RSMAS Technical Report 2006-01

Zooplankton Data Report: Distribution of Zooplankton in the Western Arctic During Summer 2002

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Introduction

The data reported here are the results of zooplankton sampling conducted in 2002 during the second phase of the National Science Foundation's Shelf Basin Interactions (SBI) program. The SBI program was developed to explore the effects of climate change on biogeochemical processes in the Arctic. Phase two of SBI emphasized fieldwork in the western Arctic, specifically the Chukchi and Beaufort Seas. Further background information may be found on the SBI website at http://sbi.utk.edu/. The motivation for our fieldwork was the question, "Will global change, particularly warming, result in more large-sized zooplankton which support a pelagic food web of fish, birds, and certain mammals over the Chukchi and Beaufort Shelves or in more smaller-sized zooplankton which will diminish the fish, birds and mammals and favor sedentary benthic organisms?" The objectives of the present study were 1) to census the regional zooplankton community and establish a baseline for comparisons with historical and future studies; and 2) to determine whether large-bodied copepods associated with deep waters of the Bering Sea or the Canada Basin were transported to the shelves in sufficient numbers to modify the food web in a region where smaller copepods often dominate the zooplankton numerically.

Methods

Zooplankton samples were collected from the USCGC *Healy* between 17 July and 24 August 2002 (cruise designation HLY0203). Sampling focused on seven sections over the shelf and slope regions in the northern and eastern Chukchi Sea and western Beaufort Sea and occasionally extended northward into the Canada Basin (Figure 1). These sections, in chronological order of sampling, were denoted as Alaskan Coastal Water (ACW), Barrow Canyon (BC); East Barrow (EB); East Hanna Shoal (EHS); West Hanna Shoal (WHS); Hanna Canyon (HC); and Herald Valley (HV). Zooplankton samples were collected early in the cruise with a 1-meter MOCNESS (Wiebe et al., 1976; 1985) fitted with 153 μm mesh nets at two stations in the northeastern Chukchi Sea (Figure 1; Table 1). Samples were collected at ca. 20 m depth intervals from near-bottom to the surface. The MOCNESS was unfortunately damaged by collisions with ice-floes during its third deployment. Heavy ice-cover and the inability to repair the MOCNESS necessitated using Bongo nets for the remainder of the cruise. Samples were collected at 31 stations

by vertically hauled Bongo nets with a 60 cm diameter net-mouth and 153 μm and 335 μm mesh nets (Sea-Gear Corporation). Net tow locations, bottom depth and sampling depths are listed in Table 1. Nets were generally lowered at 20 m min^{-1} and retrieved at 30 m min^{-1}. Maximum depths sampled were determined with a Wildlife Computers Mk9 depth recorder that was attached to the top of the Bongo frame. The volume filtered was calculated following the method described by Weikert and John (1981).

Each sample was split on board the ship in a modified Folsom splitter that delivered four subsamples of 50%, 20%, 20% and 10%. The 50% fraction was preserved in 5% buffered (sodium borate) formaldehyde/seawater solution for later enumeration and identification of copepods in the laboratory. A 20% fraction was poured through nested sieves of 1050 μm, 560 μm and 202 μm mesh. Each size-fraction was then collected on pre-weighed 9 cm Whatman number 1 filter paper and placed in a drying oven at ca. 55°C for at least 48 hours. The other 20% fraction was poured through a 150 μm mesh sieve to remove water and then preserved with ethyl alcohol (U.S.P., Aaper) for later molecular analysis of selected copepods. The 10% fraction was usually viewed under a microscope at sea for selection of individual specimens for dry weight measurements. Individuals selected for dry weights were rinsed three times in distilled water, placed in pre-weighed aluminum pans, and stored in a drying oven at ca. 55°C for the duration of the cruise. At the end of the cruise, all dry weight samples were packed in air-tight containers with desiccant for transport to the laboratory.

Laboratory analyses were performed at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. The dried bulk biomass samples from the Bongo tows were weighed on a Mettler B5 analytical balance. The data are available from the Joint Office for Science Support (JOSS)/UCAR website http://www.joss.ucar.edu/sbi/ under the Plankton tab. The individual specimens in dry weight pans were weighed on a Cahn C-35 Microbalance. *Calanus glacialis* C5 dry weight data were supplemented at several Hanna Shoal stations by sorting specimens for dry weights from formalin preserved samples in the lab. In these cases, average weights of *C. glacialis* C5 copepodites from preserved samples were compared with the average weights of those collected at sea and a weight loss factor was generated (e.g., Smith,

1988). Weight loss due to preservation of *C. glacialis* C5s in the present study was determined to be 31.3% of fresh dry weight.

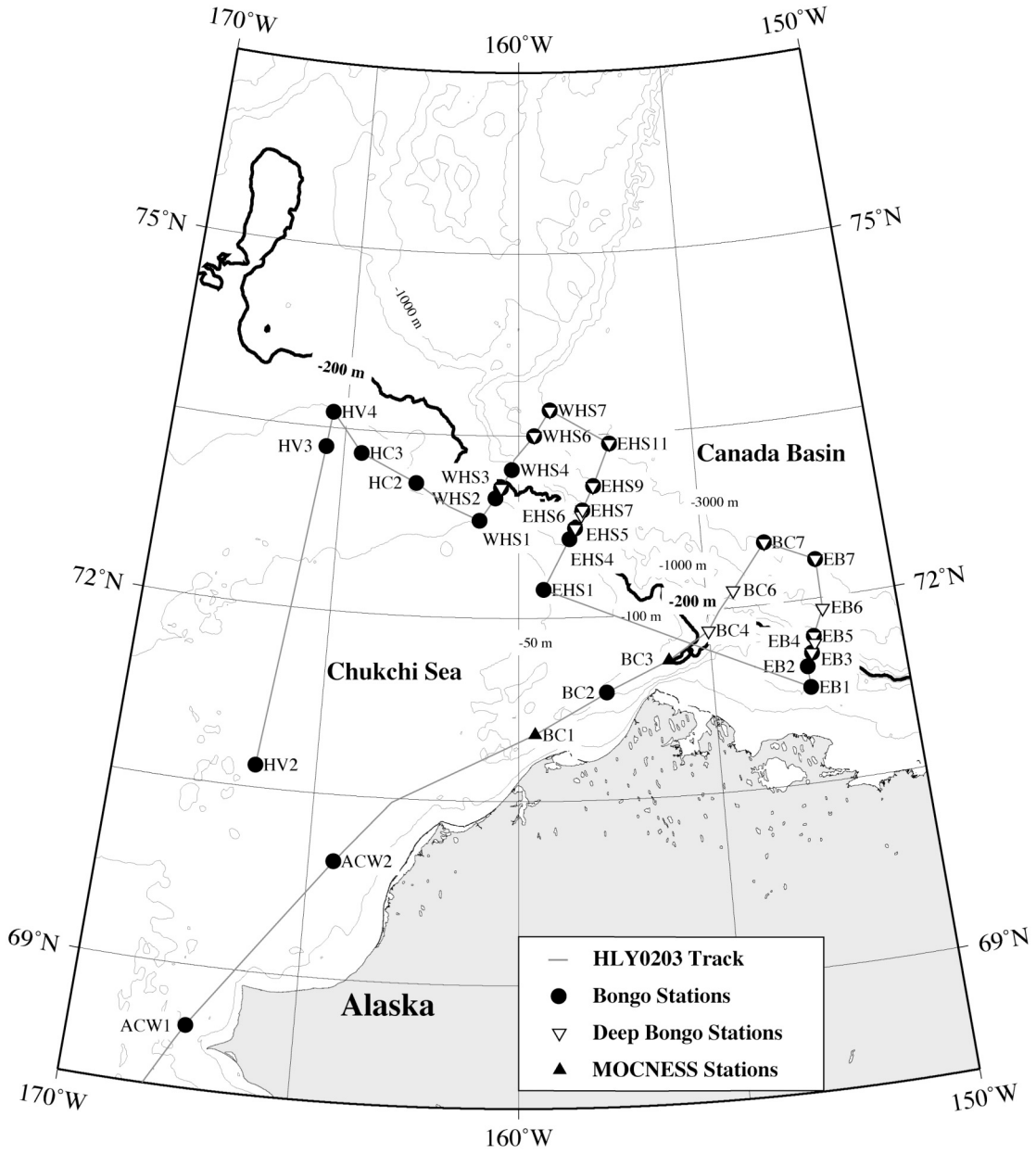

Figure 1. Station map showing zooplankton sampling sites during summer 2002 (Cruise HLY0203). Sections are denoted (in chronological order of sampling) by region as Alaskan Coastal Water (ACW), Barrow Canyon (BC); East Barrow (EB); East Hanna Shoal (EHS); West Hanna Shoal (WHS); Hanna Canyon (HC); and Herald Valley (HV).

Table 1
Summary of net tow locations during cruise HLY0203. Stations are listed in the chronological order in which they were sampled during the cruise.

Date	Latitude (°N)	Longitude (°W)	Sonic Depth (m)	Station	Master Station[a]	Gear	Sample depth(s) (m)
19-Jul-02	68.5108	167.3910	38	7	ACW1	BONGO	34-0
20-Jul-02	69.9540	164.3912	33	8	ACW2	BONGO	26-0
21-Jul-02	71.0730	159.4123	77	10	BC1	MOCNESS	67-54-35-15-1
21-Jul-02	71.3845	157.6903	119	12	BC2	BONGO	99-0
22-Jul-02	72.6917	158.4492	181	13	BC3	MOCNESS	123-100-79-59-39-11-0
23-Jul-02	71.9220	154.8970	475	14	BC4	BONGO	439-0
25-Jul-02	72.1205	154.1895	1669	16	BC6	BONGO	409-0
27-Jul-02	72.4795	153.4663	3080	17	BC7	BONGO	103-0, 690-0, 1034-0
28-Jul-02	72.3038	153.9327	3141	18	EB7	BONGO	111-0, 594-0, 1033-0
30-Jul-02	71.9287	152.0282	2241	19	EB6	BONGO	527-0
1-Aug-02	71.6882	152.4147	1105	20	EB5	BONGO	100-0, 607-0, 1014-0
2-Aug-02	71.6462	152.3762	466	21	EB4	BONGO	450-0
3-Aug-02	71.5637	152.3837	170	22	EB3	BONGO	100-0, 151-0
3-Aug-02	71.4512	152.5505	86	23	EB2	BONGO	78-0
4-Aug-02	71.2785	152.5162	48	24	EB1	BONGO	39-0
6-Aug-02	72.2243	159.3422	48	25	EHS1	BONGO	25-0
6-Aug-02	72.6032	158.7370	86	26	EHS4	BONGO	68-0
7-Aug-02	72.7017	158.6465	235	27	EHS5	BONGO	98-0
8-Aug-02	72.8343	158.2760	445	28	EHS6	BONGO	439-0
9-Aug-02	72.8797	158.2540	1259	29	EHS7	BONGO	100-0, 626-0, 1019-0
10-Aug-02	73.0662	157.9605	1979	30	EHS9	BONGO	105-0, 578-0
11-Aug-02	73.4185	157.4355	3082	31	EHS11	BONGO	96-0, 612-0, 1023-0
12-Aug-02	73.7025	159.1000	2906	32	WHS7	BONGO	102-0, 630-0, 1024-0
13-Aug-02	73.4960	159.5342	2280	33	WHS6	BONGO	97-0, 618-0
16-Aug-02	73.2198	160.2178	452	35	WHS4	BONGO	79-0
17-Aug-02	73.0715	160.4785	187	37	WHS3	BONGO	71-0, 181-0
17-Aug-02	72.9770	160.6747	80	38	WHS2	BONGO	61-0
18-Aug-02	72.7835	161.0365	54	39	WHS1	BONGO	30-0, 43-0
19-Aug-02	73.0743	162.9703	115	41	HC2	BONGO	100-0
19-Aug-02	73.2838	164.5302	74	42	HC3	BONGO	58-0, 69-0
19-Aug-02	73.6290	165.4328	126	43	HV4	BONGO	110-0
20-Aug-02	73.3382	165.5383	76	44	HV3	BONGO	54-0
21-Aug-02	70.6822	166.4953	39	45	HV2	BONGO	24-0

[a] ACW = Alaskan Coastal Water; BC = Barrow Canyon; EB = East Barrow; EHS = East Hanna Shoal; WHS = West Hanna Shoal; HC = Hanna Canyon; HV = Herald Valley

Net samples for taxonomic enumeration were split several times in a Folsom splitter (Van Guelpen et al., 1982). In general, three aliquots were counted for each taxonomic category identified. Usually the first counted aliquot contained approximately 200-400 individuals. The size of the second and third aliquots varied depending on the composition and number of species present. Abundance in terms of individuals per cubic meter (ind m^{-3}) was estimated for each category by dividing the number counted by the fraction of the sample counted for that category and dividing that result by the volume of water filtered. The use of 153 μm mesh Bongo nets precludes quantitative estimates of certain categories including copepod nauplii and copepodites of smaller calanoid, cyclopoid, poecilostomatoid and harpacticoid species, such as *Pseudocalanus* spp., *Oithona similis*, *Oncaea* spp. and *Microsetella norvegica* respectively. Nonetheless, these groups were counted to indicate their presence and to estimate their relative abundances. Species enumeration and identification were conducted with the aid of Leica Wild M10 and Wild M5 dissecting microscopes and a Wild M20 compound microscope. Prosome length measurements of selected copepods were made with a calibrated ocular micrometer at 12X magnification and converted to mm (1 division = 0.037mm). Table 2 lists species and categories enumerated during the present study. Copepod species were identified by the following criteria.

Calanus hyperboreus and *C. glacialis*. These large calanoid copepod species were the most thoroughly analyzed in this work. Prosome length (PL), distance from the anterior tip of the cephalosome to the distal posterio-lateral end of the last thoracic segment and morphological characteristics were used to distinguish adults for both species (Brodsky, 1950; Frost, 1974). The PL of randomly sorted copepodite stages C1 (781 individuals), C2 (564 individuals) and C3 (360 individuals) from several stations (EB7, EB1, EHS1, EHS11, WHS7, HV4 and HV3) were measured and length-frequency plots were constructed for each stage (Figure 2). Additional PL measurements were then made of these three copepodite stages (153 C1, 69 C2 and 53 C3) for subsequent molecular analyses to determine which PL ranges were associated with *C. hyperboreus* as opposed to *C. glacialis*. Length-frequency plots were again constructed for the specimens used in the molecular analysis performed using the mitochondrial 16s rRNA gene. The universal primer 16SASR (5'-CGCCTGTTTAACAAAAACAT-3') and the recently modified primer 16SB3R (5'-TAATTCAACATCGAGGTCACAA-3') were used to amplify the

16s rRNA gene. PCR conditions consisted of 40 cycles of denaturing at 94°C for 1 minute, annealing at 50°C for 2 minutes and extending at 72°C for 3 minutes. The last cycle was followed by an extension period of 7 minutes at 72°C. Nucleotide sequences were determined using an Applied Biosystems 3730 DNA Analyzer. Individuals were identified by comparing nucleotide sequences of the mitochondrial 16S rRNA gene with the previously described sequences of *C. glacialis* and *C. hyperboreus* collected in the Norwegian Sea (Lindeque et al., 1999). A bimodal distribution of PL is clear for stage C3 and is supported by the genetic analyses, however the C2 and C1 data present some overlap (Figure 2A, B). In the case of C2s, genetic analyses verified that 6 of 69 specimens (<10%) were *C. hyperboreus*, however the size frequency was not clearly bimodal (Figure 2B). Therefore, we chose the upper size limit of 1.5 mm given by Grainger (1963) for routine sample analyses. In the case of C1s, the genetic identification verified that only two of the 153 C1 individuals (<2%) were *C. hyperboreus* and the prosome lengths of those two specimens were both 1.03 mm. However, there were several specimens of *C. glacialis* identified genetically that had prosome lengths greater than 1.03 mm. Therefore, we used the maximum prosome length of *C. glacialis* C1 found in the literature, 1.07 mm (Grainger, 1963), so as not to underestimate the abundance of *C. glacialis* copepodites, which were far more abundant than *C. hyperboreus* copepodites in our samples. *Calanus* spp. copepodite stages C4 and C5 were distinguished following the size criteria given in Madsen et al. (2001) in addition to the presence or absence of the acute terminal process of the fifth metasomal segment. Size ranges of *Calanus* spp. prosome lengths are summarized in Table 3.

Metridia longa. Adults of this species were identified following the descriptions of Brodsky (1950) and Thorp (1980). Copepodite stages C5, C4 and C3 were identified by their body shape and presence of terminal spines on the last thoracic segment. Copepodite stages less than C3 were grouped with unidentified calanoid copepodites.

Pseudocalanus spp. Frost (1989) recognized seven species of *Pseudocalanus* and reported at least four species co-occurring in the SBI study region. In the present study, adult females of *P. minutus* were differentiated from other species by their anterior cephalosome shape (Frost, 1989). Adult males and adult females other than *P. minutus*, and copepodite C5s of this genus, were counted as *Pseudocalanus* spp. Copepodites less than C5 were grouped with unidentified calanoid copepodites (Table 2).

Table 2. Species and groups counted and identified in the laboratory.

Large-bodied copepoda	Small-bodied copepoda	Miscellaneous unidentified copepoda	Other zooplankton
Calanus hyperboreus, C1, C2, C3, C4, C5, Adults	*Pseudocalanus* spp. C5, Adults	Copepod nauplii	Amphipods
Calanus glacialis, C1, C2, C3, C4, C5, Adults	*Pseudocalanus minutus* Adult female	Calanoid Copepodites, unidentified	Barnacle nauplii
Metridia longa C3, C4, C5 - grouped, Adults	*Microcalanus pygmaeus* C5, Adults	Cyclopoid Copepodites, unidentified	Bivalve larvae
Metridia pacifica C5, Adults	*Acartia longiremis* C5, Adults	Harpacticoids, unidentified	Chaetognaths
Paraeuchaeta glacialis Copepodites - grouped, Adults	*Oithona similis* Copepodites – grouped, adults		Decapod larvae
Chiridius polaris C5, Adults	*Oncaea* spp. Copepodites – grouped, adults		Echinoderm larvae
Scaphocalanus spp. C5, Adults			Eggs
Spinocalanus spp. C5, Adults			Euphausiids
			Gastropod larvae
			Appendicularians
			Ostracods
			Polychaete larvae
			Unidentified zooplankton

Table 3. Size range of prosome lengths and distinguishing characteristics of copepodite and adult stages of *Calanus glacialis* and *C. hyperboreus*.

Stage	Number of urosome segments	Number of swimming legs	Prosome length (mm)		
			C. glacialis	*C. hyperboreus*	
C1	2	2	0.750 – 1.070	>1.070	Our results; Grainger, 1963
C2	2	3	1.100 – 1.500	>1.500	Our results; Grainger, 1963
C3	2	4	1.600 – 2.000	>2.000	Our results
C4	3	5	2.025 – 2.925	>2.925 5th metasome segment with acute process	Madsen et al., 2001
C5	4	5	2.725 – 3.900	>3.900 5th metasome segment with acute process	Madsen et al., 2001
AF	4	5	> 3.000	>4.500 5th metasome segment with acute process	Madsen et al., 2001
AM	5	5	> 3.000	>4.500	Madsen et al., 2001

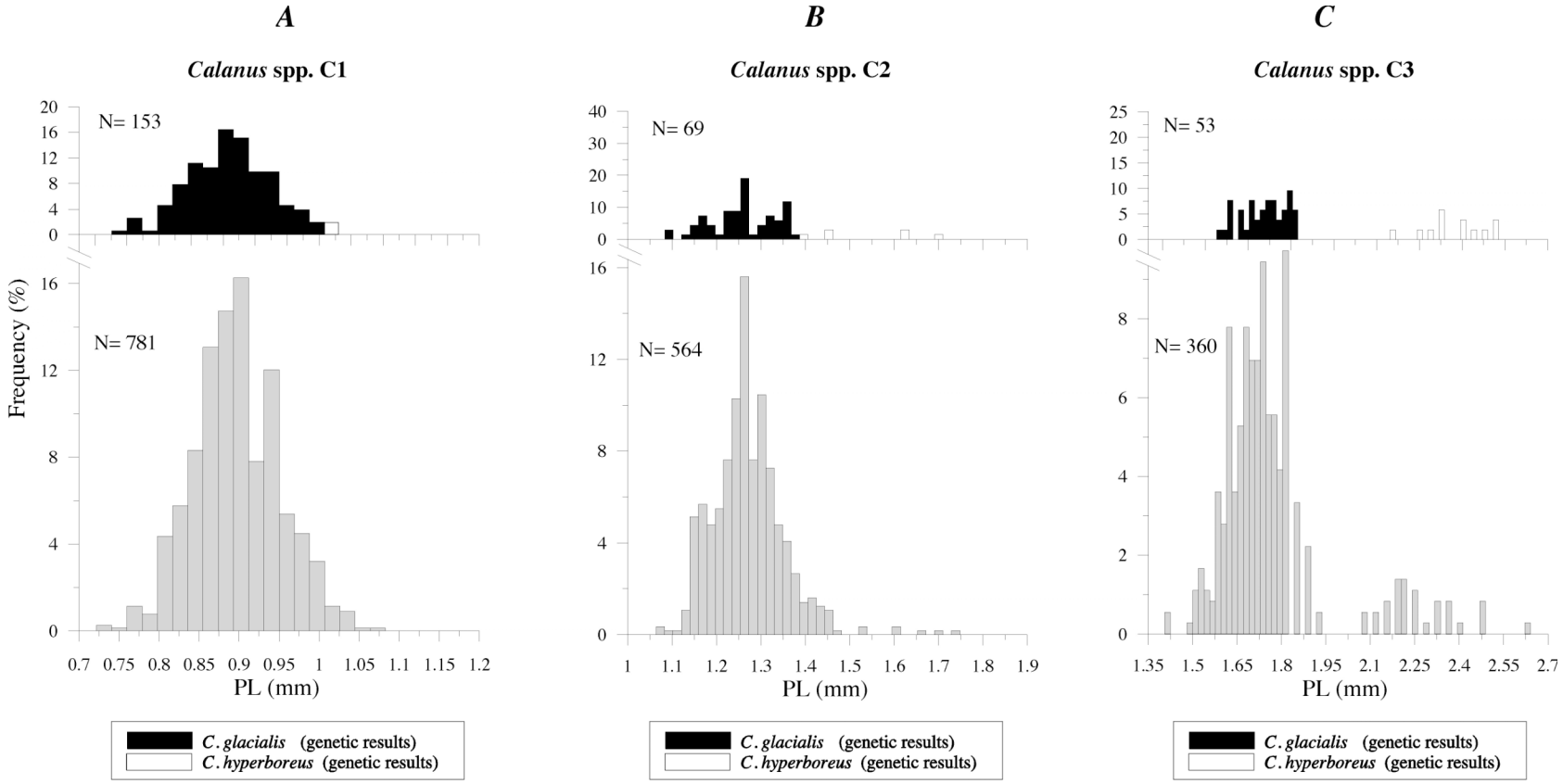

Figure 2. Length-frequency plots of prosome length of randomly sorted *Calanus* spp. copepodite stages C1 (panel A), C2 (panel B) and C3 (panel C) from stations EB7, EB1, EHS1, EHS11, WHS7, HV4 and HV3. The top plot in each panel represents only those specimens that were examined by molecular methods (these specimens were preserved in ethyl alcohol). The lower plot in each panel represents a larger sampling of the population for which no molecular analyses were done (these specimens were preserved in buffered formalin seawater). A bimodal size distribution among the genetic results was clear only for the C3 stages, therefore the size criteria published by Grainger (1963) were used to separate the two species in the C1 and C2 stages. Size ranges of all *Calanus* spp. stages distinguished in the present study are listed in Table 3.

Acartia longiremis. Adult males and females of this species were distinguished following the descriptions of Brodsky (1950) and Bradford (1976). Copepodite stages were grouped with unidentified calanoid copepodites.

Microcalanus sp. All adults were identified as *Microcalanus pygmaeus*. Copepodite stages of this species were not identified; however, they were grouped with unidentified calanoid copepodites.

Oithona similis. Adult males and females of this species were listed separately and all copepodite stages were counted as a single group. Identification was done according to Nishida (1985).

Oncaea spp. Two species of *Oncaea, O. borealis* and *O. parila*, were observed in our samples and they were grouped for the present study. All copepodite stages were counted as a single group, and males and females of this genus were distinguished by body size and shape of the genital segment (Heron et al., 1984).

Less abundant copepods. Adults and copepodite stage C5 of some less abundant copepods were easily identified to the species level by morphology (e.g. *Paraeuchaeta glacialis* and *Chiridius polaris*). *Eucalanus bungii* was observed in only three samples and its presence was noted in the comments of those stations. Other individual adults and C5 copepodites were distinguished to the genus level because of their scarcity in our samples (e.g., *Scaphocalanus* spp. and *Spinocalanus* spp.).

Other zooplankton. Identification of other zooplankton such as chaetognatha, appendicularia, and various meroplanktonic taxa was carried out only to general taxonomic groupings (Table 2).

Data

Data tables are presented following the literature cited section. Table 4 is a listing of the individual dry weights of selected copepods. The taxonomic abundance data are then listed for each station (in chronological order; Table 1). Each page includes header information describing the cruise, ship, date and time in UTC, latitude and longitude in degrees and decimal minutes, net type (Bongo or MOCNESS) and mesh, tow depth interval (m), and volume of water filtered (m^3). The copepod taxa are listed in order of taxonomic classification and are followed by the more general other zooplankton categories. For each taxon counted, the total number of individuals counted in

subsamples is listed in columnar format followed by the percent of the sample sorted for that category and the estimated abundance in number of individuals per cubic meter. The total number of specimens counted and the total zooplankton per cubic meter are given at the bottom of each list. Any comments made by the person counting the sample, for example presence of dense algae or cnidaria, are typed at the end of the list.

Acknowledgements

The authors wish to thank the officers and crew of the USCGC *Healy* and our fellow SBI scientists, especially Dr. Jackie Grebmeier for coordinating the SBI field work, and Drs. Carin Ashjian, Robert Campbell and Stéphane Plourde for their assistance at sea and for providing helpful comments during the production of this report. Dr. Gloria Scorzetti assisted with the molecular analyses used to distinguish early copepodites of *Calanus glacialis* and *Calanus hyperboreus*. This material is based upon work supported by the National Science Foundation under Grant No. OPP-0125004.

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Table 4. Average dry weights of copepods selected at various stations during summer 2002. The stations are listed in the chronological order in which they were occupied during the cruise.

Station	Species	Average Dry Weight µg/ind	Standard Deviation	Range Minimum	Maximum	N
ACW1	*Calanus glacialis* C5	574	127	355	721	7
ACW1	*C. glacialis* C4	143	27	103	164	4
BC1	*C. glacialis* AF	581	105	515	765	5
BC1	*C. glacialis* C4	256	88	156	444	11
BC4	*C. hyperboreus* AF	5040	1424	3071	6458	4
BC4	*C. glacialis* AF	717	--	--	--	1
BC4	*C. glacialis* C5	661	188	414	889	5
BC4	*C. glacialis* C4	227	50	167	280	4
BC4	*C. glacialis* C3	86	--	76	97	2
BC4	*C. glacialis* C2	67	15	51	81	3
BC4	*C. glacialis* C1	13	--	--	--	1
BC6	*C. hyperboreus* AF	4648	1904	2173	6808	4
BC6	*C. hyperboreus* C5	1047	702	386	3104	24
BC6	*C. hyperboreus* C4	446	227	307	708	3
BC6	*C. glacialis* AF	753	187	497	929	6
BC6	*C. glacialis* C5	684	344	335	1022	3
BC6	*C. glacialis* C3	112	--	--	--	1
BC6	*Metridia longa* AF	455	37	433	497	3
BC7	*C. hyperboreus* AF	3299	991	1854	4980	15
BC7	*C. hyperboreus* C5	1376	620	522	3608	25
BC7	*C. glacialis* AF	1078	364	835	1496	3
BC7	*C. glacialis* C5	553	182	244	960	16
BC7	*C. glacialis* C4	171	32	113	229	9
BC7	*M. longa* AF	366	--	--	--	1
BC7	*Pseudocalanus* sp. AF	35	2	32	37	3
EB7	*C. hyperboreus* AF	2171	732	1289	3146	7
EB7	*C. hyperboreus* C5	1029	318	563	1442	5
EB7	*C. glacialis* AF	815	172	564	950	4
EB7	*C. glacialis* C5	570	160	366	730	5
EB7	*C. glacialis* C4	255	75	168	302	3
EB7	*M. longa* AF	444	56	319	532	19
EB6	*C. hyperboreus* C5	996	544	425	1508	3
EB6	*C. hyperboreus* C4	426	--	--	--	1
EB6	*C. hyperboreus* C3	146	--	--	--	1
EB6	*C. glacialis* AF	800	184	516	987	7
EB6	*C. glacialis* C5	915	348	529	1204	3
EB6	*C. glacialis* C4	212	56	148	306	8
EB6	*C. glacialis* C3	70	17	46	96	9
EB6	*C. glacialis* C2	24	2	22	26	3
EB6	*M. longa* AF	436	66	364	491	3
EB6	*M. longa* C5	211	38	169	257	5
EB5	*C. hyperboreus* AF	3208	--	--	--	1
EB5	*C. hyperboreus* C5	2055	--	--	--	1

Station	Species	Average Dry Weight µg/ind	Standard Deviation	Range Minimum	Maximum	N
EB5	*C. hyperboreus* C4	551	--	--	--	1
EB5	*C. glacialis* AF	746	--	--	--	1
EB5	*C. glacialis* C5	524	360	234	1047	4
EB5	*C. glacialis* C4	157	55	85	238	7
EB5	*C. glacialis* C3	67	29	35	114	9*
EB5	*C. glacialis* C2	52	19	33	90	8*
EB5	*C. glacialis* C1	16	--	--	--	1*
EB5	*M. longa* AF	372	--	272	472	2
EB4	*M. longa* C5	148	42	84	198	10
EHS4	*C. hyperboreus* AF	4043	912	2770	5376	10
EHS4	*C. glacialis* AF	697	171	366	868	9
EHS5	*C. hyperboreus* AF	4691	1846	3468	7778	5
EHS5	*C. glacialis* AF	835	99	751	944	4
EHS5	*M. longa* AF	452	121	343	624	4
EHS6	*C. glacialis* AF	779	221	414	1093	12
EHS7	*C. hyperboreus* AF	2548	1108	1645	3968	4
EHS7	*C. glacialis* AF	971	308	528	1395	5
EHS7	*M. longa* AF	340	107	228	443	3
EHS9	*C. hyperboreus* AF	3680	733	2619	4252	4
EHS9	*C. glacialis* AF	1057	243	636	1245	5
EHS9	*M. longa* AF	403	--	329	478	2
EHS11	*C. hyperboreus* AF	2227	464	1831	2761	4
EHS11	*C. glacialis* AF	1153	351	659	1417	4
EHS11	*C. glacialis* C5	720	315	363	1322	9**
EHS11	*C. glacialis* C4	184	28	154	206	3
EHS11	*M. longa* AF	377	10	366	383	3
WHS7	*C. hyperboreus* AF	2214	694	1331	3174	6
WHS7	*C. glacialis* AF	1033	269	705	1479	7
WHS7	*C. glacialis* C5	915	351	477	1223	4**
WHS7	*M. longa* AF	300	27	282	331	3
WHS6	*C. glacialis* C5	552	197	294	852	12
WHS3	*C. hyperboreus* AF	6298	--	5851	6745	2
WHS3	*C. hyperboreus* C5	3655	--	2780	4530	2
WHS3	*C. hyperboreus* C4	1176	411	718	1512	3
WHS3	*C. glacialis* C5	921	293	251	1777	20**
WHS2	*C. glacialis* C5	846	285	554	1527	10**
WHS1	*C. glacialis* AF	858	157	723	1081	4
WHS1	*C. glacialis* C5	982	336	549	1834	21**

* Includes samples in which 3-10 individual specimens were pooled in each weighing pan.

** Data include a combination of fresh and preserved specimens that were sorted from samples preserved in formaldehyde/seawater solution. Dry weights of preserved specimens were corrected for weight loss of 31.3% due to preservation (see methods section).