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OUTER CONTINENTAL SHELF ENERGY PROGRAM

NOAA/BLM

FINAL REPORT

Contract No. 03-5-022-68
Task Order No. 4
1 April 1975 - 31 March 1976

Summarization of existing literature and unpublished data on the distribution, abundance, and life histories of benthic organisms (Beaufort Sea)

VOLUME I
Narrative

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General Introduction

The following document is the final report of Research Contract No. 03-5-022-68 (Task Order No. 4) completed by the Oregon State University Benthic Ecology Group for the National Oceanic and Atmospheric Administration under the auspices of the Bureau of Land Management. This final report is a summary of the present state of knowledge of the benthic ecology of the outer continental shelf of the Beaufort Sea. The report is divided into four volumes:

I. A narrative which summarizes the present state of knowledge of the structure and composition of benthic communities living on the Beaufort Sea continental shelf.

II. A list which summarizes from published and unpublished literature the benthic invertebrate species reported from the Beaufort Sea.

III. An atlas of distribution charts summarizing the distributions of selected benthic organisms reported by investigators recently active in the Beaufort Sea.

IV. An annotated bibliography summarizing the existing scientific literature on the Beaufort Sea benthos.

The total length of this final report is 789 pages.

TABLE OF CONTENTS

VOLUME I: NARRATIVE

VOLUME II: SPECIES LISTS

VOLUME II (continued)

VOLUME III Part A. SPECIES DISTRIBUTION CHARTS

VOLUME III Part B. SPECIES DISTRIBUTION CHARTS

VOLUME III Part C. SPECIES DISTRIBUTION CHARTS

VOLUME IV Part A. BIBLIOGRAPHY INDEX

VOLUME IV Part B. ANNOTATED BIBLIOGRAPHY

ABSTRACT

Quantitative benthic sampling has only recently been initiated across the Beaufort Sea continental shelf. Initial results outline a diverse benthic fauna occurring in overlapping bands which tend to follow the depth contours. Highs in biomass and numerical abundance are reported from the outer shelf below the area subject to impinging ice and dilution effects, and from the very shallow protected bays near the mouth of the Mackenzie River. Continued work is indicated to adequately describe the benthic fauna, and particularly the infaunal organisms smaller than 1.00 mm. Basic information is needed on the metabolism and reproductive rates of the bottom-dwelling invertebrates. An understanding of the dynamics of the benthic ecosystem is necessary to predict the ultimate impact of a developing petroleum industry in the region.

Section I. NARRATIVE

1. History of the Benthic Sampling in the Beaufort Sea

Until recently, few samples of the benthic fauna had been obtained from the Beaufort Sea. The lack of early extensive marine research in this area could be directly attributed to the great difficulties and expenses involved in sampling this ice dominated and relatively inaccessible portion of the Arctic Ocean. As a result, knowledge of the benthic community structure and species composition lagged far behind that of comparable northern areas such as the White Sea or the waters around Greenland. With the discovery and planned utilization of petroleum resources across the north Alaska coast, however, the need for additional intensive biological and oceanographic research has become readily apparent.

Benthic invertebrate samples were collected in the early 1880's by the U.S. Coast and Geodetic Survey schooner YUKON (1880), by the revenue steamer CORWIN (1884 and 1885) , and by members of the International Polar Expedition to Point Barrow (1881-1883). These early qualitative samples yielded only a limited number of species of echinoderms, worms, crustaceans, and molluscs. The samples served as a guide to some of the more commonly encountered marine invertebrates, but did little to elucidate the ecology of the region.

The next major sampling effort occurred during the Canadian Arctic Expedition of 1913-1918. The southern party passed along the northern coast of Alaska en route to the Canadian Archipelago, and benthic samples were obtained along the Beaufort Sea continental shelf at intervals between Point Barrow and the Mackenzie River delta. These numerous collections of marine organisms were forwarded to a number of taxonomic specialists who produced a series of reports printed by the Canadian government between the years 1919 and 1924. Volumes VII through IX of these reports recorded taxonomic descriptions with notes on natural history for arctic species representing the majority of the invertebrate phyla.

Little additional sampling was accomplished in the Beaufort Sea until the late 1940's, when Dr. G.E. MacGinitie initiated an extensive study to decribe the benthic invertebrate fauna in the Point Barrow region (MacGinitie, 1955). Between 1948 and 1950, MacGinitie sampled during both summer and winter months using dredges as well as small bottom grabs and under-ice traps. Observations were made on the natural history of the benthic organisms, including notes on distribution, abundances and reproductive activity. These data, confined to the limited area around Point Barrow, have provided the only overview of the benthic processes available from the Alaskan arctic. Until very recently, these few observations have had to suffice for all ecological generalizations made across the entire Beaufort Sea.

Only sporatic benthic sampling was undertaken during the 1950's and 1960's. The CGMV CANCOLIN occupied a single station on the continental shelf in 1951-52. Trawl samples were obtained in Beaufort coastal waters in 1953 during a U.S. Coast and Geodetic Survey cruise aboard the LCM RED. Orange peel grab samples and beam trawl collections were taken by Neave in 1954 aboard the USCGC NORTHWIND as part of the Canadian-United States Beaufort Sea Expedition in 1954. Cruises by the Canadians on the M/V SALVELINUS and M/V CALANUS were used to sample extensively throughout the Canadian arctic and several times into the Beaufort Sea (Curtis, 1975). The Fisheries Research Board of Canada conducted trawling surveys with the M/V SALVELINUS as far westward as Herschel Island near the U.S. -Canadian border. Most of these trawl hauls were at depths between 10 and 60 meters, although some were as deep as 200 meters (Squires, 1969) .

The only collections of the benthos made at abyssal depths were taken from the U.S. ice stations Bravo and T-3 (George and Paul, 1970; Paul and Menzies, 1974). These samples were collected in the Alpha Cordillera region of the high arctic north of Ellesmere Island as the stations drifted in the Beaufort gyre. This area is beyond the generally described limits of the Beaufort Sea, but they provide data on components of the deep-sea fauna that can be expected to appear as sampling progresses into the deeper sectors of the Beaufort.

Recently, as a result of the petroleum discoveries along the Alaskan north slope, there has been a marked increase in the oceanographic investigations throughout the Beaufort Sea. The exploration and planned development of large oil and gas deposits have directly stimulated marine environmental research, including detailed work on benthic ecology and systematic. As the shelf waters of the Beaufort have become more and more accessible, investigators in both the U.S. and Canada have become engaged in describing the benthic ecosystem.

Extensive sampling of the benthic invertebrate fauna was initiated by Carey in 1971 and 1972 during the Western Beaufort Sea Ecological Cruises aboard the USCGC GLACIER (Carey, et al., 1974; Carey and Ruff, unpubl. ms.). Grab stations were occupied across the shelf and down the continental slope to depths exceeding 2000 meters between Cape Halkett and Barter Island

(Fig. 1) . Additional stations were occupied where open water conditions permitted the use of otter trawls from the icebreaker (Fig. 2). Near-shore benthic sampling surveys have been undertaken by several groups, especially in regions of immediate pollution concern. These areas have included the -lagoons and barrier islands around the mouth of the Colville River sampled by the University of Alaska with otter and beam trawls (Crane and Cooney, 1974; Crane, 1974). Particular emphasis has been placed on the Prudhoe Bay area. Feder sampled in and around the bay using divers, traps, a Fager corer and an airlift system (Feder, Shaw, and Naidu, 1976). Woodward-Clyde Consultants have collected additional samples from the area adjacent to the ARCO causeway (personal communication, letter Nov. 8, 1976).

Research has also progressed in the Canadian sector of the Beaufort Sea. Beginning in 1971, the Canadian Dept. of the Environment has occupied stations throughout the Mackenzie River delta, the Eskimo Lakes region east of the Tuktoyaktuk Peninsula, and across much of the south-eastern continental shelf (Fig. 3) . Quantitative benthic sampling under the direction of J.W. Wacasey has been accomplished at these stations from a variety of research vessels, and has included observations made from the research submersible PISCES Iv (Wacasey, 1975).

Figure 1. Sampling stations occupied with a Smith-McIntyre grab in 1971 from the USCGC GLACIER

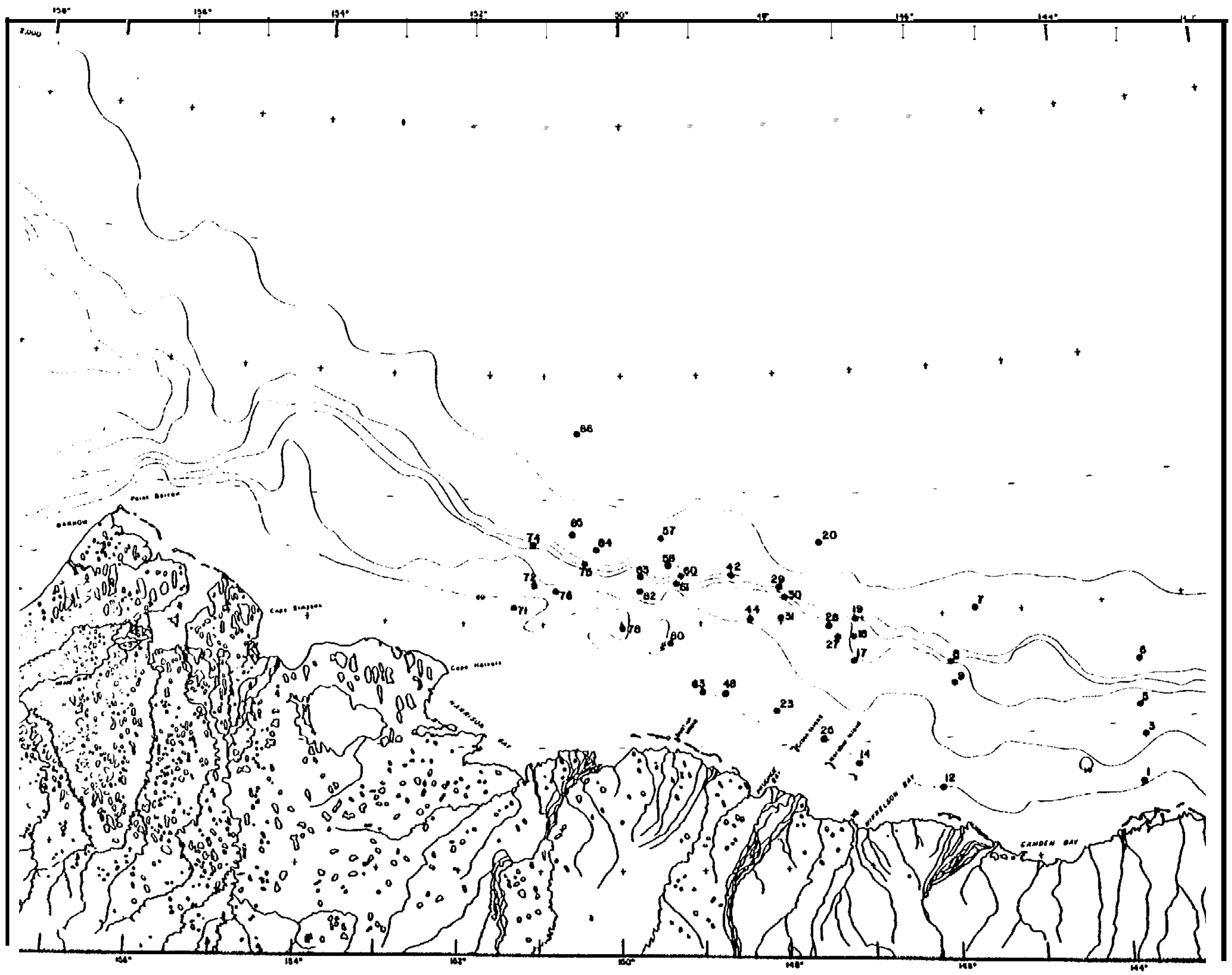


Figure 2. Otter trawl sampling locations occupied in 1971 and 1972 from the USCGC GLACIER.

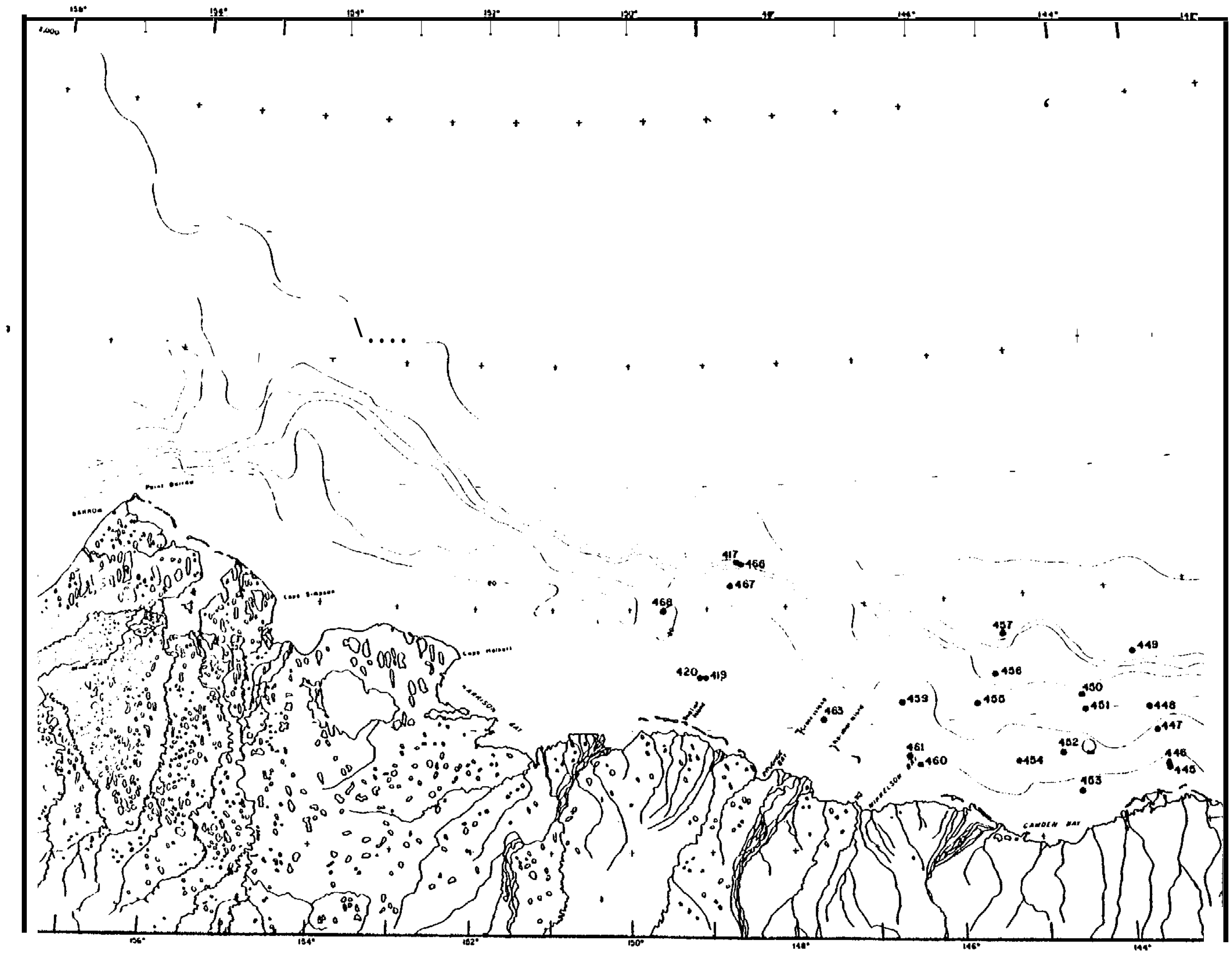
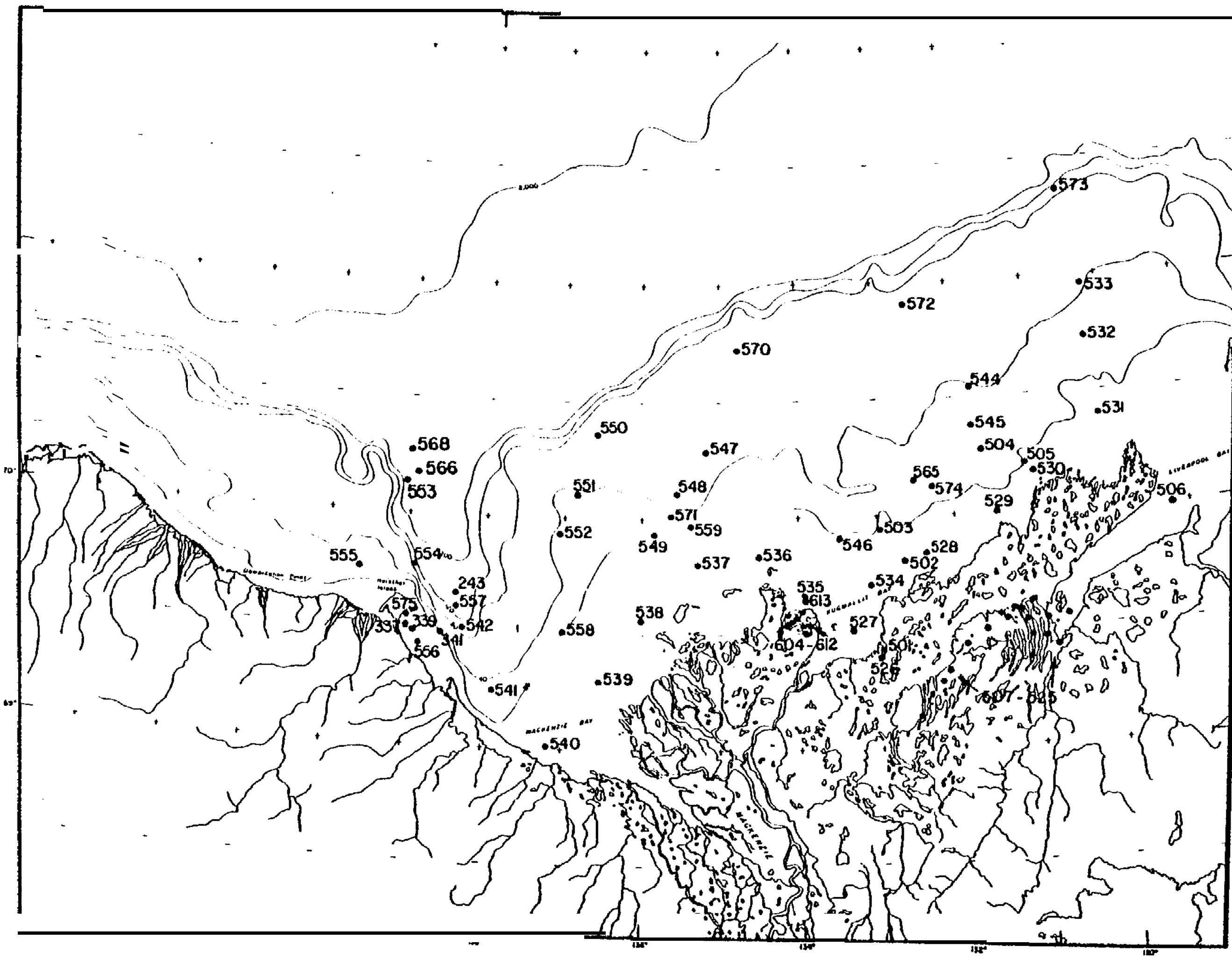


Figure 3. Sampling stations occupied by J.W. Wacasey from small vessels and the research submersible PISCES IV.



2. Recent Work on Benthic Community Structure and Composition

Prior to 1971, benthic sampling in the Beaufort Sea was both sporatic and qualitative in nature. The information derived constituted a faunistic survey, and did little to elucidate the ecology of the region. With the initiation of more recent projects, however, investigators have begun to take a closer look at the community structure and composition of the benthos across the Beaufort.

In 1974, Feder examined the benthic infauna in the nearshore marine environment in Prudhoe Bay. Much of the area is covered with ice for a large part of the year, and no macrofaunal marine invertebrates were reported in the intertidal zone or within the beach sediments. In general, very low total benthic biomass was encountered, although the numbers of organisms, biomass, and species diversity did increase with increasing distances from shore. Feder suggested that the broad distribution of shallow invertebrate species along the Alaskan coast pointed toward a widely dispersed stock available for the immediate repopulation of ice stressed areas.

Carey sampled across the Beaufort Sea continental shelf using trawls and a quantitative grab sampler in depths as shallow as 20 meters. Results from grabs taken in 1971 between Cape Halkett and Barter Island indicated high numbers of benthic infaunal organisms on the outer portion of the continental shelf and over the shelf break (Table 1). These values were comparable with other arctic and subarctic regions. Both biomass and numbers of organisms dropped to low values further down the continental slope, and were also depressed in the shallowest shelf stations, suggesting the possible destructive effects of grounding ice floes.

Table 1. Average numerical densities and biomass reported for the benthic macro-infauna in the southwestern Beaufort Sea at stations occupied by Carey in 1971. All invertebrates retained on a 1.00 mm sieve are included with the exception of single organisms weighing more than 5.0 grams. Biomass is recorded as wet preserved weight, and includes shells and worm tubes.

Station	Depth (m)	Number of Samples	Density (No./m^2)	Standard Deviation	Biomass (g/m^2)	Standard Deviation
1	33	2	2060	110	120	42
5	106	4	1280	490	59	9
6	495	5	1490	250	14	4
7	460	5	1730	420	20	3
8	84	5	1400	310	89	25
9	57	5	1830	600	111	73
12	26	4	1850	610	45	22
14	27	5	1620	1510	27	13
17	46	5	1990	520	52	11
18	146	2	1800	200	38	10
19	635	3	1960	840	18	10
20	2600	3	270	90	4	3
23	27	5	910	240	11	6
25	26	5	1120	920	26	29
27	50	5	1870	370	38	3
28	107	3	2130	530	65	31
29	360	5	2380	950	82	28
30	100	4	2300	2000	79	38
31	52	2	1760	850	36	12
42	140	3	2570	1170	227	117
44	47	3	2750	1110	66	22
48	25	2	880	960	102	38
57	1700	3	1730	590	17	16

Table 1. (continued)

Station	Depth (m)	Number of Samples	Density (No. /m^2)	Standard Deviation	Biomass (g/m^2)	Standard Deviation
58	700	5	4330	1280	90	44
61	50	5	2260	950	59	25
63	23	5	1570	1350	49	39
71	21	5	780	200	28	25
72	45	5	1950	340	61	8
74	101	1	4450	---	194	---
75	135	5	2730	460	88	27
76	47	5	2900	590	57	24
78	27	5	600	400	9	7
80	30	5	1740	840	41	25
82	44	5	2260	450	60	22
83	200	5	3010	1270	82	23
84	750	5	4210	2720	46	33
86	2300	1	330	---	16	---

Results from trawls taken by Carey in 1971 and 1972 indicated that many of the larger epifaunal organisms were found in depth zones which occurred in bands with overlapping distributions across the shelf. Possible correlations with environmental parameters were suggested, including the fresh water or food input from rivers, effects of oceanic water masses, and the local substrate encountered.

Benthic studies have also been conducted in the south eastern portion of the Beaufort Sea since 1971. Results reported by Wacasey from stations ranging from 1 to 400 meters (Table 2) have indicated that the area can be divided into four distinct areas:

Estuarine zone - characterized by lowered nutrient values and unstable temperature and salinity conditions. This nearshore region is greatly influenced by the freshwater runoff from coastal rivers.

Transitional zone - exhibits smaller temperature and salinity fluctuations, but is the area of most intense ice scour.

Marine zone - occupies the outer portion of the continental shelf, and is a region with much more stable conditions.

Continental slope zone - occurs beyond the shelf break and down the slope. This zone is defined by the presence of benthic species that are rare or absent from the shallower water. The depth of this zone was not determined, but it may coincide with the intermediate layer of Atlantic water encountered between 200 and 900 meters.

Comparison of benthic infauna data obtained by Carey and Feder in the western Beaufort and Wacasey in the southeastern sector reveals an overall similarity in trends of numerical abundance and biomass (Figs. 4-7). Wacasey reports very low species diversity and a total biomass averaging less than $2 g/m^2$ from depths less than 15 meters. Although Carey did not sample in this shallow zone, these results are in good agreement with the values obtained by Feder in Prudhoe Bay at similar depths. Both investigators noted that the values tended to increase with increasing depth and

Table 2. Average numerical densities and biomass reported for the benthic invertebrates in the southeastern Beaufort Sea at stations sampled by Wacasey between 1971 and 1975. Abundance figures include all organisms larger than 0.50 mm. Biomass is reported as dry organic weight excluding tubes and calcareous shells.

Station	Depth (m)	Number of Samples	Density (No./m^2)	Biomass (g/m^2)
501	24	6	2125	0.04
502	10	6	2270	1.89
503	19	6	1185	2.59
504	38	6	1088	13.57
505	17	6	1665	2.67
506	13	6	5095	15.89
507	25	5	16,434	141.61
508	20	28	7829	5.70
509	72	6	9712	‘3.37
510	58	17	6866	12.90
511	16	6	12,735	4.19
512	29	5	2616	4.73
513	25	5	753	0.27
514	43	5	2322	0.96
515	43	15	2546	1.94
516	11	5	22,662	297.08
517	7	5	9219	1.89
518	12	5	2118	2.61
519	43	5	1593	5.37
520	43	5	10,581	7.58
521	7	5	12,501	4.23
522	23	5	7149	3.54
523	9	5	4686	1.39
524	6	5	3513	1.37
525	9	5	7446	4.40

Table 2. (continued)

Station	Depth (m)	Number of Samples	Density (No. /m^2)	Biomass (g/m^2)
526	8	5	4752	0.95
527	5	5	1360	1.77
528	7	5	1456	0.40
529	12	5	4916	7.28
530	9	5	5336	1.42
531	15	5	3064	3.90
532	36	5	12,296	51.25
533	42	5	8724	71.37
534	7	5	4908	3.52
535	6	5	5944	6.39
536	9	5	4320	5.40
537	9	5	4344	0.88
538	5	5	432	1.35
539	3	5	88	0.02
540	4	5	1012	0.14
541	34	5	1756	5.44
542	94	5	5764	11.79
544	41	4.5	4963	31.20
545	37	4	2044	12.53
546	21	4	1828	4.30
547	56	4	1744	3.01
548	44	4	2008	1.32
549	24	4	1052	7.86
550	58	4	1372	1.66
551	42	4	1052	2.70
552	40	4	1256	1.86
553	215	3.5	1125	3.76
554	106	3.5	552	1.03

Table 2. (continued)

Station	Depth (m)	Number of Samples	Density (No. /m^2)	Biomass (g/m^2)
555	34	3.5	1218	5.50
556	54	4	904	1.87
557	125	3	3970	10.22
558	23	4	1296	1.95
559	32	4	1304	2.32
565	31	4	312	7.96
566	318	4	1356	3.57
568	408	4	1293	7.68
569	441	3	1024	0.82
570	55	3	244	6.40
571	37	3	492	1.74
572	65	3	11	37.53
573	7a	3	2944	18.68
574	32	3	168	0.78
575	10	3	1320	4.28
604	4	4	8964	8.31
605	15	4.5	2849	0.04
606	15	4.5	14,175	1.26
607	26	4.5	770	0.06
608	4	4.5	4021	2.63
609	11	4.5	1229	0.90
610	18	4.5	7144	0.54
611	3	4.5	11,441	20.73
612	7	4.5	1501	7.93
613	4	4.5	4434	1.77

Figure 4. Numerical abundance of the benthic infaunal organisms found at stations occupied on the Beaufort Sea continental shelf and slope by Carey in 1971, and in Prudhoe Bay by Feder in 1974. All invertebrates retained on a 1.00 mm mesh sieve are reported.

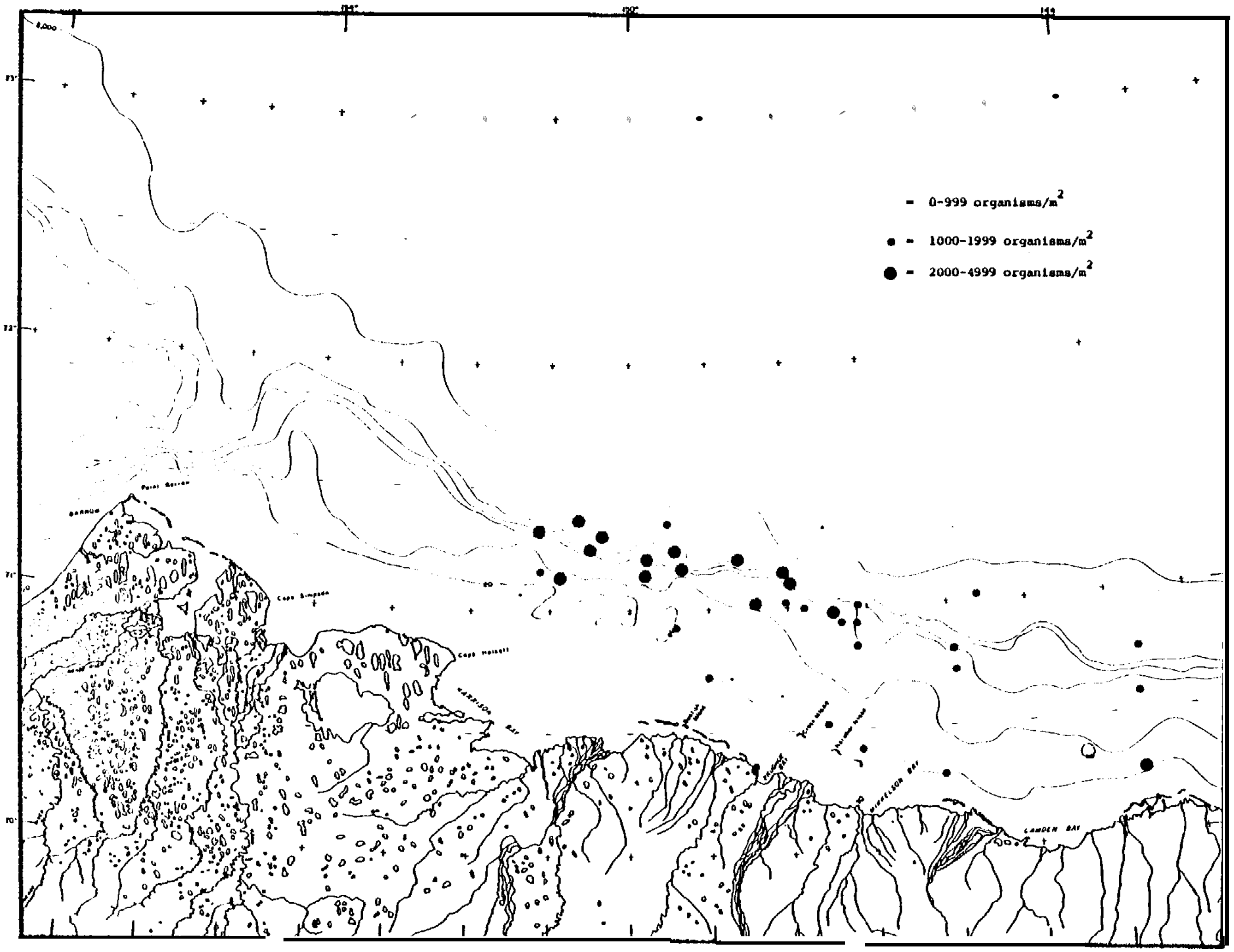


Figure 5. Biomass of the benthic infaunal organisms found at stations occupied across the continental shelf and slope by Carey in 1971, and in Prudhoe Bay by Feder in 1974. Values reported by Carey in in grams/m^2 wet preserved weight, and include tubes, shells, and other hard parts, but exclude the rare, single organisms weighing more than 5.00 g.

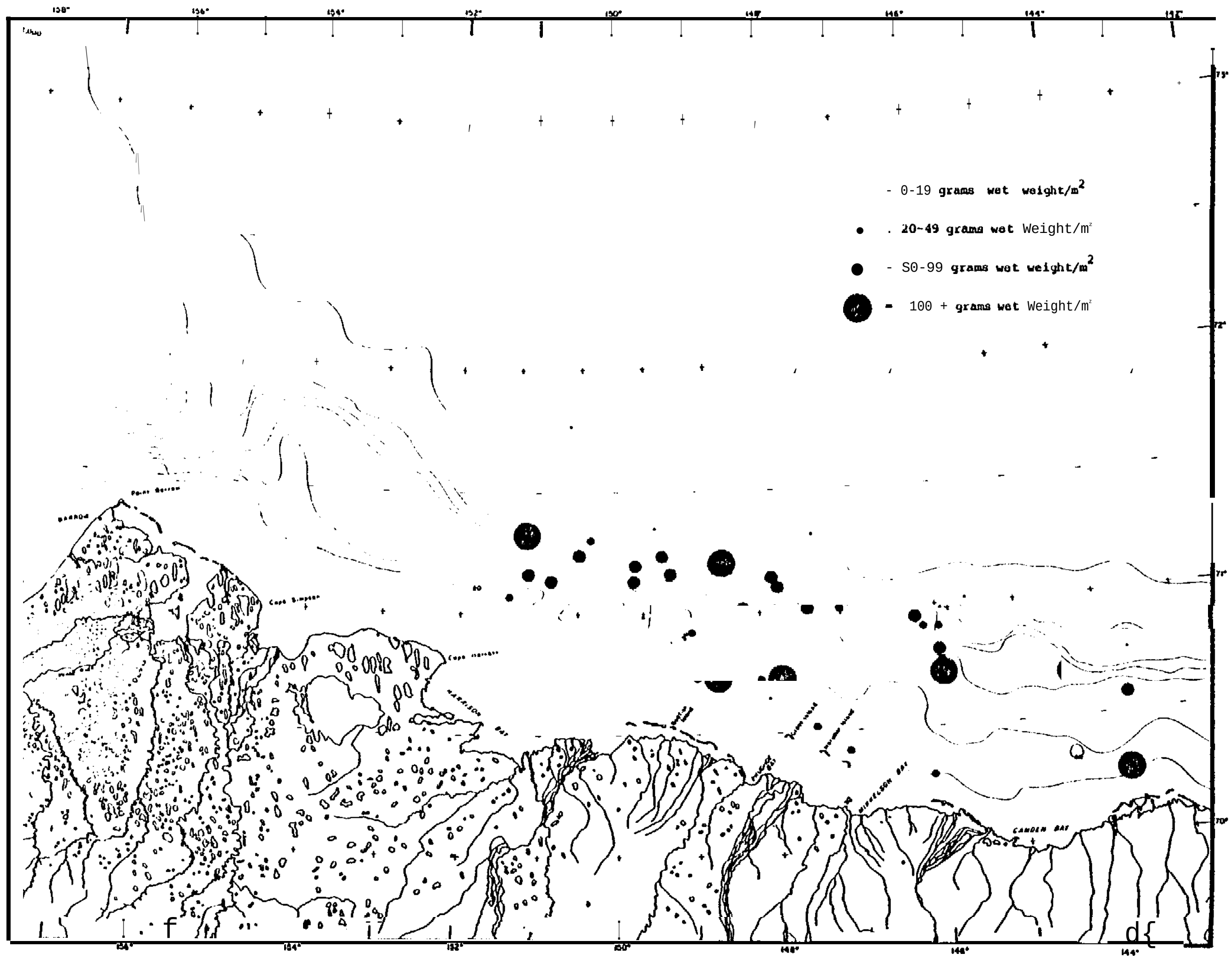


Figure 6. Numerical abundance of the benthic invertebrates occurring at stations near the Mackenzie River delta occupied by Wacasey between 1971 and 1975. All organisms larger than 0.50 mm are included.

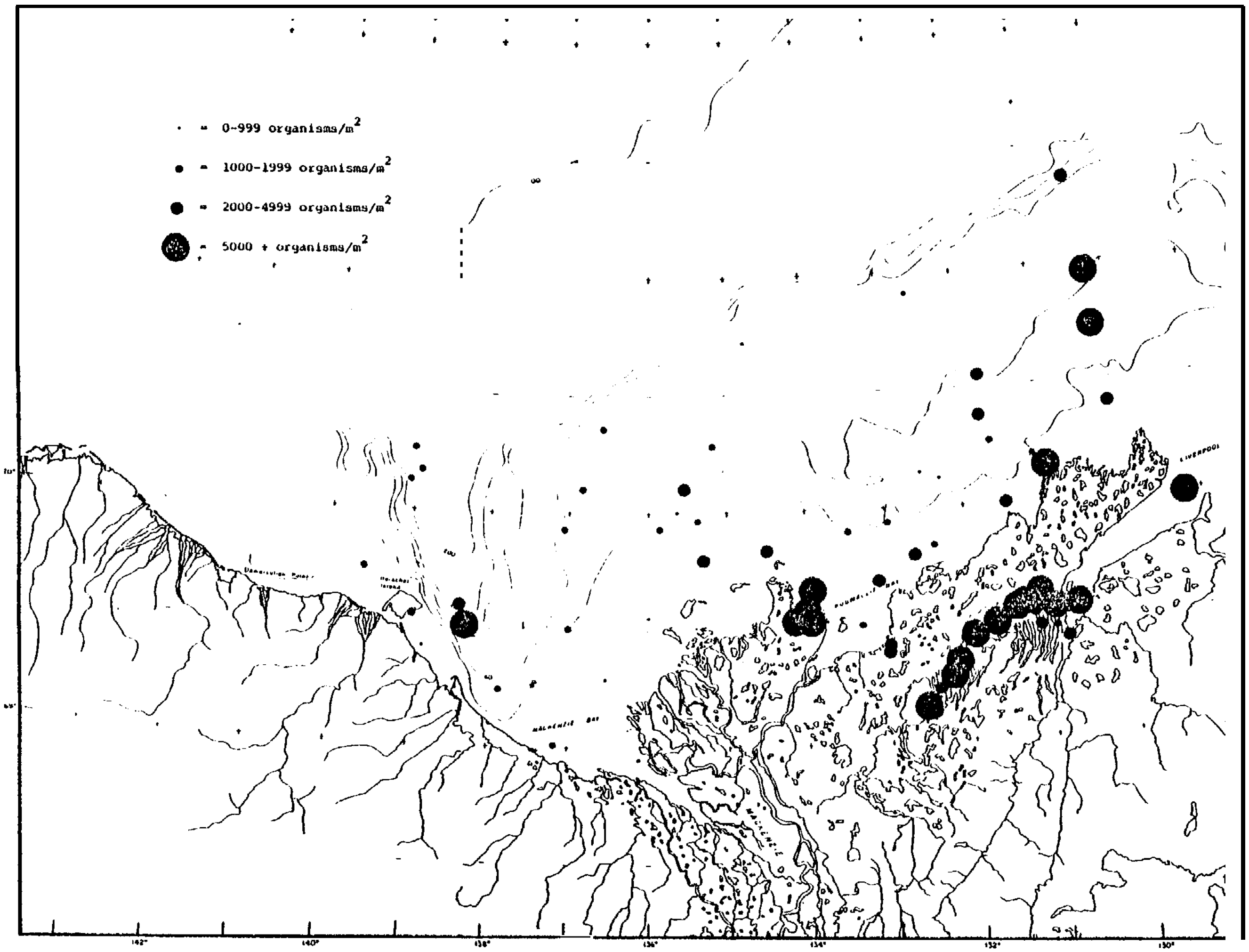
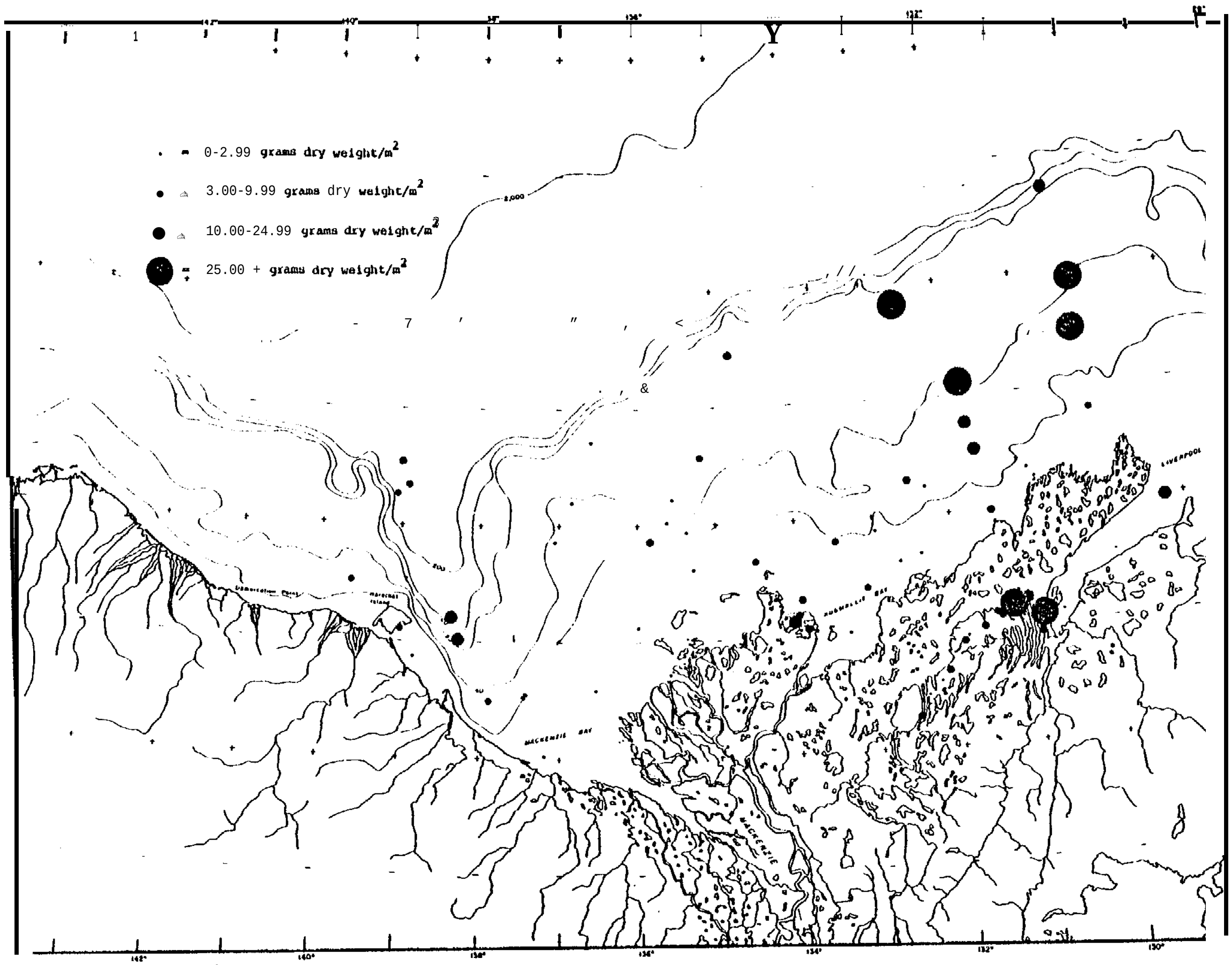


Figure 7. Biomass of the benthic invertebrates occurring at stations near the Mackenzie River delta occupied by Wacasey between 1971 and 1975. Values are reported in grams/m^2 dry organic weight excluding shells and worm tubes.



distance from shore. Wacasey also noted very high density and biomass values in the shallow bays and lakes around the Mackenzie River mouth. These results may reflect local nutrient enrichment, or the benthic community may be responding to the relatively stable conditions encountered in these protected water.

Higher values for total biomass and species diversity, and increased numerical abundance were recorded from the continental shelf in depths from 15 to 20 meters. Wacasey suggested that ice scour in this region may remove a significant portion of the substrate from production, thus depressing the productivity below values found further out on the shelf. Carey also inferred the destructive influence of grounding ice, and noted lowered values for both biomass and numerical density at comparable depths.

The highest values for total benthic biomass, numerical abundance and species diversity have been reported from the outer regions of the continental shelf, corresponding to Wacasey's Marine Zone. Carey, however, also recorded high numerical densities beyond the shelf break to depths of 700 meters on the upper slope west of Prudhoe Bay. Nutrient input coupled with the lack of ice disruption has been postulated to explain the relatively high values encountered in this deeper region. Beyond this, both investigators have found that numbers and biomass decrease to low levels at stations further down the continental slope.

Although there is agreement in the trends reported by recent benthic investigators, the results cannot be compared directly. It should be noted that there is no standardization of oceanographic techniques, and that each investigator has his own methodology. For example, Feder, Carey and Wacasey all used different sampling equipment which took differing. areas and volumes of the bottom sediments. Wacasey sieved the sediments through a 0.50 mm screen and subsequently examined all of the retained organisms. Carey initially washed *the* sediments through a 0.42 mm sieve, but he only identified and counted the invertebrates from the fraction larger than 1.00 mm. Wacasey reported dry organic weight for all organisms exclusive of worm tubes and mollusc shells. Carey measured preserved wet weight including tubes and shells, but excluding the occasional rare, large organism which would significantly bias the data from a particular station. From this it can be seen that direct comparison of the data derived from these recent studies is not feasible, and all information on the benthic community structure and composition in the Beaufort Sea must be examined relative to the methods and techniques employed by the observer.

3. Analysis of WEBSEC samples

Part of the research effort supported by the NOAA/BLM contract involved further analysis of samples collected by the O.S.U. Benthic Ecology Group during the Western Beaufort Sea Ecological Cruise in 1971. This work included:

a. the identification of the harpacticoid copepods from the WEBSEC-71 grabs samples

b. the picking and sorting of selected meiofaunal samples

c. a cluster analysis of the available species data from the WEBSEC-71 grab samples.

a. Harpacticoida (Crustacea, Copepoda)

The harpacticoid copepods collected during the WEBSEC-71 cruise aboard the USCGC GLACIER have been examined and identified (Table 3). These animals are from the macro-infauna fraction (1.00 mm and larger) of the Smith-McIntyre grab samples. A total of 356 animals were found in 71 of 199 grabs taken. It is expected that if the larger meiofauna fraction (between 0.42 and 1.00 mm) is completely picked and sorted, the number of harpacticoids found will increase by as much as ten fold.

The harpacticoid fauna of the Beaufort Sea is not well known. The only reported specimens from the Beaufort Sea were taken during the Canadian Arctic Expedition of 1913-18 (Willey, 1920). Consequently, of the 17 species found, 7 were unidentifiable. Of these it is likely the unknown genera of Cerviniidae and D'Arcythompsoniidae are new to science, as are the unknown species of _Bradya_ and _Halectinosoma_. The unknown female from the Diosaccidae cannot be identified without a companion male.

Table 3. Harpacticoid copepods examined from grab samples taken across the southwestern Beaufort Sea continental shelf in 1971 between Cape Halkett and Barter Island. Station numbers refer to locations indicated in Figure 1.

Identification	Total	Found at Stations:
Cerviniidae		
Cervinia bradya Norman, 1878	3	30, 85
Cervinia synarthra Sars, 1903	25	03, 08, 17, 18, 28, 30, 61, 76
unknown species 'A'	74	01, 03, 12, 18, 23, 25, 28, 30, 42, 44, 60, 61, 74, 75, 76, 82
Ectinosomadae		
Bradya confluens Lang, 1936	3	08, 30
Bradya unknown species 'B'	5	44, 61, 76
Halectinosoma unknown species 'C'	5	03, 14, 30, 60, 76
Harpacticidae		
Harpacticus superflexus Willey, 1920	186	01, 03, 08, 12, 14, 17, 23, 25, 28, 30, 31, 42, 44, 48, 60, 61, 63, 72, 76, 78, 80, 82
D'Arcythompsoniidae		
Unknown species 'D'	3	29, 84
Diosaccidae		
Amphiacus propinquus Sars, 1910	1	42
Paramphiascopsis giesbrechti (Sars, 1910)	5	19, 30, 42, 61
Paramphiascopsis longirostris (Claus, 1863)	2	03, 19
Typhlamphiascus confusus (T. Scott, 1902)	1	83
Paramphiascella unknown species 'E'	1	44
Amphiascoides unknown species 'F'	1	31
Unknown species 'G'	1	14
Cletodidae		
Argestes mollis Sars, 1902	5	30, 42, 60, 61
Paranannopus echinatus Smirnov, 1946	35	29, 30, 42, 61, 75, 76, 82

Harpacticus super flexus comprised 52% of all organisms found, and it's distribution also covered the broadest range in area (see distribution charts) . H. superflexus is predominantly a shallow water form, and 54% of them were found in depths surrounding 25 meters. Their abundance decreased with an increasing depth: 34% were found at depths of 50 meters, and none were found deeper than 125 meters.

The second most abundant group belonged to an unknown genus from the family Cerviniidae. All three species belonging to this family were morphologically similar. The distribution pattern of Cervinia synarthra and the unidentified species are similar to one another, but the range of the unknown species does extend further to the east. They are both most abundant at 50 meters. Whereas C. Synarthra does not occur deeper than 130 meters, 20% of the unknown species numbers were found between depths of 125-150 meters. C. bradya occurred at 90 and 1100 meters.

Paranannopus echinatus comprised 10% of all organisms found. Though this species did occur at 50 and 430 meters, 60% of them came from depths between 95-140 meters.

The unknown specimen of the family D'Arcthompsoniidae was the only exclusively deep water form, and was found at depths of 360, 750, and 930 meters.

Some community distribution patterns seem apparent by comparing the species distribution charts. H. superflexus and the unknown species of Cerviniidae show very similar distributions. They both cover the full range of the study area, and are found in shallow water near the barrier islands off Prudhoe Bay. C. synarthra seems to share this broad range of distribution except that it is not found near the barrier islands.

Argestes mollis, Paramphiascopsis giesbrechti and *Parananopus echinatus* all occur in a similar narrow range located slightly east of the Colville River delta, and in deeper water.

b. Benthic Meiofauna

Samples taken with a 0.1 m^2 Smith-McIntyre grab during the WEBSEC-71 cruise aboard the USCGC GLACIER were separated into two fractions - the macro-infauna (those organisms caught on a 1.00 mm sieve), and the larger meiofauna (those organisms which pass through the 1.00 screen but which are retained on a 0.42 mm sieve) . All the macro-infauna sampled have been sorted and many of the invertebrates have been identified to provide a picture of the benthic infaunal community. Recently, processing of the meiofauna fraction has been initiated on samples taken near Prudhoe Bay. This area was selected since it is of particular interest in terms of assessing the benthic community structure and monitoring the possible ramifications of oil pollution. Six samples have been sorted, including three from station CG 29 (338 meters depth), and three from station CG 30 at 100 meters depth (Table 4).

The number of organisms recorded from the meiofauna fraction (0.42 - 1.00 mm) is higher than the counts derived from all of the larger organisms (>1.00 mm) found in the sample (Table 5). Adding the meiofauna counts to the totals reported for the benthic macro-infauna results in a 269% increase at the shallower location. This large increase in animal density is due to the addition of numerous individuals from a few specific groups, including the nematodes, annelids, and selected classes from the phylum Arthropoda. The number of nematodes increased dramatically to 309% of

Table 4. Animal densities in the meiofauna fraction (0.42 - 1.00 mm) of grab samples taken in 1971 near Prudhoe Bay. A '+' indicates presence, although no counts of the particular organism were made.

Taxonomic Group			Station CG 29 338 m.				Station CG 30 100 m.			
			Grab 915	Grab 916	Grab 917	Total	Grab 918	Grab 920	Grab 921	Total
Protozoa:	Rhizopoda:	Foraminiferida	+	+	+	++	+	+	+	++
Cnidaria:	Hydrozoa		+	+	+	++	+	+	+	++
	Anthozoa		1	---	5	6	---	3	1	4
Nematoda			281	241	532	1054	10	48	100	158
Nemertinea			---	1	3	4	---	3	---	3
Annelida:	Polychaeta		115	89	95	299	3	27	69	99
Echiura			---	---	---	----	---	1	---	1
Priapulida			---	1	---	1	---	---	---	----
Arthropoda:	Crustacea:	Amphipoda	5	12	6	23	---	3	11	14
		Cirripedia	---	---	---	----	---	---	14	14
		Harpacticoida	10	9	11	30	3	22	52	77
		Isopoda	---	---	---	----	---	---	1	1
		Ostracoda	23	---	5	28	66	193	208	467
		Tanaidacea	8	3	1	12	1	35	39	75
		Cumacea	1	---	1	2	---	2	1	3
Mollusca:	Pelecypoda		28	20	21	69	8	36	52	96
	Gastropoda		---	1	3	4	---	---	8	8
Bryozoa			---	+	---	++	+	+	+	++
Echinodermata:	Ophiuroidea		1	---	---	1	---	1	5	6
Totals-			473	377	683	1533	91	374	561	1026

Table 5. Comparison of the total animal densities recorded from the macrofaunal (>1.00 mm) and meiofaunal (0.42 - 1.00 mm) fractions of the grabs taken off Prudhoe Bay in 1971.

Taxonomic Group			Station CG 29 338 m. Macro-Fraction	Station CG 29 338 m. Meio-Fraction	Station CG 29 338 m. Total	Station CG 30 100 m. Macro-Fraction	Station CG 30 100 m. Meio-Fraction	Station CG 30 100 m. Total
Cnidaria:	Anthozoa		4	6	10	---	4	4
Nematoda			363	1054	1417	218	158	376
Anne lids:	Polychaeta		456	299	755	221	99	320
Arthropoda:	Crustacea:	Amphipoda	13	23	36	63	14	77
		Cirripedia	---	---	----	---	14	14
		Harpacticoida	---	30	30	46	77	123
		Isopoda	---	---	----	---	1	1
		Ostracoda	25	28	53	131	467	598
		Tanaidacea	5	12	17	39	75	114
		Cumacea	1	2	3	10	3	13
Mollusca:	Pelecypoda		24	69	93	20]	96	297
	Aplacophora		1	---	1	1	---	1
	Gastropoda		1	4	5	5	8	13
	Polyplacophora		3	---	3	---	---	----
Brachiopoda			---	---	----	1	---	1
Echinodermata:	Ophiuroidea		6	1	7	22	6	28
	Asteroidea		1	---	1	---	---	----
Total			903	1528	2431	958	1022	1980

the total number reported from the macro-infaunal fraction alone. Poly - chaete worm and pelecypod mollusc counts also showed an increase. Three groups of arthropods were significantly affected: harpacticoid copepod counts rose 333%, tanaids increased 298%, and ostracod counts rose to a level 417% above the total reported from the larger size fraction.

The examination of the meiofauna has demonstrated that the aperature of the sieve used during sample washing will have a substantial effect on the estimates of standing stock, and that total community composition will change significantly with the addition of this smaller fraction (Table 6). Since there is no standardization of sampling methodology, conclusions concerning benthic community structure or species composition must be interpreted in view of the sieve size used to screen the fauna. Although there is probably a negligible effect on the total biomass per square meter of ocean bottom, the total numerical density may double or triple as the smaller animals are included. Meiofaunal energy turnover rates are higher than the corresponding rates for the larger organisms. Consequently, the meiofauna contribute substantially to the-total energy flow in the eco- system, and are an integral part of the benthic community. Much additional work is required on the meiofaunal component to gain a better understanding of the functioning of the benthos in the arctic environment.

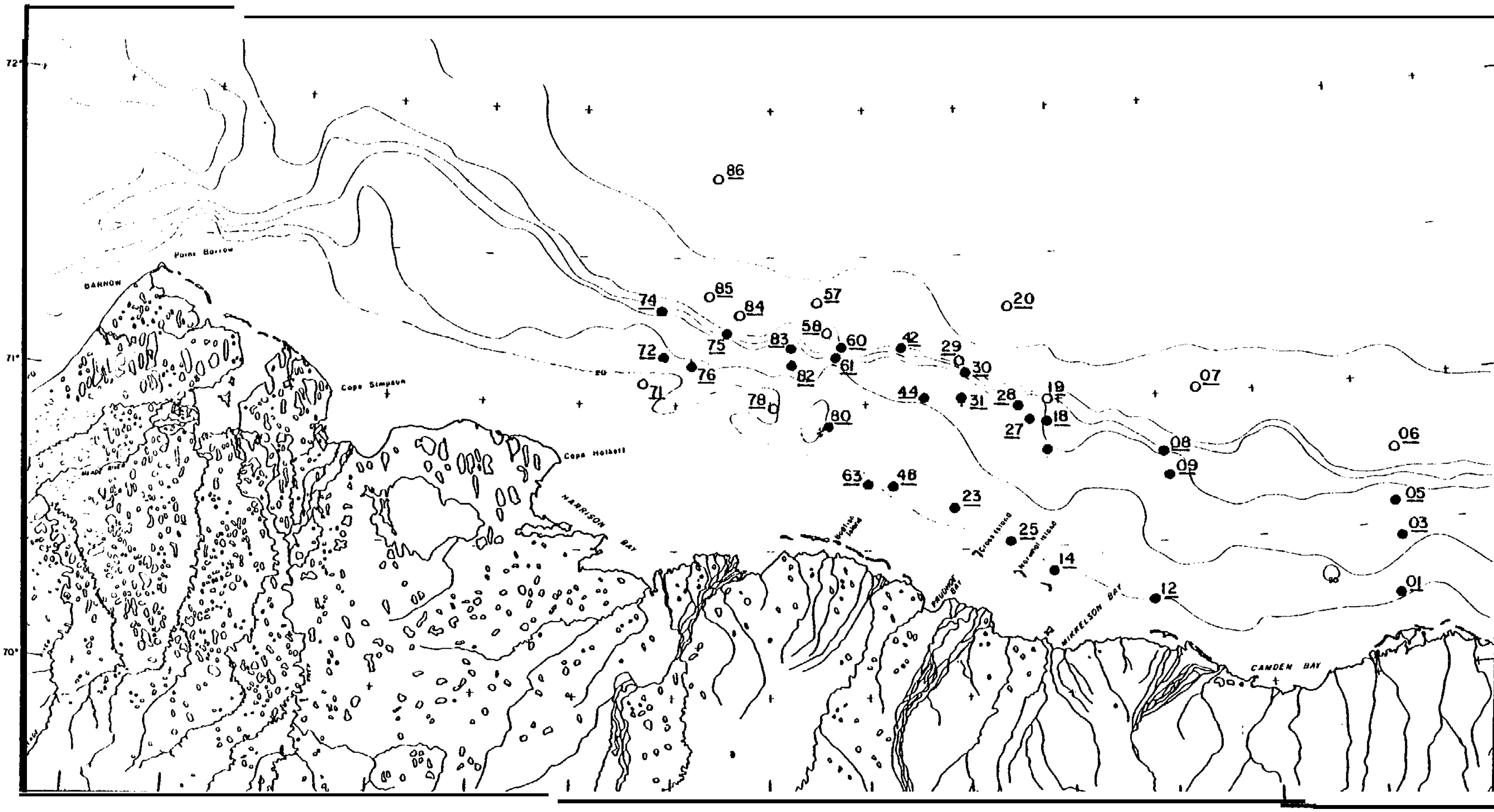
c. Cluster Analysis - Southwestern Beaufort Sea Infauna

A total of 158 benthic species were examined for analysis from 191 grabs taken at 40 stations in the southwestern Beaufort Sea (Fig. 8). A species was included in the final analysis if it was found in a minimum of 10% of these grab samples. This criterion was satisfied by 30 species,

Table 6. Benthic in fauna community composition by major taxonomic group expressed first separately for the macrofaunal (>1.00 mm) and meiofaunal (0.42 - 1.00 mm) components, and then for the combination of these two fractions.

Taxonomic Group	Station CG 29 338 meters			Station CG 30 100 meters		
	Macrofauna Fraction	Meiofauna Fraction	Total	Macrofauna Fraction	Meiofauna Fraction	Total
Nematoda	40%	69%	58%	23%	15%	19%
Polychaeta	50%	20%	31%	23%	10%	16%
Crustacea	5%	6%	6%	30%	64%	47%
Mollusca	3%	5%	4%	22%	10%	16%
Others	2%	--	1%	2%	--	2%

Figure 8. Stations occupied by Carey in 1971 which were examined for the cluster analysis. Open circles represent stations which were excluded from the final data matrix.



including 12 gammarid amphipods, 11 cumaceans and 7 pelecypods (Table 7). In spite of this reduction no stations were eliminated, although the species richness at some stations was substantially reduced. A station-species matrix was generated in the second step by averaging the species counts of any replicate grabs taken at a station. The third step imposed a limit on the species richness for any station in the matrix, and a station was dropped from the analysis if it had less than 9 species present. Thirteen stations did not meet this requirement. Of these 13 stations, 11 were at depths greater than 200 meters and the remaining two were less than 30 meters. The resulting station-species matrix contained 27 stations (rows) and 30 species (columns) from which the analysis below was performed. The similarity index SIMI (Stander, 1970) was calculated for all stations and species. A matrix of these indices was then clustered using a complete linkage algorithm (Sneath and Sokal, 1973), and phenograms were generated to visually present the results of the clustering techniques (Figs. 9 and 10). SIMI is a similarity measure between two attribute vectors, X and Y. These can be defined as a station vector having elements which represent the abundance of all species at that station, and a species vector having elements which represent the abundance of the particular species at all stations. This index was chosen for its conservative properties when rare organisms are added to the analysis, and for the fact that it operates independent of absolute magnitudes, responding only to proportional changes in composition.

$$\mathrm{SIMI} = \frac{\Sigma xi^2 + \Sigma yi^2 - \Sigma(xi - yi)^2}{2\sqrt{\Sigma xi^2}\ \sqrt{\Sigma yi^2}}$$

Table 7. Benthic invertebrate species included in the cluster analysis.

Phylum Arthropoda:

Amphipoda-

Aceroides latipes (Sars, 1892)
Ampelisca eschrichti Kroyer, 1842
Anonyx nugax (Phipps, 1774)
Bathymedon obtusifrons (Hansen, 1887)
Byblis gaimardi (Kroyer, 1846)
Haploops laevis Hock, 1882
Haploops tubicola Liljeborg, 1855
Paraphoxus oculatus G. Sars, 1879
Photis reinhardi Kroyer, 1842
Protomedeia fasciata Kroyer, 1842
Protomedeia grandimana Bruggen, 1905
Unciola leucopis (Kroyer, 1845)

Cumacea-

Brachydiastylis nimia Hansen, 1920
Cumella carinata (Hansen, 1887)
Diastylis edwardsi (Kroyer, 1841)
Diastylis goodsiri (Bell, 1855)
Diastylis oxyrhyncha Zimmer, 1926
Diastylis scorpioides (Lepechin, 1780)
Eudorella emarginata (Kroyer, 1846)
Leucon acutirostris G. Sars, 1865
Leucon nasica (Kroyer, 1841)
Leucon nasicoides Liljeborg, 1855
Diastylis rathkei (Kroyer, 1841)

Phylum Mollusca

Pelecypoda-

Astarte montagui (Dillwyn, 1817)
Cyclopecten greenlandicus (Sowerby, 1842)
Nucula bellotii Adams, 1856
Nuculana pernula (Muller, 1779)
Portlandia arctica (Gray, 1824)
Portlandia frigida (Torell, 1859)
Portlandia lenticula (Moller, 1842)

Figure 9. Station phenogram generated by a complete linkage (farthest neighbor) classification algorithm using SIMI for the similarity matrix. Groups 'A' through 'D' are indicated.

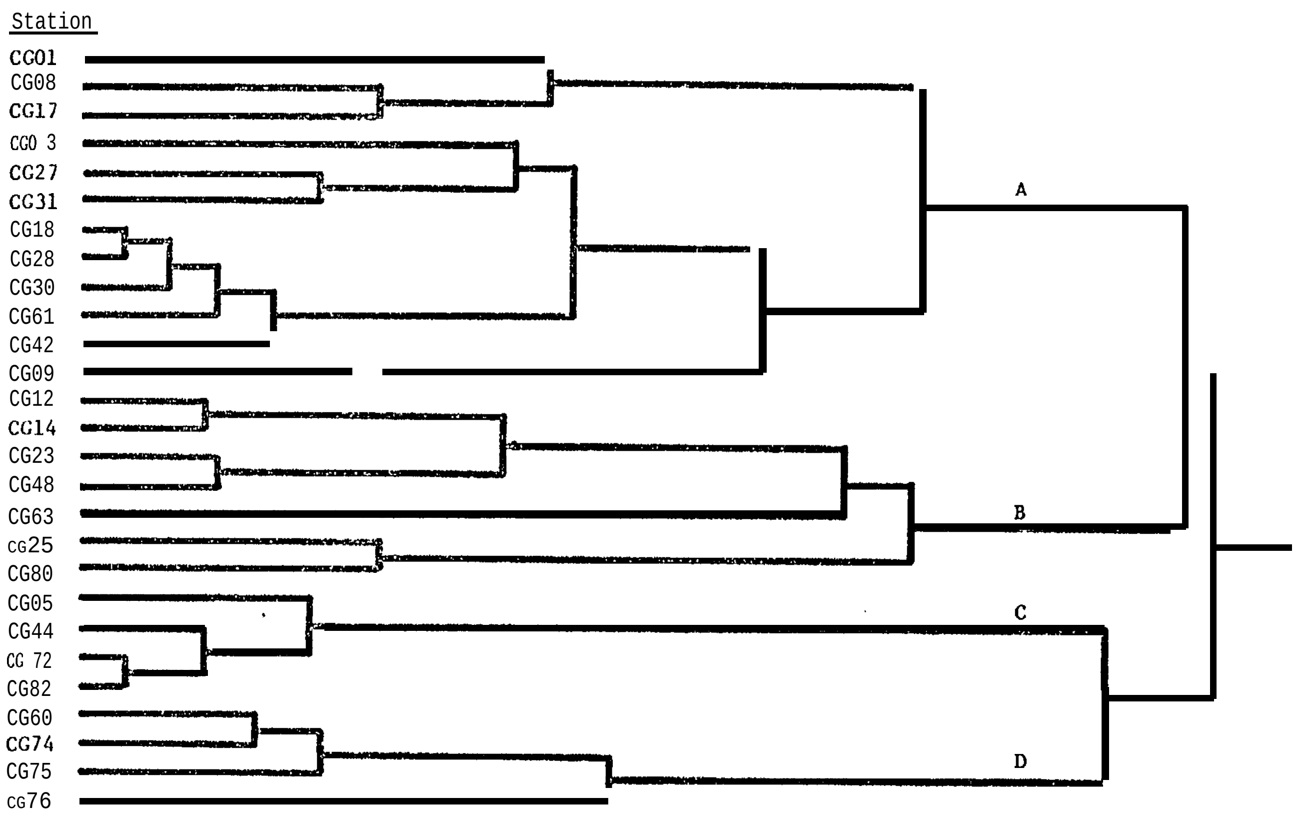
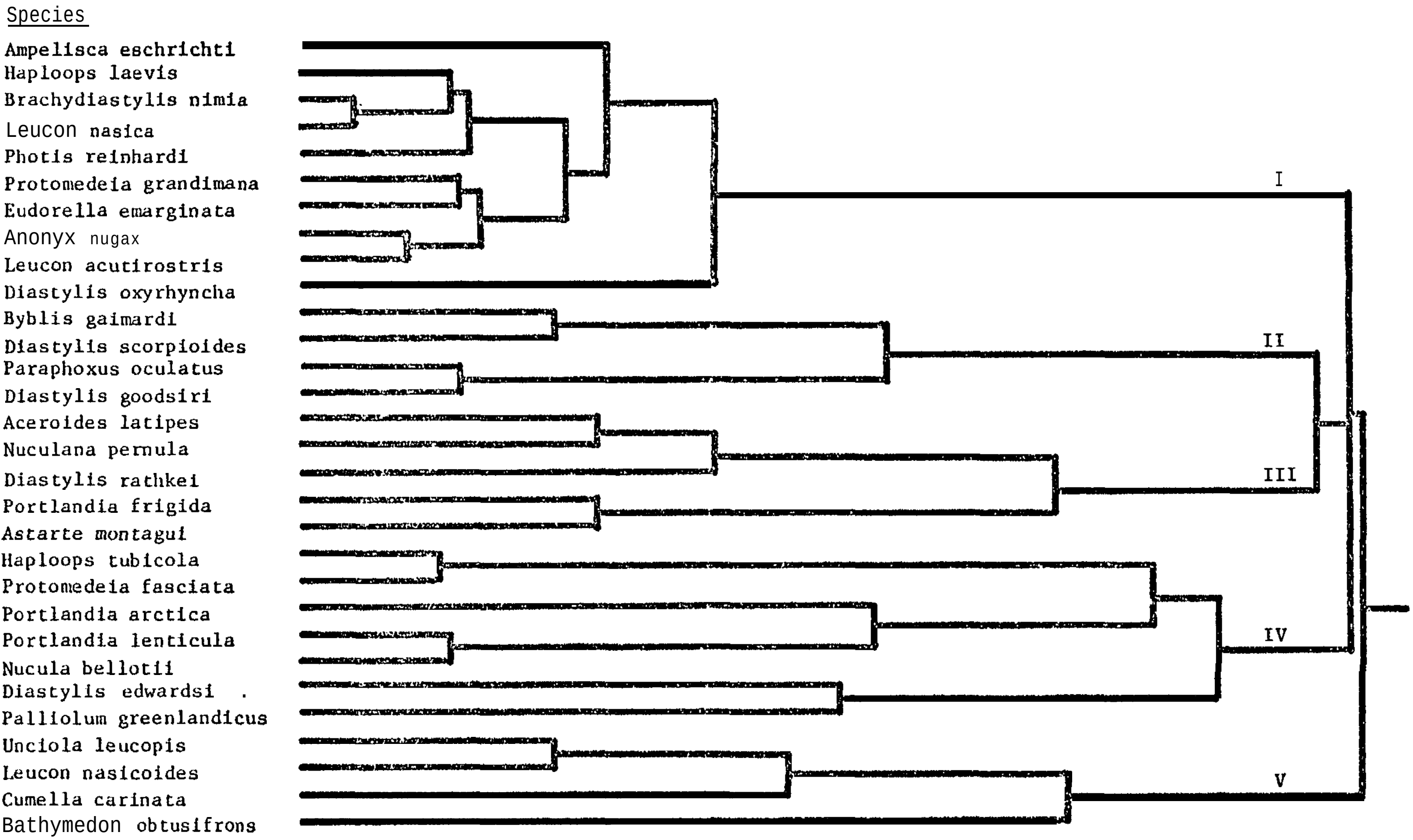


Figure 10. Species phenogram generated by a complete linkage (Farthest neighbor) classification algorithm using SIMI for the similarity matrix. Groups I through V are indicated.



Station groupings -

Four groups of stations, labeled 'A' through 'D', were generated by the clustering procedure with a convergence level for SIMI placed at less than 0.2 (Table 8). In general, these groups occur in bands with east-west axes, and are distributed with depth across the continental shelf as a nearshore group ('B'), and a midshelf group ('A'), with an intermediate group ('C') in between. Group 'D' is confined to the western portion of the study area and appears analagous to group 'A'. An additional group is formed of the deeper stations down the continental slope which were excluded from the analysis (Fig. 11) .

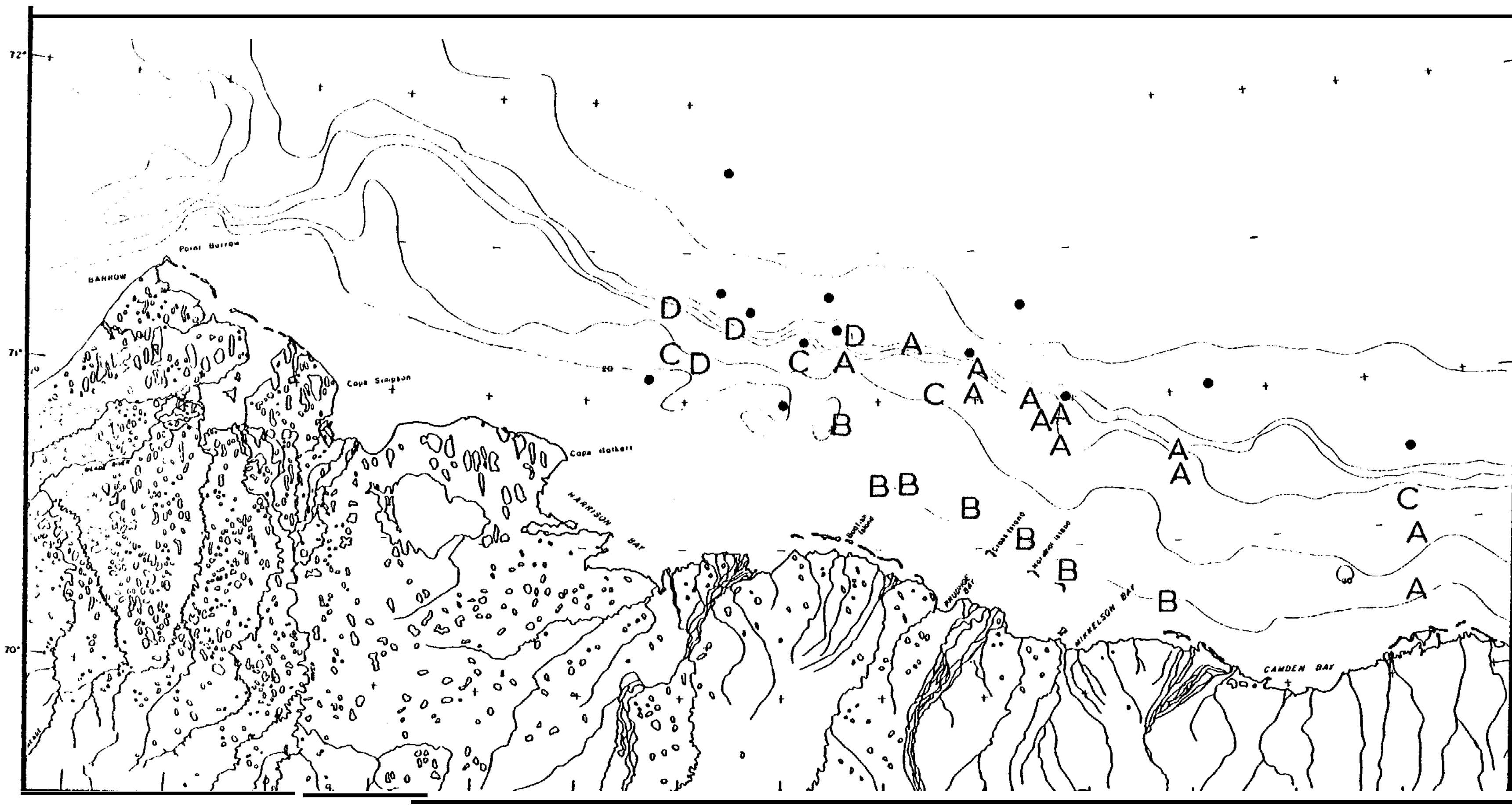
Station group 'A' consists of 12 sites with depths ranging between 33 and 142 meters. This group extends from approximately 150° west longitude to the eastern margin of the study area. Group 'B' is made up of seven nearshore stations shallower than 40 meters and in the central portion of the study area. The 'C' station group has representatives over the entire width of the study region, and confined within a narrow depth band (44-49 meters) with the exception of a single station (CG 05) off Barter Island at 106 meters depth. Finally, group 'D' is restricted to the area close to the Colville River, although it does overlap slightly with the 'A' group. The depth of the stations in this final group varies between 47 and 136 meters, comparable to the range of group 'A'.

Some additional subjective information can be inferred from the stations which were excluded from the cluster analysis by the imposition of specific limitations. Eleven of these stations occurred down the continental slope, indicating that the elimination of the rare species and the lower limit on the species richness of a station has neatly sorted out

Table 8. Benthic sampling stations on the southwestern Beaufort Sea continental shelf which tend to group together using a statistical clustering technique.

Station	Depth (Meters)
Group 'A'	
CG 01	33
CG 03	48
CG 08	84
CG 09	57
CG 17	46
CG 18	146
CG 27	50
CG 28	107
CG 30	100
CG 31	52
CG 42	140
CG 61	50
Group 'B'	
CG 12	26
CG 14	27
CG 23	27
CG 25	26
CG 48	25
CG 63	23
CG 80	30
Group 'C'	
CG 05	106
CG 44	47
CG 72	45
CG 82	44
Group 'D'	
CG 60	64
CG 74	101
CG 75	135
CG 76	47

Figure 11. Distribution of the stations grouped in a cluster analysis across the shelf. Dots represent stations which were excluded from the analysis.



the deeper stations. The two other stations excluded from the final data matrix were shallow locations near the Colville River in the same area where 'A' station grouping has been replaced by the 'D' group. Further sampling is needed to elucidate the biological processes occurring in this area. Additional sampling is also indicated at the eastern boundary of the study area around Barter Island where no nearshore station group was encountered and where a station in group 'C' was found 50 meters deeper than all similar stations to the west.

Species groupings -

The same species-station data matrix employed to group the stations was used to cluster the 30 benthic invertebrate species. Five species groups were found using a convergence level of 0.1 for the similarity index SIMI (Table 9). The benthic organisms representing species group I are cosmopolitan, although these species are more commonly found at the deeper stations and in the area around the Colville River. The species in group II are also found at the deeper stations, and they rarely occur in the shallower waters or in the Colville area. Organisms represented in species group 111 are found at most stations east of 150° west longitude. These species have a broad depth range, but they tend to be absent from the Colville River area. The species constituting group IV are part of a shallow water fauna which becomes very rare or disappears from the deeper stations, and which is also rarely encountered near the Colville. And finally, the species of group V are found consistently at stations off the Colville, but never occur in the nearshore waters represented by station group 'B'.

Table 9. Benthic invertebrate species from the southwestern Beaufort Sea continental shelf which tend to group together using a statistical clustering technique.

Group I -

Ampelisca eschrichti
Haploops laevis
Photis reinhardi
Protomedeia grandimana
Anonyx nugax
Brachydiastylis nimia
Diastylis oxyrhyncha
Eudorella emarginata
Leucon acutirostris
Leucon nasica

Group II -

Byblis gaimardi
Paraphoxus oculatus
Diastylis goodsiri
Diastylis scorpioides

Group III -

Aceroides latipes
Diastylis rathkei
Portlandia frigida
Nuculana pernula
Astarte montagui

Group IV -

Haploops tubicola
Protomedeia fasciata
Diastylis edwardsi
Portlandia arctica
Portlandia lenticula
Nucula bellotii
Cyclopecten greenlandicus

Group V -

Unciola leucopis
Bathymedon obtusifrons
Leucon nasicoides
Cumella carinata

The species groupings indicate that the southwestern continental shelf can be divided into a western area of interest off the Colville River, and an eastern region. The only species found with any regularity near the Colville River were those cosmopolitan species in group I and the organisms of group V. TO the east, the region is again divisible into shallower and deeper benthic fauna. Representatives of species groups III and IV are found in the nearshore area, but species in group V are completely absent. The stations on the deeper shelf have a more cosmopolitan composition, end include representatives from groups I, II, III. and V.

4. Relevance to Problems Associated with Petroleum Development

Extensive drilling for oil and gas on the Alaskan and Canadian north slope has the potential to significantly influence the marine environment across the Beaufort Sea continental shelf. It is impossible with our present state of knowledge to accurately predict either the short or long term consequences of petroleum development on the marine benthos. Comprehensive descriptive studies of the benthic fauna in the Beaufort have only been initiated in the last few years. These studies are a necessary first step in providing a baseline from which any future changes in the benthic environment and community structure can be evaluated.

To date, little is known about the dynamics of the benthic ecosystem in the Beaufort Sea. There have been no studies on the dynamics of the benthic populations in this region. No reliable estimates of natural mortality are available, and recruitment rates remain unknown. Little research has been done on the metabolism and growth rates of these organisms living under ice for a large part of the year. Lacking this information it is very difficult to predict how quickly benthic populations could recover from an extinction event caused by a large-scale oil spill or by other industry-related pollution.

The benthic invertebrates constitute a major source of food for the top level carnivores, including birds, seals, and occasional walrus. Any decrease in benthic populations caused by oil pollution might eventually be reflected in the populations of these larger animals. Nearshore areas would seem to be the most sensitive since it would be in these regions that pollutants would be most likely to mix to the benthic boundary.

The timing of environmental disturbances in this strongly seasonal environment may be extremely critical in determining the stresses experienced by the benthic community. For example, an oil spill in the winter on top of the pack ice could be cleaned up with little or no resultant damage to the marine benthos, while a spill of the same magnitude during a summer of open water might have significant impact. It remains to be determined if the bottom-dwelling invertebrates are more or less sensitive to oil related pollution during the summer months, but the pelagic larvae of the benthic organisms would be vulnerable to spills during periods of open water conditions.

It seems likely that the development of the oil and gas resources will bring about changes in the marine environment, but the extent of degradation in the benthic environment cannot be predicted. There remains a great scientific need for long term studies on the dynamics of the benthic populations, including year round sampling with measurements on growth, metabolism, and reproductive activity.

5. Summary and Conclusions

Due to its remoteness and relatively harsh seasonal conditions, little biological sampling has been accomplished in the Beaufort sea in the past. Benthic sampling lagged far behind comparable arctic areas, and quantitative work did not begin up until the present decade. In 1971, detailed investigations were launched by both the U.S. and Canada across the Beaufort Sea continental shelf and in the nearshore areas. Specific areas of interest included the Colville River delta, Prudhoe Bay, and the region around the Mackenzie River.

Results of these intital quantitative studies have outlined the general structure of the benthic community across the shelf. Maxima in both biomass and numerical abundance occur on the outer shelf or down the continental slope. Depressed values are found on the inner shelf, pointing to the possible effects of dilution caused by summer river runoff and the destructive influence of ice in the winter. Local highs in density and biomass occur in the very shallow embayments around the Mackenzie River where there may be higher inputs of food and where the organisms are not disrupted or destroyed by impinging ice.

Since oceanographic techniques of sample collecting and processing differ among various investigators, direct comparison of the data derived from the benthic community is not legitimate. The general trends in the data from separate studies can be compared, however. Information from the grabs taken along the southwestern shelf show that groups of invertebrate species tend to cluster into bands which roughly parallel the coastline. Similar bands are described from the southeastern sector around the Mackenzie River delta. It remains to be seen if the species composition within these bands is the same for these two areas. Anomalous regions are indicated around the Colville River and Barter Island where differences appear in the structure of the benthic community, and along the eastern margin of the Beaufort Sea where high biomass values are found. Fur the r study is required to clarify the processes occurring in these regions.

Much additional work needs to be done on existing samples before the benthic communtiy is adequately described. Initial analysis of the meio-faunal fraction from several of the grab samples taken in 1971 has demonstrated the existence of large numbers of organisms which play a significant role in the dynamics of the benthic environment. Care ful examination of the harpacticoid copepods from this fraction has shown that nearly half of the species are new to science. Similar results can be anticipated from the other major meiofaunal groups, emphasizing the need for much additional careful descriptive work. The necessary sorting of these large numbers of invertebrates from bottom sediments must be recognized as a tedious and time-consuming process, however.

In general, continued study of the benthic community is needed across the Beaufort Sea continental shelf. Information is required on the growth, metabolism, reproductive rates, recruitment, and mortality of the benthic organisms. Stations must be occupied at different times during the year to assess the responses of the invertebrates to an environment which is ice covered for nearly nine months. Accurate data on these aspects must be determined before the ultimate effects of oil related pollution on the benthic community can be meaningfully predicted.

6. Select References

The majority of the works referenced in this narrative can be found in the Annotated Bibliography in Volume IV, Part B. The few additional references not occurring in the bibliography are listed below.

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