AN ABSTRACT OF THE THESIS OF

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A multidisciplinary western Beaufort Sea Ecological Cruise (WEBSEC) was conducted from August 15 to September 20, 1971. During the cruise, one hundred ninety-nine 0.1 m^2 Smith-McIntyre grabs samples were taken at forty stations located on the continental shelf and slope of the western Beaufort Sea. The Gammaridean Amphipoda and Cumacea collected were sorted and identified. Each sample was analyzed for the number of species and specimens within those groups. The data for all samples at each station were pooled to obtain station data; these were analyzed for abundance, diversity at each station, and similarity between stations.

Environmental parameters including sediment data, temperature, salinity and organic carbon content measured during the same cruise were also analyzed for each station.

The diversity indices chosen were the Simpson index (SDI) and the Shannon-Wiener index (H'_e). The results obtained show a relatively high diversity and animal density in the outer continental shelf, but low diversity values on the inner continental shelf and slope. The lowest SDI value obtained is 0.43 at 2572 m depth. The SDI values on the outer continental shelf are higher than 0.9 and compare well with values obtained in more temperate regions.

The similarity between stations is low, and the percentage of rare species found is high. This indicates a patchy distribution of the Amphipoda and Cumacea fauna.

The variability of the processes affecting the benthic environment of the western Beaufort Sea suggest that more intensive and seasonal studies are necessary in order to understand the seasonal as well as the annual variation of the infauna of the western Beaufort Sea.

Analysis of the Benthic Cumacea and Gammaridean Amphipoda from the Western Beaufort Sea

by

Jorge Gonzalo Castillo

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Associate Professor of Oceanography
In charge of major

Redacted for Privacy

Dean of School of Oceanography

Redacted for Privacy

Dean of Graduate School

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INTRODUCTION

Since quantitative studies of the benthic fauna began (Petersen, 1911), related research has been done mainly on the continental shelf. These environments are readily accessible, and large amounts of technical and financial support are not needed. As sampling techniques improved, benthic studies were progressively extended to deeper areas of the oceans, but only in recent years have they been extended to the more desolate regions such as the Arctic and Antarctic Oceans. Here, the financial and sometimes the technical support has been a limiting factor for this kind of research.

Due to these problems, studies of the benthic fauna in polar areas have been restricted to taxonomic and biogeographic studies based on collections taken by expeditions as rather scattered qualitative samples over large areas of the polar oceans. These areas, characterized by an environment rather different from the regions usually studied, maintain animal assemblages with characteristics inferred only from results obtained in other places of the world ocean. The study of these environments should yield valuable information to the understanding of ecological problems.

An extensive program of benthic sampling was performed by the benthic ecology group of Oregon State University during a multidisciplinary Western Beaufort Sea Ecological Cruise (WEBSEC) conducted from August 15 to September 20, 1971. The quantitative analysis of the benthic infauna of the western Beaufort Sea was the objective of the benthic research.

The study of the Gammaridean Amphipoda and Cumacean fauna collected there was the objective of this dissertation. The study includes the analysis of taxonomy, distribution, abundance and diversity of the fauna.

Literature Review

Serious studies of the bottom fauna of the sea were initiated with the Challenger Expedition in 1873-76. However, the invention of the quantitative sampler may be considered the starting point of quantitative studies of the benthic fauna. The reports of Petersen (1911, 1913, 1915, and 1918) in the Skagerrak and Kattegat are the first studies of this type. Petersen was able to determine the standing crop and density of the species found in different areas and to make comparisons between them. The assemblages found were described as statistical units defined as communities.

Subsequently, studies of this type have been undertaken on the continental shelves over the world; most of them deal with the description of distribution and abundance patterns of the benthic fauna. However, in recent decades the emphasis of research has been changed to the determination of the relative importance of various factors that regulate the differences between assemblages and condition their existence.

Petersen (1913), Ford (1923), Davis (1925), Sanders (1958), Rhoads and Young (1970) consider the substrate to be more important than hydrographic parameters in determining benthic assemblages. Davis (1925) also found a relationship between the relative abundance of suspension feeders and the texture of the sediments, and Wilson (1937, 1948 and 1952) has shown that several, perhaps all pelagic larvae critically examine the bottom substrate to which they are exposed. Thorson (1957b) pointed out the correlation between the proportion of deposit feeders and silt or clay content of the sediments. Sanders (1956) determined this quantitatively.

It seems that the ecological effect of the substrate is basically through its influence on the feeding type of the species present in the assemblages. This influence would be related to the organic matter content of the sediments and to the availability of food to the animals (Davis, 1925). Dissolved organic matter is not directly available to benthic organisms but it may be obtained by deposit feeders which get the portion of dissolved organic matter present in the sedimentary particles by sorption (Whitehouse, 1955; Bader and Jeffrey, 1958; Bader, Hood and Smith, 1960; Bader, Rae and Smith, 1960; and Smith and Bader, 1961).

Fine grained sediments contain a higher amount of organic matter than coarse grained deposits (Trask, 1955) because different mineral components of the bottom sediments have differential uptakes (absorption and adsorption) (Bader, Rae and Smith, 1960).

The type of sediments also limits the distribution of burrowing organisms depending on interstitial water circulation necessary for their vital activities.

Other authors have regarded hydrographic parameters as more important than substrate to benthic assemblages (Molander, 1928; Shelford *et al*. 1935). The former author took hydrographic conditions as a basis for his classification of benthic assemblages in the study of Gullmar Fjord in West Sweden. Jones (1950) suggests that abiotic factors such as temperature, salinity and nature of substrate significantly affect the structure of natural assemblages, but biotic factors like morphology and mode of life of certain species also seems to be important.

Thorson (1946) discussed the influence of temperature upon reproduction, and Hedgpeth (1957) and Hall (1964) generalized that temperature is the main factor influencing the distribution and reproduction of marine invertebrates. Thorson (1958) concludes that temperature in different latitudes is important in the composition of the benthic assemblages.

The influence of biological interactions has been emphasized by some authors. Paine (1966) pointed out the importance of predation in the rocky intertidal assemblages, and Thorson (1966) stressed the significance of competition for food and space after the settlement of the young individuals.

Polar Regions Background

The studies of the bottom fauna of the Arctic Ocean have been concentrated over some marginal areas. Zenkevitch (1963) summarizes a large number of benthic ecology studies done in the Soviet regions of the Arctic, showing that these are the areas most extensively known of the Arctic Ocean. Comparable extensive works have been only done in the waters surrounding Greenland (Sparck, 1933; Thorson, 1933 and 1934; Vibe 1939). The Canadian Archipelago has been also fairly well studied (Ellis, 1960).

The Beaufort Sea area is poorly known and the only benthic studies were done by McGinitie (1955) in nearshore waters off Point Barrow, and more recently by Wacasey (1974) at the Mackenzie Bay in the Eastern part of the Beaufort Sea and Carey et al (1974) in the western Beaufort Sea.

The Concept of Community

Since its first use in marine ecology by Petersen (1913), the concept of community has been interpreted and used in many different ways as can be seen in the excellent reviews published recently (Whittaker, 1962; Mills, 1968; McIntosh, 1967). Clements (1916), a plant ecologist, conceived a community as representing a supra-organism capable of having its own evolutionary history (Whittaker, 1967). A strongly opposite point of view was supported by Gleason (1926) and his followers. They suggest that communities are formed by species selected only by the physical conditions of the environment and forming a continuum along environmental gradients.

Between these two extreme points of view, there exists a broad range of interpretations of the concept of community and it seems impossible to give an exact definition that includes all different interpretations.

In this study, community is used in the broad sense postulated by Mills (1968), "a group of organisms occurring in a particular environment, presumably interacting with each other and with the environment, and separable by means of ecological survey from other groups."

Faunal Diversity

Diversity has been recognized as a conservative property of the community structure. The methodology used to measure it in any kind of natural assemblage has proved to be one of the most attractive and difficult topics in marine ecology.

The regularity found in the distribution of individuals per species has been noticed for many years. Some authors have attempted to adjust the observed distribution of animals per species living in natural assemblages to theoretical curves or models. Amongst them we have the logarithmic curve (Fisher, Corbert and Williams, 1943; Williams, 1964), the lognormal curve (Preston, 1948, 1962) and the broken stick model (MacArthur, 1957). Each investigator proposing a theoretical curve has also proposed, with more or less success, some parameter of his curve as a quantitative expression of the diversity of the underlying population. The difficulties in the use of these indices of diversity are that they depend directly on the degree of adjustment of the proposed theoretical distribution curve to the natural distribution of the organisms.

Besides the indices mentioned before, there are some which do not depend on an assumed distribution of individuals among species, such as the Simpson Diversity Index (Simpson, 1949) and the Shannon-Wiener Index (Shannon, 1948) which include a measure of the relative abundance of the species.

The concept of diversity itself is, at a single level, related to the species richness of a community in a certain area. However, the extreme importance of the relative abundance of the species in the understanding of the community structure and in comparing species diversity has been also pointed out (Simpson, 1949; Margalef, 1968).

Beside the indices which are sensitive to equability of abundance of species, some indices of equitability or evenness itself have been formulated (Lloyd and Ghelardi, 1964; Fager, 1972).

The Simpson Diversity Index and the Shannon-Wiener Index are those most widely used in benthic ecology. They are sensitive to species richness and species abundance, increasing in value either with the increase of number of species and/or with an increase of the equitability of the system.

Diversity Regulation

A great deal of effort has been expended in trying to determine the role played by biotic and abiotic parameters as controlling mechanisms of the variability of species diversity found in natural communities. Pianka (1966) presents an excellent review of the mechanisms proposed, grouping them according to their similarities although most of them are not mutually exclusive. Between the most relevant mechanisms suggested are competition

(Svardson, 1949; Dobzhansky, 1950; Williams, 1964), climatic stability (Klopfer, 1959; Fisher, 1960; Dunbar, 1960; Klopfer and MacArthur, 1961; Connell and Orias, 1964), time (Simpson, 1954), spatial heterogeneity (MacArthur and MacArthur, 1961; MacArthur, 1964; Simpson, 1964), productivity (Margalef, 1963; Connell and Orias, 1964) and predation (Paine, 1966; Dayton, 1971; Dayton and Hessler, 1971).

Although these theories emphasize one factor as the principal control, they assume that other factors are playing secondary roles making their separation difficult.

Despite the complexity of the mechanisms contributing to the diversity of natural communities, an important step has been made with the development of the time-stability hypothesis which includes many of the present ideas (Sanders, 1968). According to this hypothesis, the natural communities exist between two theoretical limiting types: a physically controlled community and a biologically accommodated community. In the former, species adaptations are principally to a physical environment characterized by long term variations of high amplitude. They are characterized by a low diversity. The biologically accommodated communities are present only in environments with long term variations of low amplitude (rather constant environments). They are communities of high diversity due to minimization of the physical and biological stresses and a maximizing of biological interactions.

Description of the Area

Physiography

The Beaufort Sea is a marginal Sea of the Arctic Ocean lying, as a southern extension of the Canadian Basin, between the Chukchi Sea and the Canadian Archipelago. The western Beaufort Sea, between 143°W and 152°W, was selected for a benthic study and includes the continental shelf, upper slope and lower slope down to 2600 m.

The continental shelf is relatively shallow with a mean depth of about 64 m and a mean width of 63 km, being narrower than the eastern part of the Beaufort Sea continental shelf (Carsola, 1954b; Carsola et al., 1961). The self break is well defined and the slope, featureless with the exception of a canyon off Point Barrow (Carsola, 1954b; Carsola et al., 1961). The continental slope shows the classical steep upper portion and a more gentle lower slope descending to the floor of the Canadian Basin.

The sediments present in the area are poorly sorted muds or sandy muds (Carsola, 1954a; Naidu, 1974). Gravels are found mainly on the outer shelf and sporadically on the upper slope (Naidu,

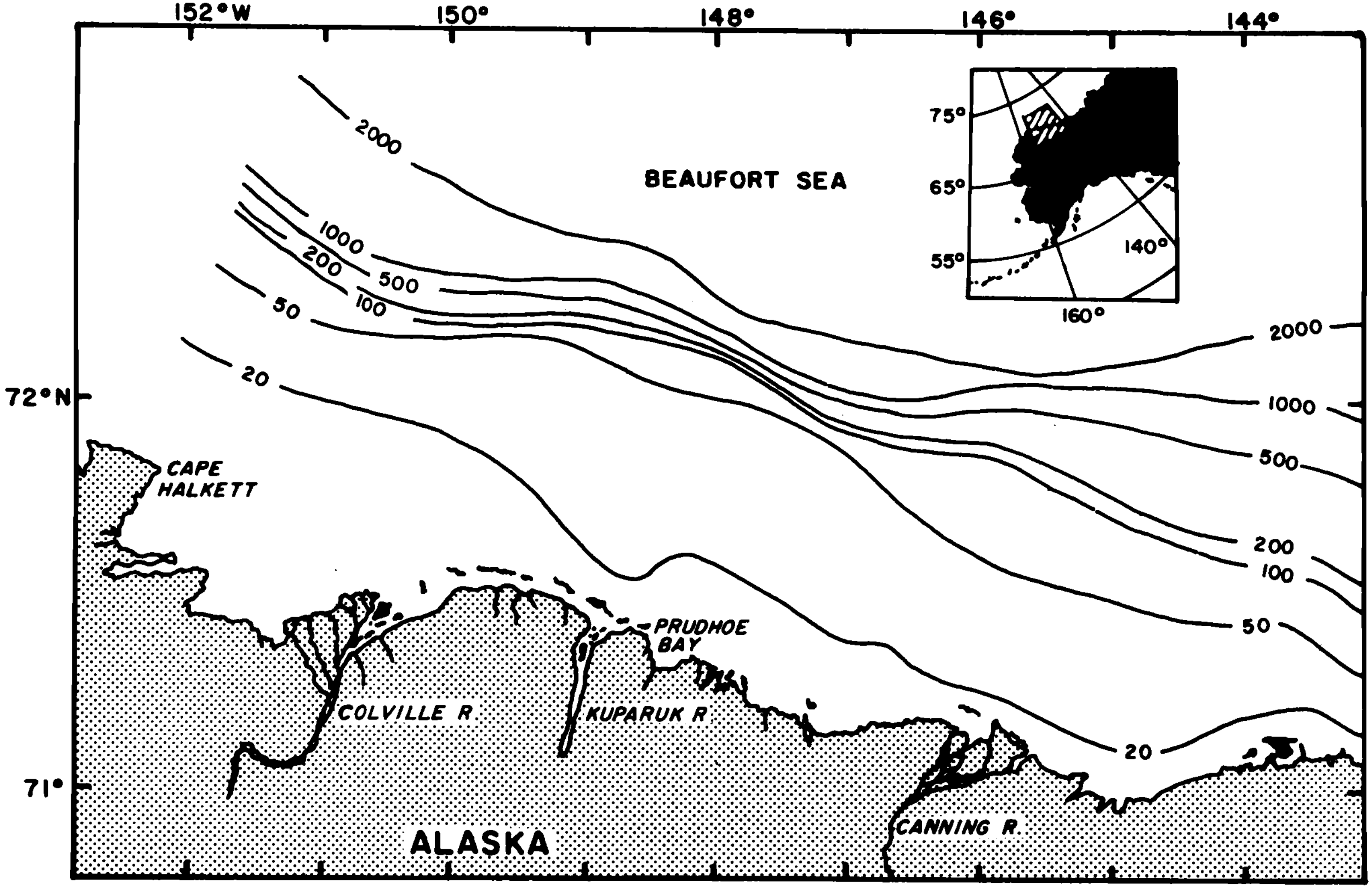


Figure 1. Area of study and bathymetry. Depth contours in meters.

1974); the reasons for their presence are not clear. It could be caused by modern ice rafted materials (Barnes and Remnitz, 1974), a relict deposit or a mixture of both (Naidu, 1974).

In general, the sediments are highly oxidized and with low organic carbon content (Carsola, 1954a; Naidu and Mowat, 1974). The clay minerals appear with a high amount of illite and a significant amount of chlorite and kaolinite (Naidu, 1974).

Five rivers discharging into the Western Beaufort Sea supply most of the terrigenous detritus. The five rivers total about 50% of the 813 $km^3 yr^{-1}$ total runoff of the Beaufort Sea (Antonov, 1958).

A net westward transport of sediments along the inner continental shelf has been suggested (Barnes and Remnitz, 1974) in accordance with the net water transport observed (Wiseman et al., 1973). A less significant eastward transport by occasional easterly currents has been also postulated (Naidu and Mowat, 1974).

Other processes influencing the sediments in this area are the wave regime and the ice gouging (Barnes and Remnitz, 1974). The former one is effective inside the 6 m contour, thus concealing the ice gouging action. Deeper than six meters the ice gouging becomes more significant although ice gouges deeper than 30 m have been considered relict (Kovacs, 1972). The density of ice gouges is as great as one hundred per km with a depth of up to five meters (Remnitz and Barnes, 1974). The action of the ice certainly contributes to the homogenization of the sediments (Barnes and Remnitz, 1974).

Water Masses and Circulation

From the oceanographic point of view, the Beaufort Sea has been considered an integral part of the Arctic Ocean (Coachman, 1963; Coachman and Barnes, 1961). Three water masses have been defined in the Arctic Ocean, all of them showing their effects over the area of study.

The arctic water mass is found from surface down to 150-200 m depth. In general, this water is characterized by low temperature (near freezing point and low salinity (up to 33.5%) in the first 50 m. Although salinity has a broad range depending on the area considered, it increases sharply below 50 m to about 34.5% (Coachman and Barnes, 1961).

The Atlantic water mass was first recognized by Nansen (1902) and is found between 200 and 900 m depth. It is characterized by higher temperature, above $0^{\circ}C$, with a maximum between 250 m and 500 m depth; the salinity varies from 34.5% to 35% (Nansen, 1902, Coachman and Barnes, 1961).

The bottom water mass is found deeper than 900 m and is characterized by low temperature (below $0^{\circ}C$) and salinities about 34.93% to 35.99% (Coachman and Barnes, 1961).

The strong variability shown by the Arctic water mass is due to several modifying processes (Coachman and Aagard, 1974). Amongst these processes are:

a) Addition of fresh water from land represented in the western Beaufort Sea by the discharge of five rivers.

b) Inflow and mixing of waters coming from the Pacific Ocean.

In the area of study the effect of the Bering Sea-Chukchi Sea water flowing continually through the Bering Strait is important. This water, after joining the Beaufort Sea gyral system effectively separates the Arctic superficial water from the underlying Atlantic water mass (Coachman and Barnes, 1971). The temperature maximum found in the 75-100 m layer has been suggested to be attributable to the inflow of Bering Sea water (Coachman and Aagard, 1974).

Being part of the anticyclonic gyral system centered in the Canadian Basin, the circulation in the upper layer of Beaufort Sea is clockwise (Coachman and Barnes, 1961). It is also accepted that the underlying Atlantic water mass follows the same pattern of circulation (Worthington, 1953; Sverdrup, 1956; Coachman and Barnes, 1963).

MATERIALS AND METHODS

The area covered extends from Cape Halkett to Barter Island, Alaska with a depth range of 21 m to 2600 m. A total of one hundred ninety-nine 0.1 m^2 grabs were collected at forty stations distributed over the area. Twenty-one of these stations (106 grabs) were taken on the continental shelf and the remaining 19 (103 grabs) were on the continental slope (Figure 2).

It is clear that with greater number of samples per station we get a better coverage of the area; however, ship time usually set a limitation to the number of grabs that could be collected per station.

Five grabs per station were chosen as the minimum number to be collected. Previous studies suggest that a total area of 0.5 m^2 sampled gives an adequate representation of the fauna of the continental shelf (Longhurst, 1959 and 1964; Lie, 1968) although five replicates may be insufficient at deeper stations on the continental slope (Sanders _et al._, 1965).

In spite of the grab problems during the sampling, thirty-eight stations are represented by five samples covering a total area of 0.5 m^2, one station on the continental shelf is represented by six samples and one on the continental slope by three samples covering an area of 0.6 m^2 and 0.3 m^2, respectively.

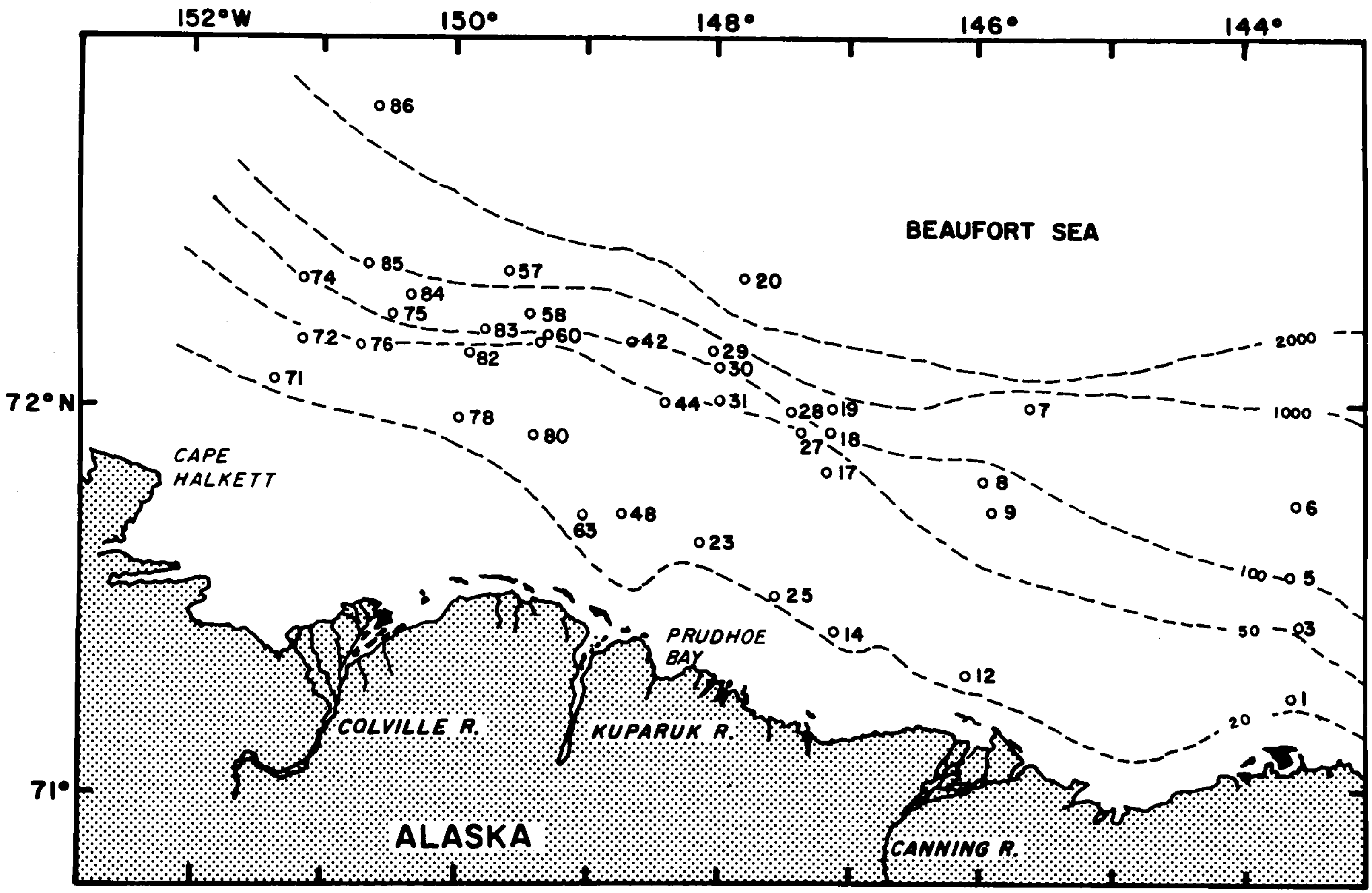


Figure 2. Locations of stations where benthic samples were collected in the western Beaufort Sea.

Sampling Gear Selection

Although many types of grabs have been invented and are being used in benthic ecology, the problem of an ideal sampler remains unsolved (Wigley, 1967; Gallardo, 1965; Holme and McIntyre, 1971). Good reviews about the samplers used currently for quantitative sampling of bottom fauna are available in recent literature (Thorson, 1957a; Hopkins, 1964; Holmes, 1964; Longhurst, 1964).

Since different grabs present different deficiencies, the selection of the appropriate grab to be used is of primary importance. Selection requires consideration of several characteristics inherent to the chosen grab, such as reliability, digging performance and efficiency of capture. However, external factors like hardness of substrate (Steven, 1930; McGinitie, 1939; Lee, 1944; Lie and Pamatmat, 1965), prevailing weather conditions (Smith and McIntyre, 1954; Lie, 1968), operator experience (Ursin, 1954; Lie and Pamatmat, 1965) and water depth have to be considered and carefully evaluated because they affect the grab performance. Sometimes these factors become limiting in benthic projects particularly those integrated into extensive oceanographic field programs.

For this study, the Smith-McIntyre 0.1 m^2 spring-loaded grab was selected (Carey *et al.*, 1974). This sampler has a good digging performance in soft and homogeneous sediments but not in hard ones (Lie, 1968). The bite pattern is not rectangular and changes with variations of bottom hardness, therefore estimates of depth penetration based on the volume are difficult to interpret (Gallardo, 1965). However, the Smith-McIntyre grab has considerable advantages for working in rough weather conditions (Smith and McIntyre, 1954; Lie, 1968) and in offshore waters (Lie, 1968). Due to its special closing mechanism it shows less pre-tripping compared with the Van Veen or Petersen grabs (Gallardo, 1965), and the variation between replicates samples is smaller than in the Van Veen grab (Lie, 1968). The effects of the shock-wave associated with all types of grabs in use, has been demonstrated to be less important in this grab than in the other types (Wigley, 1967).

The grab was selected because of the rough weather conditions prevailing in the Beaufort Sea, the large variation in the sampling depth (20 to 2600 m), poor knowledge of the substrate to be found in the area and the ship time limitations inherent to the multi-disciplinary nature of the cruise.

Sampling Process

After the sample was brought on board, its volume was estimated by measuring the distance between the top of the bucket to the surface of the sediment. After these measurements were converted to volume, it was substracted from the full volume of the bucket. The sample volume is a function of the grab digging depth which in turn depends on the type of grab and the hardness of the substrate (Ursin, 1954; Lie and Pamatmat, 1965).

Although the penetration of the Smith-McIntyre grab is highly variable and a valid estimation is difficult to obtain (Gallardo, 1965), the volumes calculated provide a rough means of weighing the grab performance.

During the cruise the samples were washed by flotation techniques through a 0.42 mm mesh size sieve, reducing them to a manageable size and concentrating the fauna. After washing, the remaining sample was preserved in 10% formalin neutralized with borax to prevent damage of the fauna caused by the acidification of the formalin with time. In 1973, the samples were transferred to buffered 70% ethyl alcohol.

Laboratory Process

In the laboratory each sample was washed through a set of 0.42 mm and 1.0 mm mesh size sieves to separate out the meio-faunal and macrofaunal components of the sample.

The macrofauna was picked from the non-living part of the sample under a dissecting microscope. The animals were immediately sorted into major taxonomic groups and preserved in 70% ethanol. The macrofaunal Gammaridean Amphipoda and Cumacea groups present in the collection were then separated into species and counted; new species are not described; they were saved for later description.

As mentioned before, the infauna of the Western Beaufort Sea is poorly known, therefore the problems involved in the identification of the groups selected are large. However, the identification was made possible by taxonomic works by several specialists and based on material from several places of the Arctic, North-Atlantic and North-Pacific Oceans.

The identification of the Gammaridean Amphipoda was based on works of Barnard (1958, 1960a, 1960b, 1961, 1962a, 1962b, 1962c, 1962d and 1969); Barnard and Given (1960); Gurjanova (1951); Sars (1895); Shoemaker (1955) and Stephensen (1923, 1925, 1931 and 1944). The principal works used in the identification of Cumacea were those of Calman (1911 and 1912); Given (1961); Hansen (1920); Hart (1930); Lomakina (1958); Sars (1900); Stebbing (1913) and Zimmer (1926).

The salinity and temperature data used were collected by the U.S. Coast Guard Oceanographic Unit. Although these data were taken at the same location as the benthic samples, the deepest measurement obtained at each station comes from about 10 m over the bottom.

Considering the small salinity and temperature variation with depth we may expect a reasonable approximation to the true salinity and temperature distribution using these data; except at about 50 m depth where the thermocline and halocline are found.

The sediment data were kindly provided by Dr. P. W. Barnes and Dr. E. Remnitz, U. S. Geological Survey. The data were taken at the same location as the benthic samples and usually at the same depth.

Data Analysis

The data were analyzed with the Oregon State Open Shop Operating System (OS3) using the computer of the Oregon State University Computer Center (CDC 3300). The programs used in the analysis were the *AIDN developed by Overton (unpublished data) for species diversity and the Benthic-3 being developed by Carney (unpublished data) for the general station analysis.

The data from samples gathered at each station (3-6, usually five samples) were pooled, although this method eliminates the analysis of within-station variation. The samples at each station were collected from a vessel with an assumed fixed position. However, the vessel position data shows, in some stations, a drifting of more than two miles and/or sampling depth variation as great as 50%. The U.S. icebreaker had to drift with the pack ice rather than maintain a fixed position. Because of the lack of a precise, fixed station position and, therefore, a clear definition of the population sampled, comparisons between the "replicate" samples appear to be meaningless.

Two diversity indices were computed by the use of the *AIDN program. The Simpson Diversity Index (SDI) and the Shannon-wiener Index (H') derived from the information theory (Shannon, 1948). Both indices include a measure of the proportion of the species represented in the sample. These analyses are sensitive to species richness (number of species represented) and equitability (distribution of individuals per species).

The Simpson Diversity Index measures the probability that two individuals sampled at random and independently from the same population, do not belong to the same species (Simpson, 1949). The SDI is a estimator of $1 - \lambda$, where λ is defined by Simpson (1949) as a parameter of the entire population and given by:

$$\lambda = \sum_{j=1}^{z} \pi_j^2 \qquad (1)$$

where:

π_j = proportion of species j in the entire population.

z = number of species in the entire population.

The value of π_j is unknown because the total population cannot be completely censused, and the λ value can only be estimated.

Simpson (1949) gives the statistic $\hat{\ell}$ as an unbiased estimator of the parameter λ, defining it as:

$$\hat{\ell} = \frac{\sum_{i=1}^{s} n_i (n_i - 1)}{N (N-1)} \qquad (2)$$

where:

n_i = individuals of species i present in the sample

N = total number of individuals of the sample

s = number of species present in the sample.

The estimator calculated by *AIDN program is Sd^2 defined as:

$$Sd^2 = \sum_{i=1}^{s} p_i^2 \qquad (3)$$

where:

p_i = proportion of species i in the sample

Sd^2 is a biased estimator λ but when N is large, the bias decreases rapidly and Sd^2 becomes a reasonable estimator of the diversity of λ (Stander, 1970). SDI then becomes an estimator of the diversity of the population and theoretically ranges from zero to one.

The second diversity index calculated for all stations was the Shannon-Wiener Index.. This is a measure of the uncertainty in predicting the species to which a given individual selected at random form the population studied will belong.

The true population diversity index (H) can be measured only if the population is indefinitely large. When dealing with finite populations (as a sample) we can obtain only an estimate (H_e') of the true parameter value, defined as:

$$H_e' = \frac{1}{N} \ell n \left(\frac{N!}{N_1!N_2!.....N_s!}\right) \qquad (4)$$

where:

N = number of individuals of the finite population

s = number of species of the finite population

If N is very large H' becomes:

$$H_e' = \sum_{i=1}^{s} p_i \ln p_i \qquad (5)$$

where p_i proportion of the i species in the sample.

The index was also obtained with a base 2 logarithm (H_2') but the analysis was performed only for H_e'.

Similarity

In order to measure the similarity between stations, a similarity Index (SIMI) was calculated. SIMI is defined (Stander, 1970) as:

$$\text{SIMI} = \frac{\text{SIM}_{12}}{\text{Sd}^2 1\ \text{Sd}^2 2} \qquad (6)$$

where:

SIM = similarity between 2 given collections

Sd^2 = estimator of λ as given in equation (3).

SIM is given by:

$$\text{SIM}_{12} = \sum_{i=1}^{s} p_{1i}\ p_{2i} \qquad (7)$$

where:

p_{1i} = proportion of species i in the collection 1

p_{2i} = proportion of species i in the collection 2

The factor $Sd_1^2\ Sd_2^2$ is a scaling factor given to SIMI a range from 0 - 1. When the samples or collections compared are identical, SIMI is maximum reaching the value 1.

RESULTS

Benthic Environmental Features

The benthic environment shows the influence of three water masses present in the western Beaufort Sea and the effects of the modifying processes characteristic of this region. The continental shelf and the upper continental slope are characterized by the Arctic superficial waters with temperatures below 0°C. Stations 27 and 31 located off Prudhoe Bay at about 50 m depth, and stations 71, 78 and 80 located in the Western part of the area studied at about 30 m depth are exceptions. Temperatures on the continental slope are below 0°C except at stations located between 500 and 600 m depth where the temperatures show a clear peak over 0°C probably corresponding to the Atlantic water mass.

The salinity distribution (Figure 3) shows clearly the effect of the fresh water due to river discharge and ice melting. Most of the continental shelf has salinities below 32 ‰; only in the western part are salinities found close to 33 ‰. Salinity increases with depth down the continental slope reaching values close to 35 ‰. The highest salinity was found at station 19 at 365 m depth.

As was expected, the sediments of the area studied are dominated by mud and sandy mud type of sediments (Figure 4). The

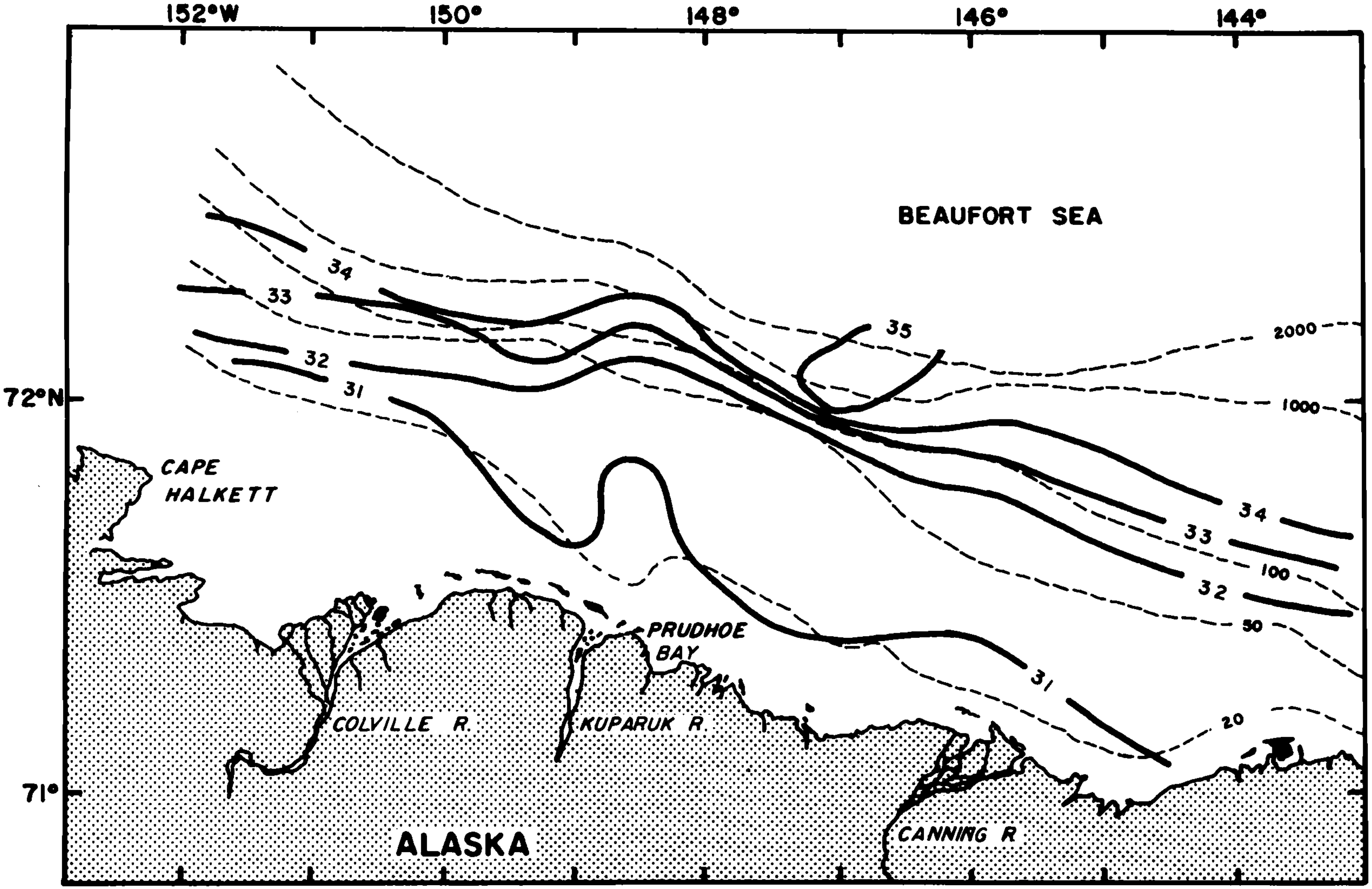


Figure 3. General salinity distribution at the sea bottom in the western Beaufort Sea.

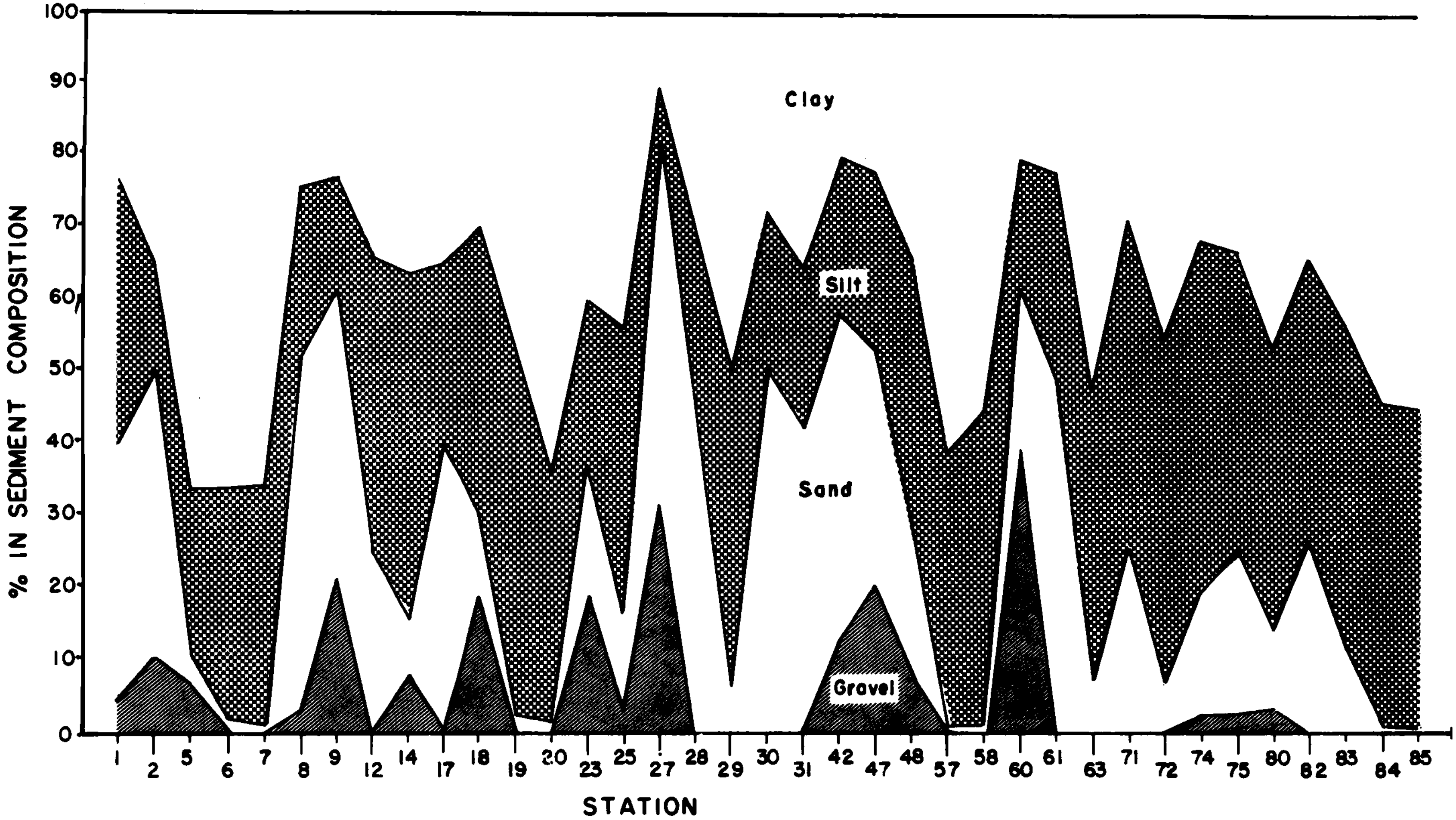


Figure 4. Sediment particle distribution by station in the western Beaufort Sea.

nomenclature used in the description of the sediments is that developed by Shepard (1954) and based on the proportions of sand, silt and clay as represented on a triangular diagram. Since gravel is not included in the system used, the stations where gravel was the dominant sediment fraction, were indicated in the diagram. The diagram includes all stations where sedimentary data were available (Figure 5). At most stations (26) the sediments were silty clay (13 stations) or sandy-silty clay (13 stations).

Silty clay sediments are located in a shallow area off the Colville River and Prudhoe Bay (Figure 6). Sandy-silty clay sediments are located on the outer continental shelf and upper slope. This sediment type is also present on the inner continental shelf off Barter Island. In the central part of the area studied, there is a narrow band containing sand or silty clay with more than 20% gravel. Silty clay is found again, deeper than the band of sandy-silty clay, except in small areas dominated by clayey silt.

Taxonomy

Any taxonomic work dealing with collections obtained in areas poorly studied involve many large problems. After completion of the taxonomic analysis of the Amphipoda and Cumacea, eight species appear as new. They remain identified only to the generic level; species descriptions will be undertaken later.

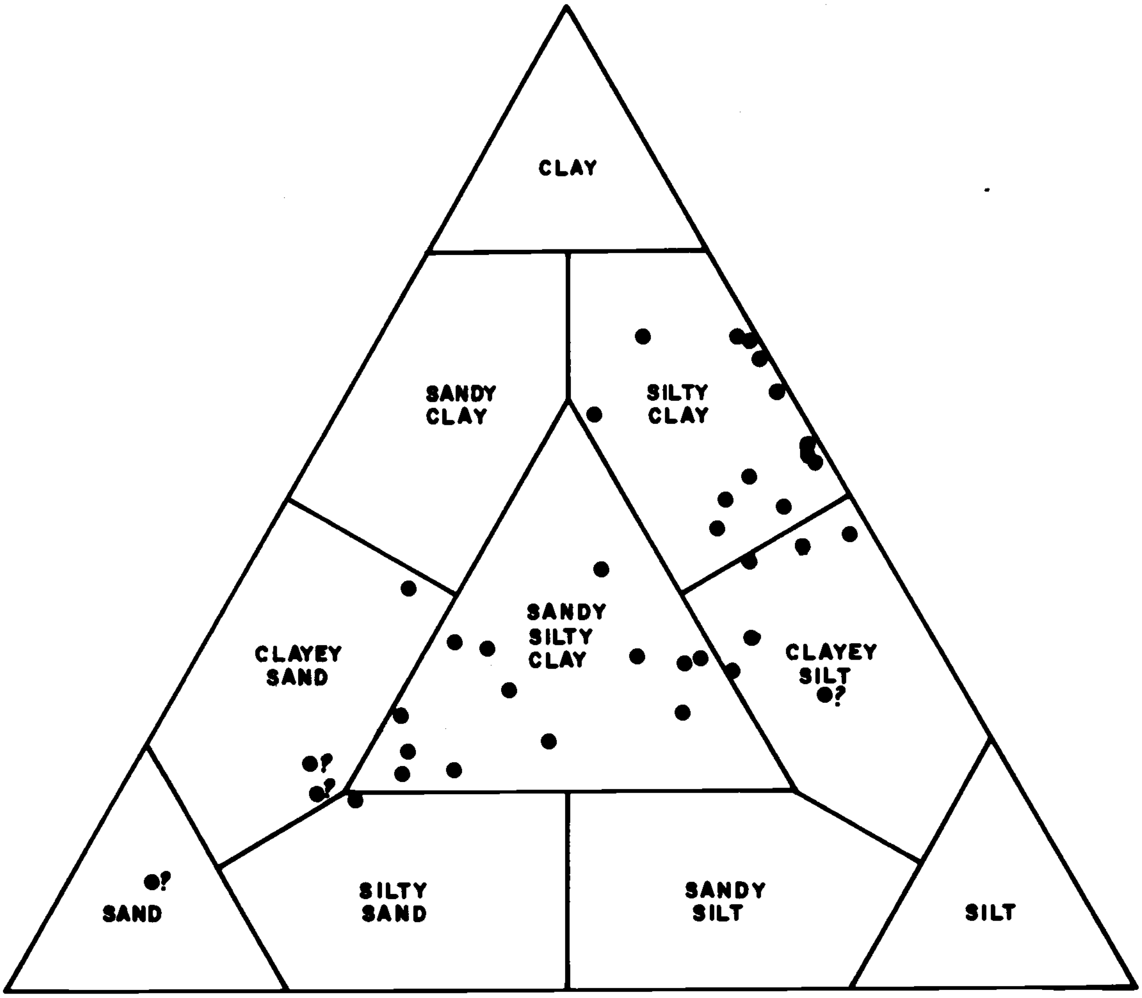


Figure 5. Triangle diagram showing the sand-silt-clay content at the WEBSEC-71 stations in the western Beaufort Sea.

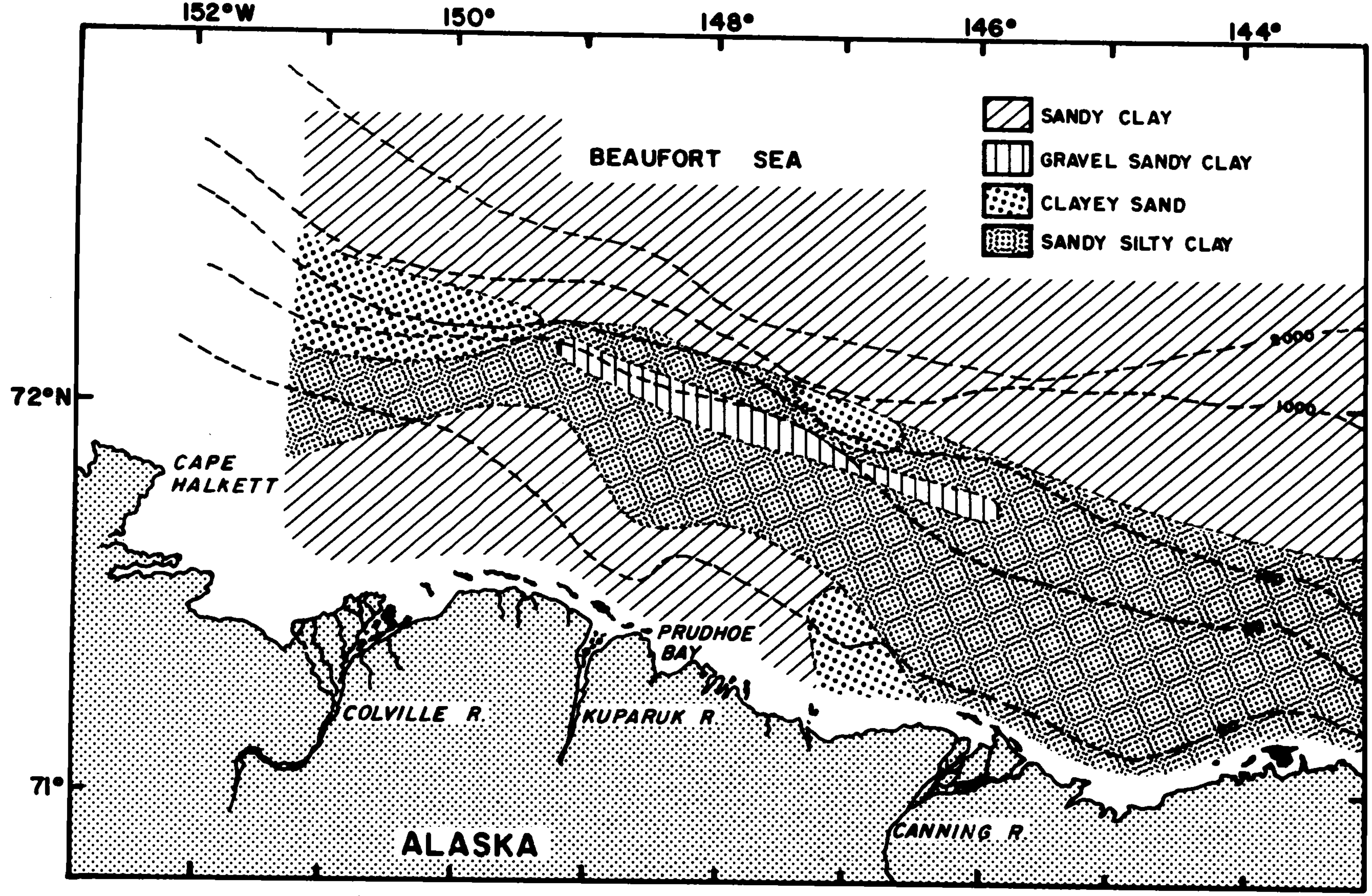


Figure 6. General sediment distribution in the western Beaufort Sea.

Ninety species of Gammaridean Amphipoda and thirty-eight species of Cumacea are represented in the collection (Table 1).

The species of Amphipoda are grouped into fifty-seven genera and twenty-two families. The families best represented are Lysianassidae with seventeen species, Oedicerotidae with thirteen species, Ampeliscidae with eleven species and Corophiidae with ten species. Only four new species were found, all of them belonging to the genus Byblis.

The species of Cumacea present in the collection belong to ten genera grouped into five families. Two families include 89.5% of all species. They are Diastylidae with eighteen species and Leuconidae with sixteen species. The four new species of Cumacea found belong to the genera Leptostylis (2 species) and Makrokylindrus (2 species).

Species Distribution

All species of Gammaridean Amphipoda have been sorted into nine groups according to their distribution with depth (Figure 7); the species found in each group and their distributional data are given in Table 2. Most of the species (Groups A - E representing 85.6%) are represented on the continental shelf and only 14.4% (Groups F - I) are species whose distribution begins deeper than 64 m, the depth of the continental shelf break.

Table 1. List of amphipod and cumacean species and code number.

Code number	Species name
1	Acanthonothozoma inflatum (Kroyer)
2	Acanthonothozoma serratum (Fabricius)
3	Odius carinatus (Bate)
4	Ampelisca birulai Bruggen
5	Ampelisca eschrichti Kroyer
6	Ampelisca macrocephala Lilljeborg
7	Byblis gaimardi (Kroyer)
8	Byblis sp A
9	Byblis sp B
10	Byblis sp C
11	Byblis sp D
12	Haploops laevis Hoeck
13	Haploops setosa Boeck
14	Haploops tubicola Lilljeborg
15	Lembos arcticus (Hansen)
16	Argissa hamatipes (Norman)
17	Atylus smitti (Goes)
18	Apherusa sarsi Shoemaker
19	Corophium acherusicum Costa
20	Ericthonius tolli Bruggen
21	Gammaropsis melanops G. Sars
22	Goesia depressa (Goes)
23	Neohela monstrosa (Boeck)
24	Photis reinhardi Kroyer
25	Podoceropsis lindahli Hansen
26	Protomedeia fasciata Kroyer

Table 1. Continued.

Code number	Species name
27	Protomedeia grandimana Bruggen
28	Unciola leucopis (Kroyer)
29	Guernea nordensjoldi (Hansen)
30	Rhachotropis aculeata (Lepechin)
31	Rozinante fragilis (Goes)
32	Maera danae (Stimpson)
33	Melita dentata (Kroyer)
34	Melita formosa Murdoch
35	Pontoporeia femorata Kroyer
36	Ischyrocerus commensalis Chevreux
37	Ischyrocerus latipes Kroyer
38	Liljeborgia fissicornis (M. Sars)
39	Acidostoma laticorne Sars
40	Anonyx debruynii Hoek
41	Anonyx nugax (Phipps)
42	Aristias tumida (Kroyer)
43	Centromedon pumilus (Lilljeborg)
44	Hippomedon abyssi Frost
45	Hippomedon holboli (Kroyer)
46	Onisimus affinis Hansen
47	Onisimus plautus (Kroyer)
48	Orchomene serrata (Broeck)
49	Orchomenella groenlandica Hansen
50	Orchomenella minuta (Kroyer)
51	Paronesimus barentsi Stebb
52	Tmetonyx cicada (Fabricius)
53	Tryphosella groenlandica Schell

Table 1. Continued.

Code number	Species name
54	*Tryphosella pusilla* G. Sars
55	*Tryphosella rusanovi* Gurjanova
56	*Acanthostepheia malmgreni* (Goes)
57	*Aceroides latipes* G. Sars
58	*Arrhis luthke* Gurjanova
59	*Arrhis phyllonyx* (M. Sars)
60	*Bathymedon obtusifrons* (Hansen)
61	*Monoculodes latimanus* (Goes)
62	*Monoculodes longirostris* (Goes)
63	*Monoculodes packardi* Boeck
64	*Monoculodes schneideri* (G. Sars)
65	*Monoculodes tuberculatus* Boeck
66	*Paroediceros lynceus* (M. Sars)
67	*Paroediceros propinquus* (Goes)
68	*Westwoodilla megalops* (G. Sars)
69	*Pardalisca cuspidata* Kroyer
70	*Pardalisca tenuipes* G. Sars
71	*Pardaliscella lavrovi* Gurjanova
72	*Pardaliscella malygini* Gurjanova
73	*Harpinia kobjakovae* Bulycheva
74	*Harpinia mucronata* G. Sars
75	*Harpinia serrata* G. Sars
76	*Paraphoxus oculatus* G. Sars
77	*Parapleustes assimilis* (G. Sars)
78	*Parapleustes gracilis* (Buchholz)
79	*Sympleustes karianus* Stappers
80	*Dulichia falcata* (Bate)

Table 1. Continued.

Code number	Species number
81	Dulichia spinosa Stephensen
82	Dulichia tuberculata Boeck
83	Paradulichia spinifera Gurjanova
84	Stegocephalus inflatus Kroyer
85	Metopa robusta G. Sars
86	Metopa spinicoxa Shoemaker
87	Metopella carinata (Hansen)
88	Metopella nasuta (Boeck)
89	Syrrhoe crenulata Goes
90	Tiron spiniferum (Stimpson)
101	Brachydiastylis nimia Hansen
102	Brachydiastylis resima (Kroyer)
103	Diastylis aspera Calman
104	Diastylis bidentata Calman
105	Diastylis edwardsi (Kroyer)
106	Diastylis glabra Zimmer
107	Diastylis goodsiri (Bell)
108	Diastylis nucella Calman
109	Diastylis oxyrhyncha Zimmer
110	Diastylis polita (S. I. Smith)
111	Diastylis rathkei (Kroyer)
112	Diastylis scorpioides (Lepechin)
113	Diastylis spinulosa Heller
114	Diastylis tumida (Lilljeborg)
115	Leptostylis sp A
116	Leptostylis sp B
117	Makrokylindrus sp A

Table 1. Continued.

Code number	Species number
118	Makrokylindrus sp B
119	Lamprops fasciata G. Sars
120	Eurorella arctica Hansen
121	Eudorella emarginata (Kroyer)
122	Eudorella gracilis G. Sars
123	Eudorella groenlandica Zimmer
124	Eudorella parvula Hansen
125	Eudorella pusilla G. Sars
126	Eudorella truncatula (Bate)
127	Eudorellopsis integra (S. I. Smith)
128	Leucon acutirostris G. Sars
129	Leucon fulvus G. Sars
130	Leucon laticauda Lomakina
131	Leucon nasica (Kroyer)
132	Leucon nasicoides Lilljeborg
133	Leucon nathorsti Ohlin
134	Leucon pallidus G. Sars
135	Leucon sp A
136	Campylaspis rubicunda (Lilljeborg)
137	Cumella carinata (Hansen)
138	Petalosarsia declivis (G. Sars)

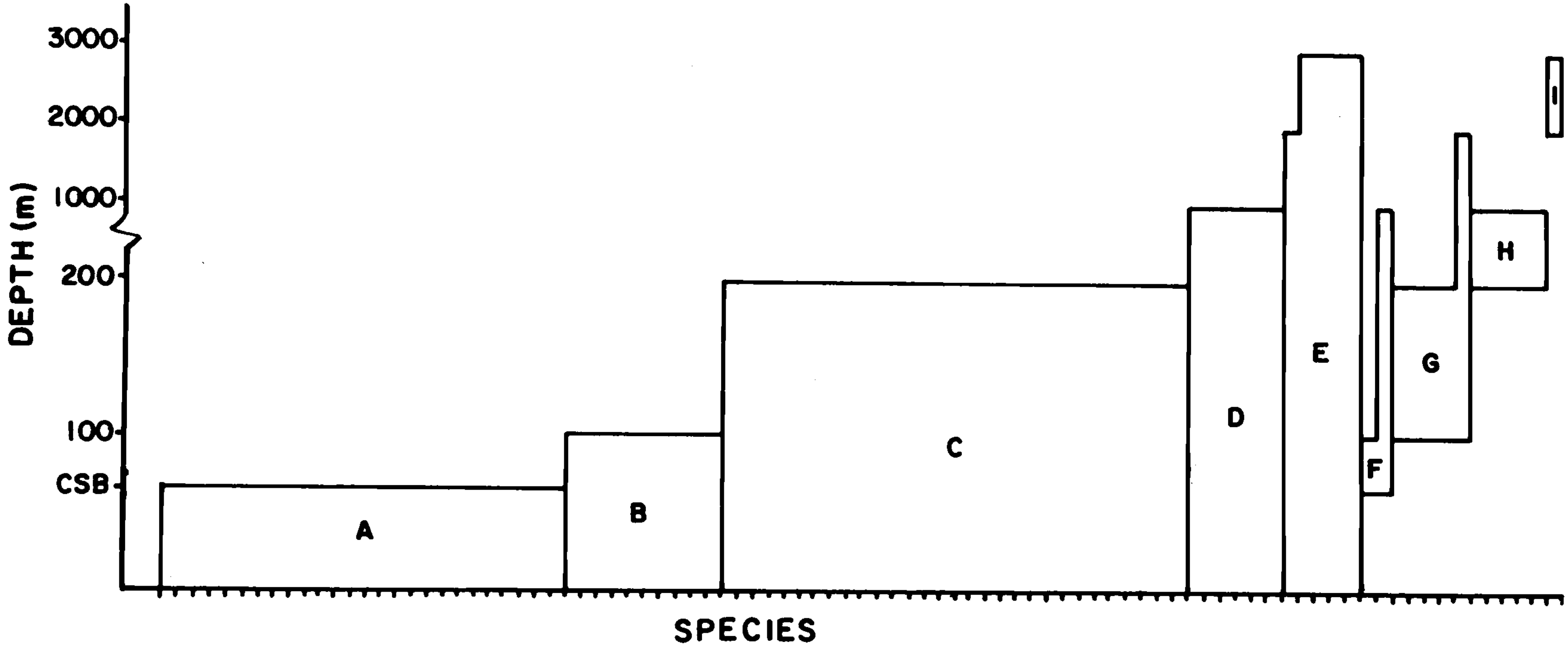


Figure 7. Bathymetric distribution of Amphipoda species in the western Beaufort Sea.

Table 2. Species depth distribution data.

Species Code	Minimum depth (m)	Maximum depth (m)	Range	Total # specimens
Group A		Amphipoda		
3	47	...	...	1
4	33	52	19	48
6	45	47	2	2
9	27	50	23	19
10	47	...	...	3
17	48	...	...	1
18	30	...	...	2
19	26	48	22	5
23	50	...	...	1
25	47	64	17	31
30	50	...	...	1
31	21	28	7	3
42	57	...	...	1
43	48	...	...	1
46	26	...	...	1
50	45	64	19	6
53	23	30	7	13
56	26	...	...	2
65	47	48	1	4
66	26	28	2	2
69	52	...	...	1
78	23	...	...	1
80	25	...	...	1
81	25	64	39	13
82	27	...	...	1
87	64	...	...	2
Group B				
13	52	101	49	3
16	26	101	75	13
20	47	106	59	46
22	26	103	77	40
27	25	101	76	52
32	46	106	60	44
36	25	83	58	46
47	26	103	77	31
62	47	99	52	7
67	25	83	58	14

Table 2. Continued.

Species Code	Minimum depth (m)	Maximum depth (m)	Range	Total # specimens
Group C				
1	45	202	157	2
5	44	136	92	64
7	21	136	115	117
8	33	136	103	34
12	23	136	113	325
15	33	130	97	70
21	30	130	100	39
24	44	136	92	118
26	25	142	117	174
28	44	136	92	191
29	46	136	90	48
33	47	130	83	46
34	30	142	112	44
37	25	142	117	69
51	26	202	176	8
60	33	136	103	30
61	44	136	92	7
64	28	130	102	7
68	25	142	117	62
70	52	136	84	15
76	44	136	92	145
77	45	142	97	5
79	45	136	91	6
83	30	136	106	19
84	44	130	86	5
85	33	136	103	10
86	25	130	105	18
88	46	130	84	13
89	46	130	84	7
90	64	130	66	14
Group D				
11	33	700	667	158
14	25	495	470	149
40	47	700	653	10
41	30	700	670	48
71	44	876	832	67
73	23	876	853	229

Table 2. Continued.

Species Code	Minimum depth (m)	Maximum depth (m)	Range	Total # specimens
Group E				
57	26	2297	2271	73
59	26	1866	1840	29
63	46	2297	2251	7
74	64	2572	2508	16
75	45	2572	2527	242
Group F				
45	83	876	793	3
52	83	...	...	1
Group G				
2	136	...	...	1
35	142	1866	1724	6
38	103	...	...	1
44	101	136	35	14
49	142	...	...	1
Group H				
39	463	...	...	1
48	689	...	...	1
55	631	689	58	5
58	202	700	498	2
72	495	...	...	4
Group I				
54	2297	...	...	14
Group AC		Cumacea		
103	33	57	24	6
104	44	...	...	1
108	21	...	...	1
109	21	52	31	31
110	23	...	...	1
117	57	...	...	1
119	23	...	...	1
126	47	...	...	1
134	33	52	19	3

Table 2. Continued.

Species Code	Minimum depth (m)	Maximum depth (m)	Range	Total # specimens
Group BC				
105	21	106	85	74
123	30	101	71	9
130	46	103	57	9
Group CC				
107	33	130	97	51
112	26	130	104	36
113	46	142	96	16
114	44	202	58	2
115	47	136	89	2
132	33	136	103	36
137	46	142	96	91
138	46	130	84	6
Group DC				
101	33	876	843	116
102	47	700	653	67
111	21	876	855	51
116	44	700	656	9
127	47	876	829	9
129	47	463	416	10
131	44	354	310	53
133	48	463	415	12
Group EC				
106	21	1866	1845	9
121	23	2297	2274	60
122	52	1866	1814	6
125	47	1866	1819	12
128	26	1866	1840	65
Group FC				
118	103	...	...	1
120	101	700	599	5
124	106	2297	2191	17
135	101	136	35	8
136	101	136	35	8

In former groups, 26 (28.9%) species have a restricted distribution being represented only on the continental shelf; 10 species (11.1%) reach the 100 m contour and 30 (33.3%) species reach the 200 m contour. The remaining eleven species, have a broader distribution and four of them, Aceroides latipes, Monoculodes packardi, Harpinia mucronata and Harpinia serrata have been found represented in samples ranging from the continental shelf to 2600 m, the maximum depth sampled during the benthic program.

Among the species found only on the continental slope, there are two species (Group F) whose distribution starts just at the continental shelf break; five species (Group G) are only distributed deeper than 100 m; five (Group H) are represented at stations located between 200 m and 1000 m depth; and one species, Tryphosella pusilla found only in one station at 2297 m depth. This is the only species found during this study to be restricted to abyssal depth in the western Beaufort Sea.

The species distribution of Cumacea show the same distributional pattern as the Amphipoda (Figure 8 and Table 2). In a similar way, they are separated into six groups according to their depth distribution. From a total of 38 species collected in the western Beaufort Sea, 86.8% (Groups AC-EC) are represented on the continental shelf, and the remaining 13.2% (Group FC) are species distributed exclusively on the continental slope.

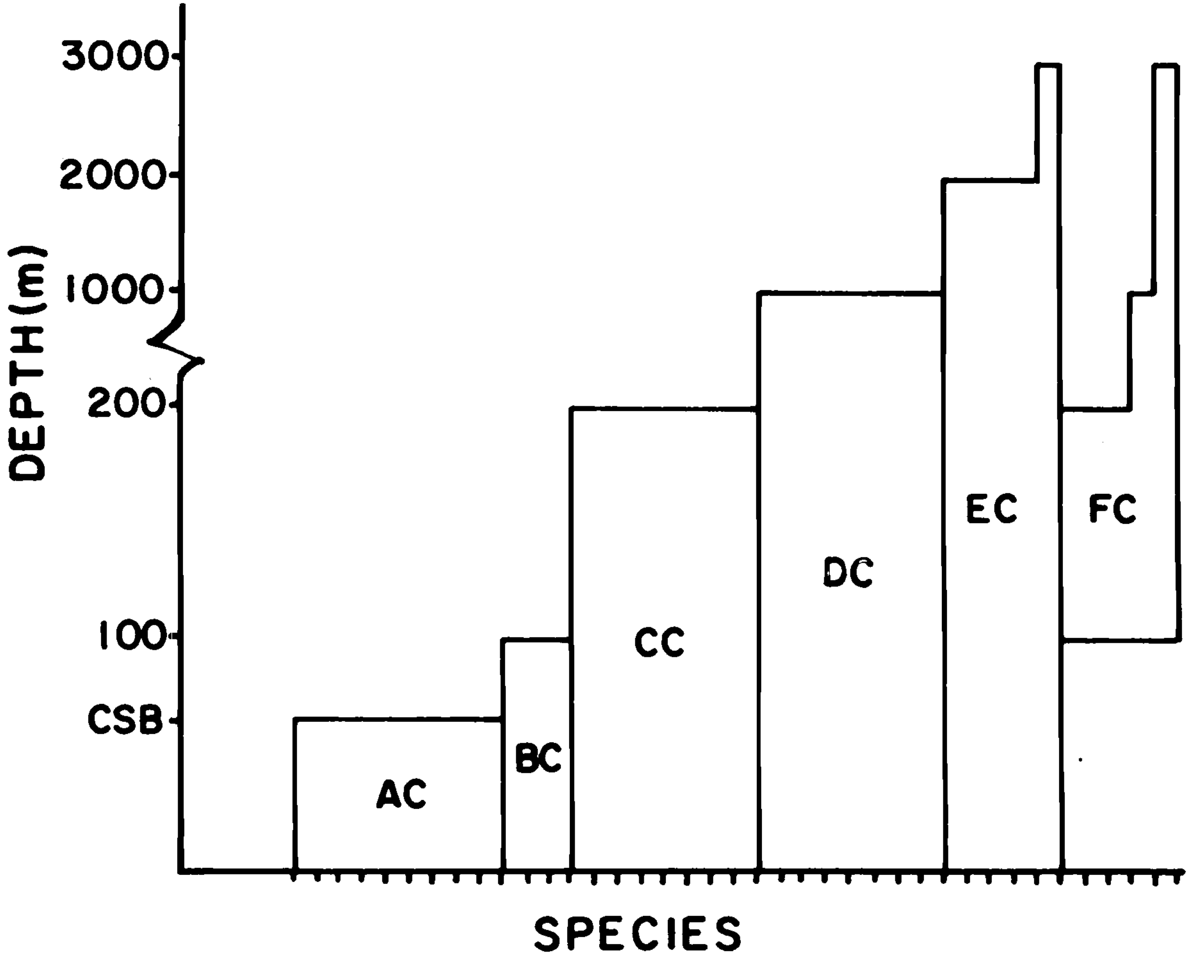


Figure 8. Bathymetric distribution of species of Cumacea in the western Beaufort Sea.

Among the species on the continental shelf, there are 9 species (23.7%) whose distribution is restricted only to the continental shelf; three species (7.9%) distributed inside the 100 m contour and 8 species (21%) inside the 200 m contour. The remaining groups (DC and EC) are composed of species with a broader depth distribution. Eight species (21%) reach down to nearly 1000 m depth, and five (13.2%) range from the shelf to more than 2000 m depth.

The last group (FC) includes five species whose distribution is restricted to the continental slope. Makrokylindrus sp A, Leucon sp A, and Campylaspis rubicunda (Lilljeborg) are distributed between 100 and 200 m depth; Eudorella arctica Hansen was found between 100 m and 700 m depth and Eudorella parvula Hansen was collected at stations located between 100 m and 2300 m depth.

The distribution of Amphipoda and Cumacea, show that a high percentage of the total number of species are represented on the continental shelf, although, in the western Beaufort Sea, this is limited to about 64 m depth. Most of the species are distributed on both the continental shelf and the continental slope. Only 34 species out of 128 were found to be restricted exclusively to the continental shelf.

The frequency of occurrence of each species (Table 2) shows that a high percentage of the species restricted to shallow waters are represented only in one sample. This fact would indicate a very patchy distribution of the species on the continental shelf. This could be expected in an area strongly affected by ice scouring as has been demonstrated to be the case in the western Beaufort Sea (Remnitz and Barnes, 1974). Since only 40 stations were sampled in the area, it may be expected that the picture obtained for Amphipoda and Cumacea distribution is incomplete and that only a more extensive sampling of the area will give true insights into the species distributional patterns of this fauna in the western Beaufort Sea.

Abundance

There is a low density of animals at most of the stations. Only 13 stations have more than 200 individuals per square meter, nine of them located in the outer continental shelf. The highest density is found at stations 3 and 44 with more than 650 individuals per m^2.

Abundance at each station, given as number of animals per unit area (m^2), was calculated by pooling the samples taken at each station and dividing the number of animals found by the area samples.

Half of the species are represented by less than ten individuals. In this group are included 21 out of 38 species of Cumacea (53.3%)

and 43 out of 90 species of Amphipoda (47.8%). From the remaining 64 species (Table 3), 53 species (76.5%) are represented by less than 100 specimens and only 11 species (23.5%) were represented by more than 100 specimens.

The presence of so many rare species indicate a high variability in the fauna of Amphipoda and Cumacea that is typical of a patchy environment.

Similarity

Station to station variation was measured by the *AIDN statistical computer program (Overton, unpublished data). As this program can analyze a maximum of 32 stations per run, the area of study was divided in two subzones, each one including 20 stations. The East subzone encloses station 1 to 31 and in the West subzone are included the remaining stations (42-86).

In the East zone the similarity index on a station to station basis is low (Table 5). Stations pairs do not have a SIMI equal or higher than 0.7. Only fourteen out of 180 possible pairs of different stations, show a SIMI higher than 0.5, and 23 have zero similarity. The stations showing the higher similarity to each other were 5-14, 8-17, 8-19, 12-23 and 18-28 with SIMI values over 0.6.

In the West zone the SIMI values are higher than in the East zone (Table 5) indicating more similarity between stations. Eight

Table 3. Abundance data of the most important species of Amphipoda and Cumacea in the Western Beaufort Sea.

Species code	Animals per species	Maximum per sample	Minimum per sample	Range	Frequency of occurrence
Amphipoda					
4	48	12	1	11	13/199
5	64	19	1	18	30/199
7	117	20	1	19	37/199
8	34	8	1	7	10/199
9	19	12	1	11	7/199
11	158	23	1	22	28/199
12	325	87	1	86	33/199
14	149	35	1	34	22/199
15	70	19	1	18	8/199
16	13	2	1	1	12/199
20	46	23	1	22	5/199
21	39	17	1	16	12/199
22	40	8	1	7	18/199
24	118	9	1	8	51/199
25	31	10	1	9	8/199
26	174	104	1	103	28/199
27	52	9	1	8	20/199
28	191	22	1	21	33/199
29	48	5	1	4	24/199
32	44	20	1	19	7/199
33	46	9	1	8	17/199
34	44	30	1	29	7/199
36	46	7	1	6	20/199
37	69	9	1	8	28/199
40	10	6	1	5	5/199
41	48	24	1	23	19/199
44	14	4	1	3	5/199
47	31	24	1	23	5/199
53	13	9	1	8	5/199
54	14	14	14	0	1/199
57	73	6	1	5	46/199
59	29	4	1	3	20/199
60	30	4	1	3	11/199
67	14	4	1	3	10/199
68	62	4	1	3	33/199
70	15	4	1	3	7/199
71	67	19	1	18	28/199

Table 3. Continued.

Species code	Animals per species	Maximum per sample	Minimum per sample	Range	Frequency of occurrence
73	229	27	1	26	40/199
74	16	5	1	4	7/199
75	242	27	1	26	40/199
76	145	15	1	14	46/199
81	13	3	1	2	7/199
83	19	6	1	5	11/199
85	10	3	1	2	6/199
86	18	5	1	4	8/199
88	13	3	1	2	10/199
90	14	7	2	5	4/199
Cumacea					
101	116	13	1	12	43/199
102	67	38	1	37	12/199
105	74	6	1	5	40/199
107	51	14	1	13	21/199
109	31	4	1	3	19/199
111	51	6	1	5	36/199
112	36	4	1	3	21/199
113	16	3	1	2	13/199
121	60	3	1	2	45/199
124	17	5	1	4	8/199
125	12	11	1	10	2/199
128	65	4	1	3	43/199
129	10	3	1	2	8/199
131	53	4	1	3	37/199
132	36	5	1	4	25/199
133	12	3	1	2	10/199
137	91	11	1	10	34/199

Table 4. Similarity Index (SIMI) matrix (x 10^4).

Station	1	3	5	6	7	8	9	12	14	17	18
1	10000										
3	1307	10000									
5	5119	1183	10000								
6	1235	135	116	10000							
7	2852	462	1736	2026	10000						
8	4031	1260	2785	1439	4820	10000					
9	1911	3559	1381	580	1810	1402	10000				
12	2455	315	64	4329	3684	1268	179	10000			
14	4554	307	6468	2208	1879	1251	413	5516	10000		
17	3521	1188	2754	110	3402	6061	4292	300	310	10000	
18	2674	716	1674	0	3448	4543	2263	70	45	4791	10000
19	3031	194	2356	0	5525	6269	1840	67	0	5727	5886
20	0	0	0	0	0	0	0	0	0	0	2918
23	2417	440	335	2631	2239	1987	812	6443	3904	644	252
25	1715	487	418	992	844	978	1029	3129	2634	2399	586
27	952	721	1462	249	424	2146	2100	215	740	4868	419
28	404	1806	593	0	232	1533	1367	101	49	852	6567
29	328	32	434	0	189	1506	480	658	1739	802	589
30	452	241	284	0	208	1222	587	0	0	1828	3523
31	1200	2913	1557	161	1241	2554	6392	406	405	5078	3252

Table 4. Continued.

Station	19	20	23	25	27	28	29	30	31
19	10000								
20	0	10000							
23	80	0	10000						
25	167	0	5748	10000					
27	608	0	898	1152	10000				
28	258	3538	709	600	475	10000			
29	671	0	490	923	733	730	10000		
30	262	1642	80	42	904	3640	4489	10000	
31	879	1244	1342	3337	2695	3319	678	2181	10000

Table 5. Similarity Index (SIMI) matrix (x 10^4).

Station	42	44	48	57	58	60	61	63	71	72
42	10000									
44	518	10000								
48	85	321	10000							
57	9	13	0	10000						
58	272	345	0	1856	10000					
60	5477	1222	181	0	88	10000				
61	1545	750	145	491	6399	467	10000			
63	123	3768	2205	138	1266	254	1296	10000		
71	47	1302	2429	107	0	599	258	7536	10000	
72	1036	5894	184	216	1664	1594	4995	2274	303	10000
74	7454	1436	334	9	428	7076	1044	373	0	2079
75	8898	1438	111	14	1067	5661	2131	665	71	2454
76	4710	3112	593	1017	1931	5286	1925	1103	293	3660
78	17	670	2464	683	245	98	734	6238	6735	854
80	6	1066	5059	0	47	59	584	345	248	76
82	670	6148	113	192	4966	662	7665	2935	156	7032
83	372	167	0	767	2795	254	791	445	0	196
84	85	263	0	43	4510	25	967	233	36	427
85	258	651	0	1159	5685	0	4922	477	147	1016
86	10	5	0	895	482	39	126	147	0	57

Table 5. Continued.

Station	74	75	76	78	80	82	83	84	85	86
74	10000									
75	8156	10000								
76	5498	5609	10000							
78	222	0	1670	10000						
80	96	32	67	1393	10000					
82	1478	1935	3133	486	365	10000				
83	487	898	1080	81	97	921	10000			
84	549	725	2920	26	16	582	183	10000		
85	430	635	1468	314	13	4109	436	3211	10000	
86	10	74	234	162	10	74	216	151	247	10000

station pairs have SIMI values between 0. 5 and 0. 6, four stations pairs between 0. 6 and 0. 7 and six values between 0. 7 and 0. 8. The stations pairs 75-42 and 74-75 are the only stations pairs where SIMI values are higher than 0. 8. Only thirteen stations pairs show no similarity to each other. Six of them are formed by station 48 located off Prudhoe Bay. This station does not show a particular similarity with any other station; 0. 5 is the highest SIMI value found for this station.

Diversity

The fauna studied has a relatively high diversity (Figure 9). Most of the stations (28) have a high Simpson Diversity Index with values ranging between 0. 80 and 0. 95. The maximum frequency (10 stations) occurs at 0. 85-0. 90 interval. From the remaining stations, seven are grouped between diversity values of 0. 55 and 0. 70. Only one station (20) has a diversity lower than 0. 5 and is located on the continental slope at 2572 m depth. It is the deepest station sampled.

Most of the environmental factors show a clear and constant variation with depth particularly in the first 2000 m. For this reason, a clear pattern of variation in the fauna with depth is usually found. The stations were grouped in ten transects of three to five stations each to analyze the variation of diversity with depth. The

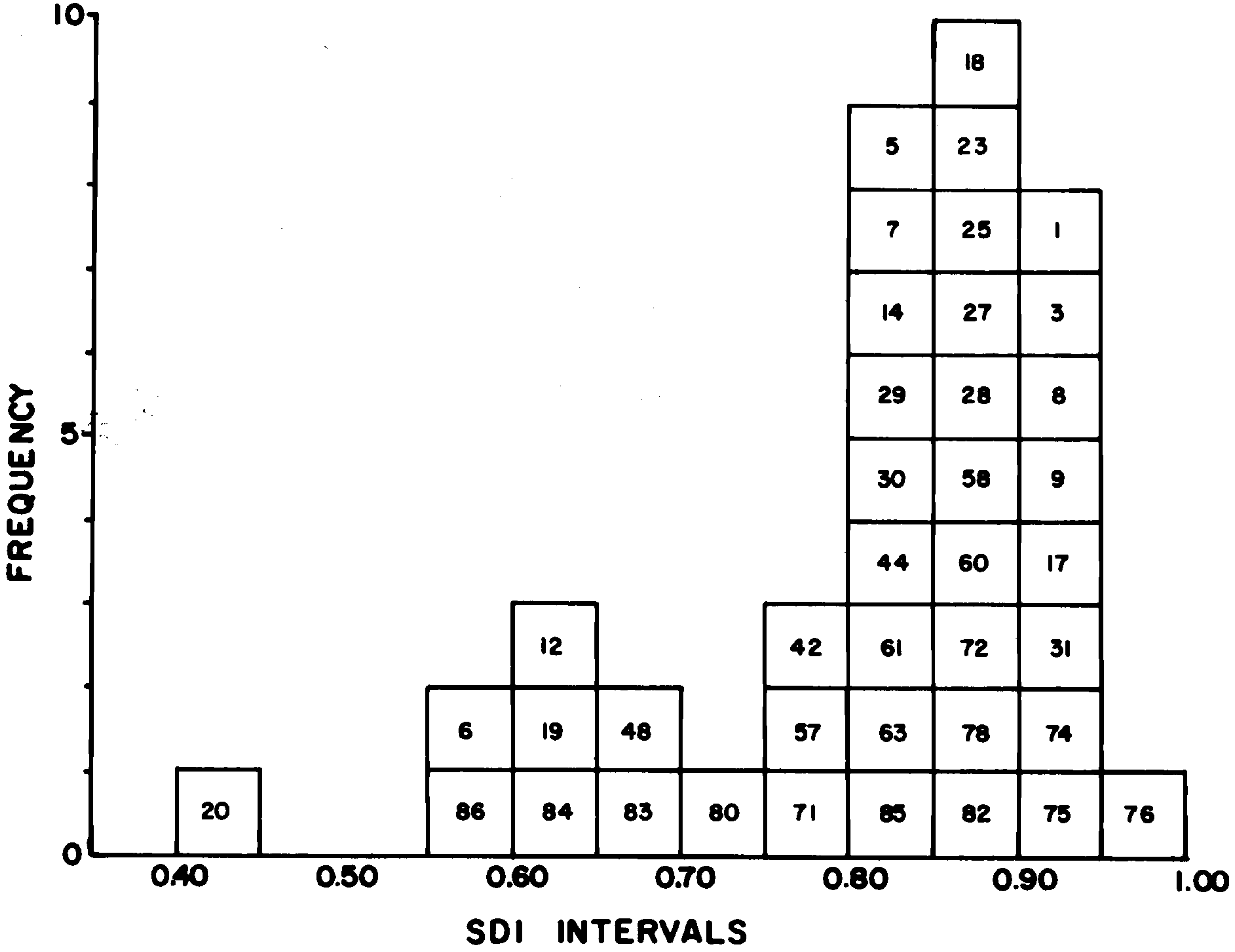


Figure 9. Frequency of stations within the Simpson Diversity Index (SDI) intervals. Based on Amphipoda and Cumacea.

first transect (I) is located off Barter Island, and the last one (X) off Cape Halkett (Figure 10).

Transect I

This transect is located off Barter Island; it is composed of four stations ranging from 33 m depth (Station 1) to 495 m (Station 6). Sand is an important component of the sediments in the two shallowest stations. The two deepest ones are dominated by mud (silty clay sediments). The Simpson Diversity Index (Figure 12A) decreases steadily with depth from 0.9244 to 0.5714. However, the information diversity index (H_e') indicates a maximum diversity at station 3, which is located on the outer continental shelf. The highest number of species and density of animals are found at station 3 at 48 m depth, and the minimum at station 6 where only three species and seven individuals were collected.

Since the H_e' is affected by sample size and the SDI overestimates the diversity in small samples, we cannot consider the values obtained at station 3 to be a true representation of the faunal diversity at this location.

Transect II

Located off Canning River, this transect goes from 26 m (Station 12) to 463 m depth at station 7. The first three stations (12,

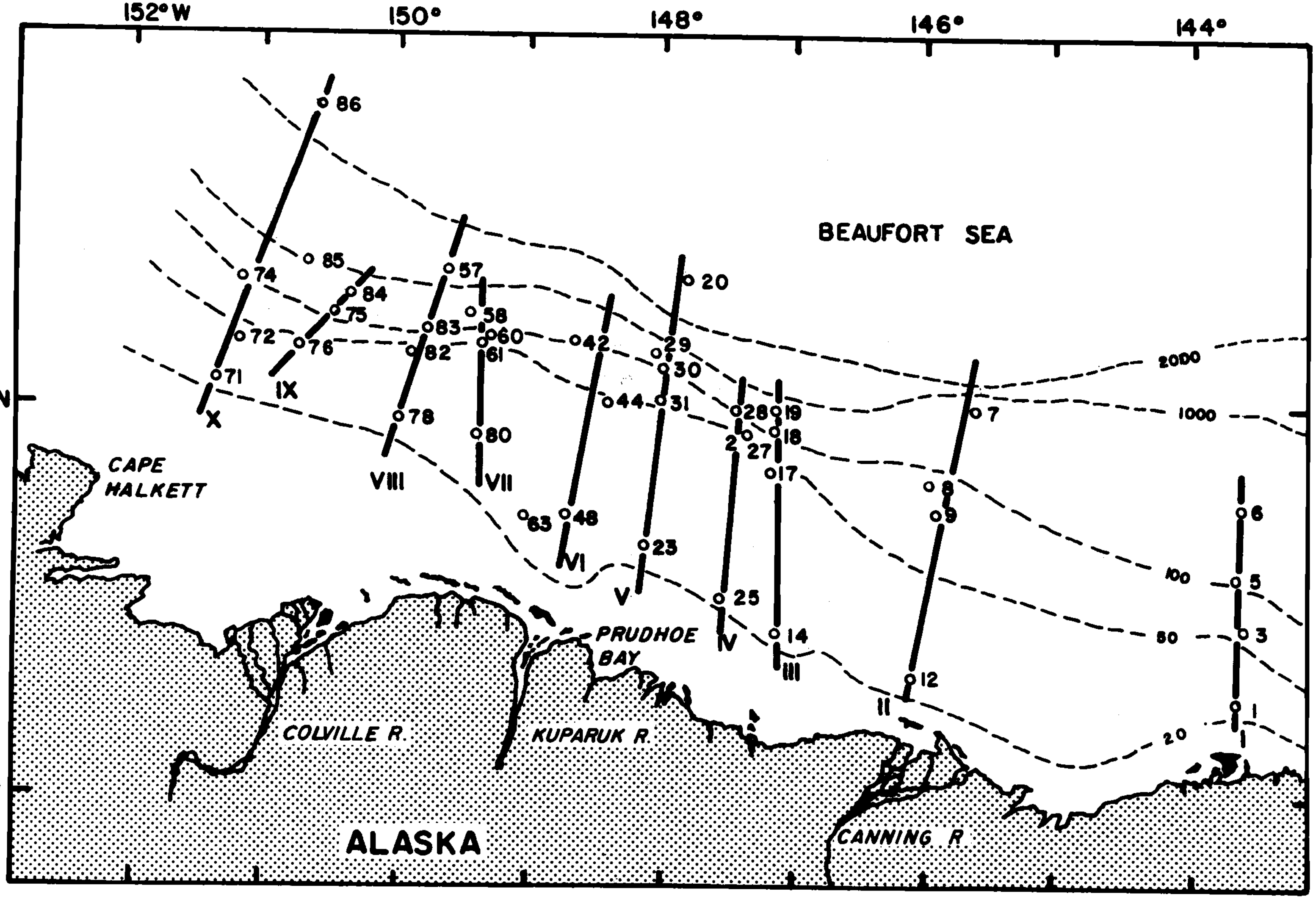


Figure 10. Location of the ten benthic transects in western Beaufort Sea.

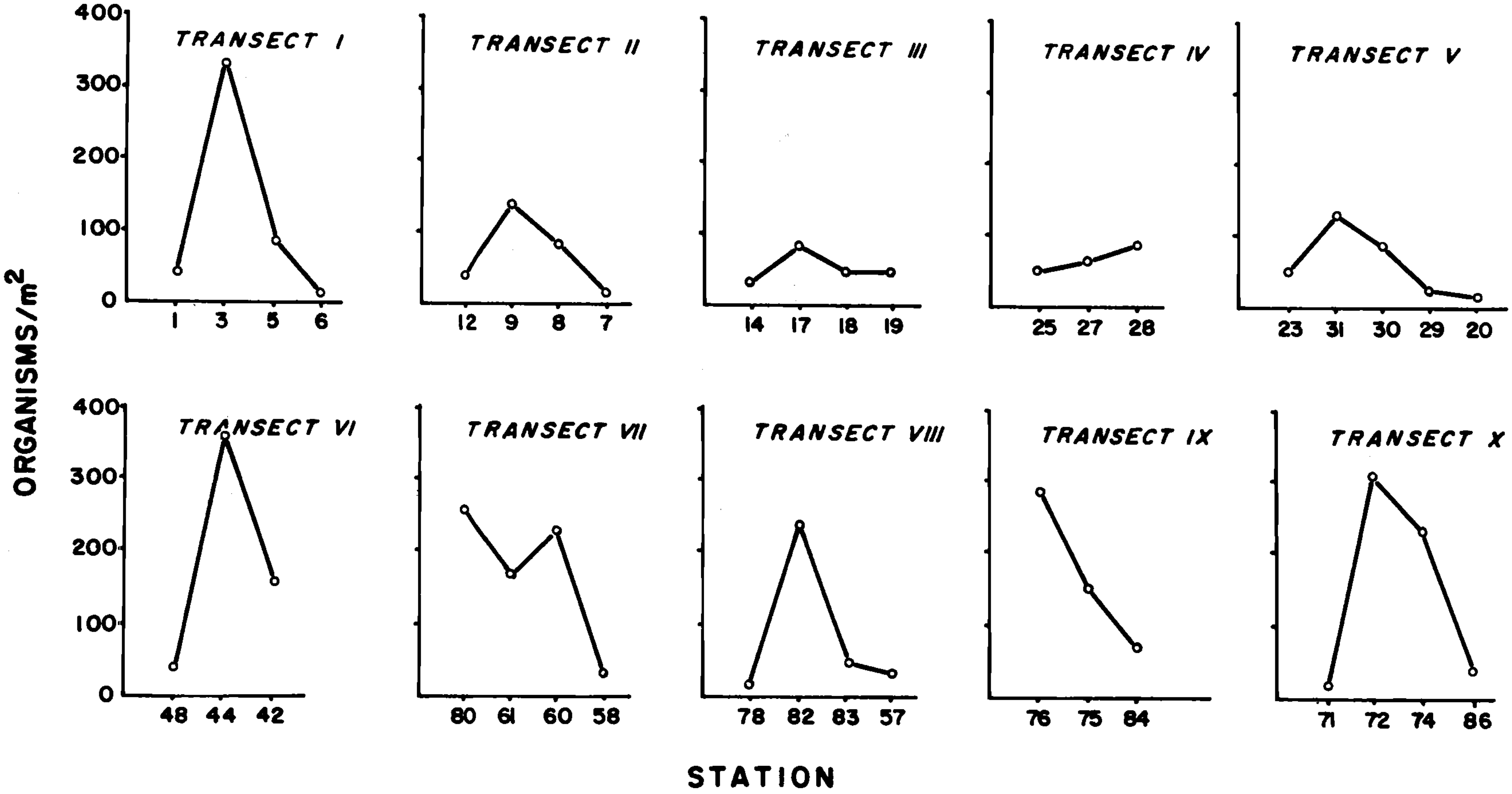


Figure 11. Variation of abundance of Amphipoda and Cumacea with depth. Transect I - X in the western Beaufort Sea.

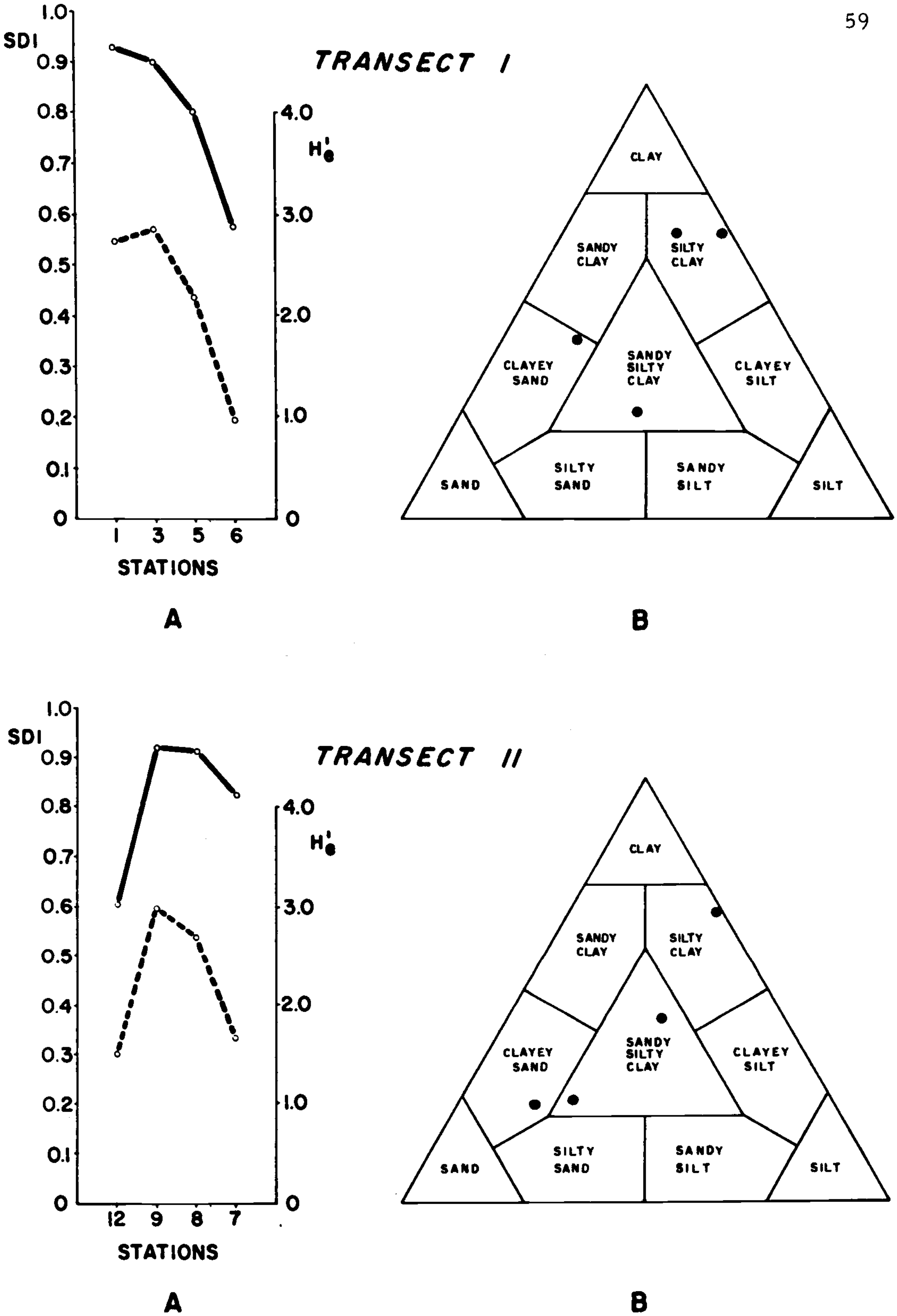


Figure 12. A) The Simpson Diversity Index (SDI) and the Shannon-Weiner Index (H'_e) at stations on transects I and II. B) Sand-silt-clay content of the sediments.

9 and 8) have sandy-silty clay sediments (Figure 12B). However, silt and clay are predominant at station 12. Sand is the best represented component at stations 9 and 8. Gravel comprises 20% of the sediments at station 9. The deepest station on this transect has 99% mud; clay is the most important component (66%).

The organic carbon content of the sediment is higher at muddy stations (7 and 12) than at stations where sand predominates.

Both diversity indices, SDI and H_e', show the same pattern of variation with depth (Figure 12A). At the shallowest station (12) the lowest diversity value was found (SDI = 0.6187). With depth, diversity increases sharply and reaches its highest value at 56 m depth (Station 9). Beyond this point, diversity decreases steadily with depth. The maximum number of species and animal density is also found at station 9 on the outer continental shelf. It is the only station where gravel is well represented.

The lowest animal density and the smallest number of species are found at station 7 (507 m depth); they are 13 and 7 respectively. Due to these low values used in the calculations and the characteristics of the diversity indices calculated, we can expect bias in the indices of diversity obtained at this station.

Transect III

Both diversity indices on this transect show the same pattern of variation with depth described for the previous transects. The highest diversity value was obtained at the station located on the outer continental shelf.

The transect is composed of four stations ranging from 28 m to 631 m depth. Sediment data are not available for station 19 and only three stations were included in the triangle diagram (Figure 13B).

Sand is predominant over silt and clay in the sediments at station 17 (46 m depth). The remaining stations (14 and 18) have muddy sediments with silt and clay as the predominant components. However, at station 18, gravel is also well represented (18%). The organic carbon at station 14 is not detectable.

All stations considered have enough individuals per species to be confident that the diversity values calculated do not have significant bias. However, samples from station 18 and 19, show variation in the estimated depth of 10-20% between sampling, indicating drifting of the vessel. For this reason, possibilities of error due to defective sampling have to be considered.

Transect IV

This transect is located near the transect III and parallel to it. The three stations composing it extend from 26 m to 103 m depth. At station 25 (26 m depth) sediments contain about 83% of mud with clay being the principal component (43.9%). At station 27 (50 m

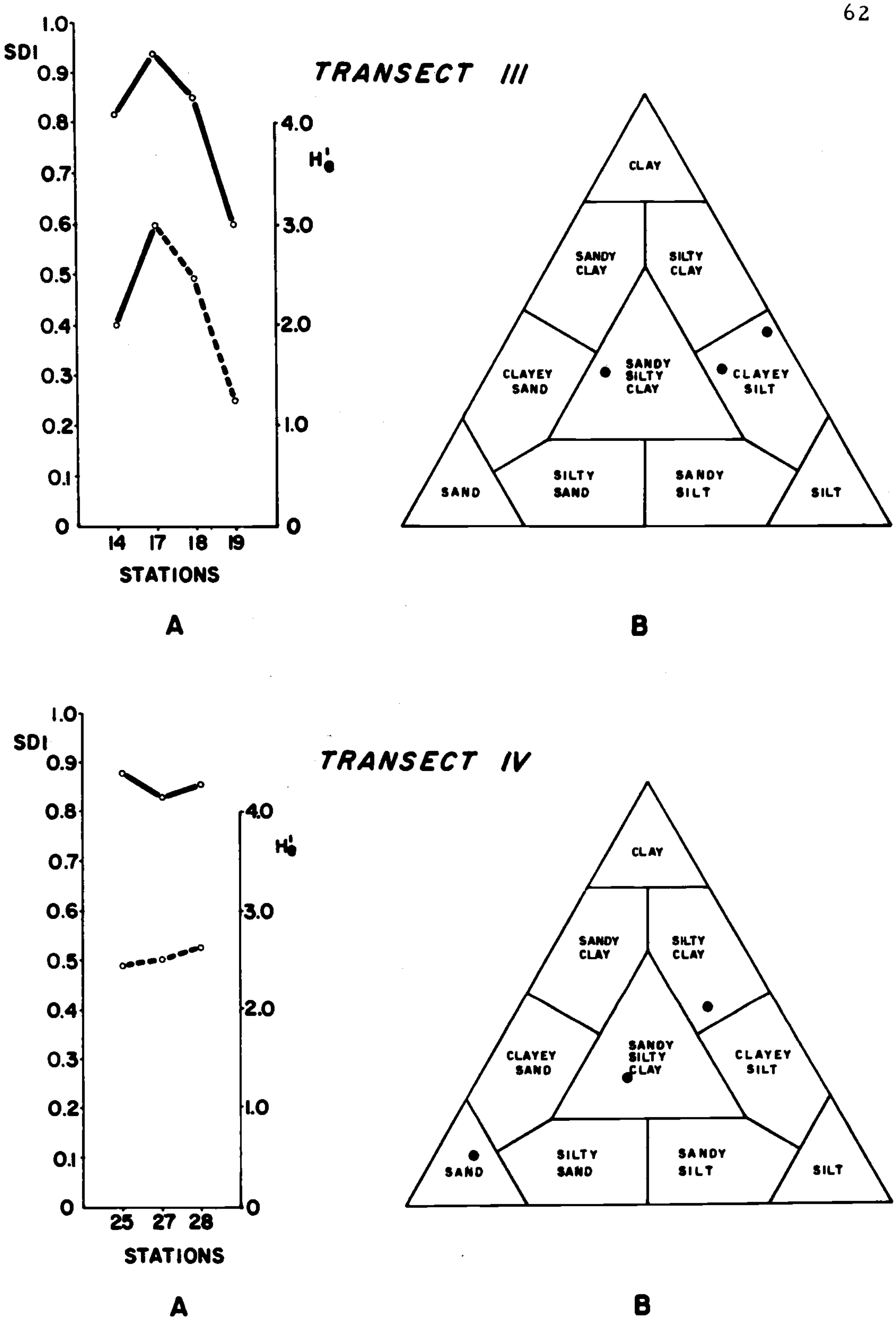


Figure 13. A) The Simpson Diversity Index (SDI) and the Shannon-Wiener Index (H'_e) at stations on transects III and IV. B) Sand-silt-clay content of the sediments.

depth) located on the outer continental shelf, sand is predominant (49.7%) followed by gravel which represents 31.5% of the sediment. In deeper water, gravel disappears and the percentage of sand decreases. At station 28 (103 m depth) the sediments are sandy-silty clays.

There is low organic carbon content but a relatively high $CO_3^=$ content at stations 25 and 27. No carbon content data for station 28 are available.

The pattern of diversity is rather different to those previously obtained along the other transects. The SDI and H_e' indices present a different pattern of variation due to the presence of rare species.

Here, the highest diversity value is found at station 28 located at 103 m depth in the continental slope. It is important to consider that station 28 shows a depth variation between samples of about 40%. This implies that the high diversity obtained may be the result of pooling samples taken at places with different environmental conditions and thus inhabited by different populations.

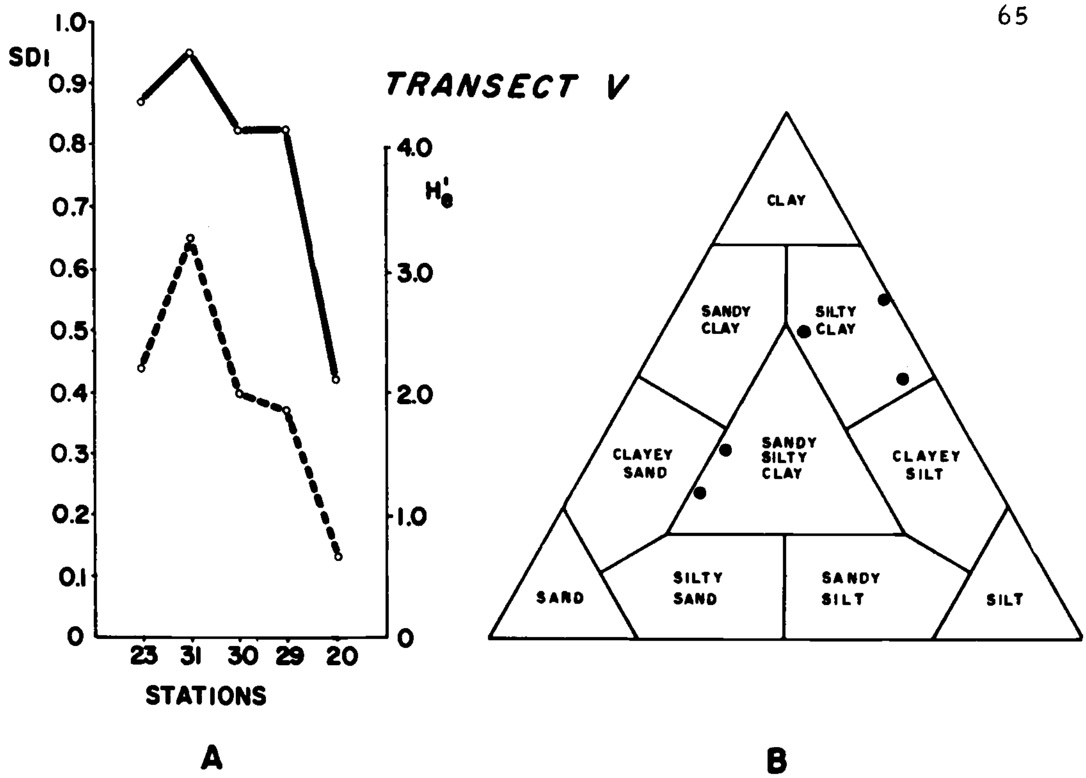
Transect V

The transect is located off Prudhoe Bay and is formed by a group of five stations extending from 27 m to 2572 m depth. At stations 23 (27 m depth) clay is the dominant component of the sediment. The percentages of gravel, sand and silt are similar to each other. Sand predominates over silt and clay at station 31 on the outer continental shelf and at station 30 on the upper slope. Deeper than station 30, sand decreases with depth and silt and clay increase, particularly at the last station which contains 64. 2% of sand (Station 20).

The percentage of organic carbon increases with depth although the total carbon content decreases with depth along transect V.

Transect V is the longest one, and the pattern of diversity is similar to those on the transects II and III. The lowest diversity value was obtained at the station located on the inner continental shelf, and the highest occurs at station 31 near the continental shelf break. The highest number of species and animal density are found at station 31. At the stations located on the slope, diversity values decrease with depth. Station 20, which is the deepest one sampled, has the lowest diversity, density and number of species found in this study.

Although the pattern is similar to the previous transects, the values obtained for the last three stations have to be considered carefully. The data vary in sampling depth by more than 20%; error in sampling is possible. As the number of animals per species at station 20 is low, diversity at this point could have been overestimated.



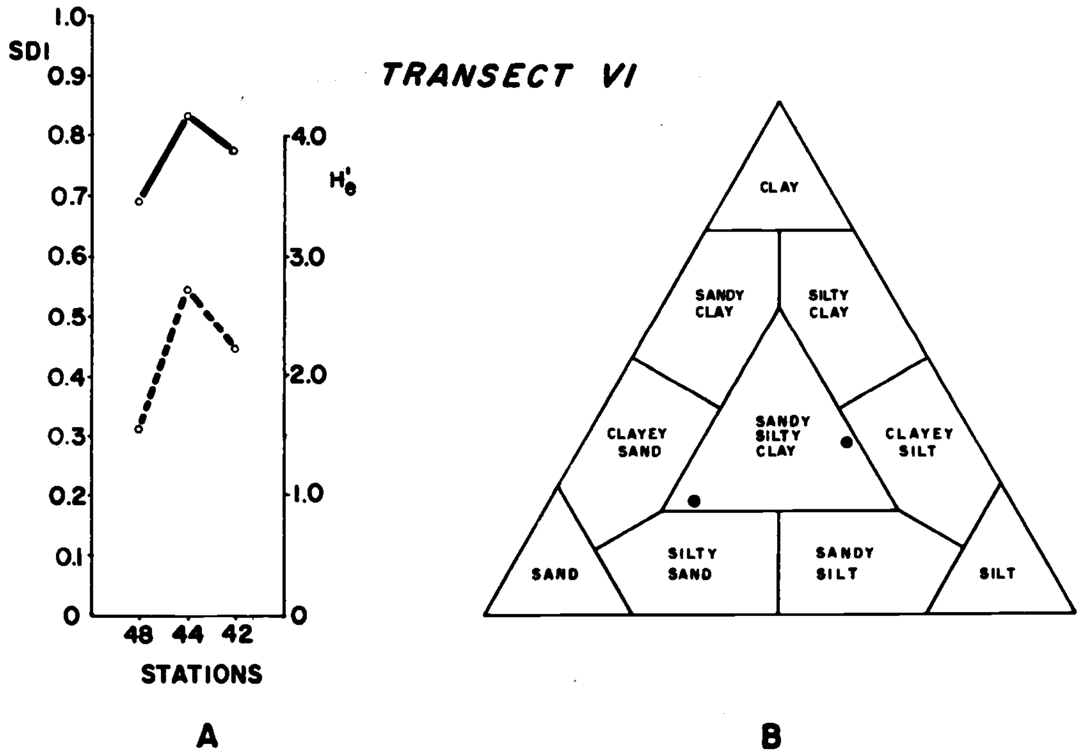


Figure 14. A) The Simpson Diversity Index (SDI) and the Shannon-Wiener Index (H'_e) at stations on transects V and VI. B) Sand-silt-clay content of the sediments.

Transect VI

This transect is located off Kuparuk River and extends from 25 m to 130 m depth. At station 48 (23 m depth) on the inner continental shelf, silt and clay predominate in the sediment, while at station 44 (48 m depth) on the outer continental shelf the most important component is sand. Sediment data for the other stations are not available.

The diversity indices follow the same pattern of variation with depth as the other transects. The lowest diversity value is found on the continental shelf (Station 48), and the highest at station 44 at 47 m depth.

The diversity value at station 42 should not be considered as the true diversity at this point. Sampling data show a depth variation of more than 50% indicating significant ship drift during the sampling. The diversity indices calculated with these data are probably biased, therefore.

Transect VII

This transect begins at 30 m depth off the Kuparuk River and extends in NW direction down to 700 m depth. Station 80 located at 30 m depth has silty clay sediments with 11% sand. Silt and clay decreases along the continental shelf but increases again at the deepest station located at 700 m depth. Sand is predominant at station 61 at 50 m depth and decreases beyond this point. Although in the triangle diagram, station 60 appears to have clayey sand sediments, gravel, not included in the diagram, is the principal component of the sediments (39.1%).

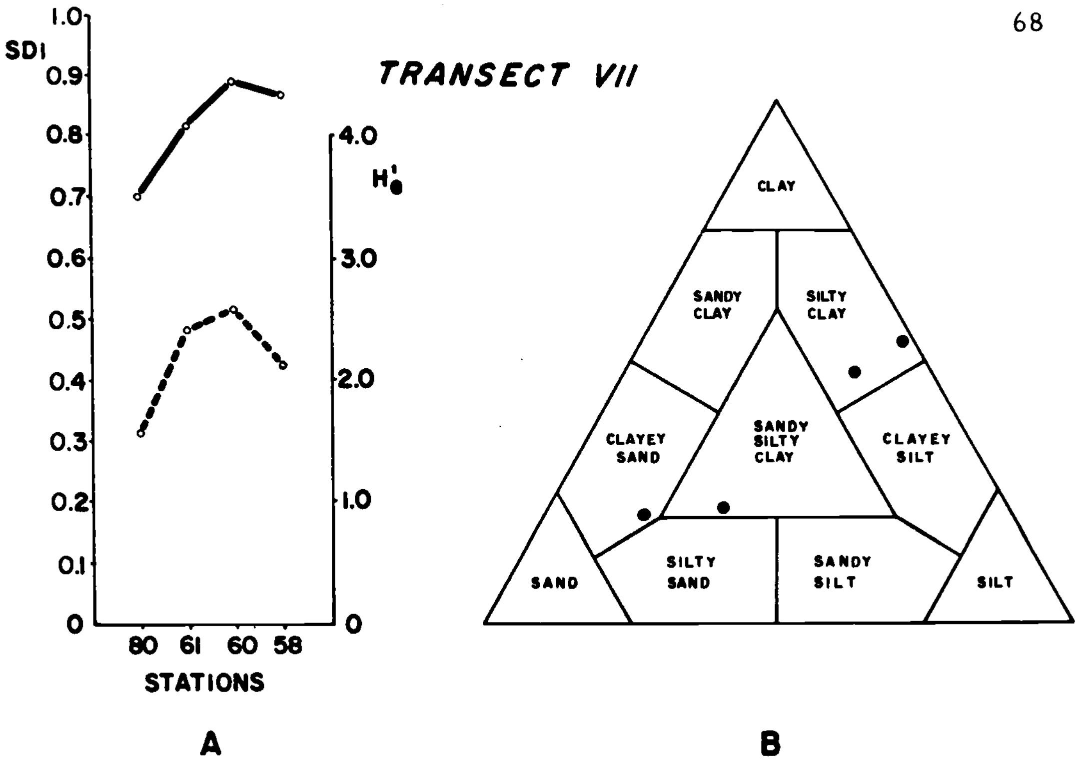
The sedimentary organic carbon content is higher at 700 m depth but $CO_3^=$ is lower at that depth. Carbon content data are available only for stations 80 and 58.

The diversity increases steadily at the first three stations. It is low on the inner continental shelf and reaches its highest value at station 61 located at 64 m depth at the continental shelf break.

Samples at station 58 located at 700 m depth show a variation in depth of more than 50%. Variation in the position was more than two miles between the first and the last sample taken. This may indicate a biased diversity value due to pooling samples from different faunistic groups.

Transect VIII

This transect is composed of four stations ranging from 30 m to 1866 m depth. The sediments are dominated by silt and clay. At 45 m (Station 82) sand represents 26.6% of the sediments and decreases with depth at the other stations. Clay increases with depth reaching 61.1% at 1565 m. Data from the shallowest station were



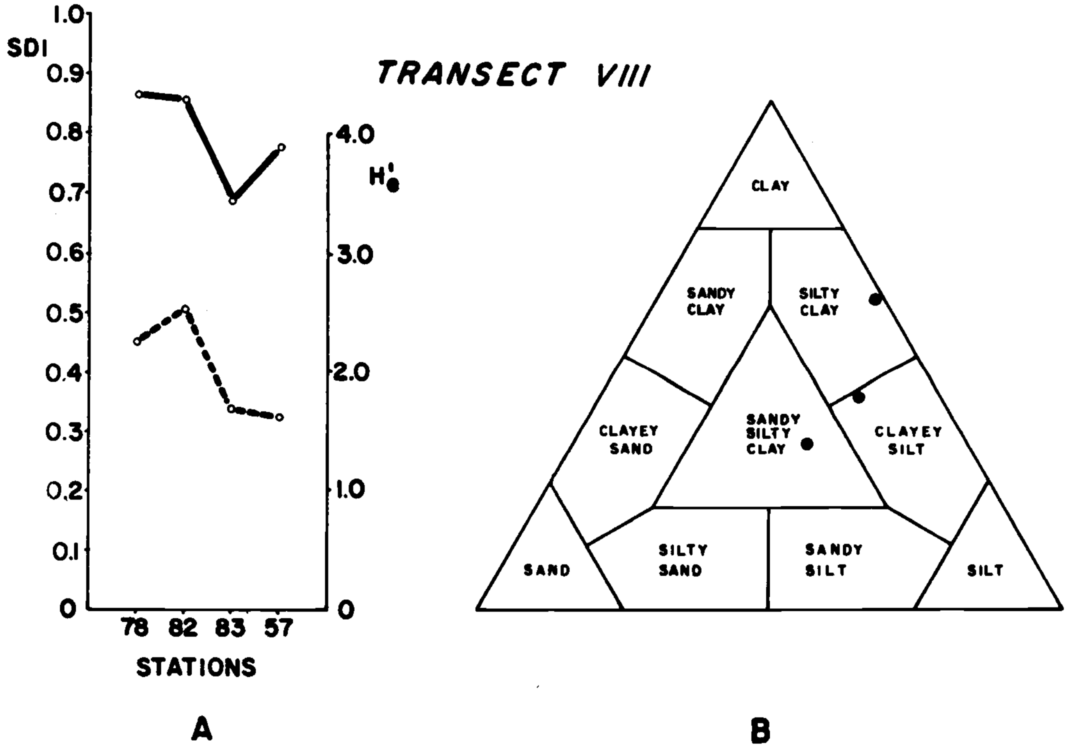


Figure 15. A) The Simpson Diversity Index (SDI) and the Shannon-Wiener (H'_e) at stations on transects VII and VIII. B) Sand-silt-clay content of the sediments.

not available, and those for station 57 do not correspond with the depth of the benthic sample.

Samples from the two deepest stations of the transect (Stations 83 and 57) show significant variation in depth. Station 57 also shows variation in position. The highest diversity value was found on the outer continental shelf (Station 82), and the lowest at station 83 if we consider the SDI, or station 57 if we consider the H'_e.

The difference between the indices at station 78 is probably due to the small number of animals at this station. This implies that the SDI calculated could be higher than the true value. The difference at station 83 is due to the presence of several rare species; the SDI is not sensitive to their presence.

Transect IX

The three stations on this transect range in depth from 47 m on the outer continental shelf to 689 m on the continental slope. The sediment at the two deepest stations is dominated by mud; sandy-silty clay is found at station 75, and silty clay at station 84. The benthic samples and the sediments analyzed do not come from the same depth; therefore the sediment data at this station should be considered only as an approximation of the real composition of the sediments.

Although there is a considerable variation in position between

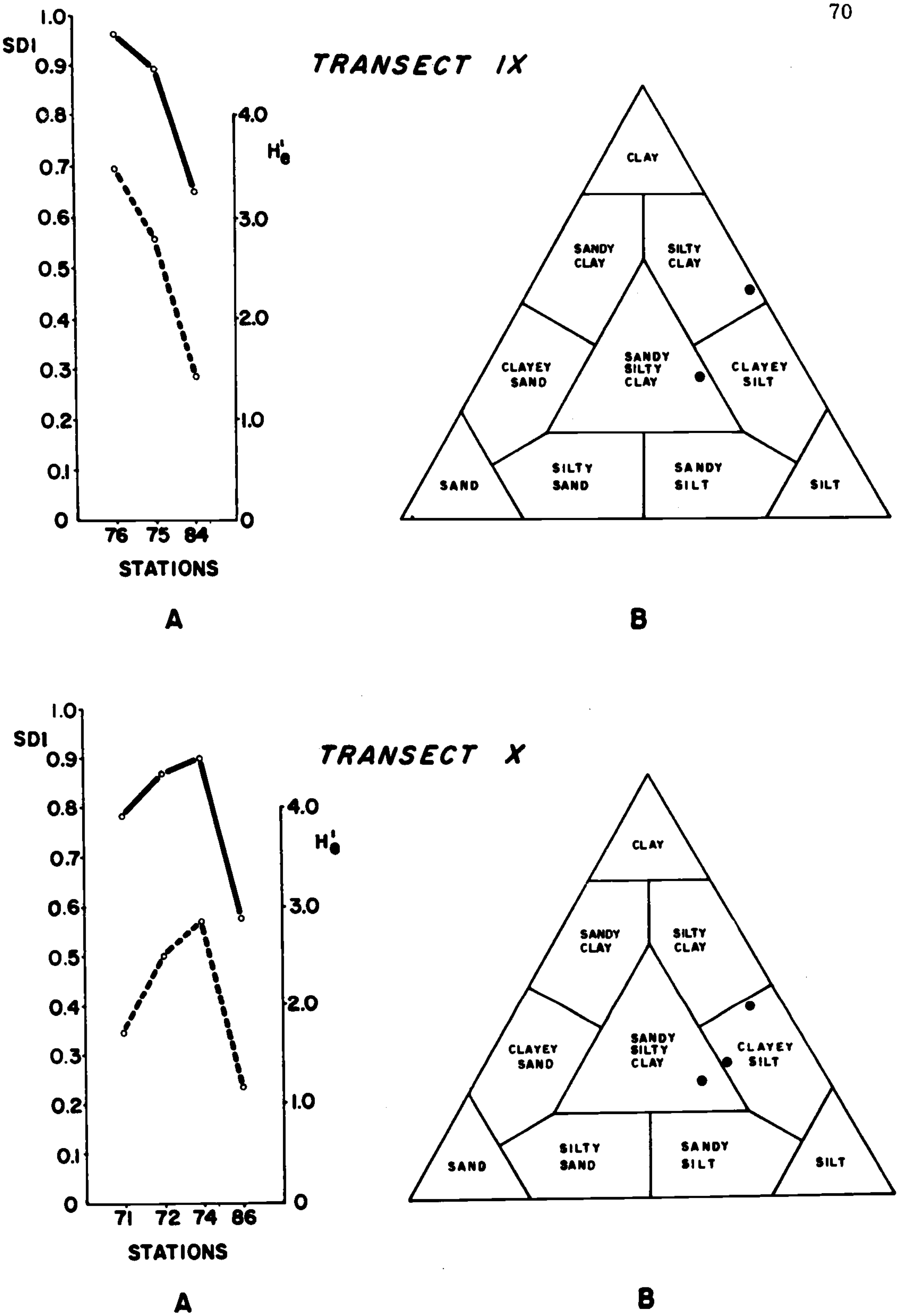


Figure 16. A) The Simpson Diversity Index (SDI) and the Shannon-Wiener Index (H'_e) at stations on transects IX and X. B) Sand-silt-clay content of the sediments.

samples at the shallowest station (Station 78), the diversity pattern obtained in this transect is similar to the others. The highest diversity is on the outer continental shelf.

Samples from the inner continental shelf were not collected on this transect.

Transect X

The last transect is located off Cape Halkett. All stations are dominated by mud. Sand is well represented only at stations 7 (21 m) and 74 (93 m depth). The organic carbon content increases with depth, but $CO_3^{=}$ is more abundant at 21 m depth.

This is the only transect where the highest diversity value was obtained on the continental slope.

DISCUSSION

Carey *et al* (1974) analyzed a transect off Prudhoe Bay; they reported that the continental shelf and slope maintain an infaunal biomass and density of organisms similar to those found in temperate regions. The analysis of the Gammaridean Amphipoda and Cumacea show similar results on the outer continental shelf and upper slope, but the inner continental shelf and lower slope show a relatively low animal density.

The number of species of benthic fauna of the western Beaufort Sea is similar to that found in the Chukchi Sea off Point Barrow by McGinitie (1955) (Table 6). There, 100 species of Amphipoda and 10 of Cumacea were found.

Table 6. Comparison of the number of species of Amphipoda and Cumacea in the Chukchi Sea off Point Barrow and in the western Beaufort Sea.

	western Beaufort Sea	Point Barrow
Amphipoda	90	100
Cumacea	38	10

Although the maximum depth sampled off Point Barrow was only about 250 m with most of the stations located on the continental shelf, the similarity in the number of species is reasonable. A large percentage of the species are distributed on the continental shelf.

The pattern of distribution with depth of the Gammaridea Amphipoda appears rather different from the pattern obtained in a transect off the Oregon Coast (Carey, unpublished data). There, only 62% of all species were present on the continental shelf, but, 49.5% of all species were restricted to the shelf.

The faunal diversity on the outer continental shelf is similar or greater than those found in more temperate regions. The pattern of variation with depth, with a peak at the outer continental shelf resembles the pattern of species abundance and the animal density. This similarity can be explained by the dependence of both diversity indices calculated on the number of species and the evenness of distribution of animals among species.

The Simpson Diversity Index (SDI) appears not to be sensitive to the presence of rare species (Fager, 1964). This characteristic of the SDI and the abundance of rare species at some stations would account for the differences found in the pattern of variation with depth of the SDI and H_e'. This, coupled with the dependence of both indices on sample size (Sanders, 1968), indicates that the diversity values calculated have to be considered as approximations to the real values exhibited by the populations there.

The very low similarity between stations (Tables 4 and 5) indicates a high faunal patchiness.

The trends obtained may be influenced by sampling deficiencies or are due to natural variability. Sampling processes could be responsible for some of the variation, especially after pooling of samples which were not always taken at the same position due to vessel drift.

Biological phenomena can also be responsible for some of the variation. Sanders (1956) pointed out that restricted environmental differences may cause local faunal variation. The trends obtained in this analysis may be caused by interaction of multiple environmental factors affecting this area.

The western Beaufort Sea is a satellite sea of the Arctic Ocean. Its coastal zone, however, has been considered as subpolar because of the high biological production reported there (Dunbar, 1954). The area is ice-covered during the winter; little is known about the oceanographic conditions found during that season. In the summer, the salinity decreases at the surface due to river discharge and ice melting. This, coupled with a small degree of superficial temperature increase, lowers the water density, leading to horizontal stratification and reduced vertical mixing.

On the other hand, although the circulation is predominantly toward the west in the Beaufort Sea, there is occasional eastward circulation over the continental shelf which is associated with periods of upwelling (Mountain, 1974). The upwelling processes are responsible for nutrient replenishment of the surface waters increasing the productivity of the western Beaufort Sea. The temporal and spatial extent of coastal upwelling in the Beaufort Sea are not well known.

In addition to planktonic productivity, an important role may be played in the Beaufort Sea by ice algae growing under the ice. These algae populations, characteristic of the polar environment, amount to about 20-30% of the total productivity in coastal waters beginning about June, some months before the planktonic productivity starts (Alexander, 1974). The temporal and spatial extent of under-ice algae are also not known.

Besides those mentioned, there are many other factors which could influence the benthic environment producing seasonal and annual variations which may be reflected on the fauna living in the area. Bottom current-produced features on the inner continental shelf (Barnes and Nenmitz, 1974), annual duration of the ice cover, and degree of ice gouging are important. Given the high rate of ice scouring in this area contributing to the mixing and reworking of the sediments, the sedimentary mosaic reported for this area is not surprising.

As the type of sediments play a major role in determining infaunal distribution (Thorson, 1957b; Rhoads and Young, 1970), ice gouging can be considered as an important factor determining the patchy distribution of the fauna in the western Beaufort Sea.

Due to natural faunal destruction caused by the ice scouring, the fauna existing may change from year to year (McGinitie, 1955). More complete studies need to be done to understand the seasonal variation occurring in this area.

Improvements in sampling procedures are necessary to get more precise information on the benthic fauna of the western Beaufort Sea. Suggested improvements include the use of a bigger type of grab to reduce the number of samples per station and careful positioning of the vessel at the station before taking each sample.

SUMMARY AND CONCLUSIONS

The sediments of the area are dominated by muddy or sandy-mud type of substrate. The variety of the sedimentary regimes and the several modifying processes affecting the area cause a sedimentary mosaic. Such a pattern has a great influence on the faunal distribution. The most important process affecting the sediment distribution appear to be the ice gouging which is also responsible for frequent destruction of the fauna, thus disrupting the infaunal populations and increasing their variability.

One hundred and twenty-eight species were identified in the collection obtained. A high percentage of them (86%) are represented on the continental shelf although only 33% are restricted to the shelf. These results contrast with results obtained off the Oregon Coast where only 49% of the Amphipods collected are represented on the shelf.

The animal density on the outer continental shelf of the western Beaufort Sea agrees well with values from more temperate regions. However, on the inner continental shelf and slope, the animal density is low. These are areas whose mud dominates the sediments.

Diversity values are higher on the outer continental shelf and compare well with values obtained in temperate waters. The lowest diversity values were obtained on the lower continental slope although this may be due to the insufficient sampling.

The similarity between stations generally is low. The stations located in the west side of the area sampled have higher similarity values than the stations located on the east side. The low similarity values obtained coupled with a high percentage of rare species indicates a patchy distribution of the fauna in the area.

The ice scouring appears to be a major factor influencing the high faunal variability. However, many other factors like uniform low temperature, organic material input, productivity of the area and sedimentary regimen undoubtedly have an important effect. The pattern of distribution obtained may be considered to be the result of the interaction of these and other factors.

At present, there are no Amphipoda-Cumacea data available to be compared with the results obtained from the western Beaufort Sea. However, as these groups are usually well represented in the benthic environment, future comparisons between data obtained in different parts of the ocean should yield valuable information about the structure of the assemblages living on the continental shelf of the world ocean.

Finally, the results obtained indicate a much more intensive study is necessary in this area in order to obtain insight on the characteristics of the infauna living in the area as well as on the degree in which environmental factors affect it.

BIBLIOGRAPHY

Antonov, V. S. 1958. The role of continental runoff in the current regime of the Arctic Ocean. Problemy Severa 1:52-64.

Bader, R. G. and L. M. Jeffrey. 1958. The exchange capacity, organic adsorption, and differential flocculation of clay minerals as related to radioactive waste disposal. Texas A. M. Research Foundation, Project 142, Ref. 58-2A. 25 p.

Bader, R. G., D. N. Hood and J. B. Smith. 1960. Recovery of dissolved organic matter in seawater and organic sorption by particulate material. Geochemistry and Cosmochimistry Acta 19:236-243.

Bader, R. G., K. M. Rae and J. B. Smith. 1960. A study of some factors concerning radioactive materials in the Sea. Texas A. M. Research Foundation, Project 142, 78 pp.

Barnard, J. L. 1958. Index to the families, genera and species of the Gammaridean Amphipoda (Crustacea). Allan Hancock Foundation Publication, Occasional Paper 19:1-145.

__________ 1960a. The Amphipod family Phoxocephalidae in the eastern Pacific Ocean, with analysis of other species and notes for a revision of the family. Allan Hancock Pacific Expedition. 18:175-368, pls. 1-75.

__________ 1960b. New bathyal and sublittoral ampeliscid Amphipods from California, with an illustrated key to Ampelisca. Pacific Naturalist 1(16):1-36.

__________ 1961. Gammaridean Amphipoda from depths of 4000 to 6000 meters. Galathea Report 5:23-128, figs. 1-83.

Barnard, J. L. 1962a. Benthic marine Amphipoda of southern California:Families Aoridae, Photidae, Ischyroceridae, Corophiidae, Podoceridae. Pacific Naturalist 3:1-72, figs. 1-32.

__________ 1962b. Benthic marine Amphipoda of Southern California:Families Tironidae to Gammaridae. Pacific Naturalist 3:73-115, figs. 1-23.

Barnard, J. L. 1962c. Benthic marine Amphipoda of Southern California: Families Amphilochidae, Leucothoidae, Stenothoidae, Argissidae, Hyalidae. Pacific Naturalist 3:116-163, figs. 1-23.

______________ 1962d. Benthic marine Amphipoda of Southern California: Family Oedicerotidae. Pacific Naturalist 3:349-371, figs. 1-10.

______________ 1969. The Families and Genera of Marine Gammaridean Amphipoda. U. S. National Museum Bulletin 271:1-535.

Barnard, J. L. and R. R. Given. 1960. Common pleustid amphipods of Southern California, with a projected revision of the family. Pacific Naturalist 1(17):37-48, figs. 1-6.

Barnes, P. W. and E. Remnitz. 1974. Sedimentary processes on arctic shelves off the northern coast of Alaska. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 439-476.

Calman, W. 1911. On the new or rare Crustacea of the Order Cumacea from the collection of the Copenhagen Museum. Part II. Zoological Society of London. Transactions 18(4): 341-385.

______________ 1912. The crustacea of the Order Cumacea in the collection of the United States National Museum. Proceedings of the U. S. National Museum 41:603-676, 112 figs.

Carey, A. G. 1966. Professor, Oregon State University. Department of Oceanography. Ecology of the Benthic fauna off the Oregon Coast. Final Report. Ref. 66-20.

Carey, A. G., R. E. Ruff, J. G. Castillo and J. J. Dickinson. 1974. Benthic Ecology of the Western Beaufort Sea Continental margin: Preliminary Results. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 665-680.

Carsola, A. J. 1954a. Recent marine sediments from Alaskan and Northwest Canadian Arctic. Bulletin of American Association of Petroleum Geologists 38:1552-1586.

Carsola, A. J. 1954b. Submarine canyons on the Arctic slope. Journal of Geology 62:605-610.

Carsola, A. J., R. L. Fisher, C. J. Shipek and G. Shumway. 1961. Bathymetry of the Beaufort Sea. In: G. O. Raasch ed. Geology of the Arctic. Toronto: University of Toronto Press. pp. 678-689.

Clements, F. C. 1916. Plant succession, an Analysis of the Development of Vegetation. Carnegie Institute Washington Publication 242:1-512.

Coachman, L. K. 1963. Water masses of the Arctic. In: Proceedings of the Arctic Basin Symposium. Tidewater Publis. Co. 313 pp.

Coachman, L. K. and C. A. Barnes. 1961. The contribution of Bering Sea water to the Arctic Ocean. Arctic 14(3):146-161.

__________ 1962. Surface waters in the Arctic Ocean. Arctic 15(4):251-278.

__________ 1963. The movement of Atlantic water in the Arctic Ocean. Arctic 16(1):8-16.

Coachman, L. K. and K. Aagard. 1974. Physical Oceanography of Arctic and Subarctic Seas. In: Y. Herman ed. Marine Geology and Oceanography of the Arctic Seas. p. 1-72.

Connell, J. and E. Orias. 1964. The ecological regulation of species diversity. The American Naturalist 98:399-414.

Davis, F. M. 1925. Quantitative studies on the fauna of the sea bottom. Part II. Results of investigations in the Southern North Sea 1921-1924. Fisheries Investigations, London, Series II, 8(4):1-50.

Dayton, P. K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecological Monography 41: 351-389.

Dayton, P. K. and R. R. Hessler. 1972. Role of biological disturbance in maintaining diversity in the deep Sea. Deep-Sea Research 19:199-208.

Dobzhansky, T. 1950. Evolution in the tropics. The American Scientist 38: 209-221.

Dunbar, M. J. 1954. Arctic and subarctic marine ecology: immediate problems. Arctic 7:75-90.

__________ 1960. The evolution of stability in marine environments; natural selection at the level of the ecosystem. The American Naturalist 94: 129-136.

Ellis, D. V. 1960. Marine Infaunal benthos in Arctic North America. Arctic Institute of North America. Technical Paper 5: 1-53.

Fager, E. W. 1964. Communities of organisms. In: M. N. Hill ed. The Sea 2: 415-437.

__________ 1972. Diversity: a sampling study. The American Naturalist 106: 293-310.

Fisher, A. G. 1960. Latitudinal variation in organic diversity. Evolution 14: 64-81.

Fisher, R. A., A. S. Corbert and C. B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. Journal of Animal Ecology. 12: 42-58.

Ford, E. 1923. Animal communities of the level sea-bottom in the waters adjacent to Plymouth. Journal of the Marine Biological Association of the United Kingdom 13: 164-224.

Gallardo, V. A. 1965. Observations on the biting profiles of three 0.1 m^2 bottom samplers. Ophelia 2(2): 319-322.

Given, R. R. 1961. The cumacean fauna of the Southern California continental shelf. Family Leuconidae. Bulletin Southern California Academy of Science 60: 130-146.

Gleason, H. A. 1926. The individualistic concept of the plant association. Bulletin Torrey Botany Club 53: 7-26.

__________ 1939. The individualistic concept of the plant association. American Midland Naturalist 21: 92-110.

Gurjanova, E. 1951. Bokoplavy mori SSR i sopredel'nykh vod (Amphipoda-Gammaridea). Opredeliteli po Faune SSSR, Akademii Nauk SSSR 41:1-1029, figs. 1-705 (in Russian).

Hall, D. J. 1964. An experimental approach to the dynamics of a natural population of Daphnia galeata mendotae. Ecology 45: 94-112.

Hansen, H. J. 1920. Crustacea Malacostraca IV. The Order Cumacea. Danish-Ingolf Expedition 3(6):1-84, 4 pls.

Hart, J. F. L. 1930. Some Cumacea of the Vancouver Island Region. Contribution Canadian Biol. Fish. 6(3): 1-18, figs. 1-5.

Hedgpeth, J. W. 1957. Marine Biogeography. In: J. W. Hedgpeth ed. Treatise on Marine Ecology and Paleoecology Geological Society of America. Memoirs 67(1):359-382.

Holme, N. A. 1964. Methods of sampling the benthos. In: Advances in Marine Biology 2:171-260.

Holme, N. A. and A. D. McIntyre. 1971. Methods for the study of Marine benthos. IBP Handbook No. 16. Blackwell Scientific Publication, Oxford. 334 pp.

Hopkins, T. L. 1964. A survey of bottom samplers. Progress in Oceanography 2:215-256.

Jones, N. S. 1950. Marine bottom communities. Biological Reviews 25:283-313.

Klopfer, P. H. 1959. Evironmental determinates of faunal diversity. The American Naturalist 93:337-342.

Klopfer, P. H. and R. H. MacArthur. 1961. On the causes of tropical species diversity: niche overlap. The American Naturalist 95:223-226.

Kovacs, A. 1972. Ice scouring marks floor of the arctic shelf. Oil and Gas Journal, October, p. 92-106.

Lee, R. E. A. 1944. A quantitative survey of the invertebrate bottom fauna in Menemsha Bight. Biological Bulletin 86(2): 83-97.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington U.S.A. in 1963-1964. Fiskeridirektoratets Skrifter serie Havundersøkelser 14:229-556.

Lie, U. and M. M. Pamatmat. 1965. Digging characteristics and sampling efficiency of the 0.1 m^2 Van Veen grab. Limnology and Oceanography 10(3):379-384.

Lloyd, M. and R. J. Ghelardi. 1964. A table for calculating the equitability component of species diversity. Journal of Animal Ecology 33:217-225.

Lomakina, N. B. 1958. Kymovye raki (Cumacea) morei SSSR. Opredeliteli po Faune SSSR, Akademii Nauk SSSR 66:1-301, figs. 1-200. (In Russian)

Longhurst, A. R. 1959. The sampling problem in benthic ecology Proceedings of the New Zealand Ecological Society 6:8-12.

__________ 1964. A review of the present situation in benthic synecology. Bulletin Institute Oceanography Monaco 63(1317):1-54.

MacArthur, R. H. 1957. On the relative abundance of bird species. Natural Academy of Sciences Proceedings 43:293-295.

__________ 1964. Environmental factors affecting bird species diversity, The American Naturalist 98:387-397.

MacArthur, R. H. and J. W. MacArthur. 1961. On the bird species diversity. Ecology 42:594-598.

Margalef, R. 1963. On certain unifying principles in ecology. The American Naturalist 97:357-374.

Margalef, R. 1968. Perspectives in Ecological Theory. University of Chicago Press, Chicago. 111 pp.

McGinitie, G. E. 1939. Littoral marine communities. American Midland Naturalist 21:28-55.

McGinitie, G. E. 1955. Distribution and Ecology of the marine invertebrates off Point Barrow, Alaska. Smithsonian Miscellaneous Collection 128(9):1-201.

McIntosh, R. P. 1967. The continuum concept of vegetation. Botanical Reviews 33:130-187.

Mills, E. L. 1968. The community concept in marine zoology, with comments on continua and instability in some marine communities: a review. Journal of Fisheries Research Board Canada 26:1415-1428.

Molander, A. R. 1928. Animal communities on soft bottom areas in the Gullmar Fjord. Kristinebergs Zoologiska Station, 1877-1927. 2:1-90.

Mountain, D. G. 1974. Preliminary analysis of Beaufort shelf circulation in summer. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 27-42.

Naidu, A. S. 1974. Sedimentation in the Beaufort Sea: A synthesis. In: Y. Herman ed. Marine Geology and Oceanography of the Arctic Seas. p. 173-190.

Naidu, A. S. and T. C. Mowat. 1974. Clay mineralogy and geochemistry of continental shelf sediments of the Beaufort Sea. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 493-510.

Nansen, F. 1902. Oceanography of the North Polar Basin. Norwegian North Polar Expedition 1893-1896. Scientific Results 3(9), 427 pp.

Overton, S. 1973. Professor, Oregon State University. Department of Statistics. Lecture notes from Quantitative Ecology. Corvallis, Oregon.

Paine, R. T. 1966. Food web complexity and species diversity. The American Naturalist 100:65-76.

Petersen, C. G. 1911. Valuation of the sea. I. Animal life of the bottom, its food and quantity. Report Danish Biological Station 20:1-81.

_______________ 1913. Valuation of the Sea II. The animal communities of the sea bottom and their importance for marine zoogeography. Report Danish Biological Station 21:1-44.

Petersen, C. G. 1915. On the animal communities of the sea bottom in the Skagerrak, the Christiania Fjord and the Danish waters. Report Danish Biological Station 23:3-28.

______________ 1918. The sea bottom and its production of the fish food. A survey of the work done in connection with the evaluation of the Danish waters from 1883-1917. Report Danish Biological Station 25:1-62.

Pianka, E. R. 1966. Latitudinal gradients in species diversity: a review of concepts. The American Naturalist 100:33-46.

Preston, F. W. 1948. The commonness and rarity of species. Ecology 29:254-283.

______________ 1962. The canonical distribution of commonness and rarity. Part I. Ecology 43:185-215.

Remnitz, E. and P. W. Barnes. 1974. Sea ice as a geologic agent on the Beaufort Sea Shelf of Alaska. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 301-354.

Rhoads, D. C. and D. K. Young. 1970. The influence of deposit-feeding organisms on sedimentary stability and community trophic structures. Journal of Marine Research 28(2):150-178.

Sanders, H. L. 1956. The biology of marine bottom communities. Bulletin Bingham Oceanographic Collection 15:345-414.

______________ 1958. Benthic studies in Buzzards Bay. I. Animal sediment relationships. Limnology and Oceanography 3(3):245-258.

______________ 1968. Marine benthic diversity: a comparative study. The American Naturalist 102:243-282.

______________ 1969. Benthic marine diversity and the stability-time hypothesis. Brookhaven Symposia in Biology 22:71-80.

Sanders, H. L., P. C. Mangelsdorf and G. R. Hampson. 1965. Salinity and faunal distribution in Pocasset River, Massachusetts. Limnology and Oceanography 10(suppl.): R216-R229.

Sars, G. O. 1895. Amphipoda: An account of the Crustacea of Norway with short descriptions and figures of all species. 1:1-711, 240 pls.

________________ 1900. Cumacea: An account of the Crustacea of Norway with short descriptions and figures of all species. 3:1-115, 73 pls.

Shannon, C. E. and W. Weaver. 1963. The mathematical theory of communication. University Illinois Press. Urbana, Illinois. 117 pp.

Shelford, V. E., A. O. Weese, L. A. Rice, D. I. Rasmussen. A. MacLean, N. Wismer and J. H. Swanson. 1935. Some marine biotic communities of the Pacific Coast of North America. Ecological Monographs 5:251-354.

Shepard, F. P. 1954. Nomenclature based on Sand-Silt-Clay ratios. Journal of Sedimentary Petrology 24(3):151-158.

Shoemaker, C. R. 1955. Amphipoda collected at the Arctic Laboratory. Office of Naval Research, Point Barrow, Alaska, by Professor G. E. McGinitie. Smithsonian Miscellaneous Collection 128:1-78.

Simpson, E. H. 1949. Measurement of diversity. Nature 163:688.

Simpson, G. G. 1964. Species density of North American recent mammals. Systematic Zoology 13:57-73.

Smith, J. B. and R. G. Bader. 1961. Preliminary investigation of the association of organic material and carbon dioxide with sedimentary particles. Texas A. M. Research Foundation, Project 142. 221 pp.

Smith, W. and A. D. McIntyre. 1954. A spring loaded bottom sampler. Journal of the Marine Biological Association of the United Kingdom 33:257-264.

Sparck, R. 1933. Contributions to the animal ecology of the Franz Joseph Fjord and adjacent waters. I-II. Meddelesser om Grønland 100(1):1-38.

Stander, J. M. 1970. Diversity and similarity of Benthic Fauna off Oregon. M. S. Thesis, Department of Oceanography, Oregon State University, Corvallis, Oregon. 72 pp.

Stebbing, T. R. R. 1913. Cumacea. Das Tierreich, Lief. 39: 1-210. 137 figs.

Stephensen, K. 1923. Crustacea Malacostraca. V: Amphipoda I. Danish Ingolf-Expedition 3(8):1-100, 22 figs.

__________ 1925. Crustacea Malacostraca. VI: Amphipoda II. Danish Ingolf-Expedition 3(9):101-178, figs. 23-53.

__________ 1931. Crustacea Malacostraca. VII: Amphipoda III. Danish Ingolf-Expedition 3(11):179-290, figs. 54-81.

__________ 1944. Crustacea Malacostraca. VIII: Amphipoda IV. Danish Ingolf-Expedition 3(13):1-51, figs. 1-38.

Steven, G. A. 1930. Bottom fauna and the food of fishes. Journal of the Marine Biological Association of the United Kingdom 16:677-706.

Svardson, G. 1949. Competition and habitat selection in birds. Oikos 1:157-174.

Sverdrup, H. V. 1956. Oceanography of the Arctic. In: The Dynamic North (U. S. N., Chief Naval Operation, June 1956). Book I, Section V, 32 pp.

Thorson, G. 1933. Investigations on shallow water animal communities in the Franz Joseph Fjord (East Greenland) and adjacent waters. Meddelesser om Grønland 10(2):1-68.

__________ 1934. Contributions on the animal ecology of the Scoresby Sound Fjord complex (East Greenland). Meddelesser om Grønland 100(3):1-67.

__________ 1946. Reproduction and larval development in Danish marine bottom invertebrates. Meddelesser Kommisionen Danmark, Fiskeridirektoratets Sksifter Havunder-Søkelse, 1:1-523.

Thorson, G. 1957a. Sampling the benthos. In: J. W. Hedgpeth ed. Treatise on Marine Ecology and Paleoecology. Geological Society of America, Memoirs 67(1):61-73.

__________ 1957b. Bottom communities (sublittoral or shallow shelf). In: J. W. Hedgpeth ed. Treatise on Marine Ecology and Paleoecology. Geological Society of America Memoirs 67(1): 461-534.

__________ 1958. Parallel level-bottom communities, their temperature adaptation, and their balance between predators and food animals. Perspective in Marine Biology. Buzzati-Traverso ed. p. 67-86.

Thorson, G. 1966. Some factors influencing the recruitment and establishment of the marine benthic communities. Netherlands Journal of Sea Research 3:267-293.

Trask, P. D. 1955. Recent marine sediments: a symposium. American Association of Petroleum Geologists, Tulsa, Okalhoma. Dover Publications Inc. New York. 736 pp.

Ursin, E. 1954. Efficiency of marine bottom samplers of the Van Veen and Petersen types. Meddelesser fra Danmark Fiskeridirektoratets Havunder-Søkelse 1(7):3-7.

Vibe, Chr. 1939. Preliminary investigations on shallow water animal communities in the Upernavik and Thule districts (Northwest Greenland). Meddelesser om Grønland 124(2): 1-42.

Wacasey, J. W. 1974. Zoobenthos of the southern Beaufort Sea. In: J. C. Reed and J. E. Sater ed. The Coast and Shelf of the Beaufort Sea. Arctic Institute of North America. p. 697-704.

Whitehouse, V. G. 1955. Preliminary consideration of selected chemical and oceanographic factors influential in the formation of the alumino-silicate fraction of some recent sediments. Ph.D. Thesis. A. and M. College of Texas. 197 pp.

Whittaker, R. H. 1957. Recent evolution of ecological concepts in relation to the eastern forest of North America. American Journal of Botany 44:197-206.

Whittaker, R. H. 1962. Classification of natural communities. Botanical Reviews 28:1-239.

Wigley, R. L. 1967. Comparative efficiencies of Van Veen and Smith-McIntyre grab samplers as revealed by motion pictures. Ecology 48:168-169.

Wilson, D. P. 1937. The influence of the substratum on the metamorphosis of Notomastus larvae. Journal of the Marine Biological Association of the United Kingdom 22:227-243.

__________ 1948. The relation of the substratum to the metamorphosis of Ophelia larvae. Journal of the Marine Biological Association of the United Kingdom 27:723-760.

__________ 1952. The influence of the nature of substratum on the metamorphosis of the larvae of marine animals, especially the larvae of Ophelia bicornis Savigny. Annals de l'Institute Oceanographic 27(2):49-156.

Williams, C. B. 1964. Patterns in the Balance of Nature. Academic Press, New York. 324 pp.

Wiseman, W. J., Jr., J. M. Coleman, A. Gregory, S. A. Hsu, A. D. Short, J. N. Suhayda, C. D. Walters and L. D. Wright. 1973. Alaskan arctic coastal processes and morphology. Louisiana State University. Coastal Studies Institute. Technical Report 149:1-171.

Worthington, L. V. 1953. Oceanographic results of project Skijump I and Skijump II in the Polar Sea, 1951-1952. Transactions American Geophysical Union 34:543-551.

Zenkevitch, L. 1963. Biology of the Seas of the USSR. Interscience Publishers, John Wiley, New York 955 pp.

Zimmer, C. 1926. Northern and Arctic invertebrates in the collection of the Swedish State Museum. Cumaceen. Svenska Vetenskapsakad Handlinger 3(3):1-88, 97 figs.

APPENDICES

APPENDIX I

List of Amphipoda and Cumacea species in the western Beaufort Sea

Phyllum Arthropoda
Class Crustacea
Order Amphipoda
Family Acanthonotozomatidae
Acanthonotozama inflatum (Kroyer)
Acanthonotozoma serratum (Fabricius)
Odius carinatus (Bate)
Family Ampeliscidae
Ampelisca birulai Bruggen
Ampelisca eschrichti Kroyer
Ampelisca macrocephala Liljeborg
Byblis gaimardi (Kroyer)
Byblis sp A
Byblis sp B
Byblis sp C
Byblis sp D
Haploops laevis Hoek
Haploops setosa Boeck
Haploops tubicola Liljeborg
Family Aoridae
Lembos arcticus (Hansen)
Family Argissidae
Argissa hamatipes (Norman)
Family Atylidae
Atylus smitti (Goes)
Family Calliopiidae
Apherusa sarsi Shoemaker
Family Corophiidae
Corophium acherusicum Costa
Ericthonius tolli Bruggen
Gammaropsis melanops G. Sars
Goesia depressa (Goes)
Neohela monstrosa (Boeck)
Photis reinhardi Kroyer
Podoceropsis lindahli Hansen
Protomedeia fasciata Kroyer
Protomedeia grandimana Bruggen

Unciola leucopis (Kroyer)
Family Dexaminidae
Guernea nordensjoldi (Hansen)
Family Eusiridae
Rhachotropis aculeata (Lepechin)
Rozinante fragilis (Goes)
Family Gammaridae
Maera danae (Stimpson)
Melita dentata (Kroyer)
Melita formosa Murdoch
Family Haustoriidae
Pontoporeia femorata Kroyer
Family Ischyroceridae
Ischyrocerus commensalis Chevreux
Ischyrocerus latipes Kroyer
Family Liljeborgidae
Liljeborgia fissicornis (M. Sars)
Family Lysianassidae
Acidostoma laticorne G. Sars
Anonyx debruynii
Anonyx nugax (Phipps)
Aristias tumida (Kroyer)
Centromedon pumilus (Liljeborg)
Hippomedon abyssi Frost
Hippomedon holbolli (Kroyer)
Onisimus affinis Hansen
Onisimus plautus (Kroyer)
Orchomene serrata (Boeck)
Orchomenella groenlandica Hansen
Orchomenella minuta (Kroyer)
Paronesinus barentsi Stebbing
Tmetonyx cicada (Fabricius)
Tryphosella groenlandica Schell
Tryphosella pusilla G. Sars
Tryphosella rusanovi Gurjanova
Family Oedicerotidae
Acanthostepheia malmgreni (Goes)
Aceroides latipes G. Sars
Arrhis luthke Gurjanova
Arrhis phyllonyx (M. Sars)
Bathymedon obtusifrons (Hansen)
Monoculodes latimanus (Goes)
Monoculodes longirostris (Goes)
Monoculodes packardi Boeck
Monoculodes schneideri (G. Sars)

Monoculodes tuberculatus Boeck
Paroediceros lynceus (M. Sars)
Paroediceros propinquus (Goes)
Westwoodilla megalops G. Sars
Family Pardaliscidae
Pardalisca cuspidata Kroyer
Pardalisca tenuipes G. Sars
Pardaliscella lavrovi Gurjanova
Pardaliscella malygini Gurjanova
Family Phoxocephalidae
Harpinia kobjakovae Bulycheva
Harpinia mucronata G. Sars
Harpinia serrata G. Sars
Paraphoxus oculatus G. Sars
Family Pleustidae
Parapleustes assimilis (G. Sars)
Parapleustes gracilis (Buchholz)
Sympleustes karianus Stappers
Family Podocaridae
Dulichia falcata (Bate)
Dulichia spinosa Stephensen
Dulichia tuberculata Boeck
Paradulichia spinifera Gurjanova
Family Stegocephalidae
Stegocephalus inflatus Kroyer
Family Stenothoidae
Metopa robusta G. Sars
Metopa spinicoxa Shoemaker
Metopella carinata (Hansen)
Metopella nasuta (Boeck)
Family Syrrhoidae
Syrrhoe crenulata Goes
Tiron spiniferum (Stimpson)

Order Cumacea
Family Diastylidae
Brachydiastylis nimia Hansen
Brachydiastylis resima (Kroyer)
Diastylis aspera Calman
Diastylis bidentata Calman
Diastylis edwardsi (Kroyer)
Diastylis glabra Zimmer
Diastylis goodsirii (Bell)
Diastylis nucella Calman
Diastylis oxyrhincha Zimmer

Diastylis polita (Smith)
Diastylis rathkei (Kroyer)
Diastylis scorpioides (Lepechin)
Diastylis spinulosa Heller
Diastylis tumida (Liljeborg)
Leptostylis sp A
Leptostylis sp B
Makrokylindrus sp A
Makrokylindrus sp B

Family Lampropidae
Lamprops fasciata G. Sars

Family Laudonidae
Eudorella arctica Hansen
Eudorella emarginata (Kroyer)
Eudorella gracilis G. Sars
Eudorella groenlandica Zimmer
Eudorella parvula Hansen
Eudorella pusilla G. Sars
Eudorella truncatula (Bate)
Eudorellopsis integra (Smith)
Leucon acutirostris G. Sars
Leucon fulvus G. Sars
Leucon laticauda Lomakina
Leucon nasica (Kroyer)
Leucon nasicoides Liljeborg
Leucon nathorsti Ohlin
Leucon pallidus G. Sars
Leucon sp A

Family Nannastacidae
Campylaspis rubicunda (Liljeborg)
Cumella carinata (Hansen)

Family Pseudocumatidae
Petalosarsia declivis (G. Sars)

APPENDIX II: Station Data Summary

Station no.	No. of species	No. of individuals per m^2	$Sd^2 \times 10^4$	Simpson Density-Diversity Index SDI $\times 10^4$	Shannon-Wiener Diversity Index $H'_e \times 10^4$
1	20	90	756	9244	27672
3	38	650	881	9119	28594
5	19	170	1939	8061	22366
6	3	14	4286	5714	9557
7	7	26	1716	8284	18446
8	26	170	815	9185	28440
9	35	248	745	9255	30743
12	11	80	3813	6187	15394
14	12	62	1717	8283	20578
17	29	158	707	9293	29754
18	18	94	1344	8656	24086
19	6	96	3915	6085	12665
20	2	38	5679	4321	6237
23	16	108	1475	8525	22431
25	18	112	1250	8750	24406
27	24	136	1497	8503	25189
28	28	178	1292	8708	26533
29	8	46	1834	8166	18575
30	16	166	1854	8146	20517
31	35	224	579	9421	31683
42	32	302	2106	7894	23271
44	46	712	1579	8421	27420
48	11	98	3053	6947	16503
57	8	64	2324	7676	16854

APPENDIX II. (Continued).

Station no.	No. of species	No. of individuals per m^2	$Sd^2 \times 10^4$	Simpson Density-Diversity Index SDI $\times 10^4$	Shannon-Wiener Diversity Index $H'_e \times 10^4$
58	13	82	1220	8780	22866
60	28	438	1061	8939	26599
61	32	364	1767	8233	24532
63	11	48	1528	8472	21266
71	7	26	2189	7811	17327
72	30	596	1320	8680	25026
74	36	438	981	9019	28138
75	32	294	1000	9000	28273
76	48	564	395	9605	24687
78	12	46	1380	8620	22234
80	20	494	2887	7113	17024
82	31	448	1415	8585	25301
83	12	104	3055	6945	17065
84	10	154	3520	6480	14463
85	8	50	2000	8000	17988
86	6	58	4339	5661	12226

APPENDIX III: Environmental Data Summary

Station no.	Mean depth (m)	Depth range (m)	Temperature (°C)	Salinity (°/₀₀)	Organic Carbon (%) of sediment weight	$CO_3^=$ (%) of sediment by weight
1	33	2	-1.33	31.377	0.89	5.29
3	48	0	-1.46	31.576	0.98	6.60
5	106	4	-1.20	------	0.15	3.35
6	495	4	0.33	34.880	0.71	2.60
7	463	33	0.36	34.867	1.08	2.07
8	83	4	-1.23	32.575	0.39	5.74
9	57	1	-1.36	31.771	----	----
12	26	0	-1.33	30.827	0.64	6.29
14	27	1	-1.44	31.342	----	----
17	46	0	-----	------	----	----
18	142	22	-----	------	0.00	10.38
19	631	112	-0.02	35.010	----	----
20	2572	533	-0.27	34.921	1.07	2.36
23	27	1	-1.29	31.360	0.07	10.56
25	26	0	-1.27	31.064	0.00	9.81
27	50	1	1.09	31.756	0.10	7.74
28	103	44	-0.80	32.392	----	----
29	354	80	0.36	34.990	0.67	2.47
30	99	26	-0.95	32.581	0.95	3.09
31	52	1	0.94	31.812	----	----
42	130	72	-0.73	32.375	----	----
44	47	1	-----	------	0.04	7.60
48	25	0	-0.75	30.987	----	----
57	1866	173	-----	-------	1.20	1.41
58	700	497	0.38	34.960	1.03	1.87

APPENDIX III. (Continued).

Station	Mean depth (m)	Depth range (m)	Temperature (°C)	Salinity (°/oo)	Organic Carbon (%) of sediment weight	$CO_3^{=}$ (%) of sediment by weight
60	64	2	-----	------	----	----
61	50	1	-----	------	----	----
63	23	1	-1.02	31.273	0.00	6.59
71	21	4	2.22	30.268	0.81	6.61
72	45	0	-0.88	32.569	0.87	2.98
74	101	3	-1.33	33.030	1.00	2.56
75	136	8	-1.23	32.858	0.88	3.34
76	47	2	-----	------	----	----
78	28	1	1.40	31.015	1.12	3.36
80	30	1	1.90	31.187	0.91	2.54
82	44	1	-----	------	----	----
83	202	63	-1.41	33.275	----	----
84	689	0	0.30	34.920	0.75	2.05
85	876	202	-----	------	0.98	1.98
86	2297	331	-----	------	0.73	3.61

APPENDIX IV: Sediment Data Summary

Station no.	Gravel %	Sand %	Silt %	Clay %	Sorting
1	----	35.8	36.3	23.9	3.19
3	10.0	39.6	15.3	35.0	4.27
5	6.2	3.9	23.7	66.1	----
6	0.0	1.5	32.2	66.3	1.41
7	0.0	0.6	33.3	66.1	1.41
8	2.8	48.5	24.1	24.5	3.00
9	20.4	40.5	15.9	23.1	4.89
12	0.0	24.9	41.2	33.8	2.72
14	7.8	15.3	40.5	36.3	3.66
17	0.0	39.4	25.5	35.0	3.10
18	18.0	12.1	40.0	30.0	6.08
19	0.0	2.0	52.0	46.0	2.03
20	0.0	0.4	35.4	64.2	1.51
23	18.1	18.1	23.7	40.0	5.06
25	3.1	13.2	39.8	43.9	2.90
27	31.5	49.7	7.8	11.0	4.47
28	0.0	39.6	30.0	30.3	3.11
29	0.0	6.1	44.8	49.1	2.23
30	0.0	50.3	21.9	27.8	2.72
31	0.0	42.2	22.2	35.6	2.91
42	----	----	----	----	----
44	20.3	32.7	24.8	22.0	5.57
48	8.3	21.0	36.9	33.7	3.96
57	0.0	0.6	38.3	61.1	1.81
58	0.0	0.8	44.5	54.7	2.05
60	39.1	22.6	18.4	19.9	5.66
61	0.0	48.9	29.3	21.7	2.83
63	0.0	7.2	40.8	52.0	2.24
71	0.0	25.3	46.4	28.2	2.54
72	0.0	6.7	48.5	44.8	2.21
74	2.2	19.3	46.9	31.5	3.07
75	2.6	22.4	42.0	32.8	2.96
76	----	----	----	----	----
78	----	----	----	----	----
80	3.2	11.0	39.4	46.3	2.62
82	0.0	26.6	39.3	34.0	2.71
83	0.0	11.9	44.6	43.5	2.31
84	0.0	0.8	45.4	53.7	2.05
85	0.0	0.7	44.7	54.6	1.74
86	----	----	----	----	----

APPENDIX V: Station List

Station no.	Date	Latitude N	Longitude W	No. of samples
CG 01	8/19/71	70° 15.5'	143° 39.6'	5
CG 03	8/20/71	70° 27.0'	143° 34.0'	5
CG 05	8/20/71	70° 34.6'	143° 38.0'	5
CG 06	8/21/71	70° 45.6'	143° 35.4'	5
CG 07	8/21/71	71° 00.5'	145° 35.0'	5
CG 08	8/22/71	70° 48.5'	145° 56.1'	5
CG 09	8/22/71	70° 44.0'	145° 52.0'	5
CG 12	8/22/71	70° 18.0'	146° 05.0'	5
CG 14	8/23/71	70° 25.0'	147° 05.0'	5
CG 17	8/23/71	70° 50.0'	147° 06.6'	6
CG 18	8/23/71	70° 56.3'	147° 05.8'	5
CG 19	8/24/71	71° 00.0'	147° 04.0'	3
CG 20	8/25/71	71° 19.3'	147° 47.1'	5
CG 23	8/27/71	70° 38.4'	148° 04.0'	5
CG 25	8/28/71	70° 31.2'	147° 31.2'	5
CG 27	8/29/71	70° 56.2'	147° 19.0'	5
CG 28	8/29/71	70° 59.0'	147° 24.0'	5
CG 29	8/29/71	70° 08.7'	148° 00.4'	5
CG 30	8/30/71	71° 06.0'	147° 57.0'	5
CG 31	8/30/71	71° 01.0'	147° 59.0'	5
CG 42	8/31/71	71° 12.0'	148° 36.0'	5
CG 44	8/31/71	71° 01.0'	148° 22.7'	5
CG 48	9/01/71	70° 43.4'	148° 41.5'	5
CG 57	9/04/71	71° 21.2'	149° 30.4'	5
CG 58	9/05/71	71° 14.5'	149° 24.3'	5
CG 60	9/06/71	71° 12.0'	149° 15.0'	5
CG 61	9/06/71	71° 10.0'	149° 18.9'	5
CG 63	9/07/71	70° 43.0'	149° 00.0'	5
CG 71	9/09/71	71° 04.1'	151° 22.1'	5
CG 72	9/09/71	71° 09.9'	151° 09.1'	5
CG 74	9/10/71	71° 19.6'	151° 09.1'	5
CG 75	9/10/71	71° 14.8'	150° 27.6'	5
CG 76	9/10/71	71° 08.4'	150° 50.1'	5
CG 78	9/11/71	70° 58.1'	149° 59.1'	5
CG 80	9/11/71	70° 55.7'	149° 23.2'	5
CG 82	9/11/71	71° 08.3'	149° 47.7'	5
CG 83	9/11/71	71° 12.2'	149° 44.8'	5
CG 84	9/12/71	71° 17.5'	150° 20.0'	5
CG 85	9/12/71	71° 22.0'	150° 38.0'	5
CG 86	9/14/71	71° 46.0'	150° 35.0'	4