

Feeding, Respiration and Excretion of the Copepod *Calanus hyperboreus* from Baffin Bay, Including Waters Contaminated by Oil Seeps

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ABSTRACT. Metabolic processes in eastern arctic copepods *Calanus hyperboreus* were analyzed during the post-bloom period (August-September). Mixed adult and subadult copepods were collected from 12 stations in Baffin Bay (Davis Strait to Lancaster Sound) by trawling from 0-300 m. Measurements were made of clearance rate, O₂-consumption and NH₃ excretion. The cruise track included 6 stations in oil-seep contaminated waters of Scott Inlet and Buchan Gulf. Physiological parameters for populations of *C. hyperboreus* from the latter stations were compared with those from non-seep stations.

Mean O₂ consumption rates (0.309-0.907 μl O₂·mg dry wt⁻¹·h⁻¹) for all stations were similar to those described for Antarctic calanoid species but were higher than reported from more northern arctic waters. Mean ammonia excretion rates (0.023-0.071 μg N·mg dry wt⁻¹·h⁻¹) were somewhat lower than reported for comparable Antarctic species and were similar to values from other eastern arctic studies. O:N ratios for 11 of the 12 stations occupied ranged between 8.4 and 22.1, indicative of protein-based metabolism. The single exception was a High Arctic station with O:N ratio 43.6. Clearance rates were low to nonexistent for all stations.

Most of the non-feeding values came from the Scott Inlet-Buchan Gulf region of western Baffin Bay. At those stations in this region a strong negative correlation ($P < .01$) exists between clearance rate and hydrocarbon contamination. This suggests that in the oil-seep region of Baffin Bay feeding may be suppressed in *Calanus hyperboreus* by low concentrations of petroleum hydrocarbons derived from sub-sea seepage.

Key words: zooplankton, *Calanus hyperboreus*, Arctic, metabolism, oil seep, petroleum, hydrocarbons, oil pollution

RÉSUMÉ. On a analysé les processus métaboliques du copépode *Calanus hyperboreus* de l'est de l'Arctique, durant la période ultérieure à la phase de prolifération du phytoplancton (août-septembre). On a recueilli dans douze stations de la baie de Baffin (du détroit de Davis au détroit de Lancaster) des populations mixtes de copépodes adultes et sub-adultes, en pêchant au chalut entre 0 et 300 m de profondeur. On a mesuré les taux de clairance, de consommation de O₂ et d'excrétion de NH₃. Le trajet du navire d'exploration passait par six stations situées dans les eaux de l'inlet Scott et du golfe Buchan, contaminées par des suitements de pétrole. On a comparé les paramètres physiologiques des populations de *C. hyperboreus* provenant des stations susmentionnées, à ceux de stations non contaminées.

Les taux moyens de consommation de O₂ (0,309-0,907 μl O₂·mg-poids sec⁻¹·h⁻¹) dans toutes les stations étaient semblables à ceux cités à propos d'espèces calanoides de l'Antarctique, mais étaient plus élevés que ceux relevés chez des espèces des eaux arctiques plus septentrionales.

Les taux moyens d'excrétion de l'ammoniac (0,023-0,071 μg N·mg-poids sec⁻¹·h⁻¹) étaient légèrement plus bas que relevés chez des espèces comparables de l'Antarctique, et semblables aux valeurs données par d'autres études sur l'est de l'Arctique. Les rapports O:N de 11 des 12 stations occupées se situaient entre 8,4 et 22,1 ce qui indiquait un métabolisme protidique. La seule exception était une station du Haut-Arctique où l'on a noté un rapport O:N de 43,6. Les taux de clairance étaient faibles à nuls dans toutes les stations.

La plupart des valeurs sur l'absence d'alimentation provenaient de la région de l'inlet Scott et du golfe Buchan, dans l'ouest de la baie de Baffin. Dans toutes les stations de cette région, il existe une forte corrélation négative ($P < 0,01$) entre le taux de clairance et le taux de contamination par les hydrocarbures. Ceci suggère que dans la région de la baie de Baffin où ont lieu des suitements de pétrole, l'alimentation de *Calanus hyperboreus* peut être arrêtée par la présence de faibles concentrations d'hydrocarbures provenant de suitements sous-marins de pétrole.

Mots clés: zooplankton, *Calanus hyperboreus*, Arctique, métabolisme, suitements de pétrole, pétrole, hydrocarbures, pollution par les hydrocarbures

INTRODUCTION

Calanus hyperboreus is a dominant member of northern marine zooplankton assemblages (Buchanan and Sekerak, 1982) and is found throughout the central (Dawson, 1978) and eastern Canadian Arctic (Huntley *et al.*, 1983). It is also of particular interest because it apparently spends most of the year in deep, cold waters as a result of seasonal vertical migration and well away from its phytoplankton food source (Conover, 1962; Widborg, 1940; Ostvedt, 1955; Ussing, 1938; Rudjakov, 1983; Dawson, 1978). Thus, during the spring phytoplankton blooms, the animals are found in the surface layers (Buchanan and Sekerak, 1982; Huntley *et al.*, 1983; Huntley, 1981). During the remainder of the year the animals reportedly survive on stored fats at a reduced metabolic level (Conover, 1968).

However, except for a single study by Lee (1974) of lipid buildup and decrease in *C. hyperboreus* from the western Arctic, very little was known of the metabolism of this or other arctic copepods. Two recent studies of grazing, respiration and nitrogen excretion (Conover and Cota, 1985) and urea-NH₄ requirements (Harrison *et al.*, 1985) have since provided the first data from the High Arctic. In this paper we present data on

the feeding (clearance), respiration and nitrogen excretion in *C. hyperboreus* collected in late summer (August-September) at a number of stations from Baffin Bay between Davis Strait and Lancaster Sound. The cruise track also included a number of stations in Scott Inlet and Buchan Gulf, along the western side of Baffin Bay. These waters are influenced by a chronic input of petroleum hydrocarbons from sub-sea oil seeps and, on the basis of a large number of water column samples, have been shown to have anomalously high hydrocarbon concentrations (Levy, 1979, 1981; MacLean *et al.*, 1981).

MATERIALS AND METHODS

Field Collection

Animals were collected by oblique plankton tows (0-300 m) at stations in Davis Strait on cruise 78-026 (25 August - 17 September 1978) (Fig. 1). The cruise track crossed areas of western Davis Strait known to have elevated levels of hydrocarbons in the surface film (Levy, 1978). All possible care was taken to minimize damage to the animals. The cod end of the plankton net contained no vents; animals reaching the cod end

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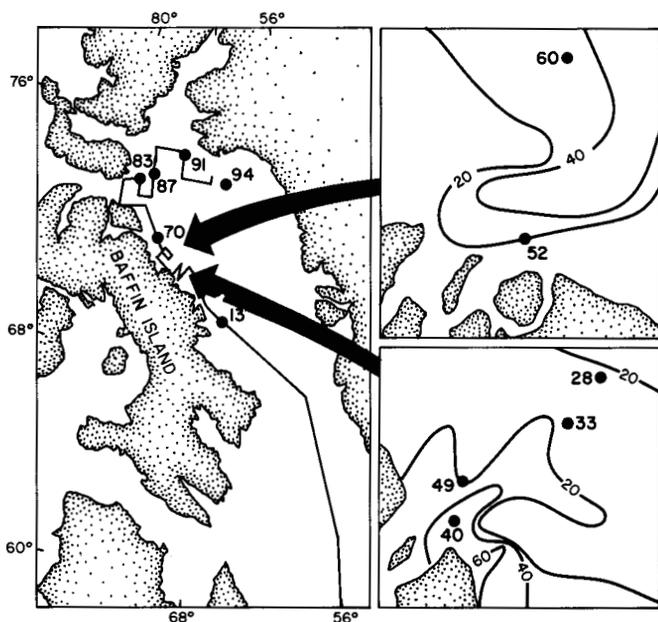


FIG. 1. Cruise track and location of sampling stations in Baffin Bay for *C. hyperboreus* plankton tows. Inset figures show petroleum hydrocarbon concentration profiles for known seep areas (after Levy, 1979).

were in relatively non-turbulent water. As soon as the net was recovered the contents of the cod end were emptied and diluted into 8-10 l of surface seawater. The animals were then maintained at ambient seawater temperature. Experimental animals were selected with a stainless steel spoon. All physiological determinations were made on adult or stage V *C. hyperboreus*, averaging 10 mg dry weight per animal. Measurements were made aboard ship within 12 h of capture. Feeding, respiration and N-excretion measurements were made on copepods from the same collection for each station occupied.

Experimental Methodology

Clearance rates, i.e., volume of water swept clear of particles per hour, were determined using a modification of the methods of Gilfillan *et al.* (1977). A glass 1 l bottle was filled with glass fiber (GF-C) filtered seawater. To this an aliquot of *Dunaliella tertiolecta* culture grown in F2 medium (Guillard and Ryther, 1962) prepared with ambient seawater was added so as to yield the approximate density of cells as found in the ambient seawater as determined using a Coulter ZBI particle counter (*ca.* 1×10^3 cells \cdot ml $^{-1}$). *D. tertiolecta* was used because it was readily cultured in the shipboard laboratory and because cells of 5 to 10 μ m have been described as typically the most abundant in these waters (Huntley, 1981).

At the beginning of each experiment five subsamples of water were taken from each bottle to establish initial food levels. The number of food-size particles was determined for each subsample (mean of five replicate counts) using a Coulter Counter, as described above. The bottles were then stoppered and incubated for 12 h in the dark, rotating (0.5 rpm) on a wheel in a 981 water bath to prevent sedimentation of either food or copepods. The water bath was maintained within 0.5°C of ambient water temperatures. Following incubation five subsamples of water were taken for particle determination from each bottle; the copepods were freeze-dried and weighed. Clearance rates were

determined in triplicate. Control bottles containing only seawater and food were incubated concurrently.

The volume swept clear of particles was calculated from the following equation, $V_f = V(\ln I - \ln F) / T$, where V_f = volume filtered, V = bottle volume, I = initial particle count, F = final particle count, and T = duration of incubation. Results were expressed as volume swept clear \cdot mg dry wt $^{-1} \cdot$ h $^{-1}$.

Oxygen consumption was determined using a mechanically refrigerated differential respirometer (Gilson) in triplicate. Five copepods were placed in 30 ml glass fiber filtered seawater in each flask. Carbon dioxide was absorbed by a concentrated KOH solution in a side arm. After an initial 1 h equilibration, readings were taken every 30 min for 150 min. Oxygen consumption was determined by regressing change in volume against time. The resulting value was divided by the dry weight of the copepods to yield respiration rate as μ l O $_2 \cdot$ mg $^{-1} \cdot$ h $^{-1}$.

Ammonia excretion was determined using an Orion specific ion electrode by the method of Garside *et al.* (1977). The method has a detection limit of 0.2 μ M of NH $_3$, a precision of $\pm 0.1 \mu$ M, and is not affected by salt. At each station five groups of ten animals were incubated in 1 l of glass fiber filtered seawater in glass-stoppered 1 l bottles for 12 h. Ammonia concentrations were measured both prior to and following incubation. Results are expressed as μ g N \cdot mg $^{-1} \cdot$ h $^{-1}$. Control bottles containing only seawater were incubated concurrently.

O:N atomic ratios were calculated by multiplying ratios of O $_2$ consumption to N-excretion by $1.428 \times 14/16$, where 1.428 is the density of O $_2$ at 1 atmosphere and 1°C, and the ratio $14/16$ corrects for differing atomic weights of O $_2$ and N $_2$.

Silicate, phosphate and nitrate concentrations for the stations sampled are reported elsewhere (Irwin *et al.*, 1980; Cruise report 78-026).

An index of petroleum hydrocarbon contamination of the water column, “%-hydrocarbon-anomalies” (Levy, 1979), was calculated from hydrocarbon concentration measurements made concurrently with our physiological measurements (Cruise report 78-026; Levy, 1979). The index represents the percentage of water samples per station from various depths with hydrocarbon concentrations greater than the established background level for Baffin Bay (mean 0.46 μ g \cdot l $^{-1}$, 99.9% confidence limits 0.41-0.52 μ g \cdot l $^{-1}$; Levy, 1979, 1981) as determined analytically (Levy, 1977, 1978, 1979).

All statistical analyses were performed using the Regress II statistical program (Human Systems Dynamics, Northridge LA, 91324).

RESULTS

Clearance rates were generally low for all stations (Table 1), with negligible to no clearance observed at six of the twelve stations occupied. Highest mean clearance rate was measured in Lancaster Sound (0.18 ml \cdot mg dry wt $^{-1} \cdot$ h $^{-1}$) at station 87. The stations with significant clearance rates, above 0.08 ml \cdot mg dry wt $^{-1} \cdot$ h $^{-1}$, were near Cape Raper in Davis Strait, Lancaster Sound and the North Water. Stations with zero to negligible clearance rates all were from the Scott Inlet/Buchan Gulf stations.

Oxygen consumption (Table 1) ranged from 0.31 to 0.91 μ l O $_2 \cdot$ mg dry wt $^{-1} \cdot$ h $^{-1}$. There were no obvious patterns of difference in respiration rate between stations. The same range of values was observed at the Scott Inlet-Buchan Gulf stations as at either Cape Raper or the northernmost stations.

TABLE 1. Feeding, respiration and ammonia excretion data for *Calanus hyperboreus* from Davis Strait-Baffin Bay, July-August 1978; data given are arithmetic means (\pm standard deviation)

| Station | Surface temperature ($^{\circ}$ C) | Feeding rate ¹ | Respiration rate ² | Ammonia excretion ³ | O:N atomic ratio | % HC anomaly |
|-----------------|-------------------------------------|---------------------------|-------------------------------|--------------------------------|------------------|--------------|
| 13 | 2.0 | .0878 (.0851) | .4916 (.4758) | .0526 (.0279) | 11.70 | + 80 |
| 28 ⁴ | 1.0 | .0000 (.0000) | .4755 (.1123) | .0708 (.0106) | 8.41 | + 56 |
| 33 | 1.0 | .0749 (.0999) | .5187 (.2264) | .0294 (.0043) | 22.07 | + 7 |
| 40 | 2.0 | .0000 (.0000) | .7906 (.0387) | .0494 (.0042) | 20.03 | + 45 |
| 45 | 1.0 | .0009 (.0012) | .3482 (.0583) | .0440 (.0217) | 9.90 | + 22 |
| 52 | 1.0 | .0000 (.0000) | .3847 (.1269) | .0277 (.0055) | 17.38 | + 47 |
| 60 | 1.0 | .0103 (.0178) | .3873 (.3573) | .0498 (.0167) | 9.73 | + 20 |
| 70 | 1.0 | .0290 (.0251) | .9067 (.1090) | .0260 (.0073) | 43.63 | + 36 |
| 83 | 1.0 | .0809 (.0244) | .3376 (.3383) | .0225 (.0069) | 18.09 | + 9 |
| 87 | 1.0 | .1801 (.1460) | .4804 (.0485) | .0626 (.0112) | 9.60 | + 29 |
| 91 | 1.0 | .1174 (.0550) | .3093 (.2688) | .0237 (.0070) | 16.33 | + 92 |
| 94 | 1.0 | .0018 (.0040) | .4133 (.1189) | .0480 (.0165) | 10.77 | no data |

¹ ml·mg dry wt⁻¹·h⁻¹

² μ l O₂·mg dry wt⁻¹·h⁻¹

³ μ g N·mg dry wt⁻¹·h⁻¹

⁴ Stations 28-70 constitute the Scott Inlet/Buchan Gulf oil seep region.

Ammonia excretion (Table 1) ranged from 0.023 to 0.070 μ g N·mg dry wt⁻¹·h⁻¹. There was no discernible difference in nitrogen excretion rates at stations from the Scott Inlet-Buchan Gulf area as compared with other stations in Baffin Bay. Mean values ranged between 0.026 and 0.07 μ g N·mg dry wt⁻¹·h⁻¹ for the former, and from 0.024 to 0.063 μ g N·mg dry wt⁻¹·h⁻¹ for the latter.

The calculated O:N ratios were quite variable. Most values were near or less than 20 (8.4 - 22.1). The single exception was station 70 near Pond Inlet, where an O:N ratio of 43.6 was obtained.

Regression analysis of the metabolic parameters measured showed no significant correlation between %-hydrocarbon-anomaly and either clearance, ammonia excretion or respiration when the data from all stations were used (Table 2). However, a highly significant negative correlation ($P < .01$) was found between clearance rate and %-hydrocarbon-anomaly in the data from the Scott Inlet-Buchan Gulf area. The best fit to the data was obtained using an exponential model, Clearance = $0.947 e^{(-0.253HC)}$ where HC is %-hydrocarbon-anomaly with coefficient of determination of 0.737 and coefficient of correlation of 0.850 (Fig. 2).

TABLE 2. Correlation between metabolism (dependent variable) in *C. hyperboreus* (clearance, respiration, NH₃-excretion) and excess hydrocarbon concentrations (independent variable) in Davis Strait and Baffin Bay, summer 1978

| Dependent variable | Coefficient of determination | F-value |
|--|------------------------------|---------|
| respiration (O ₂ consumption) | .05 | .264 |
| clearance, all stations | .018 | .163 |
| clearance, seep stations only | .737 | 14.005 |
| NH ₃ -excretion | .114 | .647 |
| O:N | .005 | .028 |

cient of determination of 0.737 and coefficient of correlation of 0.850 (Fig. 2).

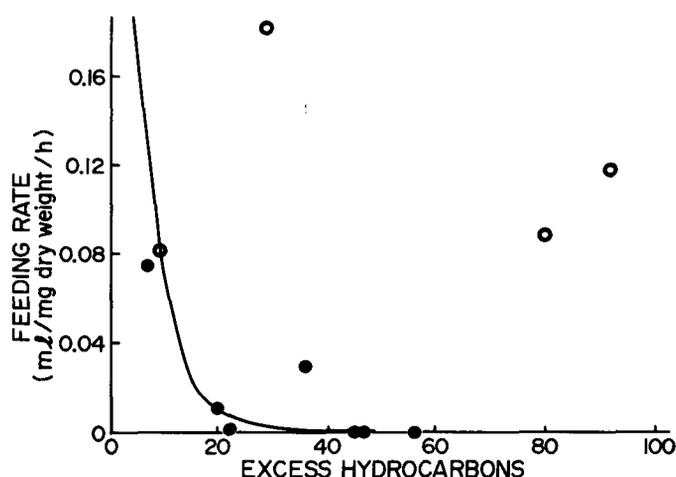


FIG. 2. Relationship between clearance rate for *C. hyperboreus* from Baffin Bay and petroleum hydrocarbon concentrations in the water column (%-hydrocarbon-anomalies). Curve is regression line for stations occupied in the seep zone (solid circles). Open circles denote stations outside of seep zone.

DISCUSSION

The observations detailed above are interesting for two reasons. They contribute to the very few measurements that have been made on a dominant arctic copepod for the months of August and September. But these data also suggest that feeding in this species may be suppressed by very low concentrations of petroleum hydrocarbons, less than 10 μ g·l⁻¹.

TABLE 3. Reported values for N-excretion, respiration and feeding rates for polar copepods

| | Season | Temperature | Rate* | Reference |
|--------------------------------|----------------|-------------|--|--------------|
| N-EXCRETION | | | | |
| Antarctic | | | | |
| Calanus tonsus | austral summer | 10 ± 2C | 4.6-6.1 µg-at·g wet wt ⁻¹ ·h ⁻¹ | (1,2) |
| Mixed copepods | Aug/Sept | -1 ± 2C | 0.8-1.8 µg-at·g wet wt ⁻¹ ·h ⁻¹ | (2) |
| Calanus spp. | Jan | | 0.1-0.11 µgN·mg dry wt ⁻¹ ·h ⁻¹ | (3) |
| Arctic | | | | |
| C. hyperboreus | Aug/Sept | 1C | 0.023-0.071 µgN·mg dry wt ⁻¹ ·h ⁻¹ | (this study) |
| C. hyperboreus | July/Aug | 0-1C | 0.4-1.8 µgN·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| C. hyperboreus | summer | 0-1C | 1.30 ± 0.67 µg-at N·mg dry wt ⁻¹ ·d ⁻¹ | (5) |
| C. finmarchicus & C. glacialis | summer | 0-1C | 1.11 ± 0.37 µg-at N·mg dry wt ⁻¹ ·d ⁻¹ | (5) |
| C. glacialis | July/Aug | 0-1C | 1.112 ± 0.386 µgN·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| Metridium longa | July/Aug | 0-1C | 0.618 ± 0.317 µgN·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| Metridia sp. | summer | 0-1C | 0.62 ± 0.35 µg-at N·mg dry wt ⁻¹ ·d ⁻¹ | (5) |
| OXYGEN CONSUMPTION | | | | |
| Antarctic | | | | |
| Rhincalanus gigas | austral winter | -1.8C | 0.110-0.140 µlO ₂ ·mg wet wt ⁻¹ ·h ⁻¹ | (6) |
| C. tonsus | austral summer | 10 + 2C | 0.430-1.080 µlO ₂ ·mg wet wt ⁻¹ ·h ⁻¹ | (2) |
| Mixed copepods | austral summer | | 0.120-0.240 µlO ₂ ·mg wet wt ⁻¹ ·h ⁻¹ | (2) |
| Eastern Arctic | | | | |
| C. hyperboreus | Aug/Sept | -1C | 0.309-1.877 µlO ₂ ·mg dry wt ⁻¹ ·h ⁻¹ | (this study) |
| C. hyperboreus | July/Aug | 0-1C | 5-30 µlO ₂ ·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| C. glacialis | July/Aug | 0-1C | 9-40 µlO ₂ ·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| M. longa | July/Aug | 0-1C | 15-35 µlO ₂ ·mg dry wt ⁻¹ ·d ⁻¹ | (4) |
| Boreal | | | | |
| copepods | Jun/Aug | 5-10C | 0.13-1.19 µlO ₂ ·mg wet wt ⁻¹ ·h ⁻¹ | (7) |
| C. hyperboreus | July/Aug | | 0.200-0.990 µlO ₂ ·mg dry wt ⁻¹ ·h ⁻¹ | (4) |
| C. hyperboreus | | | 5-20 µlO ₂ ·mg dry wt ⁻¹ ·d ⁻¹ | (8) |
| mixed copepods | Jan | -1C | 0.8-1.1 µlO ₂ ·mg dry wt ⁻¹ ·h ⁻¹ | (3) |
| O:N | | | | |
| Antarctic | | | | |
| Calanus | | -1 ± 2C | 11-20 | (2) |
| copepods | Jan | | 9.2-15.2 | (3) |
| calanoid copepods | Dec/Jan | | 15 ± 3 | (9) |
| Subantarctic | | | | |
| Calanus | | 10C | 8-16 | (2) |
| Eastern Arctic | | | | |
| C. hyperboreus | Aug/Sept | 1C | 8.41-43.63 | (this study) |
| C. hyperboreus | July/Aug | 0-1C | 13.4-36.9 | (4) |
| C. glacialis | July/Aug | 0-1C | 28.5 ± 16.6 | (4) |
| M. longa | July/Aug | 0-1C | 139.0 ± 134.0 | (4) |
| Boreal | | | | |
| C. hyperboreus | | | 16.4-34.6 | (9) |
| FEEDING/CLEARANCE RATE | | | | |
| C. hyperboreus (young stage) | Jul/Aug | | 23.56, 24.60 ml·mg dry wt ⁻¹ ·d ⁻¹ | (10,4) |
| C. glacialis (late stage) | Jul/Aug | | 52.12, 54.76 ml·mg dry wt ⁻¹ ·d ⁻¹ | (10,4) |
| C. hyperboreus (adult) | Aug/Sept | | 0-180 ml·mg dry wt ⁻¹ ·h ⁻¹ | (this study) |
| C. hyperboreus (C VI) | Apr/May | | 1-14 ml·copepod ⁻¹ ·h ⁻¹ | (11) |

(1) For conversion from wet weight to dry weight see Discussion.

(2) Biggs, 1982.

(3) Ikeda and Mitchell, 1982.

(4) Conover and Cota, 1985.

(5) Harrison *et al.*, 1985.(6) Rakusa-Suszczewski *et al.*, 1976.

(7) Ikeda, 1970.

(8) Conover and Corner, 1968.

(9) El-Sayed *et al.*, 1978.

(10) Determined from particle volume and by chlorophyll changes respectively.

(11) Huntley, 1981.

Rates of oxygen consumption observed for *C. hyperboreus* in this study are nearly identical with those observed by Conover (1968) for the same species in the Gulf of Maine (Table 3). They are also generally comparable with respiration rates obtained for a range of Antarctic copepods (Ikeda and Mitchell, 1982; Rakusa-Suszczewski *et al.*, 1976; Biggs, 1982) when the Antarctic data is converted to a dry weight basis (Table 1 in Rakusa-Suszczewski *et al.*, 1976). They are higher, however, than values obtained for adult female *C. hyperboreus* from a slightly higher latitude (northern Baffin Bay and Lancaster Sound, Conover and Cota, 1985).

Observed values for nitrogen excretion fall midway between those measured by Conover (1968) working with temperate species and those observed for Antarctic species (Ikeda and Mitchell, 1982; Biggs, 1982). Excretion values observed in this study are internally highly consistent, with low variability (see Table 1). They are also in the same range as excretion values obtained recently with *C. hyperboreus* from northern Baffin Bay (stage II to adult female, Conover and Cota, 1985; mixed stages, Harrison *et al.*, 1985).

The resultant O:N ratios, with the exception of an anomalously high value for station 70, group around a mean of 14.0 ± 4.7. This

value is in the same range as reported for Antarctic copepods (Ikeda and Hing Fay, 1981:Table 4) and is only slightly lower than reported for more northern Baffin Bay *C. hyperboreus* for July and August 1980 (Conover and Cota, 1985). These values suggest that for most of the stations reported here, *C. hyperboreus* in August to September had a largely protein-based metabolism (O:N < 20, Ikeda and Mitchell, 1982). The single exception is the high value for station 70, which is considered more characteristic of catabolism of lipids.

The clearance rates obtained here were about one-tenth of those obtained by Conover and Cota (1985) with *C. hyperboreus* in their July/August 1980 study. Because our determinations were made approximately one month later in the season, it may be that they reflect the annual decrease in feeding and reduction in metabolism that signals the seasonal descent to deeper, colder waters (Conover, 1968). However, it is also likely that these low clearance rates may result from our use of *D. tertiolecta* as food in our clearance rate experiments. Although unicellular phytoplankton form a normal part of the diet of these copepods and phytoplankton of the size of *D. tertiolecta* are abundant in these waters at this time, it is at the small end (5-10 μm) of the size spectrum for grazing by *C. hyperboreus* (Huntley, 1981). Conover and Cota (1985:Fig. 2) did observe ingestion by young stages of *C. hyperboreus* of smaller phytoplankton down to 6 μm at one of their stations (15), but we nonetheless recognize that feeding in our own experiments may not have been optimal.

Despite this potential shortcoming, we did measure clearance rates significantly greater than zero. More interestingly, because of its ecological implications, we observed a significant difference between clearance rates in animals sampled from the oil seep stations and in those from the other Baffin Bay stations that indicate a strong correlation between reduced clearance rates and the occurrence of anomalously high hydrocarbon concentrations in the waters along the east coast of Baffin Island. It is worthwhile noting, in this context, that these particular stations are not apparently different from the rest of Baffin Bay with respect to such characteristics as nutrient levels and water type (Coote and Jones, 1982; Harrison *et al.*, 1985).

Although the concentration of the presumed seep-derived petroleum hydrocarbons in these waters is not very high (< 1.25 $\mu\text{g}\cdot\text{l}^{-1}$), it is well above background levels for offshore Baffin Bay waters (0.46 $\mu\text{g}\cdot\text{l}^{-1}$). Also, all stations with such anomalously higher hydrocarbon concentrations were found to be clustered between Scott Inlet and Lancaster Sound (Levy, 1979, 1981). There is ample evidence from a number of experimental studies that concentrations of petroleum hydrocarbons as low as 10-90 $\mu\text{g}\cdot\text{l}^{-1}$ and under conditions of chronic exposure can affect the composition of planktonic communities (Lee and Takahashi, 1975; Elmgren and Frithsen, 1982; Giesy, 1980). Actual observations on natural zooplankton from oil spill sites are few, but Samain *et al.* (1981) have reported on unusual enzyme ratios (amylase:trypsin) in zooplankton populations from the English Channel in waters contaminated with 10-20 $\mu\text{g}\cdot\text{l}^{-1}$ hydrocarbons from the supertanker *Amoco Cadiz* (Marchand and Caprais, 1981). Also, reductions in clearance rate have been observed in a polluted bay in Greece (Ignatiades and Mimocos, 1977) and in meso-scale experimental studies (Elmgren *et al.*, 1980). This then raises the possibility that feeding by *C. hyperboreus* in the oil seep stations was depressed by the chronic presence of seep-derived hydrocarbons.

Details on the amount and composition of petroleum hydrocarbons in the water column in the seep area are still prelimi-

nary. Observations of surface oil films covering several km^2 have suggested that at times there was a considerable input of petroleum into the seep area (Levy and MacLean, 1981). Analytical results obtained to date indicate that the Scott Inlet-Buchan Gulf petroleum seepage constitutes a single large system extending to the vicinity of Lancaster Sound (Levy, 1981). In the areas of active seepage, concentrations of hydrocarbons in the surface microlayer were in the range from 3 to over 1700 $\mu\text{g}\cdot\text{l}^{-1}$, while concentrations within the water column were generally an order of magnitude lower, ranging from 0 to 87.5 $\mu\text{g}\cdot\text{l}^{-1}$ total extractable residues. While not remarkably high, all stations from seep areas contained water samples with anomalously high hydrocarbon concentrations. Little is known as yet of the composition of the water column hydrocarbons. Preliminary analyses of the surface microlayer, presumably representative of the source material, have indicated a broad spectrum of saturated hydrocarbons, with an unresolved envelope of saturated and aromatic hydrocarbons (MacLean *et al.*, 1981). Low molecular weight compounds, such as those observed in the unresolved envelope, are precisely those that can elicit the depression in clearance rate observed in *C. hyperboreus* in the seep area.

Regarding those stations outside of the oil seep areas that also contained high hydrocarbon contamination levels, one likely explanation is that those represent populations and sources of hydrocarbons different than found in the seep zone. The measurements on which the hydrocarbon contamination index, %hydrocarbon-anomaly, was based gives only quantitative information on hydrocarbon concentrations but contained no qualitative information on their relative composition. As has been suggested by Levy (1979, 1981), it is entirely likely that the hydrocarbons found throughout Baffin Bay originate from a number of different sources, including atmospheric, each with a different composition after weathering and with a different degree of toxicity. Therefore it is not at all surprising that some high %hydrocarbon-anomaly values were found outside the seep area that were not correlated with reduced clearance rates.

The ecological implication of partial or total inhibition of clearance by a dominant planktonic herbivore by petroleum hydrocarbons in seep areas is reduced secondary productivity. The data in Table 1 suggest that in the immediate area of the seep there may be a significant decrease in the amount of energy transferred from primary producers to the zooplankton. Thus, within the immediate seep area the amount of energy available to higher trophic levels may be largely dependent on the rate of advection of zooplankton. The significance of this reduction in secondary productivity will depend on the concentration of seep-derived hydrocarbons, the residence time of water in the seep area and the total area affected by the seep.

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