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Production Studies in the Mackenzie River–Beaufort Sea Estuary

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Summary. Production studies were carried out in the Mackenzie River/Beaufort Sea estuary during the summer of 1986. Results indicate that there were two plankton communities. One was located near the river mouth and was characterized by high dissolved organic carbon, high bacterial activity and a community of amphipods. The second community was associated with high phytoplankton production off shore and with a community of copepods, hydromedusae and ctenophores. The offshore marine/oceanic community was quantitatively much more productive than the near shore bacterial community during the summer months.

Introduction

Estuaries may differ greatly in the total quantity and species diversity of organisms which contribute to their biological productivity. At the same time there is a certain commonality of estuarine production processes which may be of varying quantitative importance in both time and space. Thus for all estuaries, two sources of metabolic energy exist, one in the allochthonous organic material derived from land and the other in autochthonous material derived from photosynthesis in the sea. In addition, various forms of exometabolic energy, such as vertical diffusivity, will affect both of these metabolic sources of energy.

Primary productivity and chlorophyll tend to maximize at some distance from a river mouth (e.g. Parsons et al. 1969) due to a variety of different reasons including vertical stability, decreased turbidity, nutrient availability, generation times of the phytoplankton and the presence of a zooplankton maximum which limits the phytoplankton bloom on the seaward side through grazing. On the other hand the supply of terrestrial dissolved organic carbon (DOC) is greatest near the river mouth and decreases with salinity in offshore waters (e.g. Mantoura and Mann 1977). A second smaller increase is known to occur in the presence of the offshore maximum in primary production. Other properties of the estuary such as turbidity, pH and oxygen usually show sharp minima and maxima in association with small changes in salinity from 0.1 to 1‰. The osmotic change in this region is sufficient to kill most freshwater organisms (e.g. phytoplankton) and decomposition of the most metabolizable substrates is carried out by euryhaline bacteria which survive up to salinities of ca 18‰ above which more halophilic species dominate (Mantoura and Mann 1977; Seki et al. 1969; Valdes and Albright 1981).

In the following study the questions being asked are whether the Mackenzie estuary entering the Beaufort Sea follows the general pattern of estuarine subarctic production described above and, secondly, what is the quantitative significance of the heterotrophic food chain based on riverine DOC compared with the autotrophic food chain based on the offshore maximum in primary productivity? In order to attempt answers to these two questions a variety of production studies were carried out during July and August, 1986 in the Mackenzie estuary (ca. 69 degrees N, 133 degrees W – see Fig. 1). Studies were carried out on the MV "Sequel" under charter to the Department of Fisheries and Oceans (DFO), Winnipeg, Canada.

Methods

Photosynthesis, chlorophyll *a* and phaeophytin, bacterial counts, glucose and thymidine uptake were all measured as described in Parsons et al. (1984). For photosynthetic measurements below Om, light screens were used to simulate in situ irradiance. For bacterial growth, a conversion factor of 1.4×10^{18} cells per mole of thymidine incorporated was employed. Quenching of radioactive samples in the scintillation counter was obtained from a previously constructed A/B count ratio curve. However, since quenching was high on all samples, radioactive uptake values may represent relative rather than absolute production. Light attenuation was measured with a "Licor" light meter and temperature and salinity with a CSTD probe. Dissolved organic carbon (DOC) was measured by reading the absorbance at 280 nm in a 10 cm cuvette filled with Millipore HA filtered seawater from each station. The method has

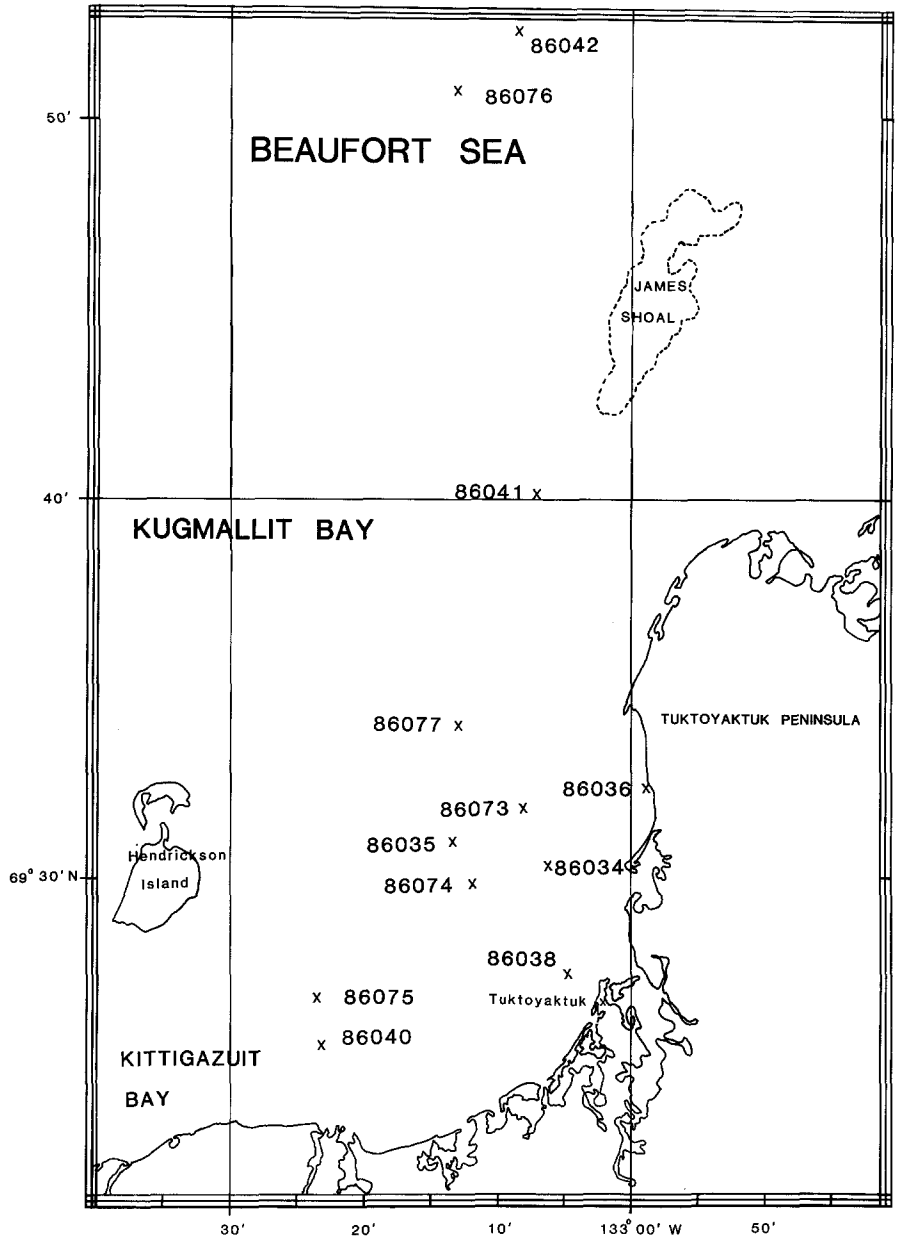

Fig. 1. Station locations

been used previously for sediment and pore waters (Krom and Sholkovitz 1977). A separate estimate of DOC by combustion confirmed the general relationship between 280 nm absorption and DOC although the slope of the line was different to that established for pore water by Krom and Sholkovitz (1977). Zooplankton samples were collected with a 350 µm, 0.5 m^2 SCOR net towed obliquely from the bottom to the surface. Phytoplankton and protozoa counts were carried out on water collected with a van Dorn bottle and samples were preserved in Lugols solution. In order to remove silt particles, all samples were concentrated on a 20 µm mesh filter, and resuspended and settled in a counting chamber. Counting was carried out at ×76 and ×192 magnification.

Two cruises were carried out on the MV Sequel; one from the 22 to 27 July and the other from 27 to 30 August. Data from these two cruises have been combined as being representative of summer conditions in the area and no attempt has been made to address seasonal change. Station locations are shown on Fig. 1; stations 86035 to 86042 inclusive were sampled during the July cruise and Station 86034, and 86073 to 86077 inclusive, were sampled during the August cruise. For photosynthetic measurements, values are reported only for Om depth due to severe light attenuation. For other data which were collected between 0 and 4 m depth, all data have been reported in the figures shown. Station numbers have been arranged in increasing order of distance from the river mouth which generally reflects changes in turbidity and salinity as shown in Figs. 2 and 3.

A Pearson correlation matrix was formed using Systat statistical software on an IBM-PC computer for all the production data in Figs. 3, 4 and 5. The 0.05 significance level was observed throughout.

Results

Figure 2 shows light attenuation data collected from 4 stations in the estuary. Light attenuation near the mouth of the river (St. 40) is so severe as to inhibit any form of primary productivity below a few centimeters. Progressing away from the river mouth near station 40, through the series St. 77, 41 and 42, one encounters clearer water so that at St. 42 the euphotic zone is approximately 10 m.

Figure 3 show that the highest chlorophyll *a* and primary productivity (St. 42) occurs in the clearest water at

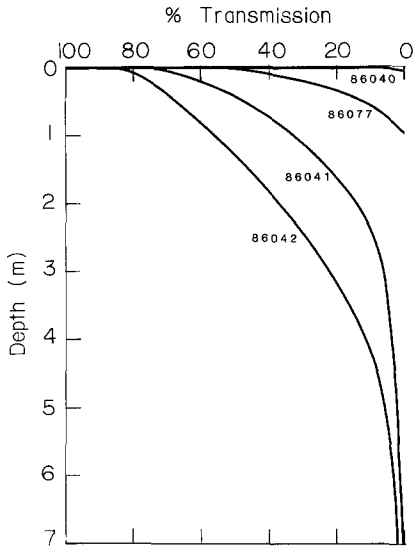

Fig. 2. Light transmission data for representative stations shown in Fig. 1

salinities of ca 30‰. One high primary productivity value at Station 38 may be an erroneous result since there was practically no chlorophyll *a* at this station and the result is not supported by water clarity or dark fixation data, both of which should be related to the primary productivity. Phaeo-pigments show a general decrease with increasing salinity; however, these pigments are also significantly correlated (r = 0.505, n = 27) with the amount of chlorophyll *a*. This indicates that there are possibly two sources of phaeopigments, one associated with marine chlorophyll *a* and the other with freshwater phytoplankton decomposing in the estuary.

Changes in dissolved organic carbon and bacterial activity are shown in Fig. 4. DOC values were highest close to the river mouth and decreased with an increase in salinity (r = −0.835, N = 21) until salinity values became >20‰, when there was another increase in DOC. The former maximum is associated with riverine DOC while the latter increase (Stations 41, 76 and 42) is probably associated with the high primary productivity and chlorophyll *a* off shore from the river mouth (cf. Fig. 3). Bacterial numbers, bacterial growth and heterotrophic activity all showed their highest values in low salinity, silt laden water. In particular, bacterial numbers had a significant inverse correlation with salinity (r = −0.501, N = 27) and a high positive correlation with DOC (280 nm absorbance, r = 0.720, N = 21). However, considerable bacterial growth and heterotrophic activity was also associated with the autotrophic production at salinities >20‰ (Fig. 3). These data seem to confirm the general pattern of estuarine bacterial activity which consists of a gradual change from non-halophiles carrying out the decomposition of terrestrial DOC in waters of less than ca. 20‰, while halophiles grow as a second community in association with primary producers at

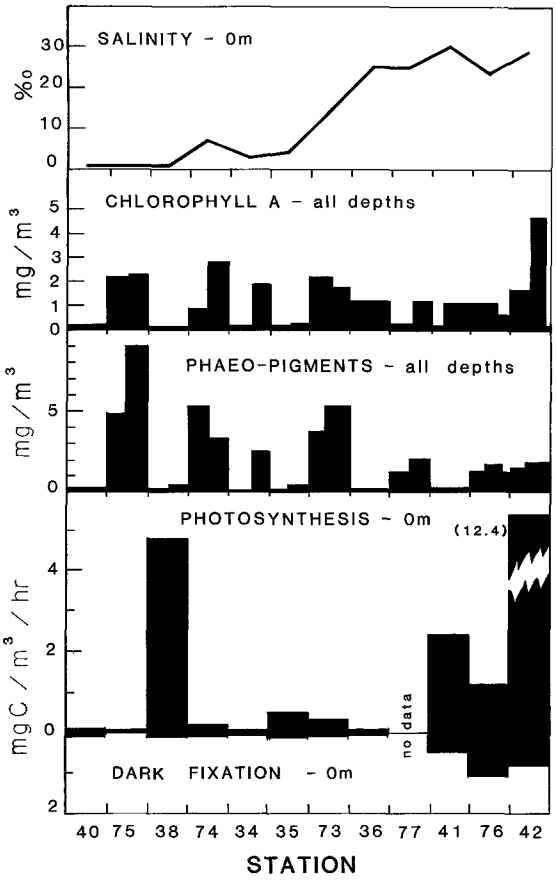

Fig. 3. Changes in salinity and primary producers in the estuary

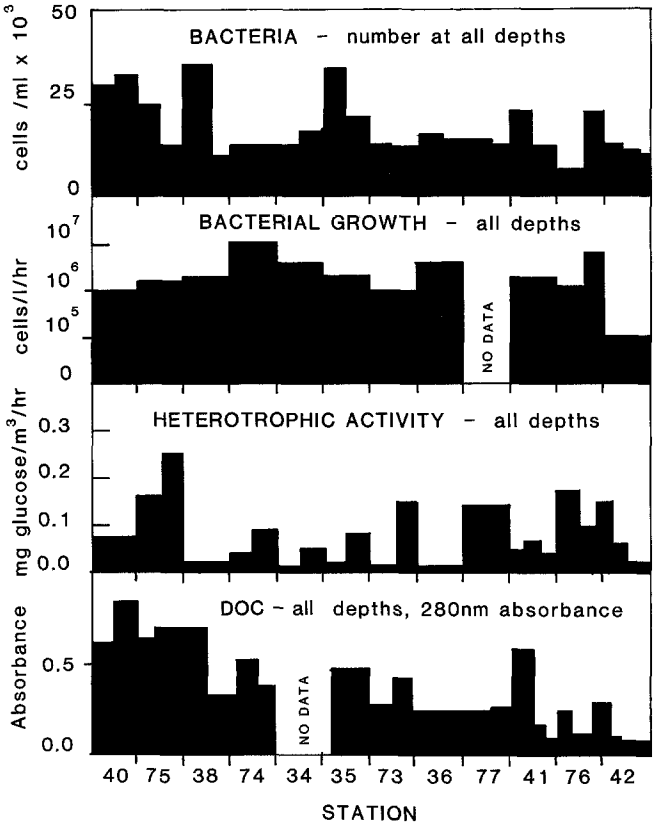

Fig. 4. Changes in DOC and bacterial production in the estuary

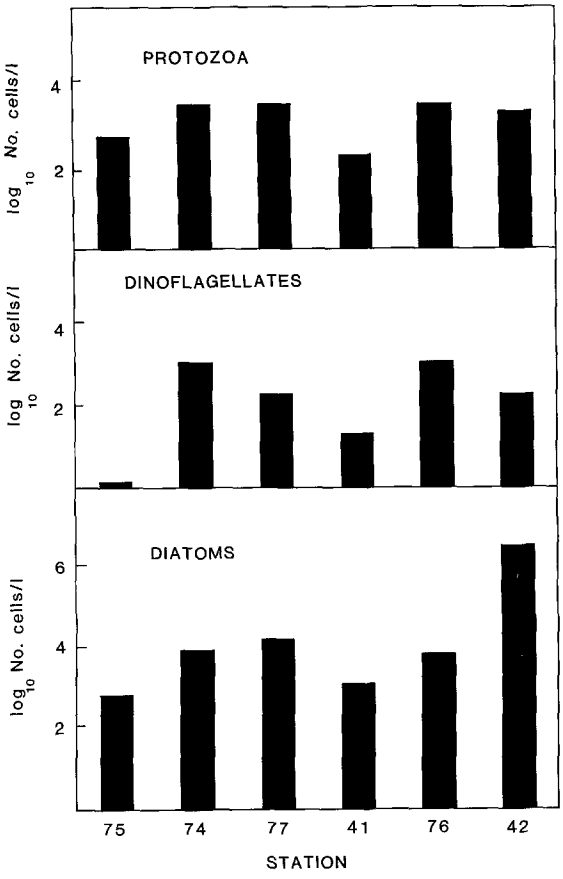

Fig. 5. Distribution of the numbers of phytoplankton and protozoa in the estuary

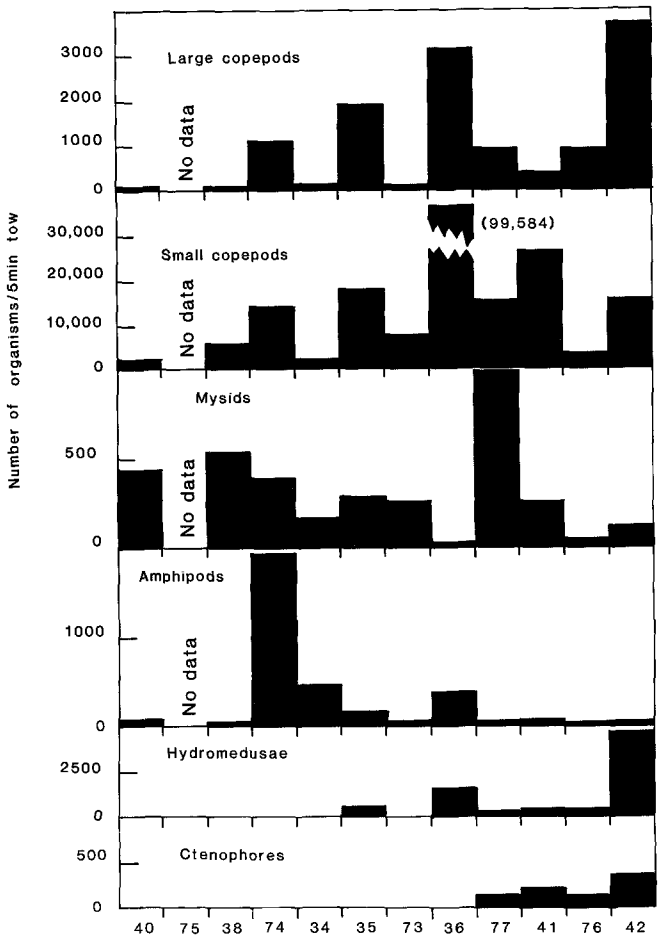

Fig. 6. Distribution of the numbers of zooplankton in the estuary

salinities >20‰ (cf. Seki et al. 1969; Valdes and Albright 1981). Total diatoms, dinoflagellates and protozoa are shown in Fig. 5. Diatom species were most abundant at station 42 in the marine oceanic habitat. The dominant species was *Chaetoceros socialis* (ca. 3×10^6 cells/l) with smaller numbers of *Chaetoceros compressus* and *Thalassiosira* spp. Dinoflagellates showed an ubiquitous distribution in the estuary; the dominant genera were *Dinophysis, Gryodinium* and *Protoperidinium*. Protozoa were dominated by ciliates and not infrequently by *Mesodinium rubrum*.

Zooplankton in Fig. 6 generally showed a rather distinct partition between marine and brackfish water communities. Small (<2 mm) and large (>2 mm) copepods, hydromedusae and ctenophores were all more abundant on the seaward side of the estuary. Amphipods were associated with the less saline waters while mysids were present in both estuarine and offshore waters.

Discussion

These results (Figs. 3 to 6) tend to confirm the existence of two plankton communities associated with the Beaufort Sea/Mackenzie River estuary. This is consistent with previous publications on estuarine ecology given in the Introduction. The results are most distinct in the gradual change of zooplankton, diatom and primary productivity distributions. The bacterial data are complex in that both halophiles and non-halophiles overlap in the region of 20‰ salinity. However the presence of appreciable DOC at the riverine end of the estuary where the highest number of bacteria, bacterial growth and heterotrophic activity were all encountered indicates a community based on energy supplied by riverine DOC, and independent of autotrophic production.

The relative importance of the brackish water bacterial community versus the marine autotrophic community can be approximated from values given in the figures. From Fig. 4, the fastest doubling time of the bacteria was about 1 h and the maximum bacterial production was 0.2 $mgC/m^3/h$ (using a conversion factor given by Fenchel (1982) of 2.5×10^5/ml bacteria being equivalent to 5 mgC/m^3). Even allowing for 24 h of production and the presence of adequate metabolizable substrate, this is a productivity of only 4.8 $mgC/m^3/day$ compared with maximum surface autotrophic production (Fig. 3) of 12.4 $mgC/m^3/h$, or about 220 $mgC/m^3/day$ if the 4 h morning productivity values are integrated over an 18 h day. Thus the nearshore heterotrophic production appears to be about 2% of the offshore autotrophic production. However, two additional considerations are that the heterotrophic production can continue both through-

out the year and throughout the water column, and secondly, that Li and Dickie (1984) have shown that arctic bacteria are very temperature sensitive. Since nearshore temperatures (e.g. Stn. 86034 and 86035) were greater than 10 °C at the surface, this could cause a significant increase in bacterial activity. An ecosystem simulation model (Parsons and Kessler 1987) used with the bacterial temperature coefficients of Li and Dickie (1984), showed that heterotrophic activity could be increased to about 5% of autotrophic production if the water is warmed in nearshore areas from 5 to 10 °C (also assuming adequate metabolizable substrate). How much of the heterotrophic production is utilized by higher trophic levels in the plankton community (especially the amphipods which appear in Fig. 6 to be more numerous in the brackish water) will be a subject for study next year using natural isotopes.

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