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# GEOCHEMICAL AND BIOLOGICAL OBSERVATIONS IN INTERTIDAL SEDIMENTS FROM COBEQUID BAY, BAY OF DUNDY, NOVA SCOTIA

edited by

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## ABSTRACT

Hargrave, B.T. (Ed.) 1978. Geochemical and Biological Observations in Intertidal Sediments from Cobequid Bay, Bay of Fundy, Nova Scotia. Fish. Mar. Serv. Tech. Rep. 782: 43 pp.

Physical-chemical properties, plant pigments, macrofauna biomass and elemental flux were measured in sediments collected on one occasion along an intertidal transect in Minas Basin, Bay of Fundy. The data permit comparison of structural and process-related features which are seldom observed simultaneously in benthic ecological studies. These features may be quantitatively in inter-related and reflect effects of water motion at different levels of the intertidal zone.



## SOMMAIRE

Hargrave, B.T. (Ed.) 1978. Geochemical and Biological Observations in Intertidal Sediments from Cobequid Bay, Bay of Fundy, Nova Scotia. Fish. Mar. Serv. Tech. Rep. 782: 43 pp.

On a mesuré les propriétés physico-chimiques, les pigments végétaux, la biomasse de la macrofaune et le flux élémentaire de sédiments préléves en une seule fois le long d'un transect intertidal du bassin des Mines (baie de Fundy). Les données recueillies permettent de comparer des caractéristiques structurales et des caractéristiques ayant trait à des processus, qu'on retrouve peu souvent ensemble dans les études de l'écologie du benthos. Il se peut qu'il y ait corrélation quantitative entre ces caractéristiques et qu'elles traduisent des effets du mouvement de l'eau à différents niveaux de la zone intertidale.

## INTRODUCTION
(B. Hargrave)

Ecological studies of sediments and organisms which they contain by definition consider interactions between biotic and abiotic components of the environment. Usually, however, investigations of benthic systems are based on questions which are primarily biological, geological or chemical in nature. This often results in restrictive analysis of inter-related factors and processes. Workers trained in one discipline, for example, are often unfamiliar with techniques and paradigms in common use in another field. Methods and formulation of questions thus often remain separate within different disciplines.

The present study provided an opportunity for biological, chemical and geological observations not usually carried out together to be made simultaneously in one location. Participants joined a one-day field trip to an intertidal mudflat near Selma on Cobequid Bay, Bay of Fundy, Nova Scotia. There were two objectives of the trip:

1. to apply methods used to describe and quantify some structural properties and processes common to all benthic environments simultaneously in one location; and

2. to generate a set of collective observations which could serve as a basis for future studies of the intertidal margins within the Bay of Fundy.

Brief descriptions of methods, results and discussion of data were obtained from participants after the field trip. These were combined and edited to form this report. Some general conclusions concerning structural and process-related aspects of the intertidal community are presented in a final section to demonstrate the value of combining observations made by different investigators working simultaneously in one sampling location. Species lists of marine macroalgae, benthic invertebrate macrofauna, fish and shore birds recorded in Cobequid Bay are given in appendices.

## SAMPLING LOCATION

The intertidal area sampled between 1000 and 1700, May 11, 1977, was located in Cobequid Bay, near Selma at the upper end of Minas Basin in the Bay of Fundy (Fig. 1).

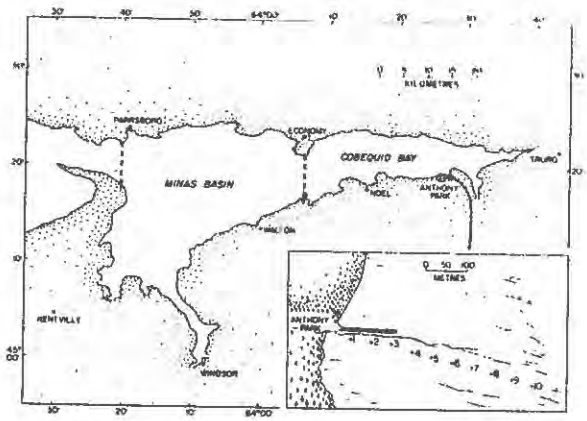


Fig. 1. Location of the intertidal transect in Cobequid Bay. Station numbers refer to sampling sites across the intertidal zone.

Minas Basin and Cobequid Bay form a triangular embayment at the eastern end of the Bay of Fundy. Total surface area of the embayment is 1140 $km^2$, with Minas Basin (836 $km^2$) and Cobequid Bay (304 $km^2$) comprising 73% and 27% of the total embayment area respectively (Table 1).

Although the area of Cobequid Bay is approximately 36% that of Minas Basin, the intertidal area is rather similar in both regions. In total, these sediments comprise 33.4% of the total embayment area. Bousfield and Leim (1960) also estimated that at extreme low water the intertidal zone accounted for more than one-third of the total area of the basin. They suggest that no other coastal area of comparable size has such a large proportion of bottom exposed at low tide. Bleakney (1972) discussed the significance of short-term acyclic variation in extreme low tides for sublittoral organisms in this area. During these events, sediments usually covered by water at low tide are exposed to increase the intertidal area.

Minas Basin and Cobequid Bay are thought to have the largest tides in the world (15.4 m average spring perigree range) with a mean tidal range near the sampling site of 11.7 m (Dalrymple et al. 1975). Tidal current velocities up to 1.5 m $sec^{-1}$ within Cobequid Bay maintain sand in suspension and create conditions of high turbidity. Secchi disc visibility was only 5 cm at 1350 (flood tide) on May 11, 1977.

Bousfield and Leim (1960), Pelltier and McMullin (1972) and Dalrymple et al. (1975) summarize characteristic physical features of Minas Basin and Cobequid Bay. Wave action (wave height generally less

Table 1. Absolute and percent of total surface area within various depth intervals in Minas Basin and Cobequid Bay. Western limits of Minas Basin and Cobequid Bay, drawn in Fig. 1, were assumed as boundaries to calculate area by planimeter from Chart D7-4010, edition 51 Dec. 23/77, Canadian Hydrographic Service. Area of intertidal estuaries is included.

| Depth Interval (m) | Minas Basin | | Cobequid Bay | | Total Embayment | |
|---|---|---|---|---|---|---|
| | $km^2$ | % | $km^2$ | % | $km^2$ | % |
| MHW-MLW (intertidal) | 202.1 | 24.2 | 178.5 | 58.7 | 380.6 | 33.4 |
| MLW-5 | 172.6 | 20.6 | 73.5 | 24.2 | 246.1 | 21.6 |
| 5 - 10 | 118.2 | 14.1 | 29.9 | 9.8 | 148.1 | 13.0 |
| 10 - 20 | 213.7 | 25.6 | 22.2 | 7.3 | 235.9 | 20.7 |
| 20 - 50 | 107.1 | 12.8 | ---- | ---- | 107.1 | 9.4 |
| > 50 | 22.2 | 2.7 | ---- | ---- | 22.2 | 1.9 |
| Total | 835.9 | | 304.1 | | 1140 | |

than 2 m) is restricted by its small size and isolation, but tidal action produces well-mixed conditions throughout the area. Prevailing winds are westerly which corresponds to the direction of maximum fetch. The Bay contains floating ice from January until March or early April and shore-fast ice accumulates along high-tide level (Knight and Dalrymple, 1976). Sediments in the intertidal sandflats are generally frozen to several centimeters in winter. This reduces scouring and erosion by ice and waves but patches of gravel and sand may be transported in frozen ice when it is refloated by tides. Salinity is reduced (25°/$_{oo}$) at the eastern end of Cobequid Bay due to the influence of the Shubenacadie river but values tend to increase (to 30°/$_{oo}$) towards the mouth of Minas Basin (Bousfield and Leim, 1960).

Sediments in Cobequid Bay are derived by erosion of Pleistocene (unconsolidated till), Triassic (basalt, sandstone, siltstone and shale) and Carboniferous (shales and fine-grained sandstones) rocks. Dalrymple et al. (1975) discuss the importance of sea-cliff erosion rather than river input as a source of sand. The topography and extent of the intertidal area, which grade from sandy lag-gravel or a megarippled coarse sand near low water to a thin (15 cm) mud veneer underlain by lag-gravel shoreward, is dependent on shoreline configuration. The presence of headlands, which protect the intertidal zone from strong tidal currents, determines the extent to which fine sediments accumulate as a veneer over gravel lag. In well protected areas, salt marsh and tidal creeks may be established in the upper intertidal area.

The sampling site, located at a provincial park (Anthony Park) with access to the shore and a government wharf, was chosen because characteristic zonation of intertidal sediments was present but the distance from L.W.L. to H.W.L. (500 m) was not as extensive as in some other locations. This has been the site of previous studies which considered certain animal-sediment interactions (Tunnicliffe and Risk, 1977; Yeo, 1978) and the dynamics of sandbar formation and movement (the Selma Bar, observed by Dalrymple et al. [1975] is located at this site). A freshwater stream, which facilitated sieving of sediment for removal of macrofauna, discharges along the eastern side of the wharf. Sampling stations were located so as to be in sediments not directly affected by freshwater runoff (Fig. 1). Stations were located at 50 m intervals across the 500 m intertidal zone. The first (upper) station was approximately 50 m below H.W.L. in the middle of a dense patch of salt marsh cord grass (*Spartina alterniflora*). This vegetation is restricted in horizontal distribution to an area between the wharf and rock outcroppings to the east. *Spartina* does not occur in other areas of Cobequid Bay where the shoreline is flat and normal to the direction of water movement. The wharf has apparently created an area where sediment deposition is enhanced and scouring by water and ice movement is reduced. The clastic sand and mud sediments, which are at least 20 cm deep in the area colonized by *Spartina*, are absent on the western side of the wharf.

Station 2 was located at the edge of the *Spartina* zone where the sediments were

predominantly fine sand and mud, although a compact subsurface layer existed below 4-6 cm. The surface layer of sand, with a high water content, was even thinner (1-2 cm) at station 3 which was located parallel to the end of the wharf. Fine sand predominated at subsequent stations along the transect (4-8) with the presence of small ripples increasing with distance from shore. The two lowermost stations (9 and 10) consisted of medium to coarse sand intermixed with gravel in large (30 cm) sand ripples.

No information concerning ground water flow through the intertidal area was obtained, but the nearby exposed rock outcroppings indicate that the water table must be near to the surface. Fresh water from the stream may also flow over the area following heavy rain. This runoff would affect the lowermost portion of the intertidal zone where the stream is shallow and there is a tendency for delta formation. The influx of freshwater may also be increased in this area by ground water seepage. Considerable variability of salinity in interstitial water probably occurs both horizontally and vertically over the intertidal area.

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## METHODS AND OBSERVATIONS

### 1. PHYSICAL-CHEMICAL PROPERTIES OF SEDIMENTS

### 1a. Grain Size Analysis (K. Kranck)

#### Methods

Grain-size analysis was carried out on inorganic fractions of surface sediment from eight stations along the transect, an upper beach station near MHW and suspended sediment in the creek and in water collected during the flood tide. These samples of suspended material were analyzed for natural (flocculated) as well as inorganic deflocculated particle size distributions.

A model T Coulter counter was used for the grain-size analysis using the basic counting and calibration techniques for the model B and modified as necessary for use with the later model (Sheldon and Parson, 1967). Latex beads (3.49 μm) were used for primary calibration of the small Coulter counter tubes and pollen grains and shrimp eggs to cross-calibrate the larger tubes. The instrument used was modified to read volume concentrations directly (Sheldon, 1973).

The suspended particulate matter was analyzed within 24 hr of collection. Freshwater from the creek was diluted with 3% NaCl to make the sample electrically conductive. Inorganic grains were measured using the same counting techniques, but samples (from a known volume of water) were first filtered, then ashed and re-suspended in saline solution (Kranck, 1975). Filters were weighed to obtain the dry weight of total suspended particulate matter. Size and concentration of particles between 1 and 100 μm were measured and the results plotted as particle spectra showing the equivalent spherical diameter of the particle volume relative to concentration in parts per million (ppm).

Surface sediments (upper 0.5 cm) were collected by spatula from cores taken at various stations. Samples were dried at less than 60°C and ashed in a low temperature asher (Tracerlab LTA600) to remove organic material without altering mineral structure. A small subsample of the ashed sample was weighed in a beaker. About 10 ml of 35% glycerine-water solution was added, the suspension ultra-sonified to break up flocs and aggregates and then diluted with 2000 ml glycerine solution in a large round bottom-beaker. A modified Coulter counter glassware unit was used to handle this large volume of sample suspension in a sufficiently dilute solution and to keep sand grains suspended. A large stirrer with an electrically isolated power supply and a large sample

stand with a Coulter tube extension were needed to accommodate the larger beaker. A stronger vacuum pump with the large volume three-way stopcock described by Sheldon and Parson (1967) was also employed. The grain size of sediment between 2 and 1000 μm was measured as volume percent of total sample assuming a specific gravity of 2.65 to convert the original weight to volume.

This method of bottom sediment size analysis was used in preference to the conventional sieve and pipette analysis to make results directly comparable to analysis of suspended sediment and to allow direct comparison of particle distributions between silt and sand sizes. Other advantages include greater resolution in determination of modal size, greater speed, and small sample size.

## Results and Discussion

Grain size spectra of surface sediments taken along the intertidal transect demonstrate that three samples with coarse sand (station HWL, 3 and 5) are multi-modal while all other samples have one mode in the form of a well-developed normal distribution (Fig. 2). The sorting of the modal portion of the distributions improves with size in the unimodal samples and all samples have a component of fine sediment (the lower tail in the distribution) with equal amounts of all particle sizes.

A "hump" and "tail" grain size spectra is a common distribution noted for sediments in estuarine and nearshore areas (Kranck, 1978). Such distributions may be interpreted by assuming that the particles within the "hump" were deposited as single grains while flocculated particles comprise the "tail". This interpretation is supported by the particle size spectra of natural suspended sediment (Fig. 2). Distributions are straight lines with equal proportions in all size categories equivalent and similar to that of the smallest particle size. This material must be kept in suspension by water turbulence and only deposited in a flocculated form.

The dividing line in size between particles, which remain in suspension and those deposited on the intertidal sediments is about 16 μ. The maximum particle size in the creek exceeds this and, thus, particles between 16 and 70 μm would be expected to settle out when this water flows over the intertidal area. These particles could contribute to the modal size fraction present at stations 1, 6 and 7.

The surface sediment along the transect was homogeneous in texture.

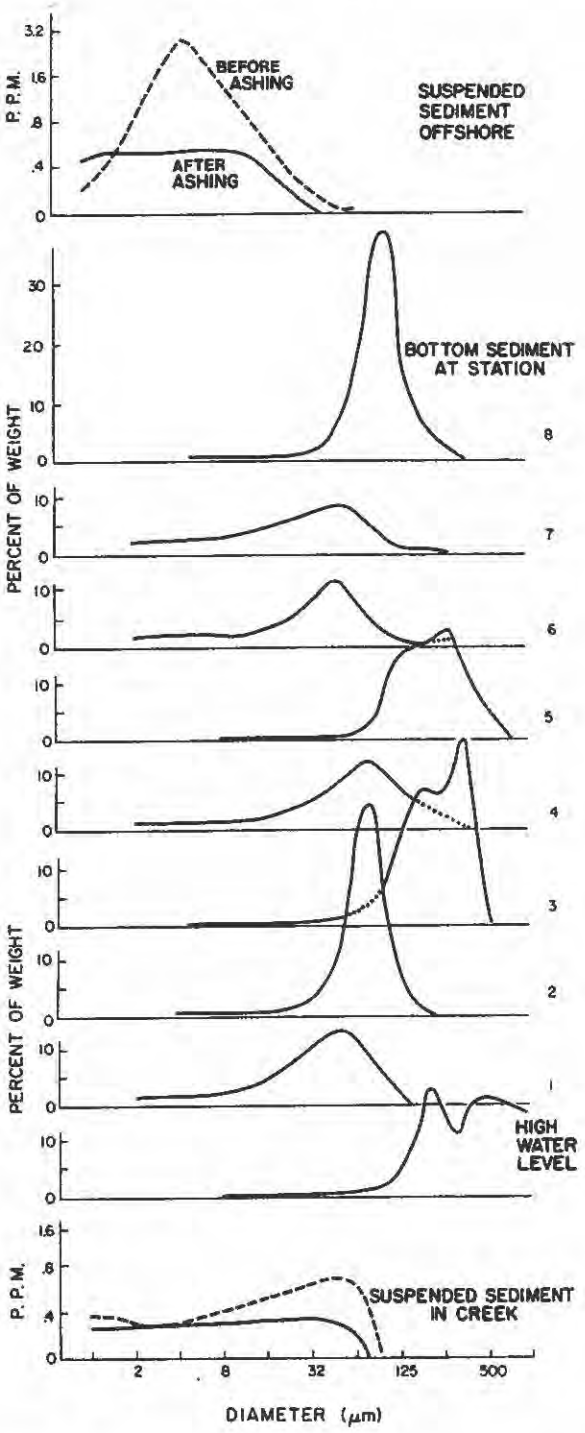


Fig. 2. Size spectra of suspended particles and surface sediment collected along the intertidal transect. Dashed lines in spectra of suspended particles indicate distributions before removal of organic matter.

Ripple marks and sand waves were present at all stations in the lower intertidal zone

(stations 7-10) and an accumulation of fine particles and detrital debris was visible within hollows between ripples. At upper intertidal zone stations, the fine sand was characterized by the presence of burrows, tracks, fecal pellets and diatom mats.

No extensive analyses were carried out but sediment from the surface at Station 1 was collected for comparison with samples of pseudofeces collected by Pasteur pipette from beside a *Macoma balthica* burrow at the same station. Several *Macoma* were also collected and contents of their stomach and intestine removed for sediment particle size analysis*. The particle size spectra (Fig. 3) illustrate no significant difference in the size distribution of

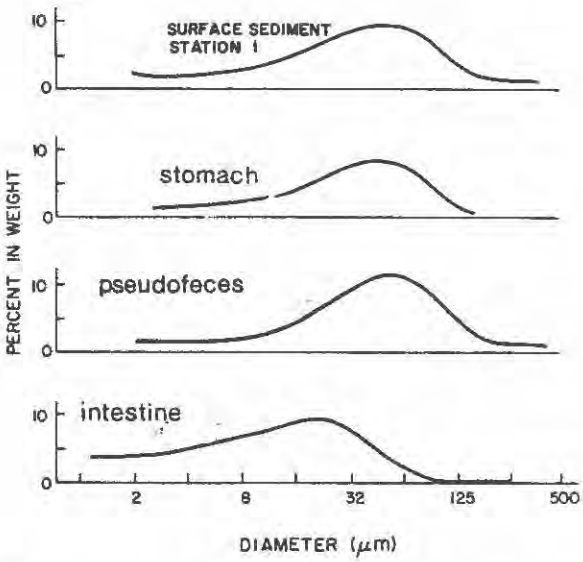


Fig. 3. Comparison of size spectra, after removal of organic matter, of particles from surface sediment, *Macoma* stomach, intestine and pseudofeces deposited on the sediment surface.

particles at the sediment surface from those in *Macoma* stomachs or those released as pseudofeces. The modal size of particles in the intestine, however, is significantly reduced. This follows from Hylleberg and Gallucci's (1975) observations with *Macoma nasuta*. Particle selection occurs on the gills and palps where coarse inorganic particles are separated and egested as pseudofeces. Further sorting or size reduction may also occur by grinding action in the stomach. Hylleberg and Gallucci (1975) observed that sand grains in the stomach had a polished look compared to grains ingested from the sediment. The observations reported here (Fig. 3) do not permit differentiation of these effects, but modal particle size in the intestine is reduced from that of particles taken in the inhalent siphon.

* Samples collected by Mr. P. Stewart, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia.

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## 1b. Redox Potential Profiles (D. Andrews)

### Methods

A platinum-tipped microelectrode was used to measure oxidation-reduction (redox) potentials at closely-spaced intervals with depth in intertidal sediments from Anthony Park. The electrode was constructed from a fine (1 mm o.d.) stainless steel supporting tube (a capillary column) through which an insulated platinum wire was threaded. The platinum tip protruding from the tube was melted to form a bead which was flattened with a file. The junction between the platinum wire and stainless steel tube was strengthened and sealed by epoxy glue. The cross-sectional area of the exposed platinum surface was about 2 $mm^2$. The electrode was mounted on a rack and pinion gear from a microscope to permit a 1 mm resolution in vertical movement.

The electrode was connected to a Radiometer Ph meter (Model 26) used as a potentiometer. A calomel electrode connected to a salt bridge of KCl in agar was used as a reference electrode. The output of the potentiometer was recorded on a Hewlett Packard strip recorder. The recording trace was used to determine the

rate of potential drift over a two-minute interval at each position of the electrode in the sediment core. Potentials at the end of this interval were then recorded.

Redox potentials were measured vertically at 0.5 or 1 cm intervals in single cores (15 cm x 5.7 cm) taken in plexiglass tubes sealed with stoppers at stations 1, 2 and 3.

## Results and Discussion

Replicate profiles measured on the core from station 3 demonstrated similar trends in potential with depth but absolute values that were different by as much as 100 mv (Fig. 4).

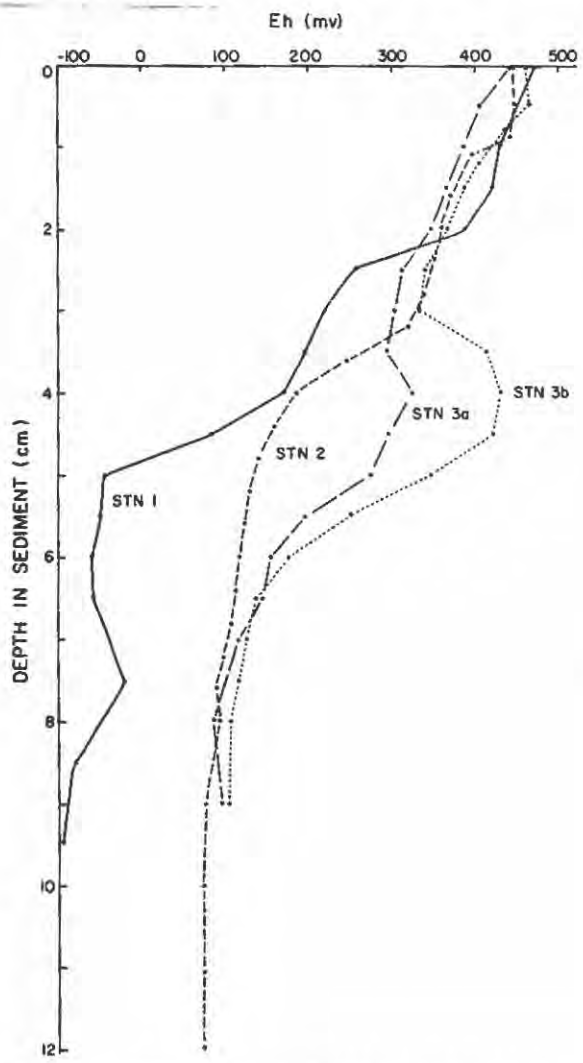


Fig. 4. Oxidation-reduction potentials measured vertically in single cores from intertidal stations as numbered made with a 2 $mm^2$ platinum electrode inserted through the undisturbed sediment surface. a and b represent replicate profiles in the same core.

The outstanding feature of the oxidation-reduction potentials in cores from stations 2 and 3 is that high redox conditions extend quite deep into the sediment with no value below +100 mv even at 12 cm depth. In addition, the sediment was uniformly light red in colour at all depths. Based on these observations these sediments would usually be termed "oxidizing".

Many authors have assumed that such high Eh potentials measured on the Pt electrode correspond to "oxidizing" conditions in interstitial water. Two hundred millivolts has even been taken as the limit of oxygen penetration (Mortimer, 1941; 1942). Although the inability to relate high potentials (above +200 mv) directly to levels of dissolved oxygen has long been recognized (Hoar, 1933; Pearsall and Mortimer, 1939; Hutchinson, 1957), workers have continued to apply the term "oxidizing" to sediments which have such high potentials. More recent studies (Hoare, 1968; Whitfield, 1974) have shown that because of platinum oxides formed on the electrode surface, the slow irreversible mixed potentials measured depend more on electrode pretreatment than on levels of oxygen present.

The profiles in Fig. 4 further demonstrate a lack of correspondence between high electrode potentials and significant levels of oxygen. By the 200 mv criterion, oxygen should penetrate at least 4 cm into the mud. Although we have no direct measurements of oxygen concentration in these sediments it is highly unlikely that oxygen exists to this depth. Oxygen consumption by re-suspended sediment (section 3b) and diffusion of oxygen through the clastic non-porous muds must proceed very slowly. In addition, the distinct nutrient gradients observed in the first 4 cm (section 1e) imply that continual re-suspension and aeration of the sediments or substantial macroinvertebrate reworking of the mud does not occur to this depth. The high potentials obtained, then, cannot be readily explained as a response to high concentrations of oxygen in interstitial water. Other couples or another couple must control the poise of the system and account for the high potentials measured. These couples themselves are very likely complex, mixed potentials (Strumm and Morgan, 1970).

The redox profiles from station 1 in the salt marsh show that conditions are quite different here than at stations 2 and 3. While cores from these stations were uniformly light red in colour and contained only small quantities of organic carbon (section 1d), the core from station 1 contained large quantities of *Spartina* roots and debris and showed a distinct

black zone apparently of amorphous FeS about 6 cm from the surface. This black zone corresponded to a zone of low redox potential (-50 to -100 mv). These low potentials are probably due to the sulfide couple ($S\bar{a}q. \rightleftarrows S^\circ + 2e^-$). The sulfide couple is the only couple that has been successfully correlated to Eh at low negative potentials (Berner, 1963; Fenchel, 1969). As in sediments at the other two stations the unusually high potentials in the surface 2 cm cannot be attributed to any particular couple.

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## 1c. Sediment Texture, Major and Trace Element Content (D. Loring)

### Methods

The textural and chemical composition of the sediments were determined using the techniques described by Loring and Rantala (1977). The main textural components of the samples (sand particles > 53 μm in diameter and mud < 0.53 μm in diameter) were determined by sieving through a 0.53 μm mesh sieve.

### Results and Discussion

#### Texture

The results (Table 2) show that the sand content increases and the mud content decreases along the transect so that the sediments are predominantly sands (91%) at station 5. In vertical section, the seaward core (5) is very sandy throughout, but nearshore, the cores have variable amounts of sand and mud which imply variations in the depositional conditions.

Table 2. Textural analysis as percent of sediment weight as sand and mud at various depths in cores along the intertidal transect.

| Stn. | Depth | % sand 53-2000 μm | % mud < 53 μm |
|---|---|---|---|
| | 0 | 15.3 | 84.7 |
| | 2 | 21.3 | 78.7 |
| 1 | 3 | 41.9 | 58.1 |
| | 5 | 23.8 | 76.2 |
| | 7 | 18.6 | 81.4 |
| | 0 | 26.4 | 73.6 |
| | 1 | 13.1 | 86.9 |
| 2 | 3 | 31.0 | 69.0 |
| | 5 | 20.8 | 79.2 |
| | 10 | 26.2 | 73.8 |
| | 0 | 27.3 | 72.7 |
| | 1 | 43.9 | 56.1 |
| 3 | 2 | 63.9 | 36.1 |
| | 5 | 50.3 | 49.7 |
| | 10 | 59.9 | 40.1 |
| | 0 | 91.4 | 8.6 |
| | 1 | 97.1 | 2.9 |
| 5 | 3 | 98.3 | 1.7 |
| | 5 | 95.4 | 4.6 |
| | 10 | 94.9 | 5.1 |

#### Chemical Composition

The major and trace element composition of the sediments are shown in Table 3.

#### Major Element Composition

The major element composition of the sediments is comparable to that found in texturally equivalent sediments elsewhere (Loring and Nota, 1973). The results show that the major inorganic constituents reflect the mineralogical composition and particle size of the sediments (Fig. 5).

Table 3. Concentrations of major and trace elements in sediment cores taken from four stations along the intertidal transect at Anthony Park.

| Transect Station No. | Depth (cm) | Major Elements (percent weight) | | | | | | | Trace Elements (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Si | Ti | Al | Ca | Mg | Fe | Mn | Zn | Cu | Pb | Co | Ni | Cr | V | Li |
| 1 | 0-0.5 | 30.9 | .45 | 6.28 | 1.10 | 1.08 | 3.44 | 910 | 77 | 24 | 24 | 14 | 42 | 72 | 91 | 52 |
| 1 | 1 | 32.8 | .44 | 5.64 | 1.20 | .96 | 2.98 | 760 | 65 | 18 | 26 | 15 | 39 | 60 | 60 | 53 |
| 1 | 2 | 31.8 | .48 | 5.76 | 1.32 | .92 | 3.12 | 650 | 78 | 22 | 26 | 18 | 53 | 68 | 73 | 58 |
| 1 | 3 | 33.1 | .42 | 4.70 | 1.96 | .66 | 2.38 | 640 | 52 | 16 | 21 | 10 | 26 | 47 | 61 | 35 |
| 1 | 5 | 33.2 | .45 | 5.13 | 1.24 | .52 | 2.72 | 620 | 62 | 16 | 21 | 11 | 27 | 56 | 70 | 42 |
| 1 | 7 | 31.8 | .42 | 5.88 | 1.04 | .92 | 3.08 | 610 | 68 | 19 | 26 | 13 | 36 | 59 | 76 | 47 |
| 2 | 0-0.5 | 31.9 | .45 | 5.64 | 1.14 | .90 | 2.92 | 870 | 67 | 18 | 16 | 11 | 38 | 61 | 73 | 43 |
| 2 | 1 | 29.6 | .44 | 6.44 | 1.04 | 1.06 | 3.38 | 880 | 78 | 22 | 30 | 16 | 40 | 69 | 87 | 55 |
| 2 | 2 | 34.2 | .53 | 4.44 | 1.76 | .64 | 2.52 | 890 | 53 | 23 | 20 | 10 | 36 | 45 | 69 | 33 |
| 2 | 3 | 32.5 | .42 | 5.30 | 1.32 | .86 | 2.78 | 660 | 61 | 18 | 21 | 12 | 30 | 51 | 70 | 42 |
| 2 | 5 | 32.3 | .41 | 5.74 | 1.10 | .92 | 3.06 | 610 | 67 | 19 | 21 | 13 | 32 | 59 | 74 | 47 |
| 2 | 10 | 32.3 | .45 | 5.76 | 1.04 | .90 | 3.04 | 630 | 66 | 18 | 25 | 16 | 33 | 59 | 69 | 48 |
| 3 | 0 | 31.1 | .50 | 5.96 | 1.12 | 1.00 | 3.32 | 940 | 69 | 22 | 21 | 13 | 35 | 64 | 74 | 49 |
| 3 | 1 | 34.7 | .42 | 5.04 | 1.24 | .74 | 2.44 | 760 | 50 | 19 | 17 | 12 | 32 | 49 | 57 | 37 |
| 3 | 2 | 36.9 | .39 | 3.84 | 1.60 | .52 | 2.06 | 660 | 36 | 13 | 20 | 10 | 22 | 37 | 56 | 26 |
| 3 | 3 | 38.2 | .52 | 2.84 | 1.92 | .30 | 1.60 | 810 | 26 | 9 | 16 | 7 | 16 | 24 | 30 | 18 |
| 3 | 5 | 35.6 | .38 | 4.34 | 2.26 | .58 | 2.20 | 690 | 41 | 13 | 18 | 9 | 24 | 44 | 56 | 31 |
| 3 | 10 | 36.2 | .41 | 4.22 | 1.26 | .60 | 2.22 | 580 | 43 | 12 | 21 | 10 | 26 | 37 | 51 | 31 |
| 5 | 0 | 36.5 | .33 | 3.36 | 3.26 | .40 | 1.68 | 500 | 23 | 8 | 14 | 8 | 16 | 26 | 23 | 19 |
| 5 | 1 | 37.0 | .73 | 2.50 | 2.26 | .24 | 1.70 | 1310 | 23 | 7 | 13 | 7 | 12 | 24 | 30 | 16 |
| 5 | 2 | 35.5 | .30 | 3.06 | 4.24 | .26 | 1.28 | 670 | 21 | 8 | 21 | 4 | 16 | 22 | 37 | 17 |
| 5 | 3 | 38.4 | .26 | 2.54 | 2.50 | .19 | 1.08 | 420 | 16 | 6 | 25 | 5 | 10 | 16 | 25 | 14 |
| 5 | 5 | 36.0 | .28 | 3.80 | 3.66 | .26 | 1.20 | 550 | 23 | 6 | 18 | 6 | 16 | 24 | 32 | 17 |
| 5 | 10 | 35.3 | .32 | 2.86 | 3.60 | .26 | 1.26 | 620 | 22 | 8 | 16 | 5 | 17 | 29 | 33 | 20 |

Silicon, the major chemical constituent, varies from 30.9% to 37.0% seaward in the surface sediment with increasing sand content. This is because most of the Si is contributed to the sediments by quartz ($SiO_2$), the major mineralogical component of the sand size material. Quartz acts as a diluent for the other major mineralogical components of the sediments - the aluminosilicate minerals such as feldspars, the clay minerals, amphiboles, pyroxenes, garnets, and accessory heavy minerals, which increase in concentration with decreasing grain size of the sediments. This is shown by the increasing concentration of Al (3.36% to 6.28%), the main constituent of the aluminosilicate minerals, with increasing amounts of mud in the samples. As a result the concentrations of Si increase and those of Al decrease seaward in those cores (Fig. 5). The concentrations of Fe, Mg and Mn also vary directly with those of Al and inversely with Si in the sediments because these elements are derived from specific aluminosilicate minerals in the sediments such as the ferromagnesian silicate group.

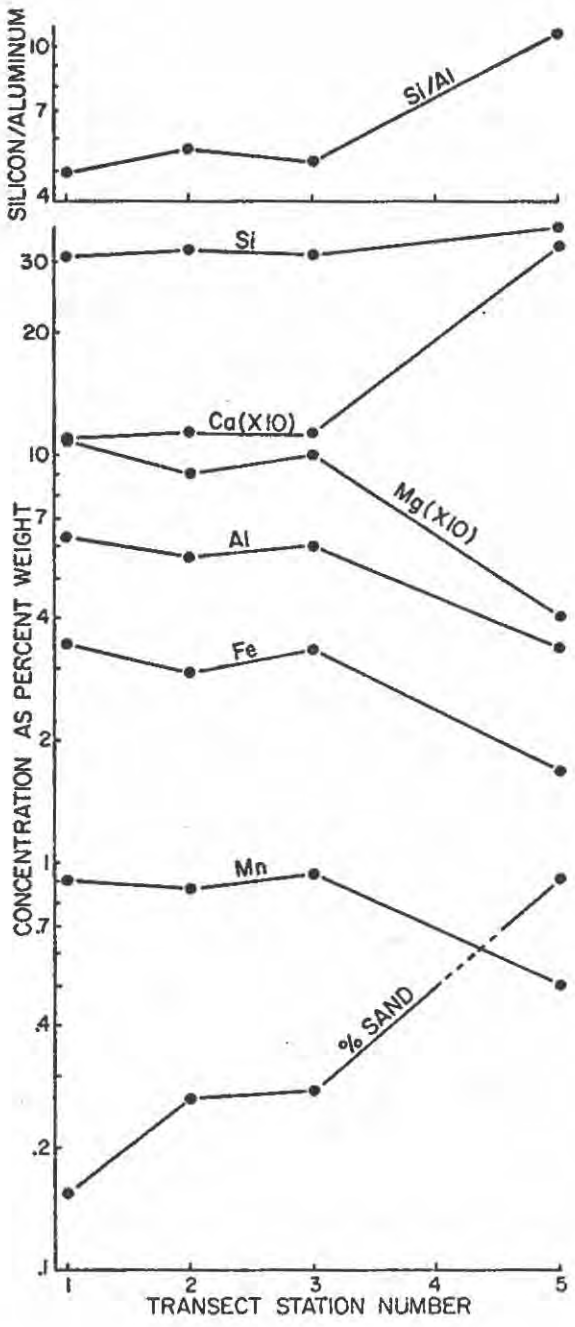


Fig. 5. Variation of major elements concentrations (as percent weight, except Mn as ppm) in surface sediments along the intertidal transect.

Vertically, the variation in the major element composition in each core reflects the variation in abundance and grain size of their primary and secondary host minerals indicated by the changes in the sand and mud content with depth.

## Trace Element Composition

The trace element (Zn, Cu, Pb, Co, Ni, Cr, V and Li) composition of the sediments (Table 3) is comparable to that found elsewhere in texturally equivalent sediments (Loring, 1976a; b). The results show that heavy metal concentrations decrease seaward with increasing sand and Si content of the sediments (Fig. 6). The

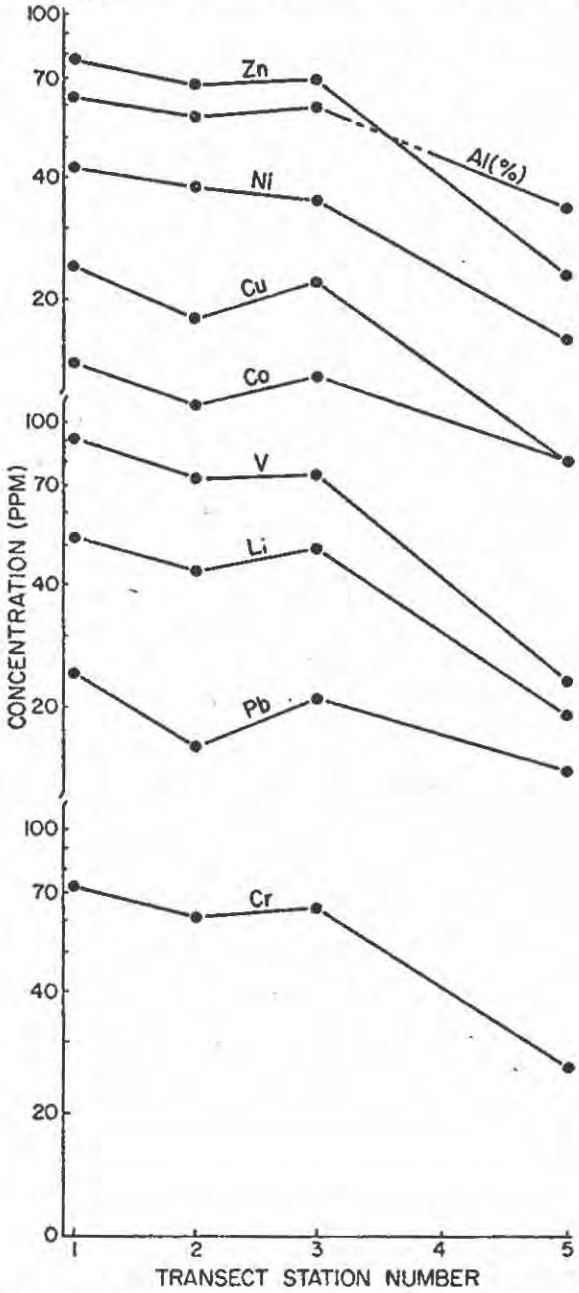


Fig. 6. Concentration of heavy metals in surface sediments along the intertidal transect.

strong inverse covariance of the heavy metals with Si, the main chemical constituent of the sands, shows that quartz ($SiO_2$) is a diluent of the host minerals for the heavy metals in the sediments. The strong positive covariance of the heavy metals with Al, the major chemical constituent of the mud size material (Fig. 5), suggests that most of the trace metals are locked up in the lattices of the aluminosilicate minerals. Vertically, the abundance and distribution of the heavy metals is controlled by the abundance and grain size of their primary and secondary host minerals and is reflected by the variation in grain size and the major chemical constituents Si and Al with depth.

In summary, the major and trace element composition reflects the abundance and grain size of their host minerals in the sediments. The variation in chemical and mineral composition is directly controlled by the physical process responsible for the lateral and vertical sedimentation patterns in this area.

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Loring, D.H. 1976b. Distribution and partition of cobalt, nickel, cnromium, and vanadium in the sediments of the Saguenay Fjord. Can. Journ. Earth. Sci. 13: 1706-1718.

Loring, D.H. and D.J.G. Nota. 1973. Morphology and sediments of the Gulf of St. Lawrence. Fish. Res. Board Can. Bull. 182: 147 pp.

Loring, D.H. and R.T.T. Rantala. 1977. Geochemical analyses of marine sediments and suspended particulate matter. Fish.Res.Bd.Can.Tech.Rept. 700, 58 pp.

## 1d. Carbon, Nitrogen, Phosphorus and Organic Matter in Sediments (B. Hargrave and P. Neame

### Methods

Clear plexiglass tubes (5.7 cm i.d., 30 cm long) with a beveled lower rim were used to collect approximately 20 cm long cores of sediment at each station. These were stored without water for 24 hr at 7°C before being extruded and sectioned in ten 1 cm layers. A sample of surface sediment (1 mm) was collected with a flat spatula. Sediment samples were dried at 60°C, ground with a mortar and pestle and stored in disposable sterile plastic Petri dishes.

Total carbon and nitrogen were determined with a Perkin-Elmer 240 Elemental CHN Analyzer. Absolute sensitivity (twice blank values) was approximately 5 µg for both C and N and sample size (approximately 200 mg dry sediment) was usually adjusted to yield weights an order of magnitude greater than this lower detection limit for analysis. Organic carbon was determined on replicate samples of approximately 300 mg dry weight. These were placed in a beaker and covered with 3 ml of 1 N HCL for 1 hr. The sediment was then rinsed with distilled water onto pre-ashed and pre-weighed silver filters (0.8 µ pore dia, Selas Flotronics[R]). After drying (48 hr at 60°C) and reweighing to determine sediment dry weight, filters were combusted for elemental analysis. There was no significant difference in carbon and nitrogen content measured in sediments which were evaporated to dryness rather than being filtered to remove acid. Thus, solubilization and loss of carbon by rinsing did not occur. Carbonate was estimated by difference between measures of total and organic carbon.

Total phosphorus and organic phosphorus in sediment samples were determined by a cold acid extraction technique (Aspila et al., 1976). Soluble reactive phosphorus in extracts was measured using standard colorimetric methods (Strickland and Parsons, 1972). Sediment organic matter was estimated as weight loss on ignition at 550°C for 4 hr.

### Results and Discussion

Tables 4 and 5 summarize the content (as percent dry weight) of organic and inorganic matter and ratios between measures in samples from different stations.

These measures changed markedly along the transect in both surface and subsurface sediment layers (Figs. 7 and 8).

Amounts of organic matter were greatest in sediments at the first three stations in the upper intertidal zone, with maximum values of carbon, nitrogen and phosphorus occurring in surface sediments at station 3 (Figs. 7 and 8). Ratios of C:N:P were similar in these sediments (Table 5) but changes in absolute amounts and the ratio between elements occurred in subsurface samples below 2-3 cm depth and at other stations. At all stations organic matter tended to reach a minimum between 2 and 3 cm depth, but the reduction was most apparent at the first three stations. Total phosphorus, but not organic phosphorus values, also show some indication of a minimum at the same depth. Organic phosphorus content was low and variable within a core with no clear trend with depth.

Carbonates in sediment also varied with depth (Table 4). Subsurface maxima occurred near 2 or 3 cm in all cores. The ratio of organic carbon:total carbon

Table 4. Organic and inorganic carbon, nitrogen, organic matter, total and organic phosphorus in sediments from various stations along the intertidal transect.

| Station | Depth (cm) | Percent of Sediment Dry Weight | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total Carbon | Organic Carbon[1] | Carbonate | Nitrogen[1] | Organic Matter | Total Phosphorus | Organic Phosphorus |
| 1 | 0 | .801 | .502 | .299 | .076 | 3.0 | .046 | .008 |
| | 1 | .757 | .560 | .197 | .059 | 3.0 | .045 | ---- |
| | 2 | .913 | .616 | .297 | .089 | 3.3 | .047 | .009 |
| | 3 | 1.372 | .629 | .743 | .069 | 2.9 | .038 | .005 |
| | 5 | .805 | .548 | .257 | .057 | 3.1 | .041 | .005 |
| | 7 | .835 | .815 | .020 | .065 | 3.5 | .042 | .007 |
| 2 | 0 | .817 | .502 | .315 | .073 | 3.5 | .045 | .008 |
| | 1 | 1.190 | .625 | .565 | .088 | 4.2 | .050 | .012 |
| | 2 | .922 | .404 | .518 | .059 | 2.3 | .043 | .005 |
| | 3 | 1.088 | .468 | .620 | .065 | 3.0 | .042 | .007 |
| | 5 | 1.055 | .631 | .424 | .083 | 3.6 | .044 | .009 |
| | 10 | 1.099 | .531 | .568 | .075 | 3.3 | .043 | .008 |
| 3 | 0 | .974 | .630 | .344 | .093 | 4.2 | .047 | .009 |
| | 1 | 1.004 | .522 | .482 | .071 | 3.0 | .038 | .005 |
| | 2 | .714 | .342 | .372 | .051 | 1.9 | .031 | .005 |
| | 5 | .763 | .393 | .370 | .046 | 2.7 | .032 | .006 |
| | 10 | .686 | .334 | .352 | .037 | 2.5 | .032 | .004 |
| 5 | 0 | .766 | .060 | .706 | .011 | 1.8 | .021 | .002 |
| | 1 | .377 | .029 | .348 | .005 | 1.1 | .025 | .007 |
| | 2 | .484 | .015 | .469 | .006 | 1.0 | ---- | ---- |
| | 3 | .678 | .014 | .664 | .005 | 1.1 | .017 | 0 |
| | 5 | .836 | .237 | .599 | .006 | 2.0 | .019 | .002 |
| | 10 | 1.240 | .140 | 1.100 | .006 | 2.8 | .027 | .003 |
| 7 | 0 | .143 | .033 | .110 | .007 | ---- | ---- | ---- |
| 8 | 0 | .404 | .032 | .370 | .007 | ---- | ---- | ---- |
| 10 | 0 | .504 | .018 | .486 | .003 | ---- | ---- | ---- |

[1] Treatment of sediment with acid for removal of carbonates resulted in an average weight loss of 5% which was similar at all stations. Percent dry weight values were not corrected for this weight loss.

(Table 5) also illustrates these differences in the relative importance of carbonates. There is a clear decrease in the proportion of organic carbon to the total with distance along the transect. At station 5, for example, carbonates comprise over 90% of the total carbon present in surface sediment (above 3 cm). At station 1, on the other hand, organic carbon accounts for over 60% of the total carbon content. This reflects the enrichment of organic matter in sediments of the upper intertidal zone.

The ratio of organic carbon:nitrogen in surface sediments (Fig. 7) illustrates differences in the quality of organic matter present along the transect. Values for the ratio in the upper intertidal zone stations are typical of nearshore marine sediments (Parsons et al., 1977) but values below 6 at other stations are unusual. They imply that the organic matter present is in the form of living organisms or freshly produced detritus. Changes in ratio values vertically in cores (Table 5) show a trend to increasing organic carbon relative to nitrogen with increasing depth. Values near 3 between 2 and 3 cm at station 5 are probably not reliable. The heterogenous nature of the coarse sand and the low amounts of organic carbon present (Table 4) reduce the accuracy of these determinations.

## References


Aspila, K.I., H. Agemian and A.S.Y. Chau. 1976. A semi-automated method for the determination of inorganic, organic and total phosphorus in sediments. Analyst 101: 187-197.

Parsons, T.R., M. Takahashi and B.T. Hargrave. 1977. Biological Oceanographic Processes. Pergamon Press.

Table 5. Ratios (by weight) of organic carbon, nitrogen, organic phosphorus and organic carbon as percent of total carbon from various stations along the intertidal transect.

| Station | Depth | $\frac{\text{Organic C}}{\text{N}}$ | $\frac{\text{Organic C}}{\text{Organic P}}$ | C:N:P | $\frac{\text{Organic C}}{\text{Total C}} \cdot 100$ |
|---|---|---|---|---|---|
| 1 | 0 | 6.6 | 63.0 | 63:11:1 | 62.7 |
| | 1 | 9.5 | ---- | | 74.6 |
| | 2 | 6.9 | 68.7 | 69: 9:1 | 67.5 |
| | 3 | 9.1 | 126.4 | 126:23:1 | 45.8 |
| | 5 | 9.6 | 112.4 | 112:16:1 | 68.1 |
| | 7 | 12.8 | 126.5 | 127:10:1 | 97.6 |
| 2 | 0 | 6.9 | 61.5 | 62:10:1 | 61.4 |
| | 1 | 7.1 | 54.1 | 54:10:1 | 52.5 |
| | 2 | 6.9 | 81.0 | 81:14:1 | 43.8 |
| | 3 | 7.2 | 63.5 | 64:12:1 | 43.0 |
| | 5 | 9.3 | 70.1 | 70: 9:1 | 59.8 |
| | 10 | 7.1 | 71.1 | 71:14:1 | 48.3 |
| 3 | 0 | 6.8 | 68.7 | 69:11:1 | 64.7 |
| | 1 | 7.4 | 100.8 | 101:19:1 | 52.0 |
| | 2 | 6.7 | 70.0 | 70: 8:1 | 47.9 |
| | 5 | 8.5 | 67.9 | 68: 8:1 | 51.5 |
| | 10 | 9.0 | 76.1 | 76:14:1 | 48.7 |
| 5 | 0 | 5.5 | 27.3 | 27: 5:1 | 7.8 |
| | 1 | 5.8 | 4.0 | 4: 1:1 | 7.7 |
| | 2 | 2.5 | ---- | ------- | 3.1 |
| | 3 | 3.1 | --- | ------- | 2.1 |
| | 5 | 39.5 | 7.8 | 8:0.2:1 | 28.3 |
| | 10 | 23.3 | 46.7 | 47: 2:1 | 11.3 |
| 7 | 0 | 4.1 | ---- | | 23.1 |
| 8 | 0 | 4.5 | ---- | | 7.9 |
| 10 | 0 | 4.5 | ---- | | 3.6 |

Strickland, J.D.H. and T.R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Fish. Res. Bd. Canada Bull. 167 (2nd edition).

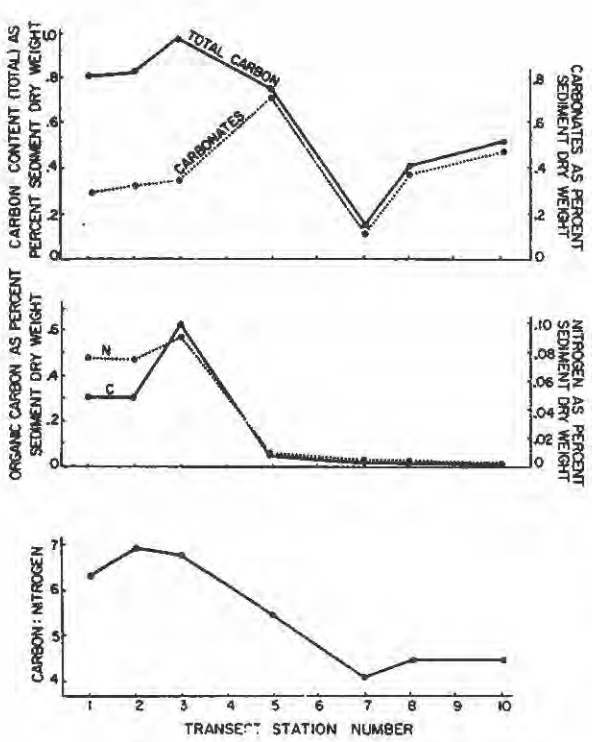


Fig. 7. Percentages of total carbon, carbonates, organic carbon, nitrogen and the ratio of organic carbon:nitrogen (by weight) in surface sediments at various stations.

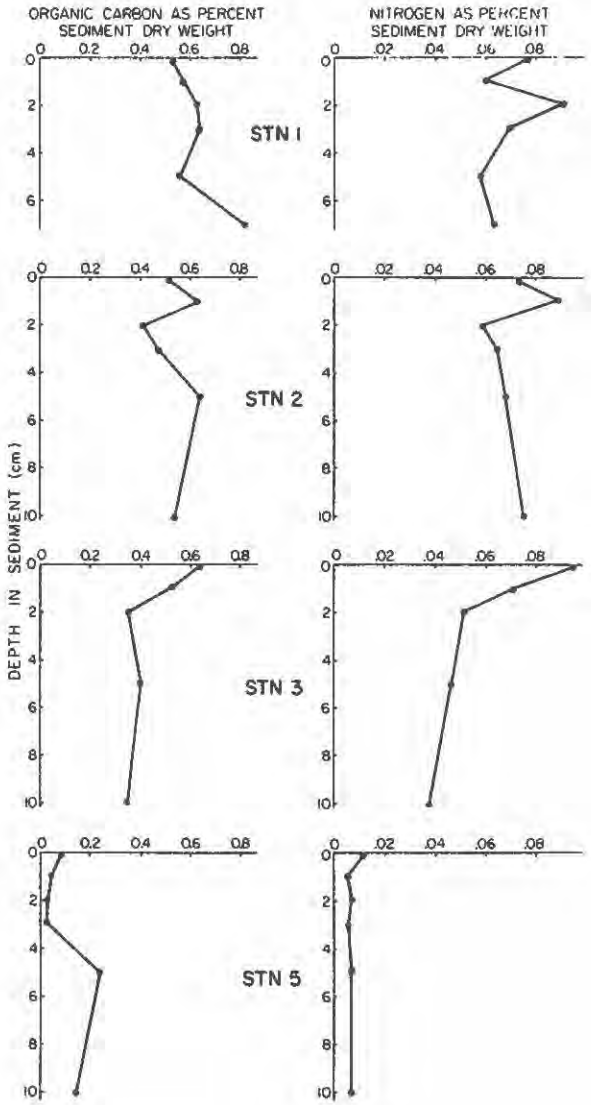


Fig. 8. Vertical profiles of percent of organic carbon and nitrogen in sediment cores from four stations.

## 1e. Pore Water Nutrient Content (P. Neame)

### Methods

Interstitial water was extracted from sediment cores collected specifically for this purpose from stations (1, 2, 3, 5). Cores (5.7 cm dia, 15 cm long) were removed and stored at 10°C for 24 hr before extrusion and sectioning at 1-cm intervals under nitrogen in a glove bag. This avoided possible oxidation of reduced sediments which could result in phosphorus adsorption from pore water. Sediment sections (1-cm thick) were transferred to a Reeburgh (1967) apparatus and pressed at 100 psi to expel interstitial water. Total soluble phosphorus, soluble reactive phosphorus and soluble reactive silicate were determined in these samples using standard techniques (Strickland and Parsons, 1972).

### Results and Discussion

Concentrations of phosphorus and silicate dissolved in interstitial water increased to 6 cm depth in all cores (Table 6). There were no large differences in concentrations of total phosphorus with depth except at 4 cm depth in the core from station 1.

Plots of pore water concentrations of reactive phosphorus and silicate with depth (Fig. 9) indicate differences in vertical distribution patterns of these two nutrients. Silicate increased in concentration with depth throughout the 10 cm core at station 1 but phosphorus, which increased sharply between 3 and 5 cm, decreased in concentration in deeper sediment layers. Lower concentrations extended further down into the sediment at station 2, indicating the possibility that a greater mixing of interstitial water and overlying water occurs in this sediment than occurs at station 1.

Changes in concentration with depth were reduced at stations 3 and 5 (Fig. 9, Table 6). These sandier sediments are probably better drained during each tidal cycle than are the more cohesive sediments of the upper intertidal zone.

Table 6. Concentrations of total phosphorus, reactive phosphorus and silicate dissolved in interstitial water at various depths in sediment cores taken along the intertidal transect. Each point represents a single determination in water squeezed from 1-cm core sections.

| Station | Depth | Total Phosphorus µg $\ell^{-1}$ | Soluble Reactive Phosphorus µg $\ell^{-1}$ | Soluble Reactive Silicate µg $\ell^{-1}$ |
|---|---|---|---|---|
| 1 | 0-1 | 113 | 116 | 30 |
| | 1-2 | 274 | 89 | 149 |
| | 2-3 | 384 | 173 | 201 |
| | 3-4 | 1096 | 619 | 235 |
| | 4-6 | --- | 2370 | 275 |
| | 6-8 | --- | 1010 | 335 |
| | 8-10 | --- | 1660 | 328 |
| | 10-12 | --- | 940 | 437 |
| 2 | 0-1 | 103 | 66 | 29 |
| | 1-2 | 145 | 90 | 72 |
| | 2-3 | 150 | 101 | 94 |
| | 3-4 | --- | 85 | 163 |
| | 4-6 | --- | 180 | 140 |
| | 6-8 | --- | 240 | 233 |
| | 8-10 | --- | 610 | 405 |
| | 10-12 | --- | 1130 | 99 |
| 3 | 0-1 | 108 | 103 | 33 |
| | 1-2 | 108 | 74 | 56 |
| | 2-3 | 203 | 143 | 55 |
| | 3-5 | 130 | 134 | 46 |
| | 5-7 | --- | 360 | 95 |
| | 7-11 | --- | 150 | 63 |
| 5 | 0-1 | 153 | 123 | 5 |
| | 1-3 | 115 | 145 | 25 |
| | 3-5 | --- | 125 | 6 |
| | 5-8 | --- | 95 | 23 |

### References


Reeburgh, W.S. 1967. An improved interstitial water sampler. Limnol. Oceanogr. 12: 163-165.

Strickland, J.D.H. and T.R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Fish. Res. Bd. Canada Bull. 167 (2nd edition).

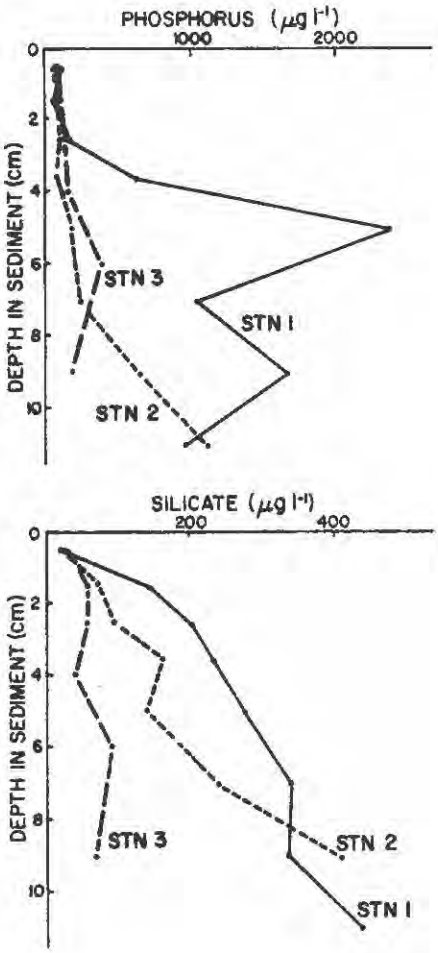


Fig. 9. Vertical profiles of reactive phosphorus and silicate in pore water at different depths in cores taken at three stations along the intertidal transect.

## 2. SUSPENDED PARTICULATE MATTER
(B. Hargrave)

### Methods

Water was collected at 1500 hr when the flood tide water level reached station 9. Water was taken in a plastic bucket and a measured volume was poured through a sieve (130 μ Nitex mesh) to separate plankton and coarse particulate debris. A spatula was used to quantitatively transfer material retained on the sieve to glass vials. Water passing through the sieve was collected in a plastic bottle and filtered on return to the laboratory (within 3 hr).

Triplicate samples of particulate material retained by the 130 μ screen were placed on three pre-ashed and pre-weighed silver filters (0.8 μ pore dia, Selas Flotronics[R]). Filters and samples were rinsed with distilled water and then were placed in a dessicator containing concentrated (11.3 N) HCL overnight to remove carbonates. After fuming, filters were dried (60°C for 24 hr) and weight was determined before combustion for elemental and organic carbon analysis as described in section 1d. The unfumed sample was dried directly after rinsing to provide a measure of total particulate carbon.

Water samples were treated in a similar way. Triplicate 25 ml aliquots of the well-mixed sample were filtered through pre-ashed and pre-weighed silver filters. Only one filter was fumed for an estimate of particulate organic carbon.

Subsamples of water were also used for plant pigment analysis (section 3a). The remainder of the water was stored at 10°C in the dark for 13 days when an additional 25 ml aliquot was filtered for analysis of total carbon and nitrogen.

### Results and Discussion

An average of 68 μg $\ell^{-1}$ of particulate matter was retained on the 130 μ screen (Table 7). All of the material was macrophyte detritus (seaweed and marsh grass debris). No planktonic crustacea were present. The carbon content was lower in the sample not exposed to HCL fumes than in those which were exposed. The variation in nitrogen content between samples is great which probably reflects the heterogeneous composition of the debris. The total weight of carbon and nitrogen suspended in this size fraction was low and variable (9-20 μg liter$^{-1}$, 1-2 μg N liter$^{-1}$) in contrast to material which passed through the screen.

Suspended particulate matter < 130 μ was present in an average concentration of 1.4 g liter$^{-1}$. Organic carbon (1.06% of the dry weight) constituted 76% of the

Table 7. Particulate organic carbon and nitrogen suspended in flood tide water over sediments of the lower intertidal zone at Anthony Park (1500 hr), May 11, 1978. * samples not acid fumed, ** samples held 13 days before analysis.

| Sample | Particulate Dry Weight (mg $\ell^{-1}$) | % N | % C | C:N | C (mg/ℓ) | N (mg/ℓ) |
|---|---|---|---|---|---|---|
| Debris retained on 130 μ sieve | .080 | 3.07 | 25.0 | 8.14 | .0199 | .0024 |
| | .064 | 2.83 | 23.7 | 8.40 | .0150 | .0018 |
| | .060 | 1.70 | 15.6* | 9.15 | .0093 | .0010 |
| Water passing 130 μ sieve | 1280 | 0.18 | 1.40* | 7.80 | 17.9 | 2.30 |
| | 1500 | 0.15 | 1.06 | 7.00 | 15.9 | 2.25 |
| | 1320** | 0.17 | 1.37* | 8.00 | 18.1 | 2.25 |

total carbon and this was not altered by storage for 13 days. Nitrogen content in this suspended material was also unchanged during storage (0.17%). The carbon: nitrogen ratio of material in the fine suspended material (average 7.6) was lower than that in the > 130 μ size fraction (average 8.6).

Subsamples of water filtered through the 130 μ sieve were also analyzed for chlorophyll *a* and pheopigments (by methods described in section 5a) within 3 hr of collection. Triplicate aliquots (25-40 ml) of the well-mixed sample contained 22.3 ($\sigma$ = 1.5) and 24.9 ($\sigma$ = 2.3) μg chlorophyll *a* and pheopigments $liter^{-1}$ respectively. Functional chlorophyll was thus 47% of the total suspended pigment concentration with a C:chlorophyll *a* ratio in suspended particulate matter (15.9 mg organic C $liter^{-1}$, Table 7) of 713. On a dry weight basis, suspended pigments were equivalent to 16.3 μg chlorophyll *a* and 18.2 μg pheopigments per gram suspended matter.

## 3. ELEMENTAL FLUX

### 3a. Measures of Epibenthic Primary Production and Benthic Metabolism by Oxygen Exchange (P. Neame)

#### Methods

Net primary production by epibenthic algae, community respiration (and gross primary production by summation) in undisturbed intertidal sediments at Anthony Park were measured *in situ* by following changes in dissolved oxygen concentration in water placed over the sediment in light and dark cores. Six core tubes (12 cm long, 5.7 cm i.d.) of clear plexiglass, beveled at the lower end, three with and three without black plastic tape as a wrapping, were inserted gently into the sediment at stations 1, 2 and 3. The chambers were placed so as to leave 1 to 3 cm projecting above the sediment surface. Cores were slowly filled with filtered (0.45 μ Millipore[R] HA) seawater with minimal disturbance of the sediment surface. The water had been purged with $N_2$ for 5 min to reduce dissolved oxygen content to between 6 and 9 mg per liter. Resuspension of surface sediment occurred on filling of cores and some particulate matter was trapped in the surface film. A spatula was used to gently mix the water, and most of the resuspended material settled slowly.

Initial measurements for dissolved oxygen were made with a portable oxygen meter (54 ARC Yellow Springs Instruments) after a 5-10 min equilibration period. Cores were immediately capped with clear or taped plexiglass covers made to seal tightly against the inner cylinder walls.

Vaseline applied to the periphery of the disc and elastic bands held by clips on the sides of cylinders ensured an air tight seal. Cores were incubated for 1 to 3 hr after which caps were carefully removed and dissolved oxygen measured. The oxygen electrode probe with

the protective cap removed was used to gently mix water until stabilized measures of concentration were obtained. Temperature was also recorded with the YSI meter before and after incubation.

Water volume contained over sediment was determined by measuring depth to the nearest millimeter with a plastic ruler held against the inside surface of each core. Water volume was estimated by multiplication of this value (in centimeters) by 25.5 (the cross-sectional core area). The accuracy of the method was verified by comparing these measures with actual volume of water decanted. Values were never different by more than 2 ml (a maximum error of 8% for the minimum volume enclosed in cores, 25.5 ml). Cores were removed by shovel and placed in individual plastic bags after water volume had been measured. These were subsequently sieved (0.5 mm mesh) for enumeration of macrofauna.

Cores were placed *in situ* on May 11, 1977 between 1145 and 1230, and removed between 1400 and 1500 (average of 2.2 hr incubation). A Belfort pyrheliograph was used to record incident solar radiation. The weather was overcast with showers, and average radiation during the incubation was 0.3 g-cal $cm^{-2}$ $min^{-1}$ (variable between 0.25 and 0.37 g-cal $cm^{-2}$ $min^{-1}$). Thus, a total of 40 g-cal $cm^{-2}$ was received over the average incubation time. Total radiation for the day was approximately 96 g-cal $cm^{-2}$.

Total concentrations of dissolved oxygen present in water in cylinders before and after incubation were calculated. Changes were expressed on an hourly and per $m^2$ basis to estimate mg $O_2$ $m^{-2}hr^{-1}$ produced or consumed. This permitted gross oxygen production to be calculated as the sum of net oxygen production (in light cylinders) and oxygen uptake (in dark cylinders) (Hargrave, 1969). The assumption that processes involved in oxygen uptake (chemical oxidation and total community aerobic respiration) proceed at similar rates in the light and dark needs to be emphasized.

## Results and Discussion

Differences existed between the three stations both in terms of the absolute amounts of oxygen flux and the relative importance of production and respiration (Table 8). Both gross and net primary production were highest at station 2, whereas oxygen uptake was greatest at station 3. Variability was higher among replicates of cores exposed to the light than for the dark cores, possibly indicating patchiness in distribution of epibenthic algae on the sediment surface. It is also possible that increased abundance of macrofauna (or meiofauna which were not enumerated) in particular cores could cause excessive oxygen consumption, but differences in numbers of macrofauna between cores were not clearly related to discrepancies in measures of net oxygen production (Table 9). Total numbers and biomass, however, were highest at station 3. This was the only station where no net oxygen production was measured when cores were exposed to the light. Macrofauna respiration could account for a significant fraction of oxygen consumption by sediments at this station. This contrasts observations that macrofauna respiratory demands usually contribute little to total oxygen uptake in undisturbed sediments (Pamatmat and Banse, 1969).

Measures of oxygen production and consumption by sediments were calculated in terms of carbon to facilitate comparison with other determinations assuming PQ = 1.0 and RQ = 0.85 (Strickland and Parsons, 1972) (Table 10). Values of carbon flux calculated in this way may not be accurate estimates of true primary production by epibenthic algae or total community metabolism, but the measures are useful indicators for the amount of organic matter produced or oxidized in sediments (Parsons et al., 1977). Cadée and Hegeman (1977) reported rates of epibenthic primary production ($^{14}C$ method) between 10 and 60 mg C $m^{-2}$ $hr^{-1}$ (assuming a 12 hr day) on intertidal sandflats in the Dutch Wadden Sea during May. If higher levels of light had occurred during the incubation in the present study, comparable production rates would probably have been measured.

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Table 8. *In situ* production and consumption of dissolved oxygen by sediment cores from three intertidal transect stations. L refers to clear cylinders which received light where photosynthesis was possible, D refers to dark cores where only oxygen uptake occurred. Filtered water added to cover sediment during incubation contained 9.0 ± 0.3 mg $O_2$ per liter and was between 5.0 and 6.0°C at the start of the experiment.

| Station | Core | Changes in Dissolved Oxygen | $\bar{x}$ | Gross Productivity |
|---|---|---|---|---|
| | | mg $O_2$ $m^{-2}$ $hr^{-1}$ | | |
| 1 | 1L | 20.6 | | |
| | 2L | 1.2 | | |
| | 3L | 1.8 | 7.9 | |
| | 13D | -4.9 | | |
| | 14D | -7.0 | | |
| | 15D | -5.5 | -5.8 | 13.7 |
| 2 | 4L | 23.8 | | |
| | 5L | 7.5 | | |
| | 6L | 11.0 | 14.1 | |
| | 16D | -7.6 | | |
| | 17D | -7.3 | | |
| | 18D | -10.5 | -8.5 | 22.6 |
| 3 | 7L | -5.8 | | |
| | 8L | -21.7 | | |
| | 9L | -30.5 | -19.3 | |
| | 19D | -31.7 | | |
| | 20D | -31.4 | | |
| | 21D | -28.1 | -30.4 | 11.1 |

Table 9. Numbers and biomass of *Macoma* and in 25.5 $cm^2$ cores incubated at three intertidal transect stations for measures of benthic oxygen production and consumption.

| Station | Measurement | Core | *Macoma* small | *Macoma* medium | *Macoma* large | Polychaetes |
|---|---|---|---|---|---|---|
| 1 | number/core | 2L | 1 | 2 | - | - |
| | | 3L | 1 | 1 | - | - |
| | | 13D | 1 | - | 1 | - |
| | | 14D | 2 | - | - | - |
| | | 15D | - | 1 | 1 | - |
| | number $m^{-2}$ | | 400 | 320 | 160 | - |
| | dry weight (mg)$m^{-2}$ | | 1520 | 4000 | 5952 | |
| 2 | number/core | 4L | - | 1 | 1 | - |
| | | 5L | 1 | - | 3 | 1 |
| | | 6L | 1 | - | 2 | - |
| | | 16D | - | - | 2 | 1 |
| | | 17D | 1 | 1 | - | - |
| | | 18D | 3 | - | 1 | - |
| | number $m^{-2}$ | | 400 | 133 | 600 | 133 |
| | dry weight (mg)$m^{-2}$ | | 1520 | 1663 | 22320 | 1609 |
| 3 | number/core | 7L | 2 | - | 2 | - |
| | | 8L | 1 | 1 | 2 | - |
| | | 9L | 1 | - | 2 | 1 |
| | | 19D | 2 | 1 | 3 | 1 |
| | | 20D | - | - | 3 | - |
| | | 21D | 1 | 2 | 3 | 1 |
| | number $m^{-2}$ | | 467 | 267 | 1000 | 200 |
| | dry weight (mg)$m^{-2}$ | | 1775 | 3338 | 37200 | 2420 |

Table 10. Average oxygen production and consumption (from Table 8, as mg $O_2$ $m^{-2}$ $hr^{-1}$) by sediments at three stations expressed as carbon equivalents by assuming PQ = 1.0 ($\Delta O_2$ x 0.536) and RQ = 0.85 ($\Delta O_2$ x 0.456). Primary production and oxygen uptake converted to daily rates assuming constant production and consumption over 10 and 24 hr respectively.

| Station | Average Net Production mg C $m^{-2}$ $hr^{-1}$ | Average Community Respiration mg C $m^{-2}$ $hr^{-1}$ | Average Community Respiration mg C $m^{-2}$ $day^{-1}$ | Average Gross Production mg C $m^{-2}$ $hr^{-1}$ | Average Gross Production mg C $m^{-2}$ $day^{-1}$ |
|---|---|---|---|---|---|
| 1 | 4.2 | -2.6 | 62.4 | 6.8 | 68 |
| 2 | 7.6 | -3.9 | 93.6 | 11.5 | 115 |
| 3 | -10.3 | -13.9 | 333.0 | 3.6 | 36 |

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## 3b. Oxygen Uptake by Stirred Sediments (B. Hargrave)

### Methods

Sediment samples, taken by spatula from the surface layer and sections of cores at various depths, were used for measurement of oxygen uptake following methods described previously (Hargrave, 1972a). The method is essentially a BOD determination where sediment is suspended and stirred in oxygenated water to determine short-term rates of oxygen uptake. Incubation time was adjusted to ensure that measurable changes in dissolved oxygen concentration occurred but that reduction did not result in oxygen deficiency.

Subsamples of wet sediment (approximately 0.5 g dry weight) were transferred by spatula to small beakers containing 5 ml of glass-fiber filtered seawater (from the Bedford Institute seawater system) which had been aerated and stored at 10°C. A Pasteur pipette was used to transfer subsamples of sediment slurry (100-250 mg dry weight) to Erlenmyer flasks (30 ml, glass-stoppered). Oxygen uptake was measured in flasks filled with filtered seawater. Replicate flasks filled with a 1% buffered (pH 7.2) formalin solution (equilibrated and aerated for at least 24 hr) were used to measure chemical oxygen consumption by sediment residual after poisoning. Flasks were filled so as to exclude air bubbles, stoppered and rotated (30 rpm) in the dark at 10°C. Incubation times between 18 and 24 hr were required to produce measurable changes in dissolved oxygen.

A Radiometer Blood Gas Analyzer with a temperature regulated (10°C) electrode chamber was used to measure dissolved oxygen concentrations in 2-3 ml samples taken in syringes from flasks after allowing sediment to settle. Measurements were accurate to at least 0.1 mg per liter and changes of at least 5% of total oxygen present were usually measured. Blank bottles with and without formalin were incubated to correct for changes in dissolved oxygen independent of those due to the presence of sediment. After samples for dissolved oxygen were taken, sediment was quantitatively transferred to pre-weighed glass fiber filters to permit calculation of oxygen uptake per g dry weight.

### Results and Discussion

Total oxygen uptake and biological respiration in sediments increased with depth at stations 1 and 2, while small gradients or a reduction in both measures of consumption occurred with depth at stations 3 and 5 (Fig. 10). Measurable biological respiration was absent above 1 cm at station 1, yet significant consumption occurred below this depth. Biological respiration did not increase with depth in cores from the other locations.

The relative importance of biological and chemical oxidation can be assessed by expressing consumption in the presence of formalin as a percentage of total uptake in unpoisoned samples (Table 11). The ratio is independent of differences in absolute rates of oxygen uptake in various samples and it demonstrates the proportion of oxidative processes which are chemical.

Since chemical oxidation accounts for more than 50% of total oxygen uptake in sediments to 3 cm at station 1 and at 10 cm depth at station 3, reduced organic and inorganic substances must be accumulated. Less accumulation with depth and a more homogeneous distribution of compounds subject to chemical oxidation occurs in the upper few centimeters of cores from stations 2, 3 and 5. This contrasts observations in mud and silt sediments where anoxic sediments occur in subsurface layers and all oxygen uptake is by chemical processes (Hargrave, 1972b). Teal and Kanwisher (1961), on the other hand, observed that chemical oxidation accounted for an average of 70% of the oxygen consumed by salt marsh sediments, with no clear effect of depth.

Rates of oxygen uptake are comparable

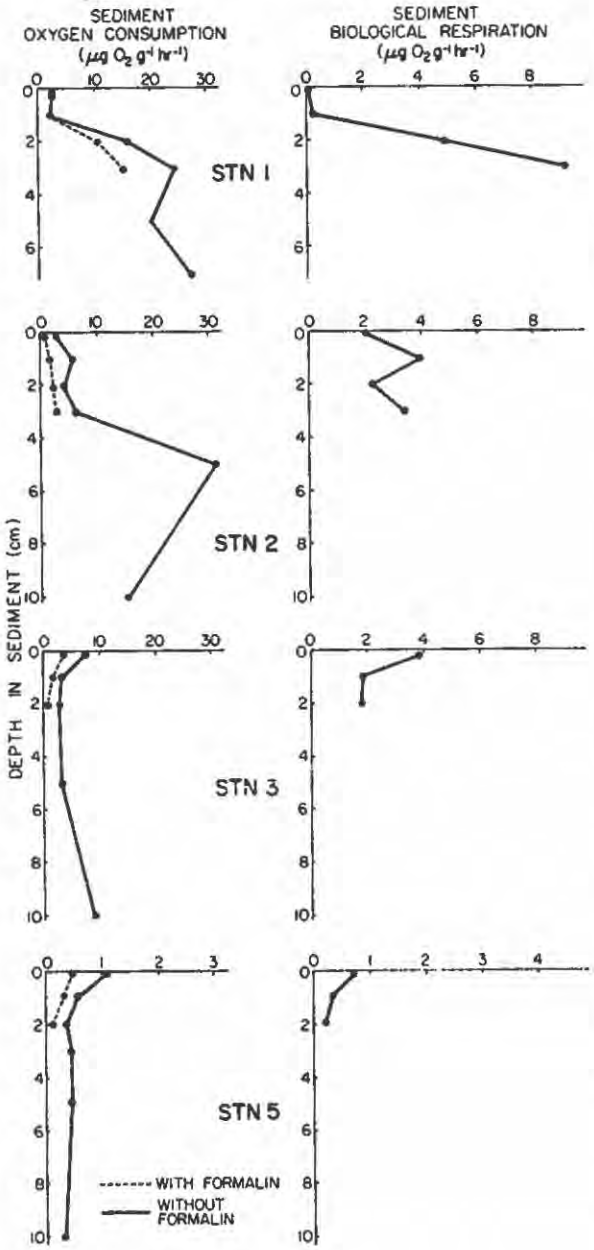


Fig. 10. Total oxygen uptake by sediment taken at various depths from cores and stirred in aerated water with and without formalin treatment (dashed and solid lines respectively). Biological respiration (assumed to cease in the presence of formalin) is calculated as the difference between these two measures. Each point represents a single measurement.

to previous observations with sand sediments but values are an order of magnitude lower than would be predicted on the basis of particle size alone (50 μ dia sand grains, 27 μg $O_2$ $g^{-1}$ $hr^{-1}$)

Table 11. Chemical oxidation as a percentage of total oxygen uptake and carbon specific rates of biological respiration in sediment samples taken from various depths in cores from the intertidal transect. Rates of biological oxygen uptake were corrected for the percentage of organic carbon (section 1d) to calculate aerobic respiration per unit carbon.

| Station No. | Depth (cm) | Oxygen Uptake by Chemical Oxidation (%) | Biological Respiration mg $O_2$ g $C^{-1}$ $hr^{-1}$ |
|---|---|---|---|
| 1 | 0-0.5 | 100 | 0 |
| | 1 | 95.2 | 0.02 |
| | 2 | 67.9 | 0.81 |
| | 3 | 60.7 | 1.49 |
| 2 | 0-0.5 | 27.6 | 0.42 |
| | 1 | 29.8 | 0.64 |
| | 2 | 48.8 | 0.55 |
| | 3 | 46.0 | 0.73 |
| 3 | 0-0.5 | 48.0 | 0.62 |
| | 1 | 50.0 | 0.33 |
| | 2 | 39.3 | 0.50 |
| | 10 | 77.0 | 0.60 |
| 5 | 0-0.5 | 35.3 | 1.83 |
| | 1 | 44.4 | 1.72 |
| | 2 | 40.0 | 2.00 |

(Hargrave, 1972a). However, calculation of oxygen uptake on an organic carbon basis (Table 11) shows that rates of biological respiration are similar to other measurements with sand (0.5 - 2 mg $O_2$ g $C^{-1}$ $hr^{-1}$) (Hargrave and Phillips, 1977). Maximum rates with similar values at all three depths occurred at station 5. These rates are much lower than those observed in attached communities on rock surface and detritus (10-50 mg $O_2$ g $C^{-1}$ $hr^{-1}$). Thus, while measurable aerobic respiration of organic carbon occurs, low rates of oxidation imply that the organic matter is largely refractory to decomposition. This would be expected if rates of organic supply and utilization by benthic fauna and micro-organisms are tightly coupled.

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## 3c. Nitrogen Fixation and Denitrification (D. Patriquin)

### Methods

Nitrogenase activity in sediments at station 1 was assayed by the acetylene reduction technique (Hardy et al., 1968). Nitrogenase will reduce acetylene ($C_2H_2$) to ethylene ($C_2H_4$), thus production of $C_2H_4$ in the presence of $C_2H_2$ can be used as a measure of nitrogenase activity and of $N_2$ fixation assuming a 3:1 molar ratio of $C_2H_2$ reduced to $N_2$ fixed:

$$C_2H_2 + 2\ e \text{ ----- } C_2H_4$$

$$N_2 + 6\ e \text{ ----- } 2\ NH_3\ .$$

One problem in conducting such assays in sediment systems is the slow diffusion of $C_2H_2$ and $C_2H_4$ through the sediment (Patriquin and Denike, 1978). To facilitate diffusion, assays can be conducted on small samples, or samples can be vigorously shaken for a few minutes after introducing $C_2H_2$ and again just before sampling the gas phase for $C_2H_4$. However, such procedures may disrupt micro-environments.

Denitrification was assayed by the acetylene blockage technique (Yoshinari et al., 1977). Acetylene blocks reduction of $N_2O$ to $N_2$:

$$NO_3^- \rightarrow NO_2^- \rightarrow (NO) \rightarrow N_2O \text{ --/--} \rightarrow N_2\ C_2H_2\ .$$

Thus, samples incubated with acetylene for assay of nitrogenase activity can simultaneously be examined for denitrifying activity. While this technique seems to be generally applicable to soil systems, blockage of $N_2O$ reduction by $C_2H_2$ may be incomplete in some marine systems (Van Raalte and Patriquin, 1977).

$C_2H_4$ and $N_2O$ concentrations in gas samples from the incubation systems were determined by gas chromatography using Poropak column packings, and a flame ionization detector (for $C_2H_4$) or one of thermal conductivity, helium ionization or electron capture detectors for $N_2O$. A Poropak Q for $N_2O$ and Poropak T for $C_2H_4$ (Patriquin and Knowles, 1974; Guerinot et al., 1977) determinations was used for measurements reported here. Gas samples can be taken and stored in evacuated blood sampling tubes if it is desired to conduct assays in the field. Where a substantial portion of the sample is water, corrections must be made for solubility of gases in the liquid phase (Flett et al., 1976). Approximate corrections can be made as follows (20°C):

$$N_2O \text{ production} = N_2O \text{ in } 0.5 \text{ ml sample (G.C.)} \times \frac{(G.P.V. + 0.67 \times Liq.vol)}{0.5 \text{ ml}}$$

$$C_2H_4 \text{ production} = C_2H_4 \text{ in } 0.5 \text{ ml sample (G.C.)} \times \frac{(G.P.V. + 0.11 \times Liq.vol)}{0.5 \text{ ml}}$$

where G.P.V. is the gas phase volume.

Samples were taken from station 1, included (i) 5 cm length sediments columns in 10 cm length by 3.8 cm diameter coring tubes, and (ii) 5 ml samples of sediment from the top few cm of sediment, mixed with 10 ml seawater in 50 ml flasks. The cores were closed with rubber stoppers; a hole in the top stopper accommodated a serum stopper used to close flasks. Samples were transported to the lab on ice. One set of flask samples was flushed with $N_2$ to remove $O_2$. Acetylene, freshly generated from calcium carbide and water, was injected through serum stoppers to give gas phase $C_2H_2$ concentrations of 10%. Some cores were vigorously shaken for 2 min following introduction of $C_2H_2$. One set of cores was incubated in an aquarium (18°C) in a greenhouse under natural lighting. All other samples were incubated in the dark at 18°C. After 24 h incubation, samples were vigorously shaken, and 0.5 ml gas samples removed with syringe and injected into gas chromatographs for analyses of $C_2H_4$ and $N_2O$.

### Results and Discussion

$C_2H_4$ was not produced in any of the samples (Table 12). $N_2O$ production in the presence of $C_2H_2$, however, was detected in sediment samples flushed with $N_2$.

$N_2O$ production by the anaerobic samples was equivalent to 13.2 to 16.9 ng $N_2O$-N.ml$^{-1}$ sediment hr$^{-1}$. These results suggest that neither $N_2$ fixation or denitrification are significant in the aerobic surface sediments. Substantial denitrification may

Table 12. Observations of $N_2O$ and $C_2H_4$ production by sediment cores from station 1 incubated with various treatments.

| Sample Treatment | $N_2O$ | $C_2H_4$ |
|---|---|---|
| 3 cores, greenhouse, + $C_2H_2$ | 0* | 0* |
| 1 core, greenhouse, no $C_2H_2$ | 0 | 0 |
| 2 cores, greenhouse, + $C_2H_2$, shaken after introducing $C_2H_2$ | 0 | 0 |
| 3 cores, in dark, + $C_2H_2$ | 0 | 0 |
| 1 core, in dark, no $C_2H_2$ | 0 | 0 |
| 3 flasks, + $C_2H_2$, air | 0 | 0 |
| 1 flask, no $C_2H_2$, air | 0 | 0 |
| 3 flasks, + $C_2H_2$, $N_2$ | 18.5 to 23.5 ng $N_2O$-N in 0.5 ml gas sample | 0 |
| 1 flask, no $C_2H_2$, $N_2$ | 0 | 0 |

* The minimum detectable amounts were 3.50 ng $N_2O$, and 0.02 nmoles $C_2H_4$ (in 0.5 ml gas phase samples).

occur at aerobic/anaerobic interfaces within subsurface deposits.

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## 3d. Nutrient Flux Across Undisturbed Sediments (B. Hargrave)

### Methods

*In situ* incubation of cores for measurement of oxygen exchange (section 3a) provided an opportunity for the simultaneous determination of changes in dissolved nutrient concentrations in water enclosed over undisturbed sediment. Water samples were taken from experimental and control cylinders (which only contained water) before and after incubation in 2-ml disposable syringes. These samples were immediately filtered into autoanalyzer vials by passing syringe contents through acid-rinsed membrane filters (Millipore [R] HA rinsed in 0.1 N HCL and soaked in distilled water) held in Swinnex filter holders. Water was subsequently analyzed for reactive phosphorus and silicate (as described in section 1e).

The technique could be altered to be more convenient. A known volume of water could be placed in uncapped cylinders partially inserted into intertidal sediment. Capping and exclusion of air bubbles is not necessary since, with the exception of ammonia, dissolved nutrients do not undergo gaseous exchange. The concentration of dissolved nutrients in water used to fill cylinders for flux measurements is important, however. If diffusion is the predominant transfer mechanism, the rate and direction of exchange could be affected by the concentration gradient across the sediment water interface. Lack of circulation in cylinders during incubation could also allow concentration gradients which limit diffusion to form. Enclosure of a small water volume, to maximize changes in concentration and short incubations, to

minimize the formation of gradients are features of experimental design, which need evaluation before the method is applied further.

Results and Discussion

Determinations of soluble reactive phosphorus[1] in water in clear plastic experimental and control cylinders incubated *in situ* for measurements of net oxygen production (section 3a) showed no significant differences in concentration (average initial and final values 25.3 and 24.3 µg P liter$^{-1}$ respectively). Dissolved silicate[2], however, increased significantly in water over sediments enclosed in duplicate clear plastic cylinders incubated for up to four hours at station 2 (average efflux of 31 µm Si m$^{-2}$ hr$^{-1}$).

Measured rates of diffusion of silica from cores of deep sea sediment vary between 1 and 10 µm m$^{-2}$ hr$^{-1}$ (Fanning and Pilson, 1974) while rates up to 500 µm m$^{-2}$ hr$^{-1}$ have been observed in sediments from upwelling regions (Rowe et al., 1975). While the rates of silicate efflux from intertidal sediments at station 2 are of similar magnitude, no measurable exchange of dissolved phosphorus occurred. The short-term incubation, as well as the use of clear plastic cores exposed to light could be of importance in determining relative rates of phosphorus and silicate flux.

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[1] analyses by P. Neame

[2] analyses by D. Andrews

4. BIOMASS DETERMINATIONS

4a. Plant Pigments (B. Hargrave)

Methods

The basic fluorometric technique described by Yentsch and Menzel (1963) as modified by Holm-Hansen et al. (1965) was used to quantify chlorophyll *a* and pheopigments in samples of sediments and water. Ten samples of sediment were collected within .025 m$^2$ at each station using a small metal cork borer (1 cm$^2$). Tape, 2 cm from the lower end of the barrel, was used as a marker to ensure penetration to a fixed depth. The corer was slowly pushed into the sediment to 2 cm and the top covered by a finger to retain sediment on withdrawal. The outer surface of the corer was wiped clean with tissue paper and the lower end placed into a scintillation vial which had been rinsed with acetone and dried before 10 ml of 85% acetone (made up with 15% distilled water) and 2 drops of $MgCO_3$ (1 g/100 ml) were added. Sediment was rinsed from the corer into the acetone by gentle agitation.

Scintillation vials were capped, mixed vigorously by hand, kept cool and stored in the dark until returned to the laboratory where they were mixed for 30 sec on a Vortex mixer. Sediment from the surface of extruded cores, or removed from wet sediment collected for vertical profiles of organic content, were treated in a similar manner except that a spatula was used to collect subsamples. Water samples of known volume were filtered with a few drops of $MgCO_3$ through Millipore filters (HA, 45 mm) which were then folded and placed in vials containing acetone. Blanks containing only filters were also prepared. Vials were stored for at least 12 hr at 5°C in the dark after shaking.

Comparison of various extraction procedures (cold methanol rather than acetone, sonication in a bath and with a probe, mechanical grinding) did not significantly alter measures of pigment concentration in sediment from those obtained by extraction over 12 hr followed by a second mixing by hand. After this second agitation, vials were kept dark and the contents allowed to settle to produce a clear supernatant (about 2 hr) which did not require centrifugation before fluorometric analysis.

Appropriate dilutions were made to permit determinations to be made with a Turner Model 110 fluorometer (Corning CS 5-60 primary filter with a Corning CS 2-60 secondary filter). Chlorophyll *a* (Sigma Chemical) was used to calibrate the fluorometer for concentrations of 0.1 to 1 µg per 10 ml of acetone. Samples were

kept dark to prevent photoxidation of pigments. Two drops of 1N HCL were added to the sample after reading to permit calculation of pheopigment concentration. Pheophytin and pheophorbide are not differentiated by this method of determining chlorophyll degradation products (Shuman and Lorenzen, 1975).

Sediment was quantitatively transferred by rinsing with distilled water onto preweighed glass fiber filters after analysis. Samples were dried at 60°C to determine dry weight extracted. Results were calculated as µg chlorophyll *a* or pheopigments per g dry weight for sediments and µg per liter for water samples. When sediment cores (taken by the cork borer) had been extracted, concentration could also be expressed as µg per $cm^2$.

## Results and Discussion

Concentrations of chlorophyll *a* and pheopigments $g^{-1}$ sediment in cores 2 cm deep were maximum at station 2 and decreased sharply with distance along the intertidal transect (Fig. 11). Concentrations expressed per unit area showed a similar trend with the largest decrease between stations 3 and 4 (Table 13). Variability was low among ten

Table 13. Average concentrations of plant pigments $cm^{-2}$ at various stations along the intertidal transect. Ten cores (1 $cm^2$, 2 cm deep) taken at each station.

| Station | Chlorophyll *a* | Pheopigments | Total |
|---|---|---|---|
| | µg $cm^{-2}$ | | |
| 1 | 5.52 | 8.29 | 13.8 |
| 2 | 3.31 | 8.40 | 11.7 |
| 3 | 3.33 | 8.40 | 11.7 |
| 4 | 1.49 | 2.46 | 4.0 |
| 5 | .92 | .59 | 1.5 |
| 6 | .76 | .25 | 1.0 |
| 7 | .87 | .14 | 1.0 |
| 8 | .94 | 0 | 0.9 |
| 10 | .51 | .07 | 0.6 |

replicates taken at the first three stations (coefficient of variation 0.2-0.3) for both chlorophyll *a* and

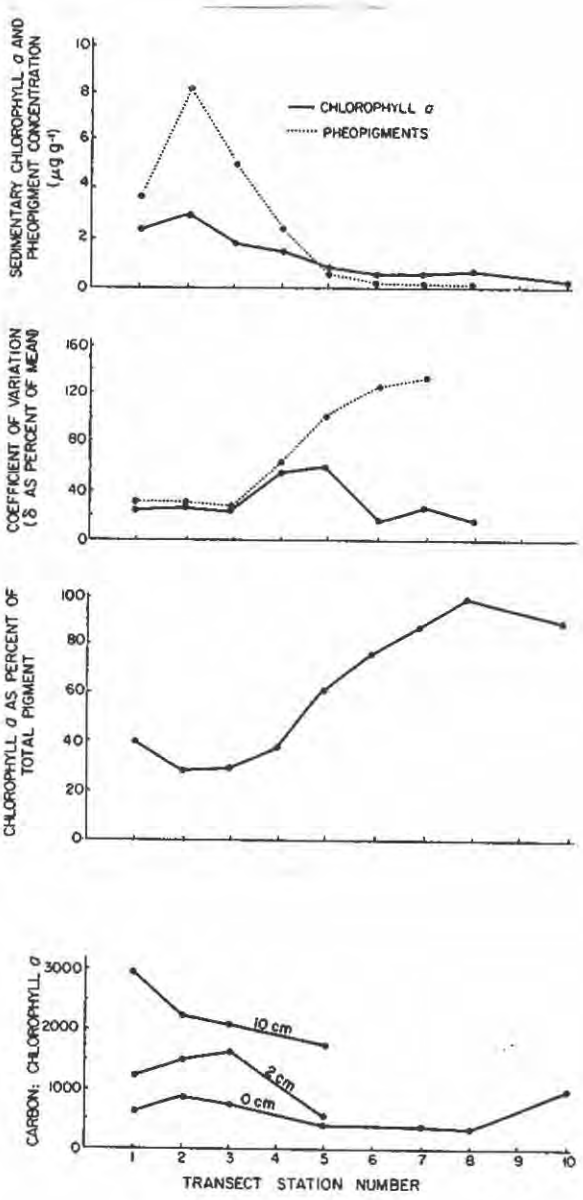


Fig. 11. Average concentrations of chlorophyll *a* and pheophytin, coefficient of variation in ten replicate samples and chlorophyll *a* as percent of total pigment in 2 cm deep sediment cores taken along the intertidal transect. Carbon:chlorophyll *a* ratios were derived by comparing measures made on subsamples of sediment taken from various depth in cores.

pheopigments (Fig. 11). At stations in the lower intertidal zone, heterogeneity in measures of pheopigment concentrations were greatly increased while chlorophyll *a* was as homogeneously distributed as at the upper stations. Chlorophyll *a* also accounted for an increasing proportion of total

pigments present in cores with distance along the transect (Fig. 11). Thus, although total concentrations of plant pigments were reduced in lower intertidal zone sediments, chlorophyll *a* was the predominant pigment.

Pigment concentrations in samples taken from the surface of cores and at 1-cm depth intervals generally decreased with depth (Fig. 12). Gradients were not uniform, being steepest in the upper 2-3 cm and discontinuities in concentrations at particular depths were reflected in both chlorophyll *a* and pheopigments. Marked vertical differences in the carbon: chlorophyll *a* ratio also reflect reduced chlorophyll *a* concentrations relative to changes in organic carbon with sediment depth (Fig. 11). Differences in this ratio between sediment at the surface and at 2 cm illustrate that sharp stratification exists in pigment concentrations independent of changes in organic carbon near the sediment surface.

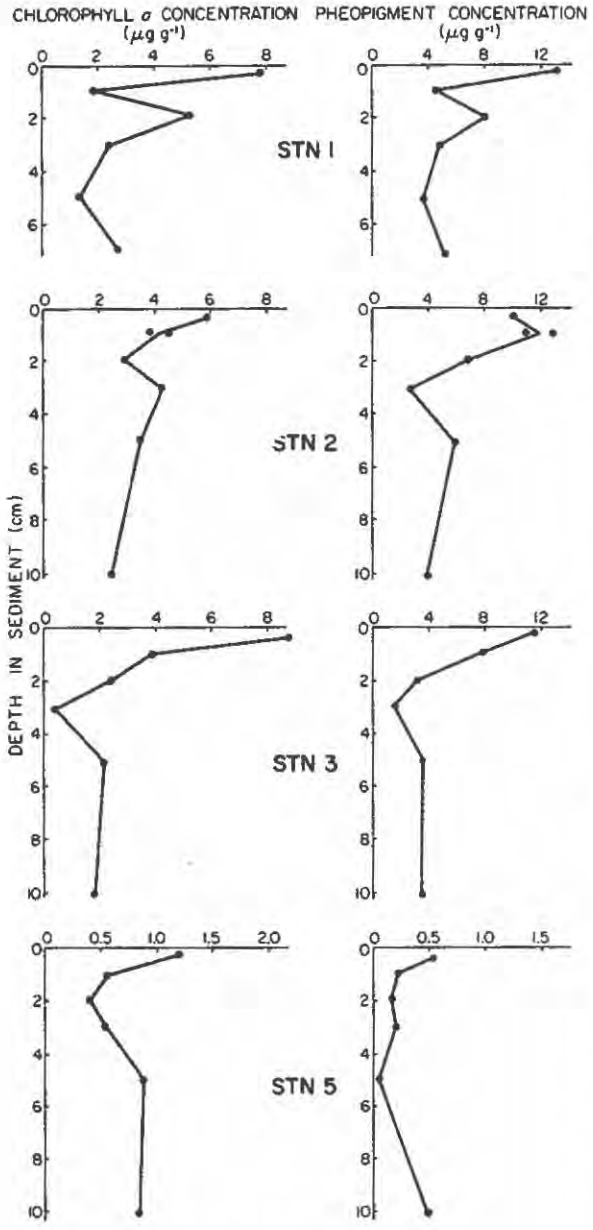


Fig. 12. Vertical profiles of chlorophyll *a* and pheopigments in sediments sampled at 1-cm depth intervals in cores from various stations along the intertidal transect. All points represent values for single determinations.

Concentrations of functional chlorophyll *a* and pheopigments are comparable to values measured previously in marine intertidal sand flat sediments (1-10 μg $cm^{-2}$) (Estrada et al., 1974; Cadée and Hegeman, 1977). The large decrease in total pigment content between stations 3 and 5 (Table 13) results from reduced amounts of both chlorophyll *a* and pheopigments. The high proportion of chlorophyll *a* in sediments at stations 5-10 show that little accumulation of degraded plant pigments has occurred in the lower intertidal zone.

Vertical profiles of pigments also illustrate that concentrations which do exist below the top few centimeters of sediments are higher in the upper intertidal area (Fig. 12). Patterns of vertical distribution are similar to those observed in other studies (Estrada et al., 1974) with large decreases occurring in the surface sediment layers. Subsurface increases in pigment concentrations within discrete depth layers (also observed for organic matter, section 1d) could be due to the presence of *Macoma*. While feeding at the surface, the mollusc excavates a burrow with a channel through which the exhalent siphon freely moves. Pigments in debris brought into the burrow could accumulate along with fecal material which is egested below the sediment surface.

Degradation of chlorophyll *a* to pheopigments by *Macoma* feeding activity could also account for the enrichment of pigment degradation products in sediments at stations 1, 2 and 3 (Fig. 11, Table 13). Planktonic herbivores can convert chlorophyll to pheophorbide with an efficiency of about 66% on a weight basis (Shuman and Lorenzen, 1975) and although quantitative feeding studies with deposit-feeding invertebrates have not been carried out, a similar conversion probably occurs when epibenthic algae are ingested. Daley (1973) and Daley and Brown (1973) considered the combined effects of photo-chemical oxidation and herbivore grazing to be the principal mechanisms of *in situ* chlorophyll diagenesis. However, pheophytin and pheophorbide were accumulated only during prolonged exposure to darkness. Thus, exposure of pigments in egested material to light at the sediment surface in intertidal

areas could substantially reduce the amount of pheopigment accumulated.

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## 4b. Fine-Scale Vertical Distribution of Plant Pigments (C. Van Raalte and B. Hargrave)

### Methods

The semi-liquid nature of fine sand sediments in the upper intertidal zone at Anthony Park, as in most soft sediments, makes extensive vertical fine-scale sampling difficult. However, vertical distributions of micro-organisms in sediments demonstrate patterns on the scale of millimeters (Jørgensen and Fenchel, 1974) and large gradients in concentrations of plant pigments also occur in the upper centimeter of sediments (see section 4a). Our observations of perpendicular erosional surfaces in sediments along the creek bank at station 2 showed the presence of discrete lamellae approximately one to two millimeters thick. Lamellae were variably shaded with varves extending horizontally as discrete layers. Although the sediment was easily sampled with cores or a spatula, this vertical structure was destroyed by these sampling methods.

*In situ* freezing of undisturbed sediment offered a method to provide sediment in which vertical structure was more likely to be retained. Block dry ice (cut into 30 x 30 x 2 cm pieces and stored in a cooler) was carefully placed on the sediment at station 2. Care was taken not to smear the surface layer on placement. The top 2-3 mm of sediment was frozen within one minute, after which a gentle pressure was applied (by a weight) to maximize contact of the dry ice with the sediment without altering vertical layering in the sediment. Maximum penetration of freezing (2 cm after 45 min) occurred without substantial loss of dry ice. The frozen slab was easily removed intact and 4-8 cm of unfrozen subsurface sediment clung to the frozen block along with the frozen surface layer. The entire piece of sediment was placed in the cooler with extra dry ice where it was frozen within 30 min. Samples were stored at -18°C until sectioned by which time the dry ice had disappeared.

The frozen sediment was fractured into small blocks with a hammer. A block with a perpendicular fracture surface was used for sampling (Fig. 13). Horizontal lamellae were visible in the fracture surface and there was no evidence of smearing. Frozen sediment was placed in an ice bath to keep it from thawing during sectioning. Two rectangular spatulas of the same dimensions were used to excavate the frozen sediment. One spatula was warmed slightly in a flame and placed on the sediment surface next to the fracture face. The second spatula was then used to scrape out melted sediment adjacent to the area (Fig. 13). These subsamples were placed in separate scintillation vials and analyzed for plant pigments (section 4a). Successive applications of the spatula permitted samples to be collected at approximately 1 mm depths as determined by measurements with venier calipers.

### Results and Discussion

Concentrations of chlorophyll *a* in the first 20 mm of sediment from station 2 generally decreased with decreasing depth (Fig. 14). Pheopigment concentrations, on the other hand, decreased greatly between 0 and 2 mm but concentrations did not change markedly below this depth. Subsurface enrichment of chlorophyll *a* occurred in approximately 5 mm thick layers (between 3 and 8 mm and 10 and 15 mm). Chlorophyll *a*

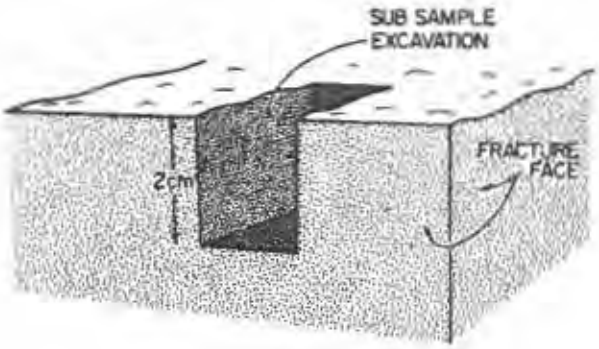


Fig. 13. Diagramatic representation of frozen section of surface sediment after removal of melted sediment through successive applications of a heated spatula.

content also accounted for an increased proportion of total pigment (up to 40%) in these layers.

The stratification of chlorophyll *a* with sediment depth is similar to that observed by Pomeroy (1959) (who also sectioned frozen sediment) and by Estrada et al. (1974). Subsurface increases in pigment concentration have also been recorded in other intertidal sediments (Fenchel and Straarup, 1971). Sections at least a few millimeters thick were analyzed in these studies. It is thus not surprising that sectioning at closer intervals of depth also demonstrates marked vertical differences in pigment concentrations.

The relatively constant pheopigment concentration in sediment below 1 mm depth implies that pigment degradation products accumulate in similar amounts irrespective of depth in the upper 2 cm of sediment. Also, lamellae visible as layers in the sediment were not correlated with the distribution of either chlorophyll *a* or pheopigments. If the varved stratification results from sequential deposition of sediment at this location, diagenetic changes after burial must form similar concentrations of pheopigments throughout the upper 2 cm of sediment. The sharp stratification of chlorophyll *a* in the surface 2 mm could also result from the active vertical migration of benthic microflora (Rowland Taylor, 1964). Resuspension of this upper layer of sediment could occur on a flood tide, but vertical stratification of algae may be rapidly reformed when the tide receeds.

Information concerning the vertical

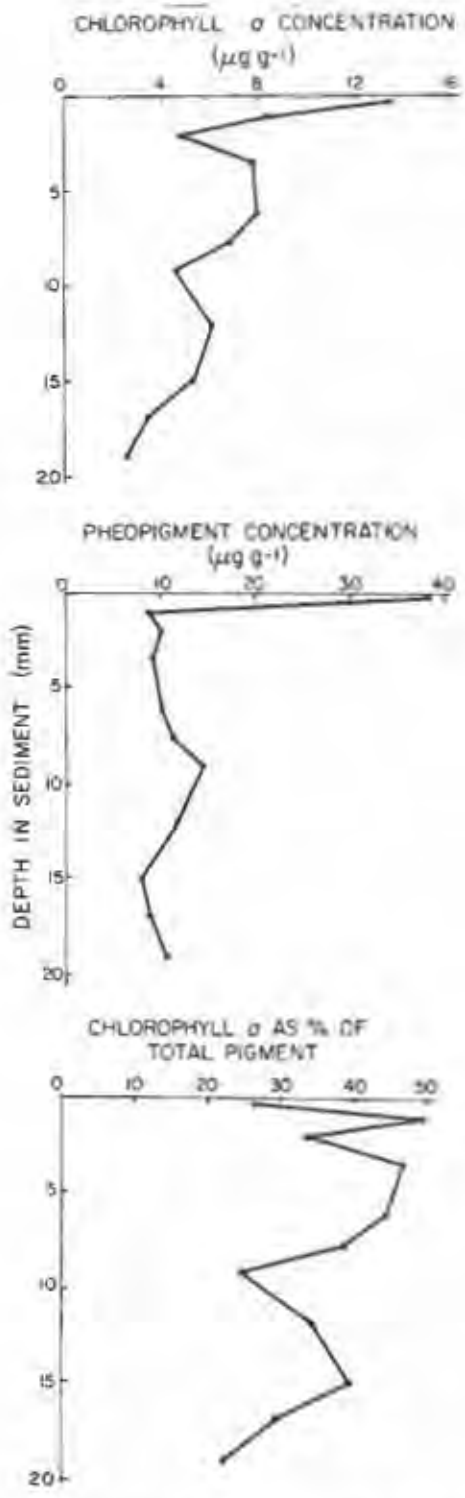


Fig. 14. Vertical profiles of chlorophyll *a*, pheopigments and chlorophyll *a* as % of total pigment at station 2.

distribution of plant pigments is important if methods to estimate concentrations are to be standardized to allow comparison. For example, when gradients occur near the sediment surface, measures of pigment concentration will depend on the depth of sediment samples. This is evident in observations of chlorophyll *a* concentration at station 2 (Table 14). Different sampling methods yield different concentrations with values determined for 2 cm deep cores being lower than those measured in samples from discrete depth layers. Samples taken by cores and spatula were taken a few meters away from the site from which frozen sediment was removed. Thus horizontal variation in pigment content could account for higher concentrations present in the subsurface samples of frozen sediment.

Table 14. Chlorophyll *a* content in sediment from station 2 determined by three different sampling methods. Measurements in samples collected by spatula and as cores summarized in section 4a. n = number of depth intervals averaged to calculate mean pigment concentration.

| Sampling Method | Depth Layer (mm) | n | Mean Chlorophyll *a* ($\mu g\ g^{-1}$) |
|---|---|---|---|
| frozen 1 mm sections | 0 | 1 | 13.6 |
| | 0-1 | 2 | 11.1 |
| " | 0-4 | 4 | 8.8 |
| " | 0-10 | 7 | 7.8 |
| " | 0-20 | 11 | 6.6 |
| spatula | 0 | 1 | 5.8 |
| | 0-10 | 2 | 4.9 |
| " | 0-20 | 3 | 4.2 |
| corer (replicates) | 0-20 | 1 | 4.6 |
| | 0-20 | 1 | 3.2 |
| | 0-20 | 1 | 2.3 |
| | 0-20 | 1 | 3.0 |
| | 0-20 | 1 | 2.5 |
| | 0-20 | 1 | 2.4 |

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## 4c. Macrofauna Biomass (D. Peer and P. Hicklin)

### Methods

Numbers and biomass of macrofauna were determined in sediments from various stations along the intertidal transect by sampling during low tide (1100 - 1500) on May 11 and 12, 1977. Replicate (n = 2 to 5) samples of 225 $cm^2$ (15 x 15 cm) were taken by either shovel or grab to approximately 10 cm depth (determined by where hard compact sediment was encountered) at various stations. Samples were washed through an 8 mm sieve in the field and preserved in dilute formalin for subsequent sorting. Animals from the May 11th collection (by D. Peer) were sorted to obtain numbers and wet weights (less shell for the mollusc *Macoma balthica*). Mollusc shell length was determined by caliper measurements. Samples from May 12th were sorted (by P. Hicklin) and an abundance of various species recorded. Samples from station 10 could not be sorted quantitatively because sediment would not pass through the sieve.

### Results and Discussion

Nine species of invertebrate benthic macrofauna were identified in the intertidal sediment samples (Table 15), but only two species were common - the tellinid deposit-feeding bivalve, *Macoma balthica* and a Nereid polychaete, *Nereis virens*. *Corophium volutator*, an amphipod previously observed during the summer in large numbers in sediments at this site (Yeo, 1978) was absent. Estimates of numbers and wet weights of these species (Table 16) in replicate samples show that *Macoma* had a remarkably uniform distribution at stations 1 and 2. A measure of this distribution (the variance/mean ratio) was 0.25, 0.59 and 1.70 for stations 1, 2 and 4 respectively. This contrasts with a value of 3 to 50 for most species of benthic macrofauna (Peer, unpublished observations).

Table 15. Abundance of macrofauna in sediment samples taken from the exposed intertidal zone at Anthony Park; Lower Selmah, N.S., May 12, 1977. Duplicate 225 $cm^2$ samples taken at each station except number 5.

| Station No. | Sample | Species | Number in Sample | Abundance (per $m^2$) |
|---|---|---|---|---|
| 2 | a | *Nereis virens* | 2 | 90 |
| | | *Macoma balthica* | 33 | 1,495 |
| | b | *Macoma balthica* | 28 | 1,260 |
| 3 | a | *Macoma balthica* | 31 | 1,395 |
| | | *Nereis virens* | 2 | 90 |
| | | *Eteone* sp. | 1 | 45 |
| | b | *Macoma balthica* | 31 | 1,395 |
| | | *Nereis virens* | 1 | 45 |
| 4 | a | *Macoma balthica* | 34 | 1,530 |
| | | *Nereis virens* | 1 | 45 |
| | | Insect larvae | 1 | -- |
| | | Oligochaeta (unid.) | 1 | 45 |
| | b | *Macoma balthica* | 31 | 1,395 |
| | | *Nereis virens* | 1 | 45 |
| 5 | a | *Nereis virens* | 2 | 90 |
| | | *Ophilia* sp. | 1 | 45 |
| 6 | a | *Macoma balthica* | 2 | 90 |
| | | *Pygospia* sp. | 1 | 45 |
| | | Polychaete (unid.) | 1 | 45 |
| | | *Nereis virens* | 4 | 180 |
| | b | *Nereis virens* | 2 | 90 |
| | | *Prionospio elegans* | 2 | 90 |
| 7 | a | *Nereis virens* | 4 | 180 |
| | b | *Macoma balthica* | 2 | 90 |
| | | Polychaete (unid.) | 1 | 45 |

A value of 1, considered to indicate a random distribution, for a *Macoma* population, was observed in the Baltic (Kosler, 1968). The range of values observed by Kosler was quite large and some of the lowest values were about 0.25.

One of the rare examples of a variance/mean ratio of less than one in previous studies was found for a population of *Tellina tenuis*, a Tellinid pelecypod with a similar mode of life to *Macoma*, in the Exe estuary. The values were between 0.30 and 0.13 and it was established that the animals actively spaced themselves by the maintenance of a minimum distance (Holme, 1950).

Although it is not possible to assign any significance to the differences between the three stations with the small number of samples taken at Anthony Park, it is interesting to speculate that older populations might position themselves to minimize overlap of feeding areas. It is known (Braefield and Newell, 1961) that *Macoma* can move themselves about on the sediment surface as well as *Tellina*. Abundance of *Macoma* is higher than that observed by Kostler (1968) (1-10 animals/ 225 $cm^2$) but, as also observed for populations in the Baltic, there was no relation between the variance/mean ratio and abundance as might be expected if density-dependent spacing occurred.

Highest numbers, greatest biomass and largest weight per individual *Macoma* occurred at station 2 while fewer and smaller animals occurred at station 1 (Tables 16 and 17). Thus, if recruitment and loss of individuals (by predation or physical removal) are similar at both stations, growth must be reduced in upper intertidal

Table 16. Mean and variance of replicate determinations of numbers and wet weight of *Macoma* and *Nereis* in 225 $cm^2$ samples taken at five stations along the intertidal transect at Anthony Park, May 11, 1977.

| | *Macoma balthica* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Station | 1 | | 2 | | 4 | | 8 | | 10 | |
| | No. | Wt. | No. | Wt. | No. | Wt. | No. | Wt. | No. | Wt. |
| | 13 | 5.7 | 23 | 19.9 | 16 | 9.0 | 0 | | 2 | 1.3 |
| | 10 | 4.6 | 27 | 18.8 | 16 | 10.0 | 1 | 0.9 | - | |
| | 13 | 5.6 | 29 | 27.4 | 12 | 7.6 | 1 | 1.3 | - | |
| | | | 33 | 20.2 | 26 | 21.5 | 0 | | - | |
| | | | 24 | 20.8 | 14 | 7.1 | 1 | 0.0 | | |
| Mean | 12 | 5.3 | 27 | 21.4 | 17 | 11.1 | 0.6 | 0.5 | non-quanti- | |
| $\sigma^2$ | 3 | 0.4 | 16 | 11.6 | 29 | 35.5 | 0.4 | 0.4 | tative | |
| Mean wet weight (g)/individual | | 0.44 | | 0.79 | | 0.66 | | 0.75 | | |

| | *Nereis virens* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Station | 1 | | 2 | | 4 | | 8 | | 10 | |
| | No. | Wt. | No. | Wt. | No. | Wt. | No. | Wt. | No. | Wt. |
| | 0 | | 1 | 0.02 | 0 | | - | | - | |
| | 0 | | 5 | 0.30 | 1 | 0.013 | - | | - | |
| | 1 | 1.08 | 2 | 0.10 | 1 | 0.005 | - | | - | |
| | | | 5 | 0.28 | 1 | 0.01 | - | | - | |
| | | | 1 | 0.17 | 1 | 0.02 | - | | - | |
| Mean | | | 2.8 | 0.17 | 0.8 | 0.01 | | | | |
| $\sigma^2$ | | | 4.2 | 0.01 | 0.02 | 0.0001 | | | | |
| Mean wet weight (g)/individual | | | | 0.06 | | 0.01 | | | | |

Table 17. Mean and standard error in parentheses of numbers and wet weights of *Macoma* and *Nereis* at four stations along the intertidal transect.

| Station No. | *Macoma balthica* | | *Nereis sp.* | |
|---|---|---|---|---|
| | $g/m^2$ | $No./m^2$ | $g/m^2$ | $No./m^2$ |
| 1 | 235.1( 15.5) | 533.3( 4.4) | | |
| 2 | 952.4( 67.5) | 1208.8( 80.0) | 7.5(2.8) | 124.4(40.8) |
| 4 | 491.5(118.6) | 746.6(106.0) | 0.4(0.2) | 35.5( 8.8) |
| 8 | 20.0( 12.0) | 26.6( 12.0) | | |

zone sediments. This could be attributed to prolonged exposure to air and thus reduced feeding time available in sediments at this tide level (Yeo, 1978). On the other hand, settlement and mortality rates could differ greatly between adjacent stations.

Length frequency histograms of all *Macoma* collected at stations 2 (n = 136)

and 4 (n = 84) demonstrate size classes at 5, 11, 15 and 18 mm lengths (Fig. 15). The

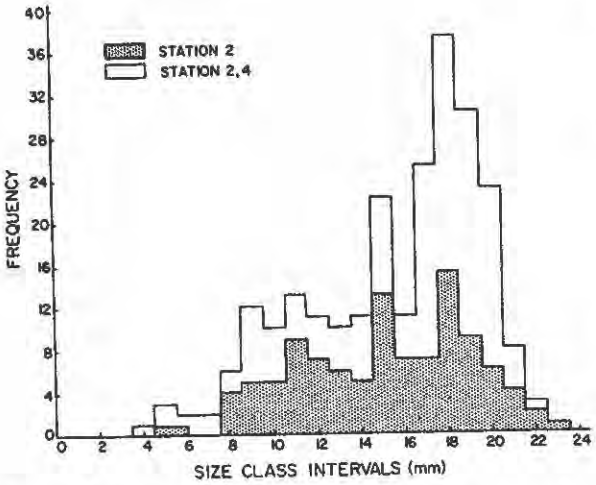


Fig. 15. Length frequency histogram of *Macoma* collected at two stations in the intertidal zone of Anthony Park, May 11, 1977.

largest size class is the most abundant and the smallest the least.

There were no animals larger than 23 mm in shell length, a size within the 18 mm size class interval. Similar maximum size and frequency distributions for *Macoma* have been observed in previous observations at Anthony Park and other sites in Cobequid Bay (Yeo, 1978). As Yeo observed, frequency distributions for *Macoma* in these populations are difficult to interpret since certain size classes may be absent - a result of physical removal by ice rafting or erosion of sediment. However, size frequencies observed here could indicate that at the time of settlement of the largest year class (18 mm), there were no other animals present. This would account for a large successful settlement and for smaller subsequent settlements. These populations are probably subject to periodic mass mortality due to a variety of physical causes. Once sediment in an area becomes stabilized, however, recruitment of young can occur. Subsequent recruitment could be limited by competition for space with older animals.

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## 4d. Macrofauna Organic Content (B. Hargrave)

### Methods

Tissues of macrofauna sieved from sediment in cores used for measurements of oxygen flux (section 3a) at station 2 were analyzed for particulate carbon and nitrogen. Individual *Macoma* were grouped in length categories (4-6, 8-12 and 16-22 mm), removed from their shells and, along with specimens of *Nereis*, rinsed briefly in distilled water. Elemental analysis of tissue was carried out after determination of dry weight (60°C for 24 hr) of individual samples (section 1d).

### Results

Average carbon and nitrogen content in all tissues was 36.7%C and 9.0%N, with no significant difference in percentage dry weight or carbon and nitrogen in *Macoma* of different sizes (Table 18).

Table 18. Average dry tissue weight, carbon and nitrogen content and C:N ratio (by weight) of *Macoma* and *Nereis* from station 2. n = number of samples.

| Sample | n | Mean individual dry weight (mg) | Percent C | N | C:N |
|---|---|---|---|---|---|
| *Macoma* | | | | | |
| 4- 6 mm | 3 | 3.8 | 36.1 | 8.4 | 4.3 |
| 8-12 mm | 2 | 12.5 | 38.7 | 9.4 | 4.1 |
| 16-22 mm | 3 | 37.2 | 39.6 | 10.1 | 3.9 |
| *Nereis* | 3 | 12.1 | 32.4 | 8.0 | 4.0 |

Percentages of carbon and nitrogen in *Nereis* were slightly lower than those in *Macoma* tissue. The values are similar to

those usually observed in marine crustaceans (Parsons et al., 1977).

References

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## SYNTHESIS OF SOME OBSERVATIONS
(B. Hargrave)

There are numerous ways in which observations made at Anthony Park on May 11th could be synthesized and compared. Consideration of factors affecting the amount, distribution and nature of particulate organic matter provides one approach. Physical, chemical and biological processes interact to affect both quantitative and qualitative measures of organic material present in sediments. Thus, the amounts and types of sedimentary organic matter present, and also the ratio of organic matter accumulated in sediments to that in tissues of organisms may serve as measures which characterize the net effect of supply, removal and accumulation of organic matter. Zonation due to differences in these processes should be apparent in organic matter distribution across the intertidal zone.

### SEDIMENT GRAIN SIZE, ELEMENTAL AND ORGANIC CONTENT

Comparison of median grain size and organic content in sediments along the transect at Anthony Park shows that the proportion of fine sand and organic matter decreases by an order of magnitude between stations 3 and 5 (Table 19). The decrease

Table 19. Comparison of median grain size, percent fine sand (< 62μm) and organic content in surface sediment from six stations along the intertidal transect.

| Station No. | Median Grain Size (μm)[1] | Percent Weight < 53μm[2] | Organic Matter[3] (%) | Organic Carbon[3] (%) |
|---|---|---|---|---|
| 1 | 50 | 84.7 | 3.0 | 0.50 |
| 2 | 90 | 73.6 | 3.5 | 0.50 |
| 3 | (165)(350)[4] | 72.7 | 4.2 | 0.63 |
| 5 | (165)(270)[4] | 8.6 | 1.8 | 0.06 |
| 7 | 50 | < 5 | --- | 0.03 |
| 8 | 110 | < 5 | --- | 0.03 |

[1] Section 1a
[2] Section 1c
[3] Section 1d
[4] Peaks of a bimodal size distribution

on the basis of particle size alone would be expected from the commonly observed inverse relation between grain size and organic content (Longbottom, 1970; Hargrave, 1972a).

Organic carbon and nitrogen measured in sediments in the present study are similar to observations in other intertidal areas for sediments of comparable particle size (Longbottom, 1970; Cadée and Hegeman, 1977). Highest concentrations of organic matter in sediments from station 3, however, were not in sediments containing the smallest median grain size and no simple relationship between inorganic grain size and organic content existed. Samples with a similar median grain size contained an order of magnitude different amounts of organic carbon, although variation in total organic matter was less (Table 19). Also, differences in organic content with depth in cores were not clearly related to differences in the relative proportions of fine and coarse sand (Tables 2 and 4).

Grain size analysis indicated that all samples contained some fine sediment (Fig. 2). Thus, comparison of organic content on the basis of median grain size alone could be misleading, since organic matter could be present in this fine fraction as well as in substantial amounts as detritus and macroscopic debris. Large decreases in organic carbon, without substantial changes in median grain size, implies that the distribution of organic matter in these sediments is not necessarily dependent on the inorganic grain size distribution. Sedimentary organic matter may be present in a variety of particle types, and not only adsorbed to inorganic surfaces (Johnson, 1974).

The distribution and concentration of major and trace elements in sediments along the transect, on the other hand, does reflect the inorganic grain size distribution (section 1c). With increasing sand and silica content, aluminum and heavy metal concentrations decreased (Fig. 5). This would be expected since trace metals are probably bound in lattices of aluminosilicate minerals. Thus, as $SiO_2$ (quartz) content increases, these minerals decrease in relative proportion.

Physical processes, which control patterns of inorganic particle sedimentation thus, directly control the distribution of major and trace elements in these sediments. Biological processes may also affect inorganic grain size distribution. Suspended sediment in flood tide water contained flocculated particles with similar proportions in all size categories up to 16 μm (Fig. 2). While these particles were present in all surface sediment samples, their abundance in intestinal contents from *Macoma* was approximately double that in surface sediment (Fig. 3). If grinding in the stomach increases numbers of small particles, *Macoma* feces constitute a supply of material which is not only copious in volume (Risk et al., 1977; Yeo, 1978) but also of a size which is easily resuspended and maintained in suspension by turbulence (section 1a).

## VERTICAL STRATIFICATION AND SEDIMENT STABILITY

Variations in vertical profiles of texture in cores from different stations imply non-homogeneous conditions of deposition with little mixing after settling at stations 1 to 3 (Table 2). Vertical heterogeneity in particles > 53 μm diameter is considerable over 1 cm depth intervals. More uniform profiles at station 5 imply more extensive mixing of surface sediment at this station. While oxidation-reduction potentials cannot be interpreted unambiguously (section 1b), profiles of Eh with depth show distinct gradients (Fig. 4) which imply that if resuspension and physical reworking does occur in upper intertidal zone stations, it must be restricted to surface layers 1 to 2 cm deep.

Profiles of dissolved nutrients in sediment pore water also demonstrate changes with depth at some stations which imply that extensive mixing with overlying water does not occur (Fig. 9). Concentrations of dissolved phosphorus and silicate at stations 3 and 5, however, did not change consistently in the upper 5 cm of sediment (Table 6). This might be expected in sandy sediments which are well drained. Vertical profiles of organic carbon, nitrogen and plant pigments also showed near-surface stratification which was reduced at Station 5 (Fig. 8 and 12).

Comparison of concentration and composition of particulate organic matter also implies that mixing between surface layers of upper intertidal zone sediment and material suspended in water in Cobequid Bay occurs (Table 20). Although concentrations of carbon, nitrogen and plant pigments in surface sediments at stations 1 to 3 were the highest observed along the transect, values are approximately 50% of those in suspended material. The nature of the organic matter is similar, however, with comparable carbon:nitrogen and carbon:chlorophyll *a* ratios. Since higher values of the ratios occur in subsurface sediments at these stations, but comparable or lower values were present in surface sediments from the lower intertidal zone (Fig. 7 and 11), it may be inferred that particulate organic matter in

Table 20. Comparison of average carbon, nitrogen and plant pigment content in suspended particulate matter in flood tide water and surface sediments (0-1 mm) from stations 1-3 in the upper intertidal zone at Anthony Park.

| | Suspended Material[1] | Surface Sediment[2] |
|---|---|---|
| Total Carbon (%) | 1.39 | 0.86 |
| Organic Carbon (%) | 1.06 | 0.54 |
| Nitrogen (%) | 0.17 | 0.08 |
| C:N | 6.2 | 6.8 |
| Chlorophyll *a* ($\mu g\ g^{-1}$) | 16.3 | 7.5-11.1 |
| Pheopigments ($\mu g\ g^{-1}$) | 18.2 | 11.6 |
| Chlorophyll as % total pigment | 47.2 | 39.3-48.9 |
| C:Chlorophyll *a* | 713 | 700 |

[1] Section 2

[2] Sections 1d, 4a and 4b

surface sediments over the entire intertidal zone contributes substantially to that suspended in the water. Resuspension of epibenthic diatoms, micro- and meiofauna and particulate detritus during tidal submergence could thus transport significant amounts of organic matter from surface sediments into the water column.

The presence of reduced inorganic compounds, which undergo chemical oxidation (section 3b), indicates that incompletely oxidized by-products of microbial metabolism accumulate in anaerobic layers or reduced microsites within these sediments. $N_2O$ production under anaerobic but not aerobic conditions (section 3c) also confirms that micro-organisms capable of anaerobic metabolism are present. Profiles of chemical oxidation in sediments show that chemical oxidation increases with depth only at stations 1 and 2 (Fig. 10). Vertical mixing of oxygenated water into sediments at other stations farther down the transect must be sufficient to prevent accumulation of these compounds.

The influence of oxidizing and reducing conditions on the distribution of elements in sediments is known to be considerable (Gorham and Swaine, 1965). Hem (1978) has also reported that scavaging and coprecipitation effects involving Mn oxides may be attributable to redox processes. Concentrations of Mn decreased with depth in cores from stations 1 to 3 where decreases in Eh values were also observed but no clear depth-dependent changes in Mn concentrations occurred at station 5 (Table 3, Fig. 4).

Oxygen uptake by sediments has also been compared to oxidation-reduction potentials since a balance between the accumulation of oxygen-consuming reduced materials, penetration of dissolved oxygen and redox potential should occur with depth in sediments (Mortimer, 1971). An inverse relation between the square root of oxygen uptake and Eh potential in sediments where sulphide is present is probably due to oxygen consumption by reduced sulphur compounds or products of their equilibrium reactions (Hargrave, 1972b). Pamatmat (1971) also observed that chemical oxygen uptake by sediment from Puget Sound was correlated with the concentration of total reduced substances in the upper 3 cm of cores. Linear regression analysis of the square root of total oxygen uptake (x) by stirred particles (Fig. 10) and values of Eh (y) at corresponding depths (Fig. 4) (n = 17) produced the equation:

$$y = 593 - 2824\ x \qquad (r^2 = 0.61)\ .$$

Despite the significance of the relationship, oxygen uptake rates are an order of magnitude lower than those measured in lake and salt marsh sediments at comparable Eh values (cf. Hargrave, 1972b). Substances poising redox potentials in these intertidal sediments are thus not comparable in their intensity of oxygen uptake to those in these other studies. Large increases in oxygen uptake at particular depths also do not correspond to large decreases in Eh (Fig. 4 and 10). Reduced compounds other than sulphides must be responsible for oxygen uptake in subsurface sediments at Anthony Park.

## BENTHIC AUTOTROPHIC PRODUCTION, COMMUNITY METABOLISM AND NUTRIENT BUDGETS

Primary production by epibenthic algae (oxygen production) and aerobic community respiration (oxygen consumption) measured simultaneously with undisturbed cores provide a quantitative assessment of the relative magnitude of aerobic autotrophic and heterotrophic processes, which contribute and remove sedimentary organic matter (Pomeroy, 1959; Hunding and Hargrave, 1973). No measures of oxygen uptake by chemical oxidation were made during incubation of cores at Anthony Park (section 3a) but reduced materials thought to cause chemical oxidation (section 3b) could have contributed a non-respiratory oxygen demand. Also, lack of circulation of water in cylinders during short-term incubations could affect oxygen production and consumption to different degrees.

Despite these methodological problems, comparison of average oxygen production and consumption rates show that net oxygen production exceeds consumption on an hourly basis at stations 1 and 2 but not at station 3 (Table 8). This reflects high rates of oxygen uptake at station 3. Numbers and biomass of *Macoma* and *Nereis* in cores from this station were also maximum (Table 9). If carbon flux is calculated on the basis of these measurements of oxygen exchange, respiratory demands by macrofauna and other organisms at this intertidal station exceed the carbon supply by epibenthic primary production (Table 10). The imbalance occurs at stations 1 and 2 as well when it is realized that primary production can only occur during daylight hours while respiration continues during both the day and night.

Measurements of production and community respiration carried out over short periods during a full 24 hr are required to quantify relationships over time (Hargrave, 1969). However, if diel periodicity is similar at different intertidal levels, the assumption that rates of respiration observed are constant over 24 hr allows comparison with measured rates of primary production. If day length is taken as 10 hr, daily gross epibenthic primary production and community respiration on the sampling date are approximately balanced at stations 1 and 2 while respiration exceeds production by an order of magnitude at station 3 (Table 10). Higher levels of solar radiation than occurred on May 11th would have increased epibenthic primary production. Thus, time-averaged production and respiration at station 3 could also be balanced.

Organic content and plant pigment concentrations in surface sediments from the three stations, which were not significantly different (Tables 4 and 13), give no indication of the relative importance of supply of organic matter from epibenthic primary production and other sources (dissolved and particulate debris). The similarity in concentrations, however, might be expected if the rate of utilization (by aerobic and anaerobic metabolism) was adjusted to the rate of supply. This seems to be a feature of many benthic communities where oxygen supply and periodic physical mixing ensure efficient degradation of organic matter (Parsons et al., 1977). The low carbon-specific rates of biological respiration in sediments from the upper intertidal zone at Anthony Park (Table 11) further illustrate a rapid turnover with little accumulation of metabolically labile organic material. The refractory nature of the organic matter would also explain the lack of significant changes in organic carbon or nitrogen content in sediment held in the laboratory for 13 days (Table 7).

The net flux of dissolved inorganic nutrients between sediments and overlying water may be either as an uptake or release. Both the direction and magnitude of these rates indicate the degree to which sediments serve as sources or sinks for nutrients. In a steady-state condition, rates of regeneration, utilization, diffusion and mass transport of dissolved nutrients across a sediment-water interface are balanced with no net flux. This appears to be the case for the transfer of soluble reactive phosphorus between sediments and overlying water at stations 1 to 3 at Anthony Park (section 3d). Significant depth-related increases in dissolved phosphorus concentration existed at all stations (Fig. 9) yet no measurable release occurred. Uptake of phosphorus by actively growing epibenthic algae in surface layers of the sediment could prevent release due to upward diffusion.

It is unclear, however, why a similar lack of release of dissolved silicate did not occur. Vertical gradients of increasing silicate concentration, with depth in the upper 2 cm of sediment, were greater than those of reactive phosphorus (Fig. 9). Also, oxidation-reduction potentials may have less effect on the solubility and distribution of dissolved silicate in interstitial water than is the case for phosphorus (Mortimer, 1942; Khalid et al., 1978). The diffusive flux of phosphorus through an aerobic/anaerobic interface within sediments can be prevented by the presence of an oxidized surface layer (Hayes, 1964), while dissolved silicate remains in solution. Unlike silicate, uniform concentrations of reactive phosphorus occurred in the upper 2 cm of cores (Fig. 9) where redox potentials were always above +350 mv (Fig. 4). Thus, both stratification of surface oxidized sediments and utilization by epibenthic algae may determine the concentration of dissolved phosphorus released from these sediments.

## RELATIVE AMOUNTS OF ORGANIC MATTER IN EPIBENTHIC ALGAE, BENTHIC MACROFAUNA AND SEDIMENTS

The horizontal distributions of organic carbon, nitrogen and plant pigments across the intertidal zone at Anthony Park show similar trends for all measures. Maximum values occurred at stations 2 and 3, where carbon:nitrogen ratios were also the highest and the proportion of plant pigments as chlorophyll *a* the least (Figs. 7 and 11). The maximum abundance of *Macoma* in these upper intertidal zone sediments (section 4c) implies that sediment stability, organic supply and turnover through *Macoma* feeding are closely inter-related and associated with accumulation of organic matter in the

sediments of the upper intertidal area.

Comparison of the distribution of organic matter in sediments and organisms might further differentiate zonation, which occurs across the intertidal area. Macroscopic invertebrates are generally not included when sediment samples are analyzed for organic matter. Thus, it is usually not possible to compare the relative amounts of organic matter in sediments (adsorbed to inorganic surfaces, as particulate detrital debris, micro-organisms and meiofauna) with that in macrofauna. Observations from Anthony Park permit such a comparison. Measurements of chlorophyll *a* were converted to organic carbon (assuming a carbon:chlorophyll ratio) to estimate organic carbon present in microalgae. Calculations of absolute organic carbon content in microalgae, macrofauna and sediments were based on a core 25.5 $cm^2$ in area and 5 cm deep (an average depth to which *Macoma* occurs). Sediments differ in water content across the intertidal transect and with depth (Yeo, 1978). Values from 70% to 25% occur in sediments at Anthony Park and a mean water content of 50% has been assumed as a general value applicable to the upper 5 cm layer at all stations.

Organic carbon in sediments accounted for 80 to 95 percent of the total present in sediments, microalgae and macrofauna (Table 21). Organic carbon in macrofauna comprised a maximum of 6.6% of the total at station 3 while the percent present in microalgae was highest (17.7%) at station 8. With the exception of this station, less than 10% of the organic carbon was present in the form of macrofauna and microalgae. Despite the somewhat arbitrary choice of a constant C:chlorophyll *a* conversion factor, and the fact that non-pigment containing microorganisms and meiofauna are included in estimates of organic carbon in sediments, the small fraction of the total present in organisms is consistent with other observations (Dale, 1974; Cadée and Hegeman, 1977). The bulk of the organic matter in these sediments must be present as particulate detritus in the form of non-living organic debris.

The total organic carbon present per core along the transect is reduced by an order of magnitude between stations 3 and 5 (Table 21). The amount of organic carbon in macrofauna and microalgae is similarly decreased but their proportion of the total does not change systematically with distance along the transect. The discontinuity is clearly seen in decreases in organic content (section 1d) and it corresponds to a location with increased heterogeneity in plant pigments, increasing proportion of pigment as chlorophyll *a*, a decrease in the carbon:nitrogen ratio and a reduction in fine sand and mud in the sediment (Fig. 7 and 11, Table 2).

Physical scouring by tidal action and horizontal currents must increase with distance down the intertidal zone to prevent the accumulation of particles < 53 μm (Table 2). Resuspension and mixing could prevent the formation of structured epibenthic algal population within surface sediments and colonization by macrofauna. While vertical stratification of plant pigments occurred at station 5, gradients were an order of magnitude lower than those observed in sediments from the upper intertidal zone (Fig. 12). However, the small amounts of organic matter present were enriched with chlorophyll *a* (Fig. 11) and had a high carbon-specific rate of biological respiration (Table 11). Resuspension of sediments and epibenthic algae in the upper intertidal zone could provide a source of particulate organic matter to the lower intertidal zone. The concentrations of particulate organic carbon, nitrogen and plant pigments suspended in water over the intertidal zone (Table 7) imply that such a downslope transport could occur.

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Table 21. Comparison of organic carbon in sediment, macrofauna (*Macoma*) and benthic microalgae in sediment cores (25.5 $cm^2$) to a depth of 5 cm at various sites in the intertidal zone at Anthony Park. An average water content (50%) and specific gravity (2.0) was assumed for sediments at all sites. Parentheses indicate percentage of total in each category.

| | Sediment Organic Carbon | | Macrofauna | | Benthic Microalgae | | Total |
|---|---|---|---|---|---|---|---|
| Station | Percent Organic C[1] | mg C[5] | Number[2] | mg C | µg Chl.*a*/g[3] | mg C[4] | mg C |
| 1 | .57 | 699 (95) | 2.3 | 11.5 (1.5) | 3.7 | 28.3 (3.8) | 738 |
| 2 | .53 | 644 (92) | 3.2 | 26.3 (3.7) | 4.0 | 30.6 (4.4) | 701 |
| 3 | .47 | 572 (89) | 4.4 | 42.0 (6.6) | 3.5 | 26.9 (4.2) | 641 |
| 5 | .07 | 77 (94) | --- | ---- | 0.7 | 5.4 (6.0) | 82 |
| 8 | .03 | 31 (80) | .06 | 0.9 (2.3) | 0.9 | 6.9 (17.7) | 39 |
| 10 | .03 | 37 (94) | .05 | 0.8 (2.0) | 0.2 | 1.5 (3.8) | 39 |

[1] Table 4 (mean of 0-5 cm depth layers)

[2] Numbers per 25 $cm^2$ (from Tables 9 and 10) x mean carbon content (Table 18) calculated on the basis of three size classes of *Macoma*. Abundance from station 10 not determined quantitatively.

[3] Average chlorophyll *a* concentration integrated between 0 and 5 cm (Fig. 12). Concentrations in surface sediment at stations 8 and 10 assumed constant with depth.

[4] C:chlorophyll *a* ratio assumed to be 60 (Cadée and Hegeman, 1977, discuss the arbitrary nature of the conversion).

[5] Organic carbon content corrected for that estimated to be present in microalgae.


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## APPENDIX I

## MARINE MACROALGAE: SPECIES LIST (C. BIRD)

Marine algae of Minas Basin, east of a line drawn from Cape Split, Kings Co., to the mouth of Ramshead River, Cumberland Co., are listed below (Table 1). This portion of Minas Channel is included as it is a probable source of the larger macrophytes and detritus derived from seaweeds cast ashore in Minas Basin and Cobequid Bay.

Microscopic epiphytes, diatoms and other unicells are omitted. Several microscopic species (e.g., the *Cyanophyceae*), however, are included as they may form macroscopic aggregates ranging from scattered colonies to extensive mats, particularly in salt marsh habitats.

Species within a class are listed in alphabetical order. Nomenclature of most classes follows the recent check-list of South (1976). Nomenclature is adopted from Parke and Dixon (1976) for the *Cyanophyceae* and *Xanthophyceae*.

Table 1. Macroscopic algae observed in Minas Basin, Bay of Fundy.

*CHLOROPHYCEAE*

*Blidingia marginata* (J.Ag.) P. Dang.
*Chaetomorpha melagonium* (Web.&Mohr.) Kütz.
*Cladophora rupestris* (L.) Kütz.
*C. sericea* (Huds.) Kütz.
*Enteromorpha flexuosa* (Wulf. ex Roth) J.Ag. subsp. *paradoxa* (Dillw.) Bliding.
*E. intestinalis* (L.) Link.
*E. linza* (L.) J.Ag.
*E. prolifera* (O.F. Müll.) J.Ag. subsp. *prolifera*.
*Monostroma grevillei* (Thur.) Wittr.
*M. pulchrum* Farl.
*Percursaria percursa* (C.Ag.) Rosenv.
*Prasiola stipitata* Suhr. in Jessen.
*Rhizoclonium riparium* (Roth) Harv.
*Spongomorpha arcta* (Dillw.) Kütz.
*S. sonderi* Kütz.
*Ulothrix flacca* (Dillw.) Thur. in Le Jol.
*Ulva lactuca* L.
*U. rigida* C.Ag.
*Urospora penicilliformis* (Roth) Aresch.
(?)*U. speciosa* (Carm. ex Harv. in Hook.) LeBlond ex Hamel.

*XANTHOPHYCEAE*

*Vaucheria compacta* (Coll.) Coll. ex Taylor.

*PHAEOPHYCEAE*

*Ascophyllum nodosum* (L.) Le Jol.
*Chorda tomentosa* Lyngb.
*Chordaria flagelliformis* (O.F. Müll.) C.Ag.
*Desmarestia aculeata* (L.) Lamour.
*D. viridis* (O.F. Müll.) Lamour.
*Dictyosiphon eckmanii* Aresch.
*D. foeniculaceus* (Huds.) Grev.
*Estocarpus siliculosus* (Dillw.) Lyngb.
*Elashista fucicola* (Vell.) Aresch.
*Fucus distichus* L. subsp. *distichus*
*F. spiralis* L.
*F. vesiculosus* L.
*Isthmoplea sphaerophora* (Carm. ex Harv. in Hook.) Kjellm.
*Laminaria digitata* (Huds.) Lamour.
*L. longicruris* Pyl.
*L. saccharina* (L.) Lamour.
*Melanosiphon intestinalis* (Saund.) Wynne.
*Petalonia fascia* (O.F. Müll.) O. Kuntze.
*Pilayella littoralis* (L.) Kjellm.
*Ralfsia verrucosa* (Aresch.) J.Ag.
*Saccorhiza dermatodea* (Pyl.) J.Ag.
*Scytosiphon lomentaria* (Lyngb.) Link var. *lomentaria*.

*FLORIDEOPHYCEAE (RHODOPHYTA)*

*Ahnfeltia plicata* (Huds.) Fr.
*Antithamnion* sp.
*Audouinella purpurea* (Lightf.) Woelk.
*Callophyllis cristata* (C.Ag.) Kütz.
*Ceramium deslongchampii* Chauv. in Duby var. *hooperi* (Harv.) Taylor.
*C. elegans* (Ducluz.) C.Ag.
*C. rubrum* (Huds.) C.Ag.
*Chondrus crispus* Stackh.
*Corallina officinalis* L.
*Cystoclonium purpureum* (Huds.) Batt.
*Dermatolithon pustulatum* (Lamour.) Fosl.
*Dumontia incrassata* (O.F. Müll.) Lamour.
*Gigartina stellata* (Stackh. in With.) Batt.
*Gloisiphonia capillaris* (Huds.) Carm. ex Berk.
*Hildenbrandia rubra* (Sommerf.) Menegh.
*Lithothamnium* sp.
*Membranoptera alata* (Huds.) Stackh.
*Palmaria palmata* (L.) O. Kuntze
*Phycodrys rubens* (L.) Batt.
*Phyllophora pseudoceranoides* (Gmel.) Newr. and A. Tayl.
*P. truncata* (Pallas) A. Zin.
*Plumaria elegans* (Bonnem.) Schm.
*Polyides rotundus* (Huds.) Grev.
*Polysiphonia lanosa* (L.) Tandy.
*P. urceolata* (Lightf. ex Dillw.) Grey.
*Rhodomela confervoides* (Huds.) Silva.

*BANGIOPHYCEAE (RHODOPHYTA)*

*Bangia atropurpurea* (Roth.) C.Ag.
*Porphyra linearis* Grev.
*P. miniata* (C.Ag.) C.Ag.
*P. umbilicalis* (L.) J.Ag.

*CYANOPHYCEAE*

*Anabaena torulosa* (Carm. ex Harv. in Hook.) Lagerh. ex Born. and Flah.
*Calothrix crustacea* Thur. ex Born. and Flah.
*Oscillatoria submembranacea* Ardiss. and Straff. ex Gom.
*Spirulina subsalsa* Oerst. ex Gom.

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## APPENDIX II

## SHOREBIRDS, FISH, BENTHIC AND PELAGIC INVERTEBRATE FAUNA: SPECIES LIST (B. HARGRAVE)

Exclusive of five species of shorebirds commonly observed at Anthony Park, published records of fish, benthic and pelagic invertebrate macrofauna listed below (Table 1) show that eighty-one species have been observed either in intertidal sediments or in pools of water during low tide on the south shore of Cobequid Bay. Bousfield and Leim (1960) collected benthic invertebrates at two stations (M10 and M11, at Noel Bay and Maitland) and since Anthony Park lies midway between these locations, species recorded at both sites have been included in the list. Fish stranded in pools at Kingsport during extreme low tides (thirty-six species) (Bleakney and McAllister, 1973) are likely to be representative of species which move extensively within Minas Basin and Cobequid Bay. For example, stomachs of alewives in Minas Basin contained amphipods, mysiids and copepods and this species migrates through Cobequid Bay to and from the Shubenacadie River (Leim and Scott, 1966). In addition, six species of pelagic invertebrates (squid, copepods and the chaetognath *Sagitta*) have been recorded from Cobequid Bay. The five species of shorebirds either commonly feed or are resident along the shoreline at Anthony Park.

Bousfield and Leim (1960) and Yeo (1978) have discussed invertebrate faunal subregions, which appear to exist within Cobequid Bay and Minas Basin. The influx of fresh water from the Avon and Shubenacadie river systems creates gradients of salinity and turbidity, which may limit the distribution of some species and produce endemic populations. Bousfield (1962) and Yeo (1978) also suggested that variable species distribution patterns between adjacent areas in Minas Basin may result from localized effects of ice abrasion and heavy deposition or erosion of sediment.

The absence of certain species on May 11, 1977 along the Anthony Park intertidal transect may also reflect variable abundance due to seasonal patterns of recruitment. Observations have demonstrated this variability in *Corophium* populations (Yeo, 1978). Other species, like the polychaete *Sabellaria vulgaris* (Verrill), may be common in some sublittoral regions only exposed during extreme low water spring tides (Bleakney and McAllister, 1973). The presence of firm substrates (sandstone outcroppings and rocks carried by ice and scattered across the lower intertidal area) also provides habitats for some species. Rock-boring molluscs and sponges (five species) (Bleakney and Mustard, 1974) are examples of fauna whose distribution in Minas Basin is determined by the availability of suitable rock surfaces.

Bousfield (1962) used data from Bousfield and Leim (1960) to compare the regional abundance of intertidal arthropod species at locations inside and outside of Minas Basin. An unusually rich arthropod fauna occurred along the north side of Minas Channel where habitat diversity was high. The upper areas of Minas Basin (Cobequid Bay), however, contained fewer species and these, along with other benthic macrofauna, were mostly deposit and detritus feeders. The scarcity of species which are suspension or filter-feeders is probably attributable to the constant presence of high levels of turbidity (Risk et al., 1977).

Table 1. Species of shorebirds, fishes, benthic and pelagic invertebrate fauna recorded along the southern shore of Cobequid Bay, Minas Basin, Bay of Fundy.

| | |
|---|---|
| BIRDS Anthony Park (Hicklin and Yeo, pers. comm.) | |
| *Limnodromus griseus* (Gmelin) | Short-billed dowitcher |
| *Ereunetes pasillus* (l.) | Semipalmated sandpiper |
| *Squatarola squatarola* (L.) | Black-bellied plover |
| *Charadrius semipalmatus* (Bonaparte) | Semipalmated plover |
| *Limosa haemastica* (L.) | Hudsonian godwit |
| FISHES Kingsport, N.S. (Bleakney and McAllister, 1973) | |
| *Petromyzon marinus* (L.) | Sea lamprey |
| *Alopias vulpinus* (Bonnaterre) | Thresher shark |
| *Carcharodon carcharias* (L.) | White shark |
| *Raja erinacea* Mitchill | Little skate |
| *Raja laevis* Mitchill | Barndoor skate |
| *Raja ocellata* Mitchill | Winter skate |
| *Acipenser oxyrhynchus* Mitchill | Atlantic sturgeon |
| *Alosa pseudoharengus* (Wilson) | Gaspereau |
| *Alosa sapidissima* (Wilson) | American shad |
| *Brevoortia tyrannus* (Latrobe) | Atlantic menhaden |
| *Clupea harengus* L. | Atlantic herring |

| | |
|---|---|
| *Salmo salar* L. | Atlantic salmon |
| *Osmerus mordax* Mitchill | American smelt |
| *Anguilla rostrata* (LeSueur) | American eel |
| *Enchelyopus cimbrius* (L.) | Fourbeard rockling |
| *Gadus morhua* L. | Atlantic cod |
| *Microgadus tomcod* (Walbaum) | Atlantic tomcod |
| *Urophycis tenuis* (Mitchill) | White hake |
| *Merluccius bilinearis* (Mitchill) | Silver hake |
| *Menidia menidia* (L.) | Atlantic silverside |
| *Fundulus heteroclitus* (L.) | Mummichug |
| *Syngnathus fuscus* Storer | Northern pipefish |
| *Liopsetta putnami* (Gill) | Smooth flounder |
| *Pseudopleuronectes americanus* (Walbaum) | Winter flounder |
| *Scophthalmus aquosus* (Mitchill) | Windowpane |
| *Roccus saxatilis* (Walbaum) | Striped bass |
| *Poronotus triacanthus* (Peck) | Butterfish |
| *Hemitripterus americanus* (Gmelin) | Sea raven |
| *Myoxocephalus aeneus* (Mitchill) | Grubby |
| *Myoxocephalus scorpius* (L.) | Shorthorn sculpin |
| *Cyclopterus lumpus* L. | Lumpfish |
| *Liparis atlanticus* (Jordan and Evermann) | Atlantic seasnail |
| *Macrozoarces americanus* (Block and Schneider) | Ocean pout |
| *Pholis gunnellus* (L.) | Rock gunnel |
| *Ammodytes dubius* Reinhardt | Northern sand lance |
| *Lophius americanus* Valenciennes | Monkfish |

BENTHIC INVERTEBRATES Noel Bay, Maitland, N.S. (intertidal) (Bousfield and Leim, 1960)

| | |
|---|---|
| *Nereis virens* Sars | Clam (sand) worm |
| *Balanus balanoides* L. | Rock barnacle |
| *Balanus improvisus* Darwin | Little ivory barnacle |
| *Neomysis americana* Smith | Mysiid |
| *Jaera marina* (Fabr.) | Isopod |
| *Idothea phosphorea* Harger | Isopod |
| *Chirodotea caeca* (Say) | Isopod |
| *Chirodotea tuftsi* (Stimps) | Isopod |
| *Tmetonyx nobilis* (Stimps) | Amphipod |
| *Bathyporeia quoddyensis* Shoemaker | Amphipod |
| *Calliopus laeviusculus* kr. | Amphipod |
| *Gammarus oceanicus* Segerstrale | Amphipod |
| *Gammarus lawrencianus* Bousfield | Amphipod |
| *Hyale nilssoni* | Amphipod |
| *Orchestia grillus* Bosc. | Salt marsh hopper |
| *Talorchestia longicornis* (Say) | Sandhopper |
| *Corophium volutator* (Phallas) | Amphipod |
| *Corophium tuberculatum* Shoemaker | Amphipod |
| *Unicola irrorata* | Amphipod |
| *Crago septemspinosus* (Say) | Sand shrimp |
| *Pagurus longicarpus* Say | Decopod |
| *Cancer irroratus* Say | Rock crab |
| *Carcinides maenas*(L.) | Green crab |
| *Libinia emarginata* Leach | Decopod |
| *Acmaea testudinalis* (L.) | Tortise-shell limpet |
| *Littorina littorea* L. | Common periwinkle |
| *Littorina saxatilis* Olivi | Rough periwinkle |
| *Littorina obtusata* L. | Smooth periwinkle |
| *Crepidula fornicata* L. | Common slipper limpet |
| *Lunatia heros* (Say) | Common moon snail |
| *Lunatia triseriata* (Say) | Three-lined moon snail |
| *Urosalpinx cinerea* (Say) | Oyster drill |
| *Thias lapillus* L. | Common dogwinkle |
| *Mitrella lunata* (Say) | Mollusc |
| *Nassarius trivittatus* (Say) | Channelled basket shell |
| *Nassarius obsoletus* (Say) | Mud snail |
| *Odostomia trifida* (Totten) | Mollusc |
| *Odostomia bisutaralis* (Say) | Mollusc |
| *Petricola pholadiformis* Lamarck | Rock boring mollusc |
| *Macoma balthica* (L.) | Mollusc |
| *Ensis directus* (Conrad) | Atlantic razor clam |
| *Mya arenaria* L. | Soft-shell clam |
| *Barnea truncata* Say | Rock boring mollusc |
| *Teredo navalis* L. | Mollusc |
| *Lyonsia hyalina* (Conrad) | Mollusc |
| *Pandora gouldiana* Dall | Mollusc |

PELAGIC INVERTEBRATES Cobequid Bay (Huntsman 1924, 1962; Jermolajev 1958; Bousfield and Leim 1960)

| | |
|---|---|
| *Loligo pealei* LeSueur | Squid |
| *Acartia tonsa* Dana | Copepod |

| | |
|---|---|
| *Pseudodiaptomus coronatus* Williams | Copepod |
| *Eurytemora herdmani* Thompson and Scott | Copepod |
| *Centropages hamatus* (Lilljeborg) | Copepod |
| *Sagitta elegans* Verrill | Chaetognaths |

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