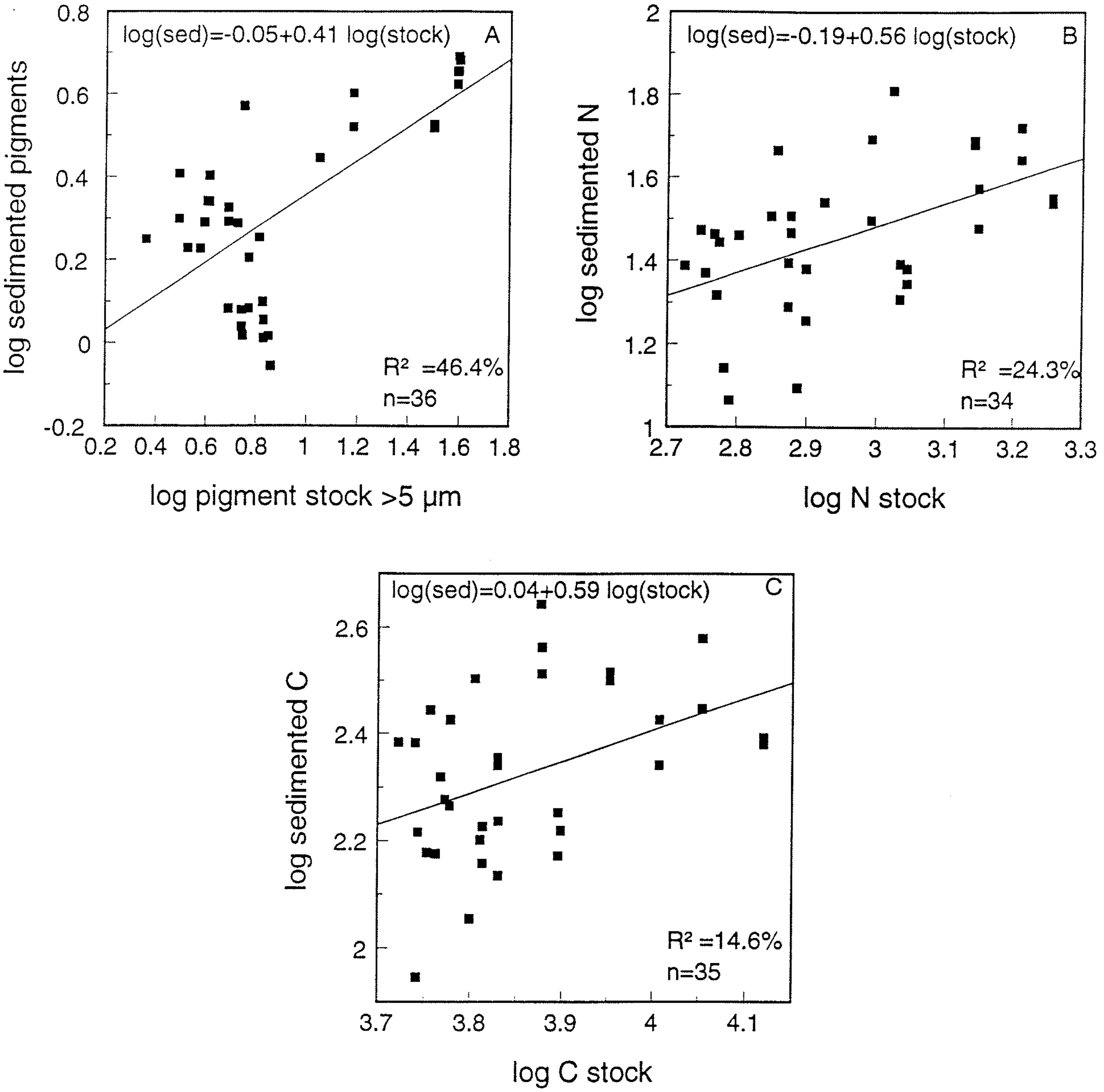

Figure 8. Relationships between A) sedimented pigments and the standing stock of pigments in particles >5 µm, B) sedimented N and the standing stock of N, and C) sedimented C and the standing stock of C in the water column. All values are $\log_{10}$ transformed. Regression lines are drawn and equations given. Units are in mg m^{-2} d^{-1} for sedimentation and mg m^{-2} for standing stock.

APPENDIX 1

Sampling calendar and sampling gear used at Gascons, June through August 1992: sediment traps (A and B), niskin, STD and fluorometrer (STD + FLUO). Shaded cells indicate days when samples were taken; dates of initial trap moorings are indicated by asterisks (*).

June 1992

Date	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Trap A	*	▨	▨	▨	▨		▨				▨				▨	
Trap B	*	▨	▨	▨	▨		▨				▨				▨	
niskin			▨		▨		▨	▨		▨	▨		▨	▨	▨	
STD+FLUO		▨	▨	▨	▨		▨	▨		▨	▨		▨	▨	▨	

July 1992

Date	1-2	3	4	5	6	7	8-9	10	11-12	13	14	15	16	17-18	19	20-21	22	23-24	25	26-27	28	29	30	31
Trap A		▨	▨	▨		▨		▨		▨			▨		▨		▨		▨		▨		▨	
Trap B		▨		▨		▨		▨		▨	*													
niskin		▨	▨	▨		▨		▨		▨			▨		▨		▨		▨		▨			
STD+FLUO		▨	▨	▨		▨		▨		▨			▨		▨		▨		▨		▨			▨

August 1992

Date	1	2	3	4	5-6	7	8-10	11	12	13	14	15-16	17	18	19	20
Trap A																
Trap B			*	▨		▨		▨	▨	▨	▨		▨		▨	▨
niskin			▨	▨		▨		▨	▨	▨	▨		▨	▨	▨	▨
STD+FLUO	▨		▨	▨		▨		▨	▨	▨	▨		▨	▨	▨	▨

APPENDIX 2

Chlorophyll *a* and phaeopigments in two size classes (<153 µm and <5 µm; mean and standard deviation based on two replicates) and total organic C and N at 1, 5, 10, and 17 m from the surface at Gascons 17 June to 20 August 1992. Units are mg m^{-3}. Unavailable data indicated by n/a.

		Chl *a*				Phaeopigment				organic C	organic N
date	depth	<153 µm		<5 µm		<153 µm		<5 µm		<153 µm	<153µm
	(m)	mean	sd	mean	sd	mean	sd	mean	sd		
17-Jun	1	1.3943	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
17-Jun	5	3.6542	0.4730	0.8099	0.1124	0.7635	0.1549	0.3256	0.0142	693.0	122.0
17-Jun	10	3.9204	0.1182	1.1046	0.0935	0.8470	0.1015	0.5205	0.0438	443.0	60.5
17-Jun	17	1.2421	0.2458	0.6812	0.1272	0.4990	0.0871	0.4182	0.1276	317.0	30.5
17-Jun	23	0.8167	0.0728	0.4394	0.0732	0.4918	0.2068	0.4422	0.2130	n/a	n/a
19-Jun	1	0.8608	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
19-Jun	5	2.8019	0.3620	0.8364	0.0164	0.9472	0.1553	0.3143	0.0080	994.3	153.1
19-Jun	10	3.9039	0.2681	0.8161	0.1422	0.9774	0.1901	0.3795	0.0177	652.6	85.7
19-Jun	17	1.4544	0.1743	0.4573	0.0424	0.6620	0.2233	0.3364	0.1782	648.6	56.6
21-Jun	1	1.5599	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
21-Jun	5	1.3591	0.1306	0.6672	0.0300	0.5847	0.1532	0.2196	0.0465	665.5	118.0
21-Jun	10	1.0651	0.2645	0.4923	0.0205	0.5226	0.1191	0.2044	0.0505	804.5	88.0
21-Jun	17	2.3586	0.4734	0.4961	0.1465	1.0548	0.3675	0.4581	0.1983	813.0	96.0
25-Jun	1	1.3799	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
25-Jun	5	2.4178	0.5136	1.2032	0.0432	0.4488	0.1310	0.4012	0.0799	611.0	97.0
25-Jun	10	0.3891	0.0611	0.3488	0.0084	0.5678	0.4124	0.4516	0.2594	335.5	42.5
25-Jun	17	0.1737	0.0234	0.1221	0.0423	0.3445	0.2233	0.2559	0.1959	306.5	22.5
29-Jun	1	13.5091	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
29-Jun	5	1.5331	0.2410	1.3760	0.1541	0.4290	0.0801	0.4227	0.1118	478.0	80.0
29-Jun	10	2.0395	0.3898	1.3977	0.2883	0.3823	0.0134	0.3456	0.0371	521.0	64.5
29-Jun	17	0.5065	0.0277	0.4538	0.0725	0.3921	0.1141	0.3161	0.1026	420.5	47.0
03-Jul	1	0.8600	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
03-Jul	5	0.7970	0.1504	0.8262	0.2901	0.3246	0.0057	0.2159	0.1478	427.5	62.5
03-Jul	10	1.0031	0.0571	0.5685	0.0885	0.2429	0.0003	0.1953	0.0749	419.0	53.5
03-Jul	17	1.5183	0.0811	1.1196	0.0937	0.3478	0.1332	0.2807	0.0380	524.0	63.5

Appendix 2, continued

date	depth	Chl *a*				phaeopigment				organic C	organic N
		<153 µm		<5 µm		<153 µm		<5 µm		<153 µm	<153 µm
	(m)	mean	sd	mean	sd	mean	sd	mean	sd		
04-Jul	1	0.5592	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
04-Jul	5	1.3674	0.0154	1.1643	0.0540	0.3200	0.0967	0.3200	0.0512	389.5	75.5
04-Jul	10	1.3675	0.1039	0.9318	0.1087	0.2582	0.1031	0.2991	0.0360	463.5	57.0
04-Jul	17	1.4185	0.0319	1.1355	0.0036	0.3103	0.0777	0.2824	0.0428	510.0	53.5
05-Jul	1	1.2525	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
05-Jul	5	1.4497	0.5042	1.1885	0.2332	0.3271	0.0681	0.3158	0.0234	444.0	54.0
05-Jul	10	0.9342	0.0140	0.7026	0.0520	0.2257	0.1651	0.2134	0.0147	483.0	53.5
05-Jul	17	0.6601	0.1325	0.5897	0.1735	0.5718	0.3785	0.4307	0.2013	391.5	40.5
07-Jul	1	0.9091	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
07-Jul	5	1.0184	0.0488	0.7831	0.0169	0.3544	0.0699	0.2586	0.0506	374.0	40.5
07-Jul	10	0.5623	0.1416	0.4354	0.0167	0.3863	0.0076	0.3356	0.0396	293.0	34.0
07-Jul	17	0.6743	0.0752	0.4821	0.0493	0.8792	0.5523	0.6870	0.4502	385.0	37.0
10-Jul	1	1.5097	0.1183	1.3979	0.2764	0.3151	0.0561	0.2246	0.1841	431.0	51.0
10-Jul	5	1.5002	0.0064	0.9570	0.1376	0.3015	0.0582	0.2563	0.0522	428.0	49.0
10-Jul	10	1.4150	0.1122	0.9912	0.3270	0.3469	0.1728	0.3714	0.0644	448.0	61.5
10-Jul	17	0.7234	0.1438	0.8717	0.5120	0.5247	0.3258	0.5003	0.1191	341.5	32.5
13-Jul	1	0.9738	0.0465	0.7969	0.0624	0.2622	0.0668	0.1944	0.1052	466.0	47.5
13-Jul	5	1.0448	0.0538	0.9537	0.0618	0.4003	0.0633	0.3434	0.0338	357.0	38.5
13-Jul	10	1.1322	0.0951	0.6128	0.0374	0.5161	0.0239	0.3129	0.0268	362.0	43.5
13-Jul	17	0.5936	0.0313	0.4843	0.0384	0.5405	0.2803	0.3990	0.1661	n/a	n/a
16-Jul	1	0.5596	0.0220	0.3799	0.0285	0.3123	0.0321	0.2264	0.0236	367.5	27.0
16-Jul	5	0.7358	0.0613	0.5035	0.0210	0.4758	0.1785	0.3260	0.0898	302.0	23.0
16-Jul	10	0.7484	0.0123	0.4597	0.0907	0.4515	0.1652	0.2628	0.0213	296.0	27.0
16-Jul	17	0.6889	0.0508	0.4991	0.1409	0.4011	0.1750	0.3014	0.0315	n/a	n/a
19-Jul	1	0.9924	0.0517	0.7966	0.0818	0.3318	0.0183	0.2583	0.0307	493.0	45.0
19-Jul	5	1.2567	0.0073	0.9236	0.0528	0.3335	0.0361	0.2464	0.0205	352.0	43.5
19-Jul	10	1.0083	0.0566	0.8167	0.0868	0.2988	0.0574	0.2239	0.0643	331.0	39.5
19-Jul	17	0.8254	0.0991	0.7279	0.1112	0.3017	0.0066	0.2621	0.0100	358.5	36.5
22-Jul	1	0.7660	0.0338	0.5442	0.0174	0.1753	0.0770	0.1585	0.0281	390.0	32.5
22-Jul	5	1.1114	0.1030	0.9372	0.0183	0.2776	0.1467	0.2618	0.1220	333.5	31.5
22-Jul	10	1.2881	0.0509	0.8956	0.1422	0.2825	0.0598	0.2052	0.0793	307.5	38.5
22-Jul	17	0.4649	0.0532	0.3579	0.0704	0.2823	0.0822	0.2133	0.0428	292.0	29.5

Appendix 2, continued

date	depth	Chl *a*				phaeopigment				organic C	organic N
		<153 µm		<5 µm		<153 µm		<5 µm		<153 µm	<153 µm
	(m)	mean	sd	mean	sd	mean	sd	mean	sd		
25-Jul	1	0.9516	0.1163	0.6383	0.0957	0.1419	0.0675	0.0933	0.0602	432.0	45.0
25-Jul	5	1.1588	0.0905	0.9634	0.0851	0.2280	0.0755	0.1686	0.0965	372.5	61.5
25-Jul	10	1.5764	0.1428	0.9742	0.1691	0.3570	0.1011	0.1636	0.0676	341.5	39.5
25-Jul	17	1.6077	0.2557	1.2411	0.1249	0.2972	0.2035	0.2556	0.1320	406.0	61.5
28-Jul	1	1.3587	0.2331	1.1492	0.2619	0.3056	0.1562	0.2179	0.1418	408.0	49.0
28-Jul	5	1.2660	0.2873	0.7851	n/a	0.3070	0.0860	0.1331	n/a	401.5	44.0
28-Jul	10	1.2562	0.0970	1.0376	0.1884	0.2222	0.0459	0.1899	0.0142	342.5	53.0
28-Jul	17	0.9480	0.0507	0.7702	0.0070	0.2549	0.0462	0.2386	0.0116	403.5	44.0
03-Aug	1	2.4774	0.3469	1.4316	0.2538	0.5075	0.1426	0.3673	0.1004	418.0	81.0
03-Aug	5	1.6650	0.2750	1.1276	0.0486	0.4035	0.1636	0.2935	0.1232	373.0	39.5
03-Aug	10	1.5842	0.0689	1.2410	0.0967	0.3216	0.0149	0.3289	0.0583	351.5	38.5
03-Aug	17	1.2932	0.1986	0.9375	0.1313	0.4001	0.0502	0.3366	0.0419	364.5	47.5
04-Aug	1	1.5711	0.2696	1.1499	0.1365	0.4678	0.0529	0.4482	0.0107	n/a	n/a
04-Aug	5	1.9512	0.0208	1.2280	0.0080	0.4942	0.1403	0.3471	0.1763	359.0	38.5
04-Aug	10	1.8958	0.1278	1.1735	0.1487	0.4273	0.1561	0.2811	0.0155	374.0	44.0
04-Aug	17	1.8065	0.1251	1.3222	0.0779	0.4434	0.1320	0.3518	0.0886	429.0	54.5
07-Aug	1	0.4128	0.0638	0.3490	0.0649	0.1555	0.0210	0.1130	0.0272	349.0	33.5
07-Aug	5	0.3050	0.0535	0.3183	0.0484	0.1542	0.0087	0.1123	0.0216	247.5	20.5
07-Aug	10	0.2815	0.0271	0.2131	0.0001	0.2109	0.0455	0.1158	0.0121	224.5	21.5
07-Aug	17	0.2301	0.0476	0.1975	0.0571	0.1942	0.0415	0.1561	0.0514	321.0	33.0
11-Aug	1	1.2841	0.0533	1.1516	0.0967	0.2576	0.0987	0.2079	0.1276	389.5	43.5
11-Aug	5	1.9430	0.1328	1.6151	0.3235	0.4935	0.0704	0.4238	0.1170	338.0	47.0
11-Aug	10	1.9919	0.3334	1.6679	0.1030	0.3491	0.1242	0.2786	0.1114	401.5	51.5
11-Aug	17	1.1216	0.2511	1.0327	0.2166	0.3935	0.0650	0.3822	0.0058	370.5	41.0
12-Aug	1	1.4327	0.2272	1.2101	0.0389	0.3583	0.1158	0.3495	0.0759	375.0	37.0
12-Aug	5	1.8511	0.0383	1.5899	0.0208	0.5181	0.0369	0.3959	0.172	323.5	37.0
12-Aug	10	1.6794	0.0548	1.3037	0.2696	0.4179	0.0302	0.3235	0.0728	323.5	38.0
12-Aug	17	0.6527	0.1430	0.5174	0.1414	0.2782	0.0216	0.3103	0.0713	305.0	31.5
13-Aug	1	0.6996	0.0226	0.6307	0.1059	0.2228	0.0322	0.1859	0.0467	361.0	33.0
13-Aug	5	0.7929	0.0803	0.7434	0.1363	0.2343	0.0107	0.1838	0.0536	307.5	27.0
13-Aug	10	0.6982	0.1019	0.6123	0.0054	0.2730	0.0353	0.2011	0.0626	243.5	22.5

Appendix 2, continued

date	depth	Chl *a*				phaeopigment				organic C	organic N
		<153 µm		<5 µm		<153 µm		<5 µm		<153 µm	<153 µm
	(m)	mean	sd	mean	sd	mean	sd	mean	sd		
13-Aug	17	0.5697	0.0819	0.5146	0.0953	0.2250	0.0773	0.2027	0.0167	293.5	26.0
14-Aug	1	0.6857	n/a	0.6162	n/a	0.1962	n/a	0.1827	n/a	394.5	34.5
14-Aug	5	1.2870	n/a	1.1329	n/a	0.2512	n/a	0.1692	n/a	340.5	40.5
14-Aug	10	1.1727	n/a	0.9839	n/a	0.2332	n/a	0.2793	n/a	380.0	48.0
14-Aug	17	1.0236	n/a	0.8944	n/a	0.2915	n/a	0.2935	n/a	415.0	48.5
17-Aug	1	1.3168	n/a	1.1926	n/a	0.2369	n/a	0.3093	n/a	422.5	56.0
17-Aug	5	1.6298	n/a	1.4857	n/a	0.2740	n/a	0.2495	n/a	355.5	45.0
17-Aug	10	1.2373	n/a	1.0335	n/a	0.2308	n/a	0.2608	n/a	348.5	49.0
17-Aug	17	0.9342	n/a	0.6460	n/a	0.3861	n/a	0.3578	n/a	342.0	38.0
18-Aug	1	0.8994	n/a	0.8795	n/a	0.1822	n/a	0.1502	n/a	378.5	41.0
18-Aug	5	1.0882	n/a	0.8547	n/a	0.3150	n/a	0.1699	n/a	299.5	29.5
18-Aug	10	0.9888	n/a	0.7304	n/a	0.4040	n/a	0.2786	n/a	288.5	35.0
18-Aug	17	1.1826	n/a	0.4472	n/a	0.4541	n/a	0.4710	n/a	410.5	41.0
19-Aug	1	1.0137	n/a	0.9789	n/a	0.1950	n/a	0.1754	n/a	374.0	32.0
19-Aug	5	1.5255	n/a	1.2522	n/a	0.2617	n/a	0.1822	n/a	331.5	36.0
19-Aug	10	1.0683	n/a	1.0286	n/a	0.3349	n/a	0.2683	n/a	324.0	38.5
19-Aug	17	0.7702	n/a	0.7453	n/a	0.8587	n/a	0.2585	n/a	320.5	32.0
20-Aug	1	1.1429	n/a	1.0137	n/a	0.0736	n/a	0.1821	n/a	410.5	33.0
20-Aug	5	1.6000	n/a	1.4410	n/a	0.3064	n/a	0.2605	n/a	374.5	40.5
20-Aug	10	0.9590	n/a	0.6807	n/a	0.3560	n/a	0.2686	n/a	243.5	28.5
20-Aug	17	0.2221	n/a	0.1919	n/a	0.2967	n/a	0.2376	n/a	266.0	19.0

APPENDIX 3

Sedimentation of total Chl *a* and phaeopigments (mean and standard deviation based on two replicates) and of total organic C and N at Gascons from 16 June to 20 August 1992. Units are mg m^{-2} d^{-1}. Two traps (A,B), collection period in days (dur).

trap	date	dur	Chl *a*		Phaeopigments		C	N
			mean	sd	mean	sd		
A	16-Jun	1	2.7189	0.1465	2.0952	0.5945	303.668	52.521
A	17-Jun	1	1.7425	0.1955	2.8650	0.4263	316.082	47.746
A	18-Jun	1	1.7399	0.1993	2.0084	0.2372	424.944	66.845
A	19-Jun	1	1.7830	0.1619	3.2305	0.2019	378.630	52.521
A	21-Jun	2	1.0975	0.0282	2.4925	0.1375	240.165	35.571
A	25-Jun	4	0.5627	0.0112	2.8738	0.1202	266.783	37.481
A	29-Jun	4	0.1780	0.0060	0.9505	0.1569	165.203	22.083
A	03-Jul	4	0.1537	0.0186	0.8400	0.0746	148.492	20.292
A	04-Jul	1	0.5471	0.1111	1.4216	0.1384	439.745	64.458
A	05-Jul	1	0.5904	0.1482	0.9577	0.3509	364.783	49.179
A	07-Jul	2	0.4645	0.0117	1.5849	0.2022	226.318	31.990
A	10-Jul	3	0.3138	0.0609	1.2099	0.1797	143.717	19.417
A	13-Jul	3	0.2577	0.0288	0.9172	0.3285	172.365	23.873
A	16-Jul	3	0.2253	0.0958	1.3609	0.2445	208.652	28.966
A	19-Jul	3	0.3634	0.0759	1.1128	0.1622	149.765	23.396
A	22-Jul	3	0.1963	0.1025	0.6374	0.3538	189.235	28.807
A	25-Jul	3	0.4450	0.1047	0.6817	0.1429	183.983	46.155
A	28-Jul	3	0.2659	0.0369	0.5581	0.0166	158.996	34.537
A	30-Jul	2	0.3995	0.1329	1.0727	0.2896	237.061	37.720
B	16-Jun	1	2.2644	0.1921	1.6072	0.2058	441.178	74.007
B	17-Jun	1	2.0652	0.1664	3.4607	0.4286	328.018	48.701
B	18-Jun	1	1.9423	0.1316	2.4405	0.3969	491.789	74.007
B	19-Jun	1	1.5828	0.7047	3.0858	0.4581	279.317	43.927
B	21-Jun	2	1.1144	0.1150	2.3830	0.2491	246.611	34.616
B	25-Jun	4	0.5705	0.1185	2.3870	0.0589	219.514	30.080
B	29-Jun	4	0.2774	0.0107	0.9696	0.1136	165.561	23.993
B	03-Jul	4	0.1679	0.0261	0.8129	0.0800	178.930	24.589
B	04-Jul	2	0.4304	0.0107	1.2575	0.1233	325.392	31.274
B	05-Jul	2	0.3977	0.1061	1.7302	0.3000	218.918	29.125
B	07-Jul	3	0.2910	0.1128	1.0519	0.5439	168.227	24.669
B	10-Jul	3	0.3356	0.1153	1.1266	0.1705	136.237	17.985
B	04-Aug	1	0.5600	0.2414	1.3723	0.4376	318.469	95.016
B	07-Aug	3	0.1622	0.0371	0.7346	0.0088	164.407	20.690
B	11-Aug	4	0.4285	0.1805	0.9832	0.2813	88.2120	11.579
B	12-Aug	1	0.6348	0.0791	1.3957	0.2704	266.425	31.990
B	13-Aug	1	0.3603	0.0264	1.0639	0.1069	242.075	24.351
B	14-Aug	1	0.5636	0.1827	0.7661	0.0666	277.885	27.693
B	17-Aug	3	0.3765	0.0081	1.2828	0.4162	113.318	12.414
B	19-Aug	2	1.2517	0.0389	2.0500	0.2817	150.640	13.846
B	20-Aug	1	0.6652	0.1489	1.6352	0.0639	241.120	29.603

APPENDIX 4

Temperature, salinity, and sigma-t at Gascons from 16 June to 20 August 1992. Standardized time (jtime), mean depth, depth, and average salinity, temperature, and sigma-t for five depth intervals (0.8-1.2 m, 4.8-5.2 m, 9.8-10.2 m, 16.8-17.2 m, 23.8-24.2m). Standardized time is the day plus the fraction of the day, where day 1 refers to 1 January.

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
167.38	1.14	1	25.243	10.559	19.261
167.38	5.00	5	25.321	10.291	19.363
167.38	9.92	10	25.414	10.075	19.468
167.38	16.99	17	25.838	8.562	20.015
167.39	0.93	1	24.279	10.918	18.456
167.39	5.07	5	25.071	10.447	19.144
167.39	10.06	10	25.278	9.933	19.383
167.39	16.99	17	25.880	8.233	20.092
167.39	23.91	24	26.138	7.570	20.378
167.52	1.07	1	25.215	11.435	19.099
167.52	5.10	5	25.268	9.642	19.419
167.52	10.05	10	25.759	8.796	19.921
168.35	1.14	1	25.179	10.426	19.232
168.35	5.00	5	25.239	10.205	19.313
168.35	10.06	10	25.340	9.343	19.518
168.35	17.06	17	25.606	8.336	19.864
168.35	24.14	24	25.811	7.769	20.097
168.38	5.00	5	25.430	10.274	19.451
169.39	0.98	1	25.227	11.117	19.160
169.39	4.97	5	25.321	10.820	19.281
169.39	9.96	10	25.403	10.402	19.409
169.39	17.02	17	25.673	9.332	19.779
170.32	4.93	5	25.342	10.764	19.306
170.32	9.99	10	25.534	8.926	19.728
170.32	17.06	17	25.776	7.959	20.046
170.4	0.93	1	24.986	12.159	18.799
170.4	5.14	5	25.231	10.762	19.220
170.4	9.85	10	25.473	8.977	19.673
170.43	17.06	17	25.620	8.162	19.898
172.3	0.93	1	25.138	13.024	18.764
172.3	5.03	5	25.299	12.547	18.974
172.3	10.06	10	25.455	12.402	19.120
172.3	16.92	17	25.978	7.694	20.238
172.37	5.00	5	25.291	12.596	18.959
172.37	9.89	10	25.366	12.588	19.018
172.37	17.02	17	25.726	9.687	19.769

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
173.42	1.01	1	25.167	13.206	18.753
173.42	10.06	10	25.549	12.646	19.149
173.42	17.02	17	26.286	8.289	20.402
173.42	23.95	24	27.418	3.660	21.788
173.54	1.14	1	25.117	13.234	18.709
173.54	5.04	5	25.279	13.007	18.876
173.54	16.99	17	26.192	6.635	20.532
173.54	23.91	24	27.725	2.678	22.106
173.6	0.95	1	25.252	13.223	18.815
173.6	5.00	5	25.343	12.917	18.941
173.6	9.99	10	25.695	10.767	19.579
173.6	16.97	17	27.055	4.738	21.408
173.6	23.98	24	28.012	1.927	22.382
173.67	0.93	1	25.384	13.262	18.910
173.67	9.92	10	25.801	9.248	19.891
173.67	16.92	17	27.261	3.981	21.638
173.67	23.84	24	27.745	2.535	22.131
173.73	1.04	1	25.424	13.183	18.955
173.73	5.00	5	25.466	13.106	19.002
173.73	9.98	10	25.451	11.233	19.314
173.73	16.88	17	27.445	3.457	21.826
173.73	23.98	24	28.145	1.511	22.511
175.38	1.04	1	25.275	13.474	18.786
175.38	5.00	5	25.580	13.293	19.055
175.38	9.96	10	25.680	10.153	19.664
175.38	17.04	17	28.093	1.876	22.450
175.42	1.07	1	25.329	13.490	18.826
175.42	5.09	5	25.579	13.363	19.042
175.42	10.04	10	25.493	11.445	19.313
175.42	16.92	17	27.551	3.493	21.907
175.42	24.05	24	28.513	0.488	22.855
175.46	0.96	1	25.172	13.548	18.694
175.46	4.92	5	25.565	13.426	19.018
175.46	9.92	10	25.523	13.017	19.062
175.46	17.03	17	26.162	7.872	20.359
175.46	24.20	24	28.125	1.449	22.499
175.5	5.00	5	25.563	13.456	19.012
175.5	9.94	10	25.577	13.129	19.083
175.5	16.99	17	26.218	7.666	20.429
175.5	24.05	24	28.034	1.918	22.400
175.54	1.14	1	24.949	13.751	18.483
175.54	4.89	5	25.543	13.432	19.001
175.54	9.96	10	25.568	13.137	19.075

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
175.54	17.08	17	26.071	8.238	20.240
175.54	24.17	24	28.120	1.730	22.479
175.59	1.00	1	25.184	13.940	18.628
175.59	4.89	5	25.553	13.390	19.017
175.59	9.92	10	25.535	12.851	19.101
175.59	17.03	17	26.218	7.777	20.415
175.59	24.05	24	28.290	1.285	22.640
175.63	0.99	1	25.203	13.982	18.635
175.63	5.14	5	25.465	13.446	18.938
175.63	10.05	10	25.476	12.808	19.064
175.63	17.06	17	26.192	7.453	20.435
175.63	24.05	24	28.503	0.668	22.840
175.67	1.00	1	25.238	14.135	18.633
175.67	5.14	5	25.543	13.403	19.006
175.67	10.14	10	25.363	12.247	19.076
175.67	16.92	17	26.781	5.694	21.098
175.67	23.91	24	28.570	0.203	22.912
175.71	1.14	1	25.219	14.195	18.606
175.71	5.07	5	25.462	13.676	18.892
175.71	9.85	10	25.548	12.840	19.114
175.71	17.09	17	27.089	4.260	21.477
175.71	24.02	24	28.525	0.207	22.875
175.75	5.03	5	25.237	13.893	18.678
175.75	9.85	10	25.536	12.863	19.100
175.75	16.91	17	26.781	5.503	21.118
175.75	24.02	24	28.570	0.157	22.913
175.79	5.07	5	25.153	13.648	18.660
175.79	9.92	10	25.625	11.493	19.407
175.79	17.01	17	27.134	4.200	21.518
175.79	24.13	24	28.594	-0.075	22.940
176.38	1.00	1	23.948	13.815	17.701
176.38	4.93	5	25.473	12.800	19.063
176.38	10.14	10	26.910	5.383	21.232
176.38	16.99	17	28.404	0.460	22.768
176.44	1.00	1	24.168	13.712	17.889
176.44	4.93	5	25.472	12.896	19.044
176.44	10.06	10	26.389	7.017	20.643
176.44	16.92	17	28.328	0.721	22.696
176.44	23.84	24	28.686	-0.214	23.019
178.35	1.07	1	24.617	12.974	18.371
178.35	5.14	5	25.233	12.698	18.895
178.35	9.99	10	25.657	12.060	19.335
178.35	16.99	17	28.428	0.051	22.802

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
178.35	24.20	24	28.696	-0.259	23.028
178.4	1.07	1	24.617	12.974	18.371
178.4	5.14	5	25.233	12.698	18.895
178.4	9.99	10	25.657	12.060	19.335
178.4	16.99	17	28.428	0.051	22.802
178.4	24.20	24	28.696	-0.259	23.028
178.44	0.86	1	23.746	12.944	17.704
178.44	10.14	10	25.565	11.302	19.392
178.44	16.99	17	28.329	0.028	22.723
178.44	24.20	24	28.961	-0.538	23.250
178.48	1.00	1	23.805	12.900	17.758
178.48	10.03	10	26.188	7.488	20.426
178.48	24.05	24	28.956	-0.547	23.247
178.52	0.86	1	24.626	12.999	18.373
178.52	5.07	5	25.306	12.674	18.956
178.52	10.06	10	26.287	7.064	20.557
178.52	17.13	17	28.419	-0.140	22.801
178.52	24.02	24	28.935	-0.533	23.229
178.57	1.00	1	24.860	13.412	18.478
178.57	5.14	5	25.203	12.762	18.861
178.57	9.92	10	24.793	10.842	18.867
178.57	17.06	17	28.198	0.213	22.612
178.57	23.91	24	28.890	-0.515	23.192
178.6	1.14	1	25.024	13.470	18.593
178.6	4.85	5	25.452	12.789	19.048
178.6	10.06	10	25.911	10.084	19.853
178.6	24.05	24	28.821	-0.434	23.135
178.65	1.07	1	25.226	13.102	18.817
178.65	17.06	17	28.140	0.604	22.549
178.65	24.16	24	28.585	-0.050	22.933
178.69	1.07	1	25.295	13.185	18.855
178.69	5.07	5	25.405	13.065	18.962
178.69	9.92	10	25.699	12.121	19.357
178.73	1.14	1	25.435	13.386	18.926
178.73	5.14	5	25.422	13.315	18.929
178.73	16.84	17	26.016	6.727	20.383
178.73	23.91	24	28.057	1.145	22.459
178.77	4.85	5	25.375	13.446	18.869
178.77	9.85	10	25.599	13.048	19.115
179.33	0.93	1	24.899	13.097	18.566
179.33	5.00	5	25.172	13.189	18.760
179.33	9.99	10	25.357	12.947	18.947
179.33	17.02	17	26.678	6.360	20.946

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
179.33	23.84	24	28.241	0.498	22.636
179.38	4.96	5	25.236	13.215	18.804
179.38	9.85	10	25.355	12.753	18.980
179.38	16.92	17	26.908	2.648	21.456
179.38	24.03	24	28.770	-0.362	23.091
179.42	5.00	5	25.421	13.326	18.927
179.42	16.99	17	27.971	0.912	22.401
179.42	23.91	24	28.610	-0.315	22.961
179.46	0.89	1	25.202	13.239	18.774
179.46	5.10	5	25.253	13.215	18.818
179.46	10.14	10	25.555	12.494	19.180
179.46	16.99	17	28.240	0.699	22.626
179.46	24.09	24	28.595	-0.303	22.948
179.5	0.96	1	25.230	13.274	18.789
179.5	16.99	17	27.456	1.972	21.935
180.62	1.04	1	25.156	14.051	18.586
180.62	9.99	10	25.241	13.324	18.788
180.62	16.99	17	25.962	8.947	20.059
180.62	24.05	24	27.366	3.348	21.771
184.34	1.07	1	25.475	12.326	19.149
184.34	5.03	5	25.609	12.288	19.258
184.34	9.92	10	25.717	12.371	19.327
184.34	17.13	17	26.025	11.047	19.790
184.4	1.14	1	25.429	12.385	19.102
184.4	4.93	5	25.513	12.370	19.170
184.4	10.14	10	25.598	12.365	19.237
184.4	17.13	17	25.953	11.316	19.691
185.34	1.07	1	24.991	12.437	18.755
185.34	4.92	5	25.540	12.657	19.140
185.34	9.99	10	25.683	12.561	19.268
185.34	17.06	17	25.699	12.530	19.285
185.34	24.05	24	26.055	10.001	19.978
185.4	1.00	1	25.153	12.642	18.844
185.4	9.99	10	25.673	12.618	19.250
185.4	23.84	24	26.113	9.620	20.081
186.35	1.00	1	25.334	12.563	18.997
186.35	5.00	5	25.341	12.565	19.002
186.35	9.92	10	25.756	11.622	19.486
186.35	24.10	24	26.697	7.862	20.780
186.42	0.93	1	25.397	12.839	18.997
186.42	4.85	5	25.466	12.830	19.052
186.42	17.13	17	26.337	10.106	20.181
186.42	24.02	24	26.810	7.436	20.922

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
188.34	1.00	1	23.119	13.027	17.206
188.34	4.93	5	25.529	11.935	19.258
188.34	10.06	10	26.310	10.113	20.160
188.34	16.84	17	26.929	6.652	21.109
188.34	23.91	24	27.524	3.924	21.851
188.41	10.14	10	26.171	10.762	19.950
188.41	16.92	17	26.507	7.944	20.620
188.41	23.98	24	26.946	6.510	21.139
194.32	4.89	5	25.909	11.258	19.666
194.32	10.14	10	26.615	7.473	20.765
194.32	16.99	17	27.051	6.413	21.233
194.32	24.08	24	27.313	5.338	21.554
194.38	0.93	1	24.407	14.342	17.954
194.38	4.85	5	25.481	12.661	19.094
194.38	9.92	10	26.563	7.522	20.717
194.38	17.02	17	27.086	6.278	21.275
194.38	23.95	24	27.473	4.834	21.729
196.37	1.07	1	10.843	n/a	n/a
196.37	5.07	5	26.368	9.762	20.258
196.37	9.99	10	26.615	8.437	20.639
196.37	17.06	17	27.080	8.018	21.059
196.37	24.01	24	27.194	7.126	21.262
196.44	1.07	1	26.165	10.417	20.000
196.44	5.00	5	26.415	9.541	20.327
196.44	10.14	10	26.604	8.850	20.574
196.44	17.02	17	27.004	8.197	20.977
196.44	24.02	24	27.095	7.691	21.114
197.29	0.86	1	26.315	8.687	20.371
197.29	5.00	5	27.213	8.959	21.034
197.29	10.06	10	27.276	9.082	21.066
197.29	17.09	17	27.368	9.246	21.114
197.29	23.91	24	27.620	8.175	21.461
197.34	4.85	5	26.765	8.713	20.719
197.34	17.13	17	27.266	8.592	21.127
197.34	24.20	24	27.582	8.300	21.415
200.36	0.93	1	27.197	12.889	20.378
200.36	4.85	5	27.384	12.131	20.660
200.36	10.06	10	27.404	12.027	20.693
200.36	17.06	17	27.400	11.879	20.716
200.36	24.12	24	27.580	10.408	21.102
200.41	1.07	1	27.154	12.980	20.328
200.41	5.00	5	27.305	12.631	20.509
200.41	10.14	10	27.390	12.411	20.615

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
200.41	17.06	17	27.444	11.528	20.811
203.36	1.00	1	26.679	13.528	19.858
203.36	5.00	5	27.233	12.100	20.548
203.36	16.95	17	27.583	10.139	21.147
203.36	24.05	24	27.778	8.854	21.491
203.43	1.00	1	26.827	13.854	19.911
203.43	5.00	5	27.273	12.627	20.485
203.43	16.99	17	27.643	10.341	21.161
203.43	24.05	24	27.819	8.796	21.531
203.44	1.04	1	26.975	13.854	20.024
203.44	4.93	5	27.505	12.217	20.738
203.44	9.85	10	27.523	11.583	20.863
203.44	16.95	17	27.698	10.150	21.235
203.44	23.91	24	27.834	8.781	21.545
206.32	1.00	1	27.109	13.928	20.113
206.32	4.85	5	27.183	13.321	20.287
206.32	9.92	10	27.287	13.091	20.410
206.32	17.06	17	27.404	12.591	20.592
206.32	24.05	24	27.613	11.265	20.987
209.34	1.07	1	26.914	14.427	19.865
209.34	4.93	5	27.077	14.235	20.028
209.34	9.99	10	27.236	14.138	20.170
209.34	16.84	17	27.223	14.026	20.182
209.39	0.93	1	26.818	14.447	19.787
209.39	9.85	10	27.172	14.168	20.114
209.39	16.99	17	27.184	13.950	20.167
209.39	23.84	24	27.330	13.023	20.456
213.47	0.98	1	27.514	10.798	20.987
213.47	5.09	5	27.550	10.750	21.023
213.47	10.14	10	27.770	9.353	21.412
213.47	16.84	17	27.856	6.527	21.854
213.47	24.20	24	28.088	5.495	22.150
215.33	0.92	1	26.483	12.857	19.832
215.33	5.00	5	26.745	12.732	20.057
215.33	9.92	10	26.881	12.801	20.150
215.33	16.92	17	27.004	12.598	20.282
215.33	23.91	24	27.172	12.237	20.476
215.35	0.96	1	26.676	13.038	19.948
215.35	4.85	5	26.889	12.872	20.143
215.35	10.06	10	26.985	12.730	20.243
215.35	16.99	17	27.091	12.477	20.371
215.35	23.91	24	27.221	11.978	20.560
216.32	0.96	1	26.801	12.912	20.068

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
216.32	5.14	5	26.853	12.789	20.130
216.32	9.99	10	26.778	12.762	20.078
216.32	17.04	17	26.876	12.323	20.232
216.32	23.98	24	27.238	11.525	20.651
216.35	1.07	1	26.384	13.005	19.729
216.35	5.14	5	26.673	12.833	19.984
216.35	9.99	10	26.751	12.661	20.075
216.35	16.99	17	26.842	12.513	20.172
219.27	0.93	1	27.239	10.663	20.796
219.27	5.07	5	27.669	8.847	21.406
219.27	10.14	10	27.778	7.467	21.678
219.27	16.92	17	27.727	4.599	21.953
219.27	24.09	24	28.476	2.912	22.688
223.31	0.96	1	25.718	13.535	19.117
223.31	4.92	5	26.754	12.042	20.188
223.31	9.99	10	26.849	11.712	20.319
223.31	16.84	17	27.122	11.244	20.609
223.31	24.01	24	27.579	9.928	21.176
223.4	0.96	1	26.213	13.292	19.543
223.4	5.10	5	26.749	11.908	20.207
223.4	10.06	10	26.849	11.717	20.318
223.4	16.99	17	27.081	11.376	20.555
223.4	23.95	24	27.864	8.486	21.610
224.29	0.94	1	26.867	12.069	20.270
224.29	5.07	5	27.019	11.758	20.443
224.29	9.85	10	27.139	11.243	20.622
224.29	17.06	17	27.437	10.383	20.995
224.29	23.98	24	27.864	8.359	21.628
224.33	0.92	1	26.871	11.899	20.303
224.33	4.96	5	27.053	11.662	20.485
224.33	9.96	10	27.150	11.194	20.640
224.33	16.99	17	27.401	10.434	20.958
224.33	23.91	24	27.938	8.163	21.712
226.29	0.93	1	26.673	13.774	19.807
226.29	5.00	5	26.808	11.812	20.269
226.29	10.03	10	27.134	11.317	20.606
226.29	16.99	17	27.320	10.780	20.839
226.29	23.98	24	27.327	10.776	20.845
226.32	0.93	1	26.593	13.877	19.726
226.32	5.00	5	26.888	11.907	20.315
226.32	9.99	10	27.139	11.671	20.550
226.32	16.99	17	27.278	10.773	20.808
226.32	23.98	24	27.341	10.714	20.867

Appendix 4, continued

jtime	mean depth (m)	depth (m)	salinity (psu)	temp. (°C)	sigma-t
229.32	0.87	1	26.745	13.258	19.961
229.32	5.00	5	26.928	12.405	20.258
229.32	9.92	10	27.141	11.140	20.642
229.32	17.06	17	27.289	10.660	20.835
229.32	24.02	24	27.606	9.618	21.245
229.41	0.94	1	26.364	13.305	19.658
229.41	4.93	5	27.228	10.842	20.758
229.41	10.02	10	27.259	10.785	20.791
229.41	16.92	17	27.429	10.277	21.005
229.41	23.91	24	27.456	10.179	21.041
230.31	1.07	1	26.574	15.326	19.421
230.31	4.96	5	27.182	11.240	20.656
230.31	9.96	10	27.292	10.837	20.808
230.31	16.99	17	27.344	10.415	20.917
230.31	24.02	24	27.799	8.983	21.488
231.32	1.11	1	26.592	14.468	19.609
231.32	4.96	5	26.962	13.218	20.135
231.32	10.03	10	27.361	11.065	20.824
231.32	17.02	17	27.683	9.689	21.294
231.32	24.09	24	27.989	7.373	21.856
231.38	1.04	1	26.294	14.611	19.351
231.38	4.96	5	27.070	12.282	20.389
231.38	9.96	10	27.340	10.920	20.832
231.38	17.06	17	27.467	10.150	21.054
231.38	24.02	24	27.938	8.903	21.609

APPENDIX 5

Kendall's tau correlation matrix between variables of the water column: chlorophyll *a* (Chl *a*), phaeopigments (Phaeo), combined pigments (pigment), organic carbon (C), organic nitrogen (N), carbon to nitrogen ratio (C/N), and water density stratification (D_S). Size classes are noted in parentheses (total=>0.7-153 µm; 5-153 µm; <5 µm). Boldface indicates P>0.05.

	Chl *a* (total)	Chl *a* (5-153)	Chl *a* (<5)	Phaeo (total)	Phaeo (5-153)	Phaeo (<5)	pigment (total)	pigment (5-153)	pigment (<5)	C	N	C/N	D_S
Chl *a* (total)	1												
Chl *a* (5-153)	**0.60**	1											
Chl *a* (<5)	**0.40**	-0.01	1										
Phaeo (total)	**0.28**	**0.47**	-0.16	1									
Phaeo (5-153)	0.22	**0.45**	**-0.29**	**0.51**	1								
Phaeo (<5)	**0.37**	**0.35**	0.03	**0.65**	0.17	1							
pigment (total)	**0.84**	**0.66**	**0.31**	**0.44**	**0.28**	**0.49**	1						
pigment (5-153)	**0.53**	**0.84**	-0.07	**0.52**	**0.61**	0.26	**0.55**	1					
pigment (<5)	**0.49**	0.14	**0.72**	0.09	-0.20	**0.31**	**0.49**	0.04	1				
C	**0.44**	**0.45**	0.02	**0.39**	0.14	**0.42**	**0.53**	**0.35**	0.22	1			
N	**0.55**	**0.48**	0.13	**0.30**	0.14	**0.32**	**0.59**	**0.39**	**0.32**	**0.86**	1		
C/N	**-0.63**	**-0.45**	-0.25	-0.16	0.01	-0.27	**-0.60**	**-0.34**	**-0.39**	**-0.67**	**-0.81**	1	
D_S	-0.14	-0.13	-0.25	0.15	-0.04	0.13	-0.03	-0.12	-0.15	0.03	0.07	0.04	1