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SUMMER DISTRIBUTION OF PARTICULATE ORGANIC MATTER IN A SALT-MARSH ESTUARY ON THE NORTHUMBERLAND STRAIT

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The summer distribution of particulate organic matter and relevant hydrographic characteristics are described in Merigomish Harbour, a salt-marsh estuary on the Northumberland Strait. The estuary is characterized by low phytoplankton biomass relative to similar estuaries in eastern United States. This is interpreted to be due to the low nutrient concentration in the source of the bottom water. Short-term fluctuations in stratification, surface nutrients, turbidity, and phytoplankton biomass appear to be controlled by short-term fluctuations in freshwater runoff. This control of short-term variability in estuarine characteristics by freshwater runoff may be characteristic of estuaries associated with small drainage basins. The particulate organic matter is dominated by detritus which is interpreted to be the degradation product of species of *Spartina*. Given the short residence time of the estuary and the high seston concentrations, Merigomish Harbour and similar estuaries along the western Gulf of St. Lawrence are significant sources of particulate organic matter to the coastal zone of the Gulf of St. Lawrence.

Les distributions estivales du matériel organique particulaire et des caractéristiques hydrographiques pertinentes, sont presenteés pour l'estuaire de type marois salant de Merigomish Harbour, region situee dans le détroit de Northumberland. Cet estuaire se caractérlse par une biomass phytoplanctonique faible par faible par rapport à des estuaires comparables de la côte est des Etâts-Unis. Ce resultat est attribué à une faible concentration en sels nutritifs de la couche d'eau de fond. La variabilité à court terme de la stratification, de la concentration des sels nutritifs de la couche de surface, de la turbidité et de la biomasse phytoplanktoniaire semblent sous le contrôle des fluctuations à court terme des apports d'eau douce. Un tel contrôle exercé par l'apport d'eau douce sur la variabilité a court terme des caractéristiques estuariennes est possiblement caracteristique des estuaires à faible bassins de drainage. Le matériel organique particulaire est principalement composé de matieres détritiques provenant, selon notre interprétation, de la dégradation de différentes espèces de *Spartina*. Considérant son court temps de résidence ainsi que ses fortes concentrations sestoniques, l'estuaire de Merigomish Harbour, de même que les autres estuaires comparables situés le long de la côte ouest du golfe Saint-Laurent représentent des sources importantes de matériel organique particulaire pour la zone cotière du golfe St.-Laurent.

Introduction

Because of the relative ease of repetitive sampling and the relative productivity of this environment, many studies have described the seasonal distribution of particulate organic matter (POM) in estuaries. Most estuaries have both a high concentration of POM in the water column and considerable temporal variability relative to offshore waters of the same latitude. The detrital component of POM, especially in shallow salt-marsh estuaries, is dominant (Darnell 1967; Odum & de la Cruz 1967; Biggs & Flemer 1972; Heinle & Flemer 1976; Haines 1977). Most of the above studies showed that detritus originates primarily from the transport of marsh grass to the open estuary and its subsequent decomposition in the water column. The phytoplankton component of the POM during the growth season (although often a small fraction of the total) is a dynamic fraction that may be rapidly replacing itself. Phytoplankton production over the growth season in many estuaries is often higher than in the contiguous offshore waters (Riley 1967).

The marked short-term temporal variability in the phytoplankton component of the POM has frequently been associated with parallel fluctuations in the degree of vertical density stratification (see review by Sinclair et al. 1981). In most cases, however, the factors controlling short-term variability in either the physical or plankton distributions have not been adequately defined owing to inadequate sampling intensity. The short-term temporal variability in the detrital component has in one study been linked to the combined effects of neap-spring and semi-diurnal tidal components (Odum & de la Cruz 1967).

The aim of this study is to describe adequately and hopefully explain the summer temporal distribution (absolute concentration as well as variance) of both the detrital and phytoplankton components of the POM in a shallow salt-marsh estuary. The study area, Merigomish Harbour (Nova Scotia, Canada; Fig 1), is one of many similar salt-marsh estuaries bordering the western portion of the Gulf of St. Lawrence. According to Teal and Teal (1969), these Gulf of St. Lawrence estuaries are among the few that have not been abused by mankind. Thus, the conclusions of the study may be generally applicable to the relatively unpolluted salt-marsh estuaries in the Gulf of St. Lawrence.

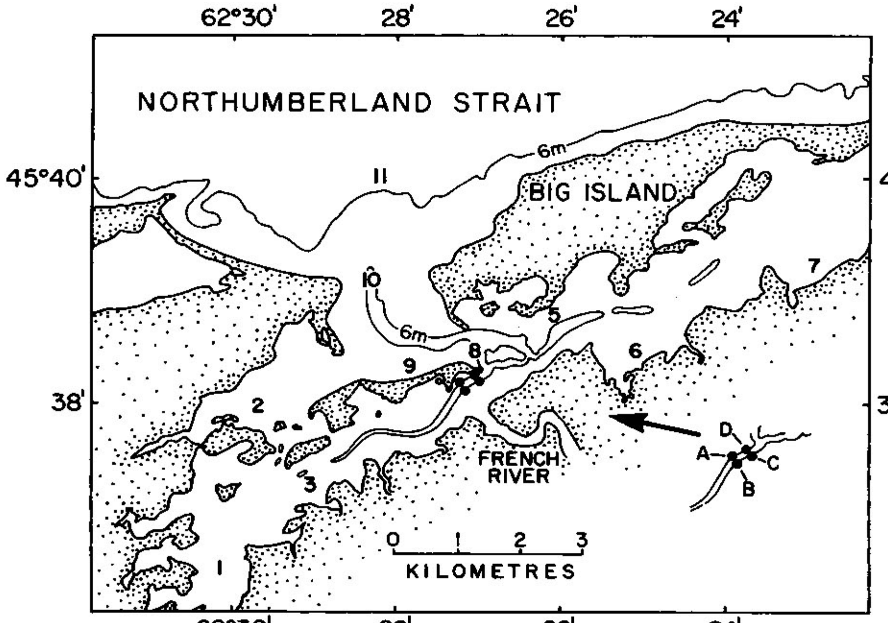

Fig 1 Sampling locations within Merigomish Harbour. Stations 1 to 11 were sampled during the spatial distribution study on July 16 only (Station 4 was at Location A). Stations A, B, C, and D were sampled hourly during the semi-diurnal tidal variability study. Station A was routinely sampled during the overall study period (May through August).

Methods

Merigomish Harbour, bordering on the Northumberland Strait, is a shallow estuary (<15 m depth) with an average tidal amplitude of 0.8 m. Its surface area barely exceeds 14 km^2. The estuarine banks are densely populated by *Spartina alterniflora*. The estuary can be classified as mesotidal following Haynes (1975), because of its narrow opening to the sea and many internal channels.

The sampling program extended from 4 May to 29 August 1977 at several sampling stations (Fig 1). Three different sampling schemes were used: 1) Station A was visited 3 times daily (0900, 1200, and 1500 h) during 3 different days of the week over most of the study period; 2) a spatial series was made on 16 July 1977, at Stations 1 to 11 and A, to see if Station A was representative of the estuary as a whole; and 3) a semi-diurnal time series with hourly sampling was made for two transects (Stations A-B and C-D) in order to examine the major mixing processes of the estuary.

All variables were sampled at 0, 1, 3, 5, 8, and 10 m at Station A. For Stations 1 to 11, sampling depths were selected according to the depth of the water column. Samples for several biological variables were collected in triplicate from a 5 l Niskin bottle, all water samples being prefiltered with a 202 μm Nitex screen aboard the boat. Salinity and temperature were measured using a cruciform drag device first described by Jacobson (1909) and later modified by Pritchard and Burt (1951). Light extinction coefficients were estimated using a 30 cm Secchi disk and Holmes' (1970) numerical equation. Other physical variables such as freshwater runoff, wind speed and direction, precipitation, and solar radiation were obtained from nearby stations operated by the Department of Lands and Forests of Nova Scotia, and Environment Canada, Charlottetown (P.E.I.).

All particulate material was collected on a Whatman GF/C filter of pore size equivalent to 0.8 μm. For adenosine triphosphate analysis, a volume of 100 ml was filtered. Small volumes of water are important to eliminate the non-linear effects introduced when using large volumes of seawater (Sutcliffe et al. 1976; Sinclair et al. 1979). The method of Holm-Hansen and Booth (1966) was used for the ATP analysis. Chlorophyll *a* was determined using the modified method of Yentsch and Menzel (1963) as described in Strickland and Parsons (1972). Amounts of nitrate, phosphate, and silicate were estimated by the Auto-Analyzer (Technicon) following the method of Strickland and Parsons (1972). Analyses of particulate organic carbon and nitrogen were performed with a Perkin Elmer Elemental Analyser as described by Strickland and Parsons (1972).

Results

Physical Data

The temporal distributions of daily averaged salinity, temperature, and σ_t for Station A are shown in Figure 2. There were intermittent pulses of low-salinity water at the surface throughout the sampling period, resulting in variable salinity stratification with depth. In contrast, the water column was relatively isothermal with depth by the end of June. Subsequently the whole water column progressively warmed to 20°C. Vertical temperature differences therefore did not contribute significantly to density stratification of the water column during the latter half of the summer. The pulses of low-salinity water, presumably from runoff from the drainage basin, caused marked changes in the degree of density stratification in the water column (Fig 3). It is also of interest that, at least over the period sampled, there was little seasonal decrease in stratification following spring freshet; short-term variability was more important than seasonal variability.

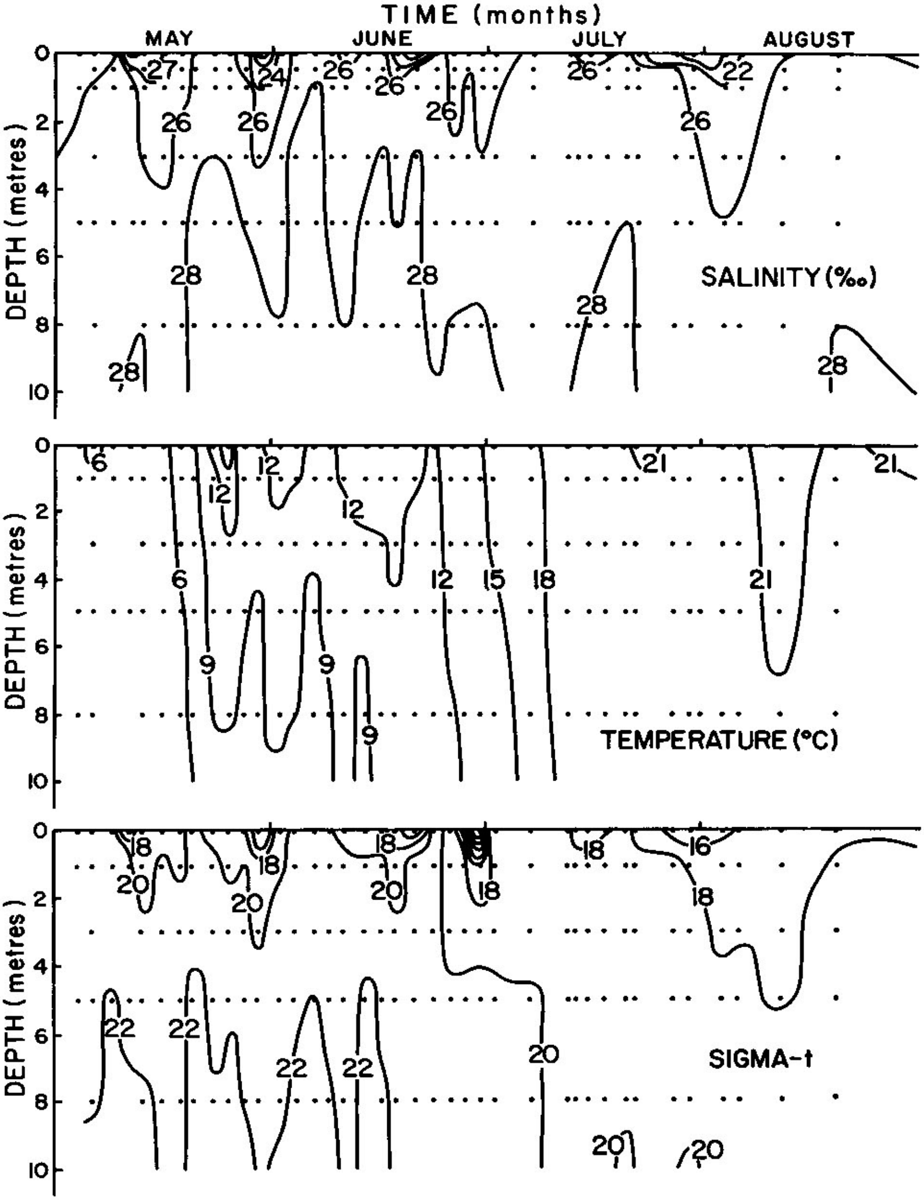

Fig 2 Depth distribution of salinity, temperature, and Sigma-t at Station A during the study period.

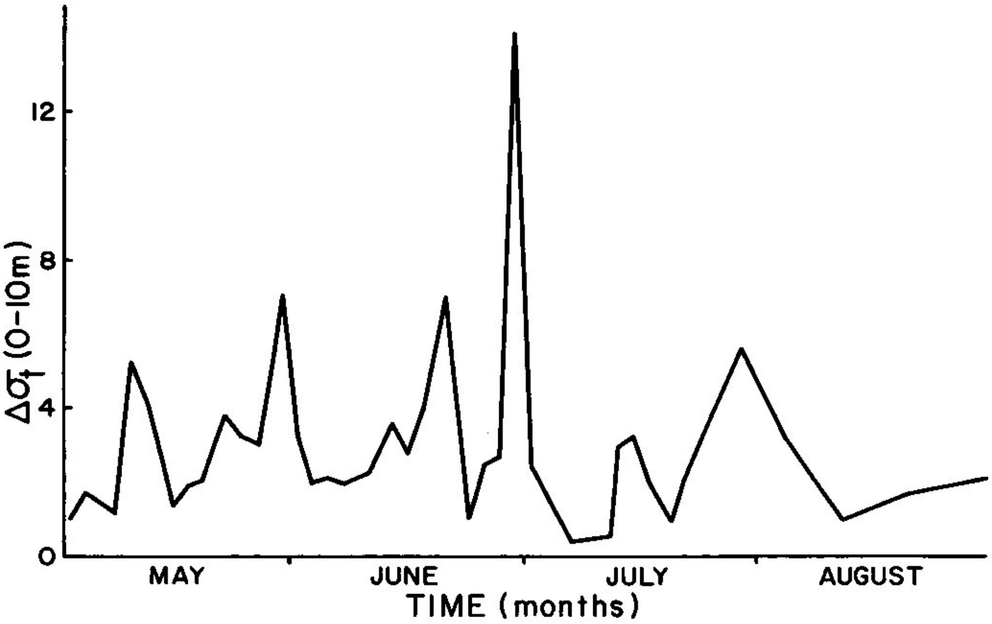

Fig 3 Temporal variability in water column density stratification at Station A during the sampling period.

It was expected that the relative importance of physical variables (Fig 4) on the water-column stratification could be inferred from a correlation matrix (Table I). Precipitation, however, was the only variable significantly correlated with density stratification. Temporal variations in incident solar radiation and the coefficient of light extinction reveal 2 points of interest. There was some correspondence between light extinction, reflecting turbidity changes, and density stratification, inferred to be a function of short-term variability in freshwater runoff. Secondly, from critical-depth considerations (Sverdrup 1953) the water column was not light-limited with respect to phytoplankton dynamics over the sampling period (Couture 1979). Precipitation was positively correlated with both $\Delta\sigma_t$ and light extinction (Table I), suggesting that stratification and turbidity were functions of freshwater runoff (even though freshwater runoff itself was not significantly correlated with any of these 3 variables). Probably the estimates of freshwater runoff do not adequately represent runoff from the drainage basin.

Circulation and mixing characteristics of the water column were examined using the classification diagram of Hansen and Rattray (1966). During neap-tide, when the currents were estimated, Sections A-B and C-D fall in Area 2a of the diagram (Figure 6, upper; Table II). According to their model, circulation in the estuary is dominated by a two-layer flow system, where salinity stratification is slight. More than 90% of the mixing is accomplished by turbulent diffusion (Fig 6, lower). Residence time can be estimated for the estuary using Ketchum's (1950) model. The model assumes complete vertical mixing (no water column stratification), which is not strictly upheld for Merigomish Harbour. Thus the estimated residence time of four days must be considered as a minimum value (or an underestimate).

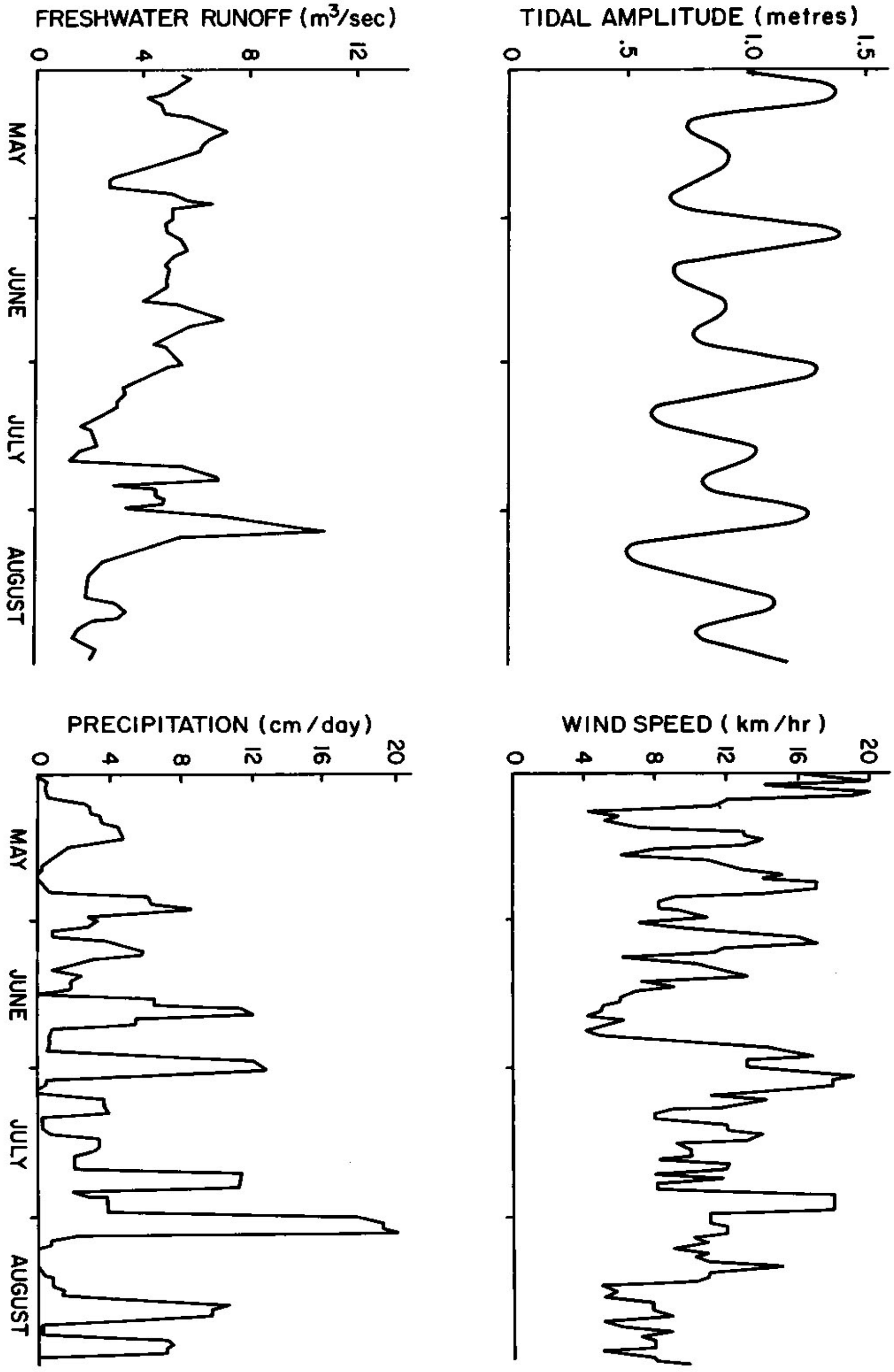

Fig 4 Temporal variability in factors contributing to density stratification at Station A over the sampling period.

Table I Correlation matrix[1] of various variables estimated for Merigomish Harbour Estuary

	Tidal Amplitude	FW Runoff	Precipitation	Wind	Coefficient of Extinction	Nitrate	Silicate	Phosphate	Particulate Organic Carbon	Particulate Organic Nitrogen	Detritus	Chlorophyll a
Δ t	· ·	· ·	0.74 0.43	· ·	0.71 0.67	· ·	0.55 ·	· ·	· 0.57	0.44 ·	· 0.65	· ·
Tidal Amplitude		· ·	· ·	0.43 ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
FW Runoff			· 0.40	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
Precipitation				· ·	0.71 0.58	· ·	0.62 0.44	· ·	· ·	0.47 ·	· ·	0.47 ·
Wind					· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
Coefficient of Extinction						· ·	0.72 0.59	· ·	0.47 0.75	0.59 0.53	0.45 0.71	0.64 ·
Nitrate							· 0.41	· 0.65	· ·	· 0.46	· ·	· 0.83
Silicate								·	· 0.52	0.57 0.59	· ·	· ·
Phosphate									0.54 ·	0.53 0.54	0.53 ·	· 0.86
Particulate Organic Carbon										0.79 0.80	0.99 0.94	· ·
Particulate Organic Nitrogen											0.65 0.57	0.52 0.58
Detritus												· ·

[1] The first value of r for each pair is that for the months of May and June, the second value is that for the months May to August. Only correlations significant at the 1% level are indicated.

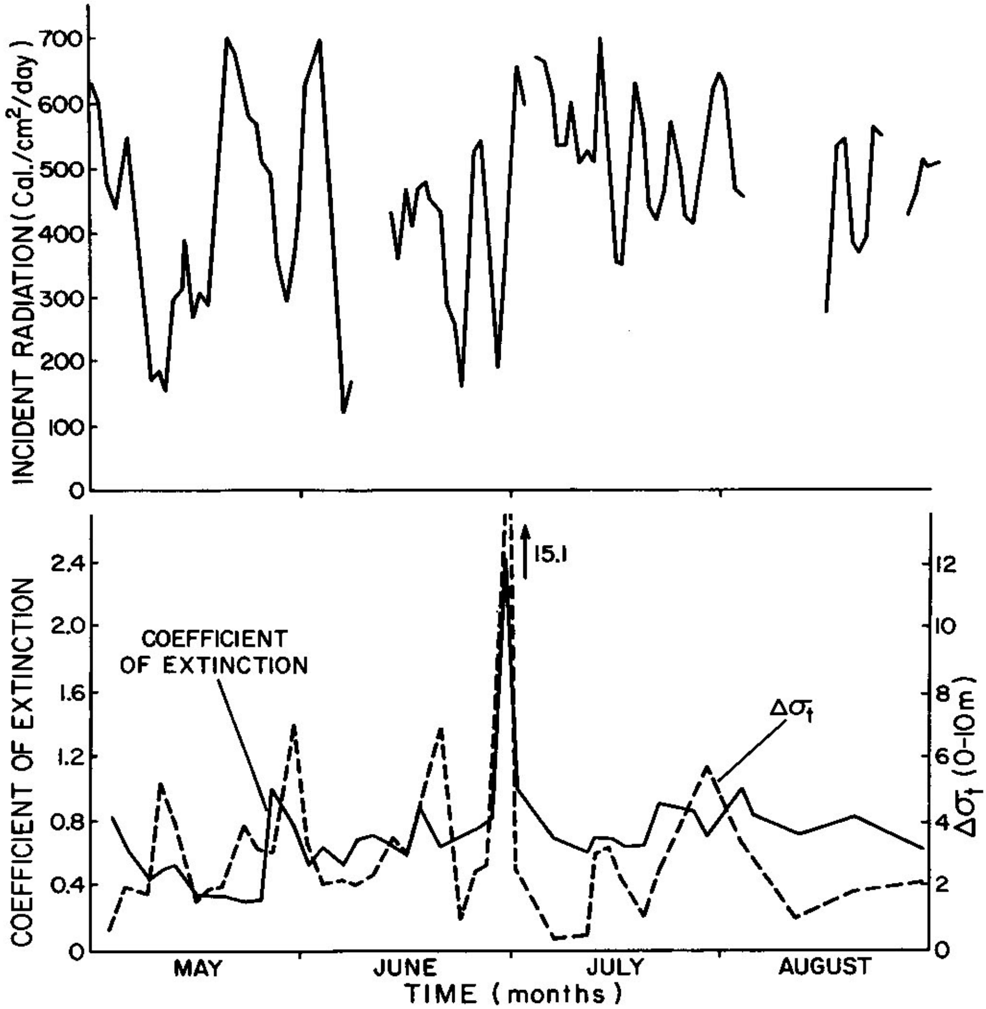

Fig 5 Temporal variability in incident radiation (3-day running means), the coefficient of extinction, and density stratification at Station A during the sampling period.

Biological Data

A one-way analysis of variance of data between all stations and depths on July 16 revealed no significant difference in the spatial distribution of chlorophyll *a* within Merigomish Harbour (Table III, see Fig I for station locations). On this basis, it may well be that the relatively high-frequency temporal observations at Station A were representative of the estuary as a whole. The semi-diurnal variability in chlorophyll *a* was also clearly low in relation to the sampling variability between days (Fig 7). It is clear that the day-to-day variability in phytoplankton biomass in the estuary was not masked by higher frequency variability as has been observed in other estuaries (Welch & Isaac 1967).

During the study period chlorophyll *a* concentrations varied from 0.26 to 2.27 mg/m^3 (mean 0.66 mg/m^3). The water column concentration varied within relatively narrow limits (ca. 4 to 8 mg/m^2) until mid-July. Subsequently, there was a

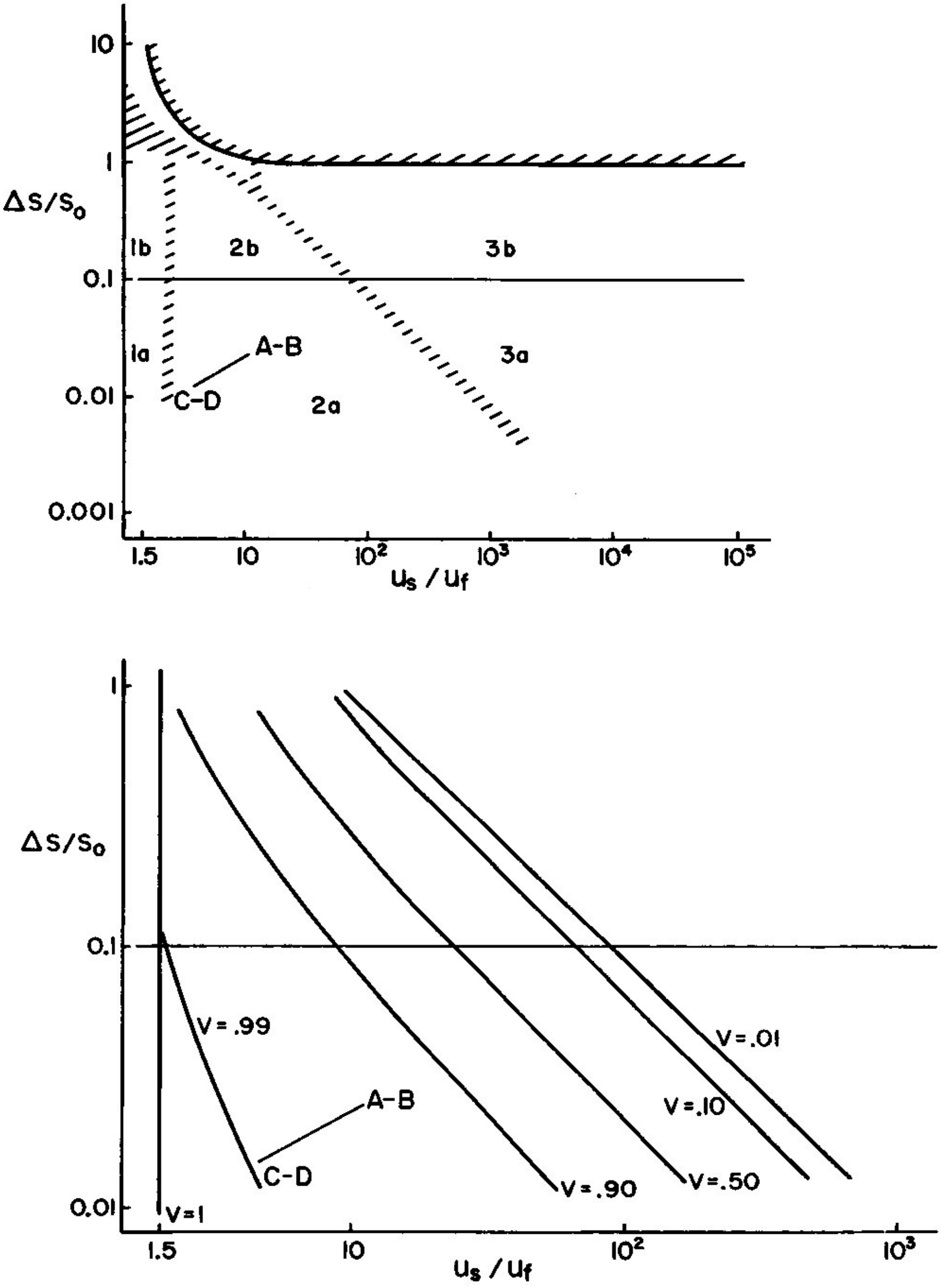

Fig 6 Location of Transects A-B and C-D in the estuarine stratification—circulation model of Hansen and Rattray (1966).

Table II Values of parameters necessary for the Hansen and Rattray (1966) stratification-circulation estuarine classification model. (ΔS is the top-to-bottom salinity difference, S_o is the mean salinity over the section, U_s is the net surface current, and U_f is the mean freshwater velocity through the section.)

Parameters	Station A	Station B	Station C	Station D
U_s (m/s)	0.100	0.060	0.040	0.035
U_f (m/s)	6.7×10^{-3}	6.7×10^{-3}	6.7×10^{-3}	6.7×10^{-3}
ΔS (‰)	1.10	0.92	0.51	0.50
S_o (‰)	27.07	27.03	27.08	27.08

steady increase to the end of August (Fig 7). The phytoplankton biomass estimates are low relative to those of other shallow estuaries on the eastern seaboard of the United States (Riley 1967).

The time-depth variability in inorganic nutrient concentrations in relation to the chlorophyll *a* distribution is shown in Figure 8. There was considerable surface variability in dissolved silicate and nitrate but not in phosphate concentration. The increases in nutrients at the surface, rather than in the bottom water, indicate that freshwater runoff was a more important source of nutrients than was estuarine entrainment of bottom water or regeneration from sediments. As in the phytoplankton biomass, there was a gradual seasonal increase in nitrate and phosphate, but no trend in silicate.

Over the whole study period chlorophyll *a* and nitrate as well as chlorophyll *a* and phosphate were positively correlated (Table I). However, for the months of May and June, which were characterized by considerable physical variability, these variables were not significantly correlated. Silicate concentrations were correlated with precipitation, stratification, and turbidity, but not with chlorophyll *a*. During the first two months of the study, chlorophyll *a* concentration was also statistically related to precipitation and turbidity.

The summer distribution of living carbon (from A.T.P.), total particulate organic carbon, and non-living organic carbon (detritus) is shown in Figure 9. The general

Table III Analysis of variance of chlorophyll a, estimated during a spatial-distribution study within Merigomish Harbour Estuary

Source of Variation	Sum of squares	Degrees of freedom	Mean squared	F
Between Group	0.18	10	0.018	0.86*
Error	0.36	17	0.021	
Total	0.54	27		

*n.s. at P – 0.05

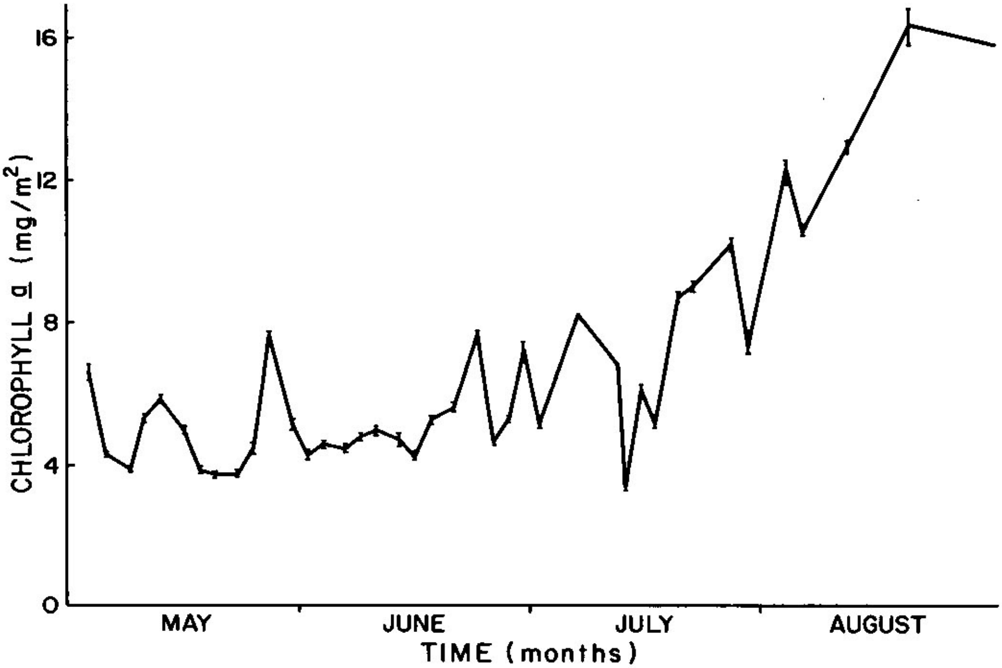

Fig 7 Temporal variability in an estimate of water column phytoplankton biomass at Station A during the sampling period. Error bars are S.D. based on 3 estimates within 6h.

pattern of distribution of living carbon resembled that of phytoplankton biomass (chlorophyll *a*), but the short-term variations were not in phase (the two variables not being significantly correlated). Detritus was the predominant component, contributing 82% in May and June and 67% in July and August. There was not a trend of increasing detritus or seston during July and August, as was the case for the living biomass (both chlorophyll *a* and A.T.P.) and two of the inorganic nutrients (nitrate and phosphate). Living carbon was significantly correlated with stratification and turbidity. There is a linear relationship between particulate organic carbon and particulate organic nitrogen (Fig 10), indicating a C:N ratio of ca. 6 (g:g) at mean levels of these variables.

Discussion

Phytoplankton biomass during the summer months within Merigomish Harbour was low in comparison with other shallow salt marsh estuaries along the eastern seaboard of the United States (Riley 1967). The vertical distribution of nitrate suggests that the source of bottom water within the estuary is nutrient poor. The source is no doubt the upper mixed layer water from the Northumberland Strait, which would be expected to be poor in nutrients during the summer months. Thus, estuarine entrainment within Merigomish Harbour does not appear to be an important mechanism for vertical nutrient transport as it is in many estuaries (Riley 1967; Sinclair et al. 1981). From mid July to the end of August there was a gradual increase in both nitrate and phosphate, as well as in phytoplankton biomass (chlorophyll *a* A.T.P.). It is of interest to speculate on the nutrient sources during this period of increase. Prior to mid July the nitrate and silicate concentrations

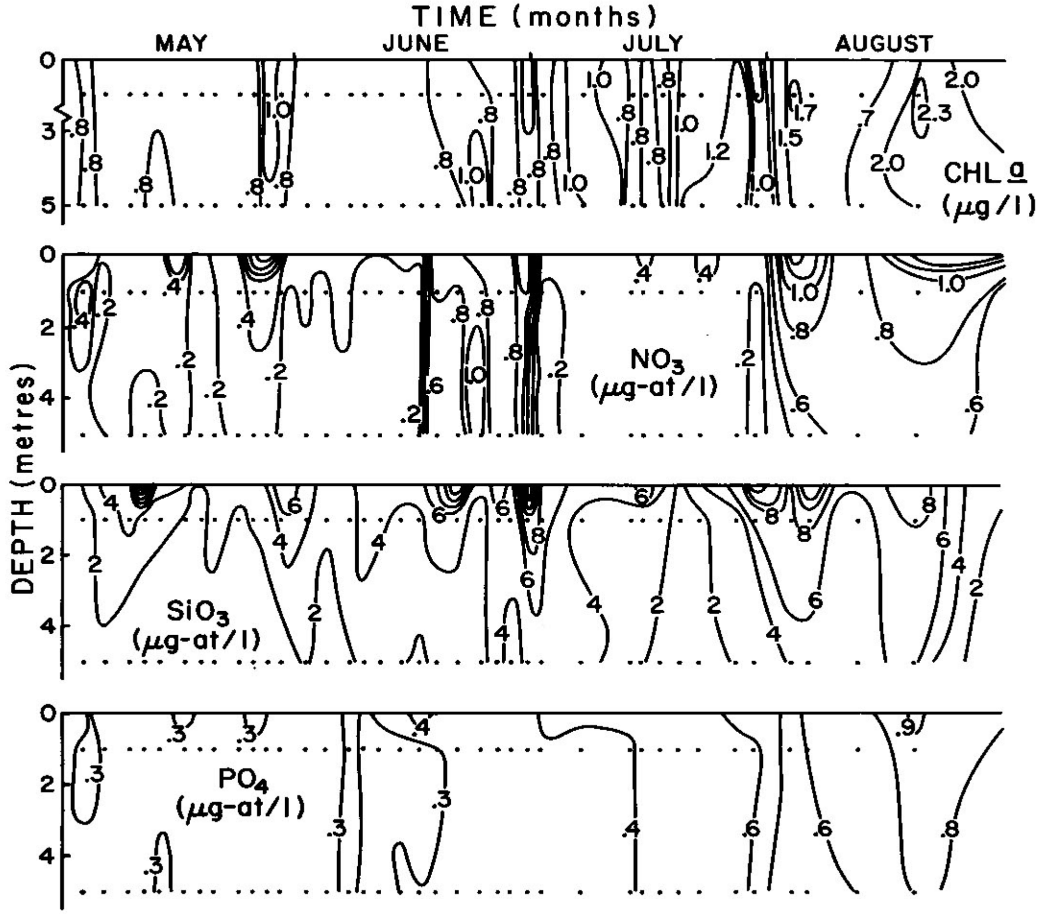

Fig 8 Depth distribution of an estimate of phytoplankton biomass and inorganic nutrients at Station A during the sampling period.

paralleled one another, interpreted to be in response to short-term fluctuations in freshwater runoff. In contrast, during the latter half of the study period nitrate and phosphate concentrations behaved similarly (increasing) but silicate concentrations continued to reflect the runoff variability. Thus, it can be interpreted that the new source of nitrate and phosphate was from regeneration of organic detritus (probably from *Spartina* breakdown).

As in many estuaries (Sinclair et al. 1981), Merigomish Harbour is characterized by marked short-term variability in water column density stratification (Fig 3). The correlation analysis (Table I) suggests that this variability in stratification is a function of freshwater runoff. This is unusual and is probably due to the small size of the drainage basin. In estuaries with a large drainage basin runoff is relatively smooth, the dominant characteristic being the spring freshet. The short-term variability in stratification of most estuaries has been interpreted to be a function of neap-spring tidal variability or to be wind induced (Sinclair et al. 1981). In this estuary the short-term variability in runoff is greater than seasonal variability and appears to dominate the observed fluctuations in the estuarine characteristics. The short-term variability in precipitation, stratification, nutrients, chlorophyll, and

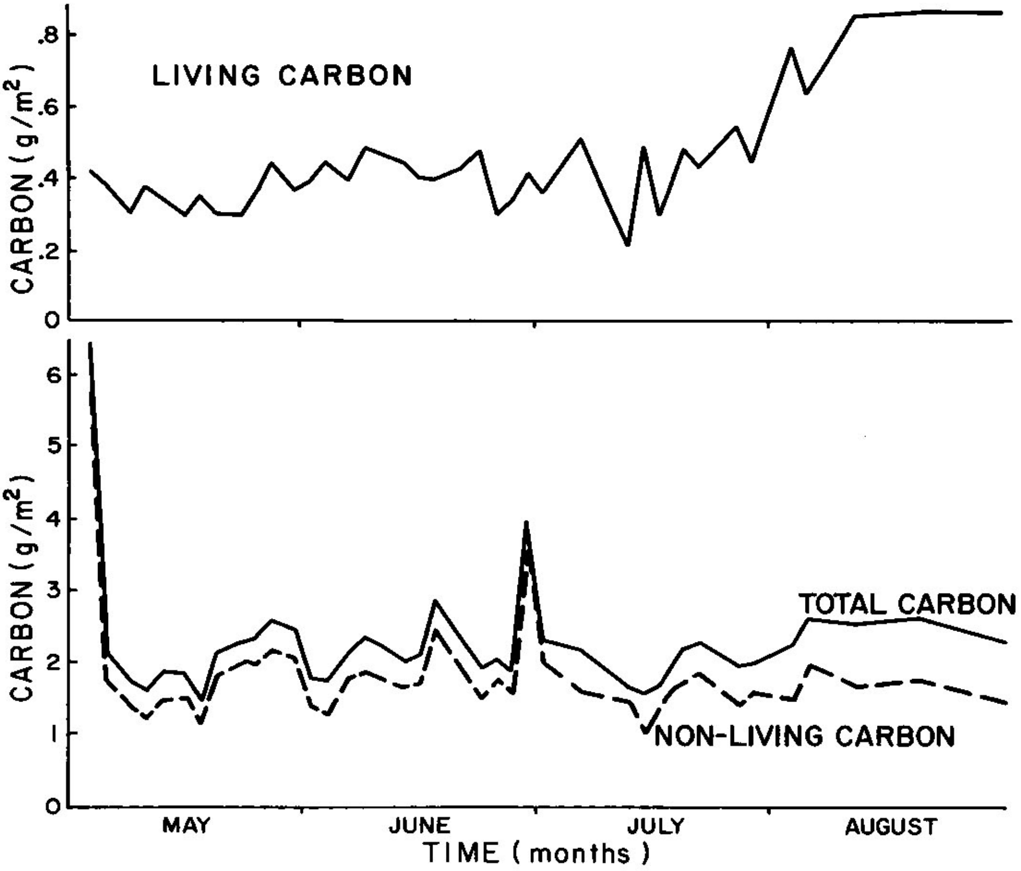

Fig 9 Temporal distribution of living, non-living, and total particulate carbon in the water column at Station A during the sampling period.

A.T.P. are related in a plausible manner (Table I). It appears that pulses in runoff provide a nutrient source for moderate increases in phytoplankton growth.

As is characteristic of salt-marsh estuaries (Heinle & Flemer 1976; Biggs & Flemer 1972; Odum & de la Cruz 1967), detritus was the dominant fraction of the particulate carbon in the water column. By inference from studies in similar environments it is probable that the source of detritus is *Spartina* (Darnell 1967; Day et al. 1973; Gosselink et al. 1974; Teal 1962; Axelrad et al. 1976). The particulate C:N ratio of Ca. 6 is not expected, if the source is predominantly *Spartina* ratio 22.5:1 for living material; McIntyre and Dunstan 1976). As the particle size of *Spartina* detritus decreases, however, the C:N ratio has been observed to decrease (Gosselink and Kirbey 1974). The low C:N ratio of the detritus, if it is indeed from *Spartina,* may result from bacteria on the particles (Meyers et al. 1970; 1971; Hood and Colmer 1971; Berrie 1972). The short-term variability in detritus does not appear to be a function of neap-spring tidal variability (as observed by Odum and de la Cruz 1967) but may be influenced by the freshwater runoff (Table I; correlations with precipitation, tubidity, and stratification).

Due to the estimated short residence time of Merigomish Harbour water and the high concentration of particulate organic carbon [three times higher than that

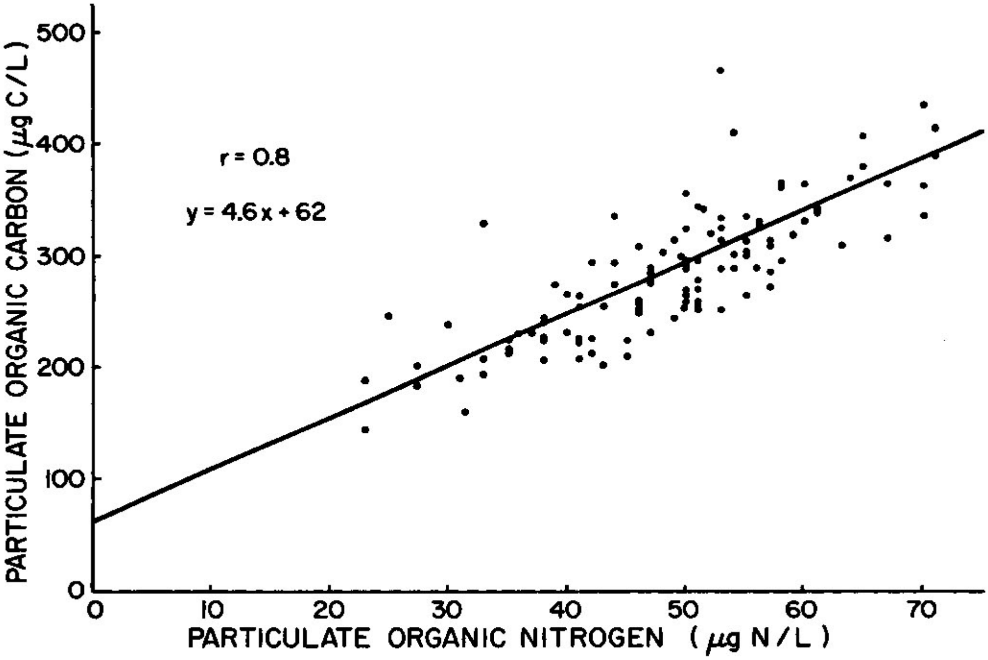

Fig 10 Relationship between particulate organic carbon and nitrogen at Station A during the sampling period.

measured by R. Pocklington (pers. comm., Bedford Institute of Oceanography, Dartmouth) for the Gulf of St. Lawrence] the estuary is an important source of POM to the contiguous offshore waters. This is expected to be true of other salt marsh estuaries along the western border of the Gulf of St. Lawrence.

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