

**Oceanographic assessment of the planktonic communities in
the Klondike and Burger Survey Areas of the Chukchi Sea**

Report for Survey year 2009

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EXECUTIVE SUMMARY

Surveys of the planktonic communities over both the Klondike and Burger survey areas were completed 3 times over the majority of the ice-free period in 2009. Chlorophyll and nutrient concentrations suggest that sampling had occurred post-phytoplankton bloom in both the Klondike and Burger areas; concentrations of nutrients and chlorophyll remained low throughout the entire water column. In total, 70 taxonomic categories of zooplankton, including 11 meroplanktonic larval categories, were observed during the 2009 field year. The greatest taxonomic diversity was observed within the copepods (23 species, plus juvenile categories), followed by the cnidarians (10 species), with all species typical for the region and largely of sub-arctic Pacific origin. An average abundance of 7030 individuals m^{-3} and 20.4 mg DW m^{-3} was captured by the 150 μm net and an average of 196 individuals m^{-3} and 7.0 mg DW m^{-3} captured by the 505 μm net. The contribution by meroplankton forms to both abundance and biomass was substantial, but less than observed in 2008. Despite the relative proximity of the survey areas to each other, they could generally be separated based on community structure. Not surprisingly, a temporal evolution of the community structure was apparent over both areas. Although both temperature and chlorophyll influenced the observed community structure, the amount of variation attributed to them within this study was relatively low.

INTRODUCTION

Purpose of Study and Rationale

Chukchi Lease Sale 193 occurred in February 2008, followed by the completion of the first year of a 3-year multidisciplinary environmental studies program operated by ConocoPhillips in partner ship with Shell Exploration & Production Company. The 2009 field effort represents a second year of data collection that will aid in the preparation of a defensible NEPA document in support of exploratory drilling. Pelagic biological oceanography forms one aspect of the baseline studies program, because the productivity of the water column determines the flux of energy to the seafloor as well as productivity transferred through zooplankton to higher trophic levels such as fish, seabirds and marine mammals. Alterations to water column productivity as a result of inter-annual variability, long-term climate change or human activity, could have direct impact on the ecosystem, including the more visible vertebrates. The data collected through this studies program, combined with historical and region-wide data will provide us with direct observations of community composition and biomass, the only means to compare temporal variation in biological communities to environmental change.

Objectives of Study

The major objective of this study is to describe the spatial and seasonal characteristics of the plankton (phytoplankton and zooplankton) communities, with specific detail in the two study areas. Planktonic communities are strongly coupled to the underlying physical oceanography, with major differences in water-masses generally reflected in the plankton. The study areas are near the historical transition between Alaska Coastal waters and Bering Shelf waters, both of which have unique assemblages of zooplankton. Simultaneous measurement of the physical, chemical, and biological oceanographic setting is therefore essential to forming an understanding of the patterns and the range of seasonal and inter-annual variability characteristic of the region. A secondary goal, sampling of zooplankton in areas of observed bowhead whales feeding was not exercised due to the absence of such situations.

Brief History of Planktonic Biological Oceanography in Chukchi Sea

The Chukchi Sea represents a complex ecosystem at the Pacific Ocean's gateway into the Arctic where climate variation combines with the complex interplay of several distinct water masses of Pacific origin with those of the central Arctic Ocean and its continental-shelf seas. Large quantities of Pacific nutrients, phytoplankton and zooplankton enter the region through the Bering Strait, in a complicated mixture of water masses (i.e. Alaska Coastal, Bering Shelf, and Anadyr Water), each with unique assemblages and quantities of zooplankton (Springer *et al.*, 1989; Coyle *et al.*, 1996; Hopcroft *et al.*, 2010). It has been estimated that 1.8 million metric tons of Bering Sea zooplankton are carried into the Chukchi Sea annually (Springer *et al.*, 1989) and that this, along with the entrained phytoplankton communities, are responsible for the high productivity of the Chukchi Sea in comparison to adjoining regions of the Arctic Ocean (e.g. Plourde *et al.*, 2005).

During the ice-free season, the southern Chukchi zooplankton fauna is primarily Pacific in character. During summer, the Pacific inflow is diluted by Coastal Arctic waters carried along by the East Siberian Current and water carried in from the deeper waters of the Canada Basin or

Chukchi Plateau (Grebmeier *et al.*, 1995). Nonetheless, Pacific species are carried northward as far as the eastern side of Wrangel Island (Hopcroft *et al.*, 2010), as well as to the shelf break in the northeastern Chukchi Sea (Lane *et al.*, 2008). The influx of these “rich” Pacific waters determines the reproductive success of both the imported and resident zooplankton communities (Plourde *et al.*, 2005). Both inter-annual and long-term variation in climate affect the relative transport of these various water masses and hence the composition, distribution, standing stock, and production of zooplankton and their predators within the Chukchi Sea.

A regional and basin-wide review of Arctic zooplankton, their composition, seasonal life cycles, and trophic interactions was completed nearly two decades ago (Smith and Schmack-Schiel, 1990). A more recent effort emphasizing the Russian literature for just the Bering Sea has also been completed (Coyle *et al.*, 1996), as well as a review of zooplankton in polynyas (Deibel and Daly, 2007). The most current review is specific to the Chukchi and Beaufort Seas and has an extensive review of the literature for zooplankton as well as other groups (Hopcroft *et al.*, 2008). One common shortcoming of research prior to the 1990s was that sampling techniques were not standardized, and in particular, the use of only a single net of 303 to ~600 μm mesh as employed in these studies missed the majority of the zooplankton community numerically, and a substantial proportion of the community biomass and diversity. For the most part, Arctic studies have now standardized on 150 μm mesh nets (e.g. Kosobokova and Hirche, 2000; Ashjian *et al.*, 2003; Lane *et al.*, 2008; Kosobokova and Hopcroft, 2010) that more completely sample the numerically dominant copepods in the genera *Oithona*, *Oncaea*, *Microcalanus* and *Pseudocalanus* (*ibid*; Auel and Hagen, 2002; Hopcroft *et al.*, 2005). In fact, to ensure that all developmental stages of these species, including nauplii are sampled, a mesh as fine as 53 μm is required (Hopcroft *et al.*, 2005). Furthermore, these more recent studies have been conducted primarily in deeper waters, while in the shallow target area of this project we can expect an even larger contribution of smaller neritic species in several of the water masses that will be encountered (Conover and Huntley, 1991; Hopcroft *et al.*, 2010).

Although we now have a relatively complete idea of the species that have been described regionally in the Arctic (e.g. Sirenko, 2001), we still lack comprehensive estimates of the abundance, biomass and composition of the zooplankton in the Chukchi Sea, due to sampling deficiencies of the past. Significant progress was made toward this end by the RUSALCA (Russian American Long-term Census of the Arctic), SBI (Shelf-Basin Interactions) and Arctic Ocean Biodiversity (ArcOD) programs. To a large extent, the spatial distribution of zooplankton communities in the Chukchi Sea is tied to the different water masses present in this region (Hopcroft *et al.*, 2010). Within the Chukchi Sea there is considerable diversity of both small and large jelly-fish, hydromedusae and ctenophores that are often overlooked: more than a dozen species were encountered in RUSALCA 2004 (Hopcroft *et al.*, 2010), and more are reported from the nearby deep basins (Raskoff *et al.* 2005, 2010). There were also considerable populations of larvaceans, particularly the large arctic *Oikopleura vanhoeffeni* throughout the sampling area. Larvaceans are increasingly implicated as key players in polar systems (e.g. Acuna *et al.* 1999; Hopcroft *et al.*, 2005, 2010; Deibel *et al.*, 2005) due to their high grazing and growth rates. Shifts from copepod dominated communities to larvacean dominated communities can have large consequences on the export of phytoplankton to the benthos (Gorsky and Fenaux, 1998; Alldredge, 2005). As in many ecosystems chaetognaths remain an important and neglected predatory group (Ashjian *et al.*, 2003; Hopcroft *et al.*, 2005, 2010; Lane *et al.* 2008), The meroplanktonic larvae of benthic organisms were also exceptionally common throughout the

sampling region in 2004, and better knowledge of them is of high relevance to understanding recruitment to the productive benthic communities in this region.

METHODS

Survey Design

The 2009 schedule consisted of three 25-day cruises occurring between August and mid October collecting data and samples at 2 survey areas around the historic Klondike and Burger wells (Fig. 1). Sampling conducted during 2009 occurred within of a 30 x 30 NM box at each prospect, with a grid of 5x5 stations, at ~7.5 nm spacing, within each study site, on all cruises. Bottom depth over both survey areas was similar and relatively constant, varying between approximately 35 and 45 m. Inorganic macronutrients, phytoplankton (as chlorophyll) and zooplankton were sampled on each cruise, following collection of CTD measurements at six depths per station.

Collection Procedures

Phytoplankton were assessed as chlorophyll *a* concentration from samples collected with a Seabird 55 CTD rosette (Weingartner and Danielson, 2010) on upcasts at 6 depths per station: 0, 5, 10, 20, and 30 m, plus 3m above the sea floor. Samples were filtered under low pressure onto Whatman GF/F filters and frozen for post-cruise analysis (Parsons *et al.*, 1984). Nutrient samples were taken from the same bottles as chlorophyll, frozen immediately and analyzed post-cruise (Whitledge *et al.*, 1981; Gordon *et al.*, 1993).

Smaller zooplankton was collected routinely by a pair of 150 μm mesh Bongo nets of 60 cm diameter hauled vertically from within 3 m of the bottom to the surface at 0.5 m s^{-1} . The volume of water filtered was measured by Sea-Gear flow-meters in each vertical net. The meters are rigged not to spin during descent, but can be problematic - when measured values were unreasonably large they were constrained to 40 m distance. To target larger, more mobile zooplankton, a set of 60 cm diameter 505 μm Bongo nets was deployed in a double oblique tow with the ship moving at 2 knots. General Oceanic flow-meters installed in each Bongo net were used to estimate the volume of water filtered. Upon retrieval, one sample of each mesh size was preserved in 10% formalin, and the other in 95% ethanol (required for molecular identification). When present, large cnidarians and ctenophores were removed, sized, identified and discarded prior to sample preservation.

Analytical Procedures

Frozen filters were extracted for chlorophyll *a* in 95% acetone and concentrations determined fluorometrically post-cruise (Parsons *et al.*, 1984) using a Turner Fluorometer. Measurements can be used to calibrate *in vivo* fluorescence profiles measured at stations. Integral chlorophyll concentration was calculated by assuming each depth represented the concentration to the midpoint depth between each sampling interval. Frozen nutrient samples were measured post-cruise using an Alpkem Rapid Flow Analyzer (Whitledge *et al.*, 1981) and conformed to WOCE standards (Gordon *et al.*, 1993).

Formalin preserved samples were processed for quantitative determination of species composition, and prediction of biomass, at 13 stations for each survey grid. During taxonomic processing, all larger organisms (primarily shrimp and jelly fish) were removed, enumerated and

weighed (to $\pm 10 \mu\text{g}$), then the sample was Folsom split until the smallest subsample contained about 100 specimens of the more abundant taxa. Specimens were identified, copepodites staged, enumerated, and measured (Roff and Hopcroft, 1986). Each larger subsample was examined to identify measure, enumerate and weigh the larger, less abundant taxa, particularly in the 505 μm net which typically captures the largest taxonomic diversity. A minimum of 300 individual organisms were identified from each collection. Where necessary, specimens were compared to the voucher set housed at UAF, and periodic cross-comparison occurred between the 2 co-authors processing samples. Larval fish were excluded from analysis, and passed to the fisheries ecology team for their analysis.

For some congeneric species, where earlier copepodites could not be distinguished, they have been grouped with the sibling species. Adults were identified to species. In the case of *Calanus*, excessive lipid storage in most samples made it difficult to view the ocellus which would distinguish *C. marshallae* from *C. glacialis*, and other features used to separate the adults are difficult to routinely employ, thus these species were grouped for consistency. The larger *C. hyperboreus* would have been distinguished by size (e.g. Unstad and Tande, 1991; Hirche *et al.*, 1994), but was not encountered. The weight of each specimen was predicted from species-specific relationships, or from those of a morphologically similar species of holozooplankton (Table 1). Such relationships were unavailable for merozooplankton. Notably, although a relationship has been published for *Oithona similis* (Sabatini and Kjørboe, 1994), its slope of 2.16 is unrealistically shallow and thus overestimates weights for early stages, hence we use that for a congeneric species of similar body form. Where necessary, ash-free dry weight (AFDW) was converted to dry weight (DW) assuming 10% ash (Båmstedt, 1986). A Carbon weight (CW) to DW conversion does not exist for larvaceans, so we assumed it to be 40% of DW for *Oikopleura vanhoeffeni*, as is typical of many copepods (Båmstedt, 1986). For *Acartia longiremis* where CW was 50% of DW, weights were more consistent with other relationships determined for this genus (e.g. Uye, 1982).

In addition to a descriptive summary, community patterns were explored using the Primer (V6) software package which has been shown to reveal patterns in zooplankton communities (e.g. Clarke and Warwick 2001; Wishner *et al.*, 2008). Analyses were performed independently for both abundance and biomass data. Data sets were power transformed (4th root), and the Bray-Curtis similarity index between stations was calculated employing all taxonomic categories that contributed at least 3% to any sample in that dataset. Significant groups within the hierarchical clustering were established with the SIMPROF routine, and these clusters were superimposed on the 2D and 3D plots of the multi-dimensional scaled (MDS) datasets, as well as spatial plots of the data. Relationships between zooplankton community composition and other variables were explored with Primer's BEST routine using normalized physical data (above and below the thermocline) and integral chlorophyll data.

Table 1. Relationships employed to predict weight from length for the holozooplankton encountered in the study region. Where species-specific relations were not employed we used relationships from: * *T. japonica*, ** *Macrosetella*, *** *Oithona nana*, + *F. pellucida*, ++ *Pseudocalanus*. DW- dry weight, AFDW- ash-free dry weight, CW- carbon weight, TL-total body length, PL- prosome length, CL- carapace length

Species Regression		Units	Source
<i>Themisto pacifica</i> *	DW=0.0049·TL ^{2.957}	mm, µg	Ikeda & Shiga, 1999
<i>Themisto libellula</i>	DW=0.006·TL ^{2.821}	mm, µg	Auel & Werner, 2003
<i>Acartia longiremis</i>	CW=1.023·10 ⁻⁸ PL ^{2.906} µm,	µg	Hansen <i>et al.</i> , 1999
<i>Calanus glacialis/marshallae</i>	logDW=4.034·logPL-11.561	µm, µg	Liu & Hopcroft, 2007
<i>Centropages abdominalis</i>	log DW = 3.00·log PL-7.89	µm, µg	Uye, 1982
<i>Eucalanus bungii</i>	LogDW=3.091·logPL-0.0026	mm, µg	Hopcroft <i>et al.</i> , 2002
<i>Eurytemora hermani</i>	logDW = 2.96·logPL-7.60	µm, µg	Middlebrook & Roff, 1986
<i>Metridia pacifica</i>	logDW = 3.29·logPL-8.75	µm, µg	Liu & Hopcroft, 2006b
<i>Neocalanus plumchrus/flemingeri</i>	logDW=3.56·logPL-2.32	mm, mg	Liu & Hopcroft, 2006a
<i>Neocalanus cristatus</i>	LogDW=4.001·logPL-11.776	µm, µg	Kobari <i>et al.</i> , 2003
<i>Paraeuchaeta</i> spp.	AFDW=0.0075·PL ^{3.274} mm,	mg	Mumm, 1991
<i>Pseudocalanus</i> spp.	logDW=-2.85·logPL-7.62	µm, µg	Liu & Hopcroft, 2008
<i>Oithona similis</i> ***	logAFDW=3.16·logPL-8.18	µm, µg	Hopcroft <i>et al.</i> , 1998
<i>Oncaea</i> spp.***	logAFDW=3.16·logPL-8.18	µm, µg	Hopcroft <i>et al.</i> , 1998
<i>Oikopleura vanhoeffeni</i>	logC=3.20·logTL-8.93	µm, µg	Deibel, 1986
<i>Fritillaria borealis</i> +	logDW=3.21·logTL-9.11	µm, µg	Fenaux, 1976
Other calanoids** <i>Microcalanus</i> , <i>Jaschnovia</i>	logDW=-2.85·logPL-7.62	µm, µg	Liu & Hopcroft, 2008
Ostracods AFDW=0.02	28·PL ^{2.3698} mm,	mg	Mumm, 1991
<i>Thysanoessa inermis</i> (<i>T. rachii</i>)	Log DW=2.50·logCL-1.162	mm, mg	Pinchuk & Hopcroft, 2007
<i>Evadne</i> & <i>Podon</i>	logDW=4.0·logTL-10.5	µm, µg	Uye, 1982
<i>Tomopteris</i>	DW=0.005·L ^{2.25}	mm, mg	Matthews & Hestad, 1977
<i>Eukrohnia hamata</i>	DW=0.00032·PL ^{3.00}	mm, mg	Matthews & Hestad, 1977
<i>Parasagitta elegans</i>	DW=0.000064·PL ^{3.30}	mm, mg	Matthews & Hestad, 1977
<i>Aglantha digitale</i> & other jellies	DW=0.00194·PL ^{3.05}	mm, mg	Matthews & Hestad, 1977

Quality Control Procedures

In the field samples were always collected in duplicate, so any discrepancy in the flow meter readings become readily apparent. Replicate samples are not routinely analyzed, but serve as insurance in the event one sample is compromised. Where necessary, specimens were compared

to the voucher set housed at UAF, and periodic cross-comparison occurred between the 2 co-authors processing samples.

RESULTS

Chlorophyll and Nutrients

Chlorophyll concentrations were uniformly depleted across the sampling grids and remained low for the entire season, indicating that sampling had occurred post-spring phytoplankton bloom (Fig. 2). Integrated chlorophyll concentrations were slightly higher at the Burger prospect than Klondike with exception of the September/October cruise, but in general no clear trend was observed (Table 2). On all cruises, chlorophyll was low at all depths, without an obvious subsurface maximum (Fig. 3, 5, 7, 9, 11, 13).

Table 2. Average integral chlorophyll concentration (mg m^{-2}) at the Klondike and Burger survey grids during 2009

Cruise	Klondike	Burger
August	17.6	21.4
August/September	16.0	20.1
September/October	27.2	25.1

Nitrate, silicate and phosphate were virtually absent from surface waters even during the first cruise, generally increased toward the seafloor, and were somewhat irregular in their profiles within each grid (Fig. 3-14). Nutrient concentrations at depth were generally higher at Burger than Klondike, with a notably undepleted deep pool of silicate present at Burger during the first cruise (Fig. 6), while nitrate and phosphate were already exhausted at all depths. All nutrients were low over the Klondike prospect and remained low for the entire season (Fig. 3,4).

Zooplankton

In total, 70 taxonomic categories of zooplankton, including 11 meroplanktonic larval categories, were observed during the 2009 field year. An average abundance of 7030 individuals m^{-3} and 20.4 mg DW m^{-3} was captured by the 150 μm net and an average of 196 individuals m^{-3} and 7.0 mg DW m^{-3} captured by the 505 μm net. The greatest diversity was observed within the copepods (23 species, plus juvenile categories), followed by the cnidarians (10 species). The relative importance of taxa varies depending on which net is considered, and if abundance or biomass are used for such assessment. For the 150 μm nets, abundance was dominated by the small larvacean *Fritillaria borealis*, followed by the copepod *Oithona similis*, the *Pseudocalanus* species complex, the pteropod *Limacina helicina*, calanoid copepod nauplii, barnacle larvae (nauplii and cyprids), bivalve larvae and polychaete larvae, all averaging more than 100 m^{-3} . Biomass in the 150 μm nets was dominated by several of these taxa, plus rarer species of larger individual biomass, with the copepod *Calanus marshallae*, barnacle larvae (nauplii and cyprids), the chaetognath *Parasagitta elegans*, the copepod *Oithona similis* followed by the *Pseudocalanus* copepod species, followed by, the ctenophore *Mertensia ovum* and finally polychaete larvae.

Table 3. Zooplankton species observed during 2009, in the Klondike and Burger surveys, along with their average abundance and biomass across all samples examined. Data is presented for both vertical 150 µm collections and the 505 µm oblique tows. 'Trace' refers to taxa observed only once or twice during analysis.

	150 µm net		505 µm net	
	Abundance (indiv m ⁻³)	Biomass (mg DW m ⁻³)	Abundance (indiv m ⁻³)	Biomass (mg DW m ⁻³)
Copepods				
<i>Acartia</i> juvenile	66.618	0.009	0.182	0.000
<i>Acartia longiremis</i>	27.670	0.106	0.317	0.002
<i>Acartia hudsonica</i>	6.178	0.017		
<i>Calanus marshallae/glacialis</i>	57.663	6.831	12.625	2.481
<i>Centropages abdominalis</i>	15.300	0.035	0.140	0.002
<i>Epilabidocera amphitrites</i>			0.002	0.000
<i>Eucalanus bungii</i>	13.587	0.137	3.294	0.054
<i>Eurytemora</i> juvenile	0.828	0.011		
<i>Eurytemora pacifica</i>	0.220	0.000	0.002	0.000
<i>Metridia pacifica</i>	3.076	0.012	0.073	0.001
<i>Neocalanus plumchrus</i>			0.009	0.005
<i>Neocalanus cristatus</i>	0.017	0.103	0.003	0.012
<i>Pseudocalanus</i> male	6.525	0.041	0.023	0.000
<i>Pseudocalanus</i> juvenile	494.878	0.993	0.339	0.001
<i>Pseudocalanus minutus</i>	0.674	0.010	0.031	0.001
<i>Pseudocalanus acuspes</i>	6.257	0.055	0.013	0.000
<i>Pseudocalanus newmani</i>	33.778	0.169	0.186	0.001
<i>Pseudocalanus mimus</i>			0.018	0.000
<i>Tortanus discaudata</i>			Trace	Tra
<i>Oithona similis</i>	1235.526	1.458		
<i>Scolecithricella ovata</i>			Trace	Tra
<i>Triconia (Oncaea) borealis</i>	49.436	0.072		
Harpacticoida	3.367	0.018		
calanoid nauplius	295.759	0.195		
cyclopoid nauplius	90.120	0.025		
calanoid nauplius (large)	28.798	0.085		
Larvaceans				
<i>Oikopleura vanhoffeni</i>	2.046	0.003	0.062	0.000
<i>Fritillaria borealis</i>	3808.510	0.044	165.949	0.030
Pteropods				
<i>Limacina helicina</i>	525.0676	0.900	0.172	0.053
<i>Clione limacina</i>	0.008	0.008	0.007	0.015
Euphausiids				
Euphausiid nauplius				
Euphausiid calyptopis	0.250	0.101	0.006	0.000
Euphausiid juvenile	0.300	0.036	0.973	0.105
<i>Thysanoessa longipes</i>			Trace	Tra
<i>Thysanoessa inermis</i>			Trace	Tra
<i>Thysanoessa raschii</i>			0.233	0.736
<i>Thysanoessa spinifera</i>			Trace	Tra

Table 3 continued	150 µm net		505 µm net	
	Abundance	Biomass	Abundance	Biomass
Shrimps and Mysids				
Pandalidae			0.005	0.019
Hippolytidae (juveniles)			0.025	0.009
Chaetognaths				
<i>Parasagitta elegans</i>	53.478	3.928	3.234	0.327
Cladocerans				
<i>Podon leuckartii</i>	0.466	0.001		
Amphipods				
<i>Themisto abyssorum/pacifica</i>			Trace	Trace
<i>Themisto libellula</i>			0.006	0.547
<i>Hyperoche medusarum</i>			0.002	0.001
Gammaridae			Trace	Trace
Hyperiididae	0.005	0.013	0.007	0.005
Amphipod (misc.)			0.041	0.002
Ctenophore				
<i>Mertensia ovum</i>	0.990	0.577	0.134	0.560
Ostracoda				
			0.004	0.000
Cnidarians				
<i>Aglantha digitale</i>	12.701	0.221	0.944	0.679
<i>Aurelia aurita</i>			0.011	0.679
<i>Rathkea octopunctata</i>	0.434	0.002	0.029	0.111
<i>Aeginopsis laurentii</i>			Trace	Trace
<i>Catablema laevis</i>	0.020	0.017	0.039	0.010
<i>Melicerium octocostatum</i>			0.000	0.000
<i>Obelia</i> spp.	1.600	0.015	0.020	0.001
<i>Cyanea capillata</i>	0.008	0.030	0.032	0.522
<i>Chrysaora melanaster</i>			Observed	
TOTAL Holozooplankton	6400.671	14.326	189.193	6.973
Bivalve larvae	153.210	0.043	0.026	0.000
Decapod zoea	1.378	0.015	0.906	0.008
Pagurid zoea			0.133	0.001
Barnacle cyprius	274.481	5.250	5.120	0.118
Barnacle nauplius	22.687	0.018	0.574	0.001
Zoea (unspecified)	0.283	0.121		
Megalops	0.130	0.031	0.238	0.026
Polychaete larvae	132.000	0.548	0.023	0.001
Ophiuroid larvae	34.617	0.002		
Asteroid bipinnaria	0.366	0.000		
Echinoid larvae	6.225	0.002		
TOTAL Meroplankton	625.377	6.030	7.020	0.155
TOTAL Zooplankton	7026.048	20.356	196.213	7.128

In contrast, abundance ranking for the 505 μm nets was also led by the larvacean *Fritillaria borealis* and was the only species observed to reach an average abundance of over 100 individuals m^{-3} . Although *Fritillaria* was the single most abundant species recorded they can be categorized as bycatch due to their size class, as they were adequately represented by the 150 μm nets and should have been expelled through the greater porosity of the 505 μm nets but were easily retained on algal tuffs during the collection process. The copepods *Calanus marshallae/glacialis* and *Eucalanus bungii*, barnacle larvae (nauplii and cyprids) and the chaetognath *Parasagitta elegans*, averaged between 3 and 13 individuals m^{-3} . Biomass in the 505 μm nets was substantially different than the pattern for counts, and dominated by the copepod *Calanus marshallae/glacialis*, the euphausiid *Thysanoessa raschii*, the jellyfish *Aurelia aurita* and *Cyanea capillata*, the ctenophore *Mertensia ovum*, and the chaetognath *Parasagitta elegans*.

Summarizing the averages for each cruise by major taxonomic groups, in terms of abundance larvaceans and copepods appear to dominate in numbers, remaining relatively stable over successive cruises, while pteropods, copepod nauplii and meroplankton appear somewhat variable but stable in number (Fig. 15). In terms of biomass, there were pronounced differences in magnitude for three major taxa when compared across the sampling season. During the first cruise meroplankton, chaetognaths and copepods co-dominated the biomass for both Klondike and Burger prospects. Copepod biomass remained high over the Klondike prospect for both the middle and last cruise. Chaetognaths and meroplankton biomass declined after the first cruise and became more evenly distributed in terms of importance with the other major taxonomic groups, creating more of a homogenous representation for the latter two cruises (Fig. 16). Chaetognaths, euphausiids and the “other” group category contribute relatively little in term of abundance, but make notable contributions to biomass, especially on a relative basis within the 505 μm net.

Changes in the relative contributions of the different groups are more striking when viewed at the station level (Fig. 17-20). For the 150 μm nets, both sites appear relatively similar with abundances being dominated by larvaceans, copepods and meroplankton (Fig. 17). The survey grids appear to diverge on the second cruise, with meroplankton and larvaceans declining slightly in number over Klondike, and pteropods contributing to a greater percentage of the community composition for both regions. Copepods remained of greater importance at Klondike compared to Burger during the sampling season. By the third cruise, larvaceans abundance increased over both Klondike and Burger where pteropods decreased at Klondike. In terms of biomass, in the 150 μm nets, copepods, chaetognaths and meroplankton dominated overall, with typically greater contributions by copepods at Klondike than Burger (Fig. 18). For the 505 μm nets, abundance was significantly dominated by larvaceans in both Klondike and Burger over the entire sampling season. By the second cruise, copepod abundance increased in the southern region of Klondike and persisted slightly into the third cruise. For Burger, chaetognath abundance increased as the sampling season progressed, with high contributions in the third cruise (Fig. 19).

In contrast, the distribution of biomass in the 505 μm nets was distinctly different from the 150 μm nets, with scyphozoans, hydrozoans and pteropods prominent over the first two cruises. During the second cruise, cnidarian contribution dropped due to substantial contribution by the copepods in the southern region of Klondike. By the third cruise hydrozoan biomass had greatly dropped off and chaetognaths became more important over Burger. The “other” category, which

varies in contribution to biomass, consists of amphipods, mysids, shrimps and ctenophores (Fig. 20).

Looking more closely at the species and genus level, faunal differences become apparent between the cruises and survey areas. For the 150 μm nets, the copepods, *Pseudocalanus*, *Calanus marshallae/glacialis*, *Oncaea* and *Centropages* showed no limited pattern. The numerically dominant *Oithona similis* as well as *Acartia* and copepod nauplii increased in both Klondike and Burger across the sampling season (Figs. 21 & 22). The large copepod *Eucalanus bungii* was only present during the August/September and was observed in the Klondike study area only. The larvacean *Fritillaria borealis* dominated all zooplankton categories with abundances remaining relatively stable in Burger and increasing on the last cruise in Klondike. The chaetognath *Parasagitta elegans* remained relatively stable in numbers for both the Klondike and Burger prospects with greater abundances found in Burger. The cnidarian *Aglantha digitale* was rather variable in abundance throughout the season but showed a large increase in numbers from the first to the second cruise in Burger (Fig. 22 & 24). Barnacle cyprids showed a peak in abundance at the beginning of the season and then decreased during the second and third cruises, while bivalve larvae saw heightened increase of individuals as the season progressed, with relatively even numbers in both regions by the third cruise (Fig. 23). The pteropod *Limacina helicina* peaked in abundance during the second cruise and then declined during the third cruise. The larvacean *Oikopleura vanhoeffeni* saw an early spike during the first cruise and continued to decline as cruises progressed in both Klondike and Burger (Fig. 24).

For the 505 μm net, abundances were lower for all species of zooplankton than observed in the 150 μm net (Fig. 25a & b). The more robust data on these larger species in the 505 μm nets shows the neritic *Calanus marshallae/glacialis* to be more abundant at Klondike. The larvacean *Fritillaria borealis*, the copepod *Eucalanus bungii*, the chaetognaths *Parasagitta elegans* and the cnidarian *Aglantha digitale* all showed similar patterns to the 150 μm net with the exception that *Fritillaria* numbers declined in Burger for the last cruise (Figs. 25a & b). The ctenophore *Mertensia ovum* was not observed during the first cruise in either region and was more prominent over Klondike than Burger (Fig. 25a). Meroplankton for decapods and urchins both saw a peak in abundance during the middle cruise, where urchin larvae was more abundant in Klondike and decapods larvae was more abundant in Burger (Fig. 25a). Shrimp and mysids also were observed to have a peak in abundance during the middle cruise with numbers relatively even between the two regions. Euphausiids (and amphipods) did not show a clear pattern over the season but euphausiids were more abundant in Klondike for all three cruises (Fig. 25b). The scyphozoans *Cyanea* and *Aurelia* both exhibited a similar pattern where numbers continued to decline as the season progressed and higher abundances were seen in Burger than Klondike (Fig. 25b).

Cluster analysis of sample Bray-Curtis similarity on the 150 μm abundances suggested 12 distinct clusters within the samples, with 6 or 7 major clusters emerging at the 70-80% similarity level and several stations from the first 2 Klondike cruises appearing distinct from the other stations (Fig. 26). In general stations within a survey grid tended to cluster together, as also supported by the multidimensional scaling (MDS) of the data (Fig. 27). MDS plots also suggest collections are moving along a temporal trajectory. Clustering analysis of the 505 μm zooplankton abundances produced less clear clustering (Fig. 28), and more overlap in MDS space (Fig. 29). Primer's BEST routine indicated that consecutive day of sampling was better at explain these patterns (Spearman's $r=0.33$ for 150 μm data) as was temperature, salinity or

fluorescence alone (Spearman's $r=0.26-0.28$). In combination with physical data sample date, temperature (or salinity) and fluorescence yielded slightly stronger correlations (Spearman's $r=0.41-0.42$) than the best 3-variable physical models (Spearman's $r=0.37$). Inclusion of more than 3 variables produced numerous combinations of variables with little improvement in explanatory power. Slightly less variation could be explained by equivalent models for the 500 μm nets (max Spearman's $r=0.34$).

The zooplankton communities appear to be distinctly different between 2008 and 2009 with little overlap in their clustering and distinct domains for multidimensional scaling of both 150 μm (Fig. 30) and 505 μm (Fig. 31) abundances. Interestingly, the 2008 data show higher within-year similarity than 2009 for the 150 μm samples, while the opposite is true for the 505 μm samples, suggesting one of the greatest differences between years will be for the larger zooplankton species.

DISCUSSION

Chlorophyll and Nutrients

In previous studies, phytoplankton pigments and size-fractionated biomass in the Chukchi Sea did not any show spatial or temporal variations during the spring and summer related to water-column irradiance and nutrient concentration (Hill *et al.*, 2005; Lee *et al.*, 2007). High concentrations of nutrients in the surface waters during spring are typically depleted rapidly during bloom conditions along the ice edge, or in open water and rapid stratification limits replenishment of nutrients from below the mixed layer to the surface. During our 2009 surveys, low nutrient concentrations were persistent in surface waters, as were surface chlorophyll concentrations during the surveys conducted in 2009, consistent with such previous observations. The low chlorophyll and nutrient concentrations observed over both Klondike and Burger throughout the water column indicated sampling occurred post-bloom and concentrations remained low throughout the remainder of the season. This is in contrast to the first cruise of the 2008 field season, where higher concentrations of nutrients and chlorophyll indicated the spring bloom was at least partially captured. By the second cruise in 2008, nutrients were exhausted in surface waters, chlorophyll was declining at Burger, and chlorophyll had stabilized at Klondike to the values similar to those observed throughout 2009.

Zooplankton composition

The Chukchi Sea displays a similar level of diversity, but high biomass compared to the adjoining East Siberian (Jaschnov, 1940; Pavshikov, 1994) and Beaufort (e.g. Horner, 1981) seas. In contrast, the Chukchi Sea has lower diversity than is present in the adjoining vertically-structured central Arctic basins where depths can exceed 3000 m (e.g. Kosobokova and Hirche, 2000; Kosobokova and Hopcroft, 2010). As was observed during the 2008 field program, most copepod species observed in this study were common to the subarctic Pacific Ocean and/or the Bering Sea rather than specific to the Arctic (Brodsky, 1950, 1957), due to the generally northward advection of waters through Bering Strait (e.g. Weingartner *et al.*, 2005). Nonetheless, the species composition is generally similar to that observed during the summer ice-free period in this region when similar-sized finer collecting meshes are employed (e.g. Springer *et al.*, 1989; Kulikov, 1992; Hopcroft *et al.*, 2010), or similar coarser nets are compared (e.g. Wing, 1974; English and Horner, 1977).

In contrast, our estimates 7030 individuals m^{-3} and 20.4 mg DW m^{-3} (~ 0.75 g DW m^{-2}) captured by the 150 μm net, and the average of 196 individuals m^{-3} and 16.0 mg DW m^{-3} (~ 0.5 g DW m^{-2}) captured by the 505 μm net are on the low side compared to previous studies from the Chukchi Sea, although they are similar to (but higher than) our observations from 2008. In waters to the south and west of the Klondike and Burger survey areas an average of 5760 individuals m^{-3} and 42 mg DW m^{-3} were recently determined using identical techniques with a 150 μm vertical net (Hopcroft *et al.*, 2010). There is also a broad range of older biomass estimates for the region, ~ 2 g DW m^{-2} for herbivorous zooplankton in summer north and south of Bering Strait (Springer *et al.*, 1989), 2.5-5.5 g DW m^{-2} on the US side of the Chukchi sea or 1.3 g DW m^{-2} spanning both sides of the Chukchi (Turco, 1992a, b). Furthermore, 14.8 g WW m^{-2} (Kulikov, 1992) and 356 mg WW m^{-3} (14.2 g WW m^{-2} - Pavshikov, 1984) for all mesozooplankton spanning the Chukchi Sea is also close, if we assume DW is 10-15% of WW (Wiebe *et al.*, 1975). It is however notable that these higher values are based largely on samples collected to the south of our study area. Our observations do overlap the range of recent observations (3-58 mg DW m^{-3}) to the north of the Klondike and Burger survey areas near the shelf break (Lane *et al.* 2008; Llinás *et al.*, 2009), but remain lower than typical for the upper 50m (42 mg DW m^{-3}) further into the adjoining basin (Kosobokova and Hopcroft, 2010).

In terms of composition, the species observed in this study have all been reported previously for this region, but not consistently within a single publication. Our 505 μm data is directly comparable to data from the ISHTAR (Inner Shelf Transfer and Recycling) program (Springer *et al.*, 1989; Turco, 1992a,b), who noted the predominance of *Calanus marshallae/glacialis*, *Pseudocalanus* spp., *Acartia longiremis* and *Oikopleura* among the herbivorous grazers. In addition to awareness of difference between collecting mesh size, detailed comparison to many previous studies also requires an awareness of changes in taxonomic resolution, and taxonomy itself; for example, *Pseudocalanus* prior to the revision of the genus (Frost, 1989), separation of *Neocalanus plumchrus* into *N. plumchrus* and *N. flemingeri* (Miller, 1988), separation of the subarctic *Calanus marshallae* (Frost, 1974) from the closely related *C. glacialis*. Even today routine morphological separation of several of these species is difficult (Llinás, 2007; Lane *et al.*, 2008). Other holoplanktonic crustacean groups, such as euphausiids and cladocerans, present less of a taxonomic challenge and are generally accurately reported in previous works, although sometimes not to the species level. Non-crustacean groups have been recorded with variable resolution and proficiency in previous studies. This study is consistent with an emerging realization that considerable populations of larvaceans, specifically the large arctic *Oikopleura vanhoffeni* and the much smaller *Fritillaria borealis*, are present in the northern Bering and Chukchi Sea (e.g. Kulikov, 1992; Lane *et al.*, 2008; Hopcroft *et al.*, 2010) at times reaching high biomass (Springer *et al.*, 1989; Shiga *et al.*, 1998, Hopcroft *et al.*, 2010).

The dominant predators in terms of abundance and biomass were the chaetognaths, exclusively *Parasagitta elegans*, consistent with other studies from the region (e.g. Cooney, 1977; Neimark, 1979; Springer *et al.*, 1989; Kulikov 1992; Lane *et al.*, 2008; Hopcroft *et al.*, 2010). Consistent with these studies there was considerable biomass in both small and large gelatinous organisms: *Aglantha digitale* and *Rathkea octopunctata* being most common, but larger species periodically captured although poorly quantified. Finally, suspension-feeding meroplanktonic larvae of benthic organisms were extremely common throughout the sampling region. High abundance of meroplankton is typical of summer-time data in this region (e.g. Cooney, 1977; Neimark, 1979; Springer *et al.*, 1989; Kulikov, 1992; Hopcroft *et al.*, 2010), and knowledge of their abundance and distribution is relevant to understanding recruitment to the

rich benthic communities in this region (Bluhm *et al.*, 2009), and relation to the work by Blanchard *et al.* given their apparently large contribution to the zooplankton biomass in the prospect areas, relationships between the size and weight for meroplanktonic groups need to be better quantified to more fully appreciate their role in this region.

Community patterns

The spatial distribution of the zooplankton communities in the Chukchi Sea has been frequently tied to the different water masses in this region. Such patterns were first recognized by Russian researchers as early as the 1930s (Stepanova, 1937a,b), and are to a large extent a continuation of patterns observed in the northern Bering Sea (see review by Coyle *et al.*, 1996). These patterns were reiterated by later Russian studies (e.g. Pavshikov, 1984) that identified at least three water types in the region. Although the first years of the ISHTAR program were restricted to sampling in US waters, oceanic Anadyr waters, continental shelf and low-saline nearshore waters were all recognized (Springer *et al.*, 1989). Cross-basin studies by the international BERPAC (Bering-Pacific) program also identified three zooplankton clusters within the Chukchi Sea, but failed to articulate their species assemblages or associate them with specific water masses (Kulikov, 1992). Recent sampling to the south also confirms strong ties to water masses (Hopcroft *et al.*, 2010).

Despite the relative proximity of the survey areas, we were frequently able to separate them based on community structure, and also able to determine a temporal evolution to the communities as well. Although temperature, salinity and fluorescence (as an index of chlorophyll) could be statistically correlated to the observed community structures, the amount of variation explained was relatively low. Probably related to the study area's distance from shore, a strong Alaska Coastal Current signal was not obvious in the zooplankton communities compared to some other studies (i.e. Hopcroft *et al.*, 2010), but these coastal species (i.e. *Podon* and *Evadne*, *Acartia hudsonica*, *Eurytemora* species) were observed in low numbers throughout our study area. Integration of the surveys' biological and physical data in the near future, including broader scale information from satellites, and information on currents around the prospect regions should help resolve some of these questions.

Inter-annual comparison

The inter-annual variability observed for the planktonic communities between the 2008 and 2009 sampling seasons can be correlated to the physical parameters. Sea surface temperatures in 2008 were low throughout the entire season at Burger (i.e. generally below 1°C) but warmed over the season at Klondike reaching between 3 and 6°C (Weingartner and Danielson, 2010). Overall this retarded zooplankton growth and development, resulting in lower abundances and smaller body sizes across major taxa. In 2009 ice retreat was earlier than the previous year and sea surface temperatures (SSTs) were already 5-7°C at Klondike and slightly cooler at Burger by the first cruise. Temperatures declined slowly over subsequent 2009 cruises, but there was notably more "heat" in the system during 2009 (Weingartner and Danielson, 2010). Warmer temperatures should have allowed more rapid growth and reproduction, allowing for greater zooplankton abundances in 2009 (i.e. the 2 fold increase in 150 µm nets abundances). This appears to have supported more energy rich larger-bodied zooplankton earlier in the 2009 season. Given the cold temperatures and timing of the algal bloom in 2008, it is likely that more algal production was exported to the benthos in 2008 than in 2009 (Blanchard *et al.* 2010).

Observed differences in the meroplankton between the study years are consistent with greater export of energy to the benthos in 2008 stimulating greater production of meroplanktonic larvae, as well as delaying their release into the plankton.

The most striking feature of the zooplankton community for 2009 was the overwhelming abundance of a single species of larvacean, *Fritillaria borealis*, as well as a greater abundance of the pteropod *Limacina helicina* than what was observed for 2008. Species that greatly contributed to the overall higher abundance of copepods observed during the 2009 season are *Oithona similis* and *Pseudocalanus* spp. which are small-bodied copepods typical of the shelf community for the Chukchi Sea. The peak in copepod abundance and biomass observed over Klondike during the August/September time frame (WW0903) was from the infiltration of two larger bodied copepods, *Calanus marshallae/glacialis* and *Eucalanus bungii*, both of which then declined as the season progressed and temperatures cooled. Overall, a lower number of the larger bodied copepod *Neocalanus* spp. was observed in 2009, but a two fold increase in the biomass of *Calanus marshallae/glacialis* and *Eucalanus bungii* measured for 2009 suggests that lipid-rich later copepodite stages (C5s) and adults were present in greater numbers than the previous year. The 505 μm nets showed that euphausiids were more abundant in 2009 than 2008, with the majority of euphausiid biomass occurring as adults and subadults rather than larvae and juveniles. The predominant euphausiid also shifted from *Thysanoessa inermis* in 2008 to *Thysanoessa raschii* in 2009.

Changes in the abundance and relative contribution of crustacean zooplankton – in particular larger-bodied copepods and euphausiids – can help us to interpret the degree of dissimilarity expressed from clustering and MDS between 2008 and 2009 for the 505 μm nets. Despite overall similarity in average annual abundance and biomass between 2008 and 2009, when compared at the cruise and station level, the two sampling years are significantly different from one another, with much of the variability related to the different temporal progression of the physical variables that structured the planktonic communities for each year. Specifically, we believe several larger key species were more apparent in 2009 than 2008 because the “productive” season started earlier yielding oceanographic conditions (i.e. temperature) were more optimal for their growth and/or reproduction, either locally or in the source waters “down stream” of the study area. These factors placed populations of larger crustacean zooplankton in the survey areas sooner, at a time when they could be usefully exploited by fishes, planktivorous seabirds and other higher trophic levels. These differences likely contributed to the contrasting seabird populations observed between the 2008 and 2009 field years (Gall and Day, 2010).

CONCLUSIONS AND OUTLOOK

Despite differences in water temperatures and timing of the phytoplankton bloom in 2008 and 2009, seasonally and spatially averaged zooplankton community values were relatively similar. This first cut similarity hides numerous changes in timing and magnitude at the species level that appear to have large consequences for high trophic levels. In addition to confirming the known importance of crustacean zooplankton, these surveys are establishing the unappreciated importance of both larvaceans and meroplankton in the north-eastern Chukchi Sea. Sampling during the summer of 2008 and 2009 in the Chukchi Sea is allowing us to recognize the level of inter- and intra-annual variability of a plankton community primarily Pacific in faunal character. Surveys during 2010 will further help to refine these “averages” and the scales of variability.

Data collected during the 1980s by the ISHTAR program (Turco, 1992a,b) suggests that large seasonal and inter-annual difference can occur in the northern Bering and southern Chukchi Seas, however their observations are problematic to fully interpret because they lacked a consistent set of stations on which to standardize their data. A major strength of this program is the use of a consistent sampling design capable of capturing differences in both timing and intensity of the planktonic communities and other ecosystems components. Observations concurrent with this study's September 2009 surveys conducted by NOAA's RUSALCA program show some interesting consistencies within their preliminary data (e.g. high abundances of the pteropod *Limacina helicina*, and low abundances of the larvacean *Oikopleura vanhoeffeni* in 2009). A more complete and rigorous comparison of these datasets will be undertaken during the coming year, as well as comparison to other concurrent sampling efforts in the region. As with most observational programs, the challenge will be in forming an understanding of the linkages between the different trophic levels being studied in the current assessment program.

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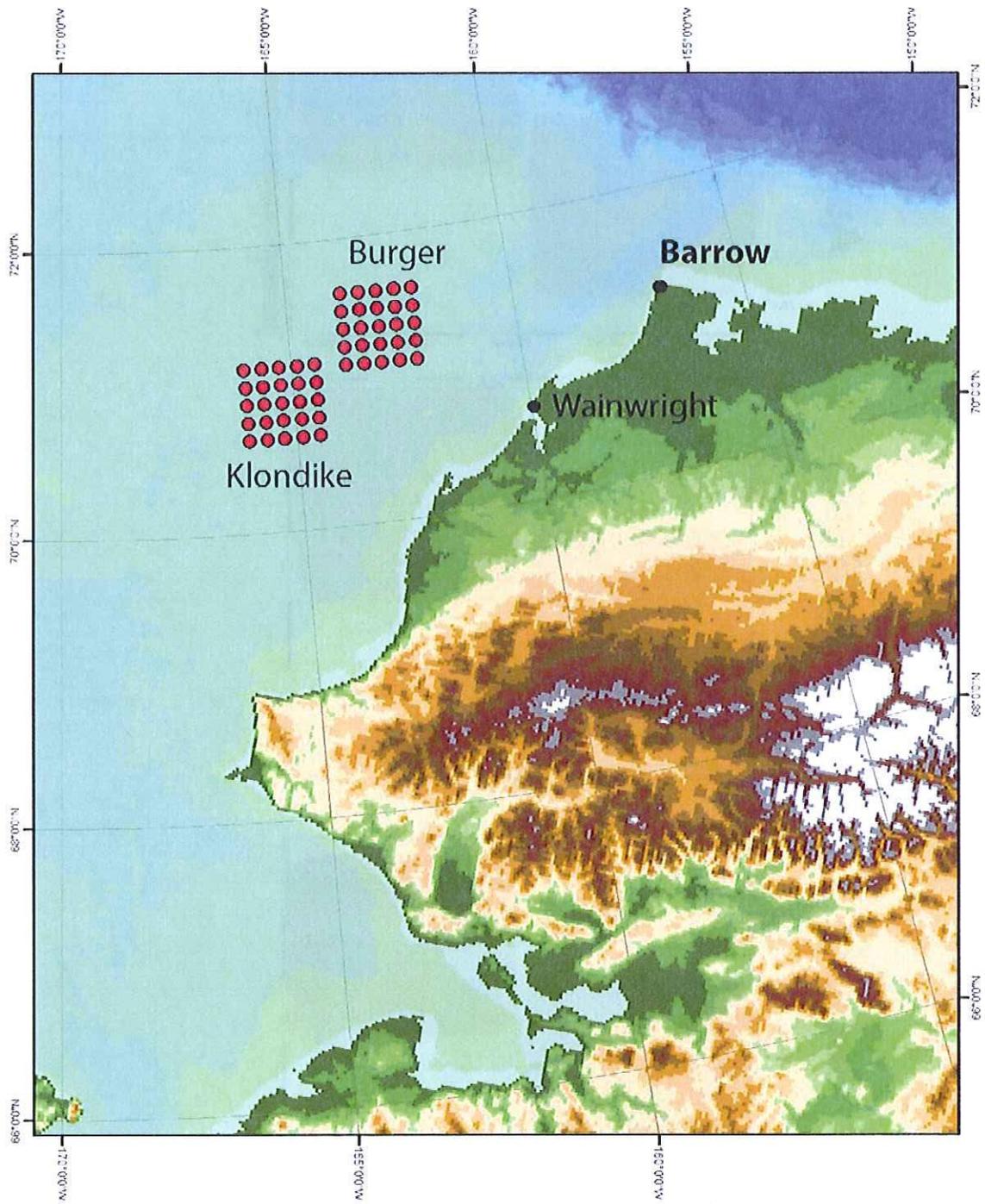


Fig. 1. Locations of the Klondike and Burger survey grids in the northeastern Chukchi Sea.

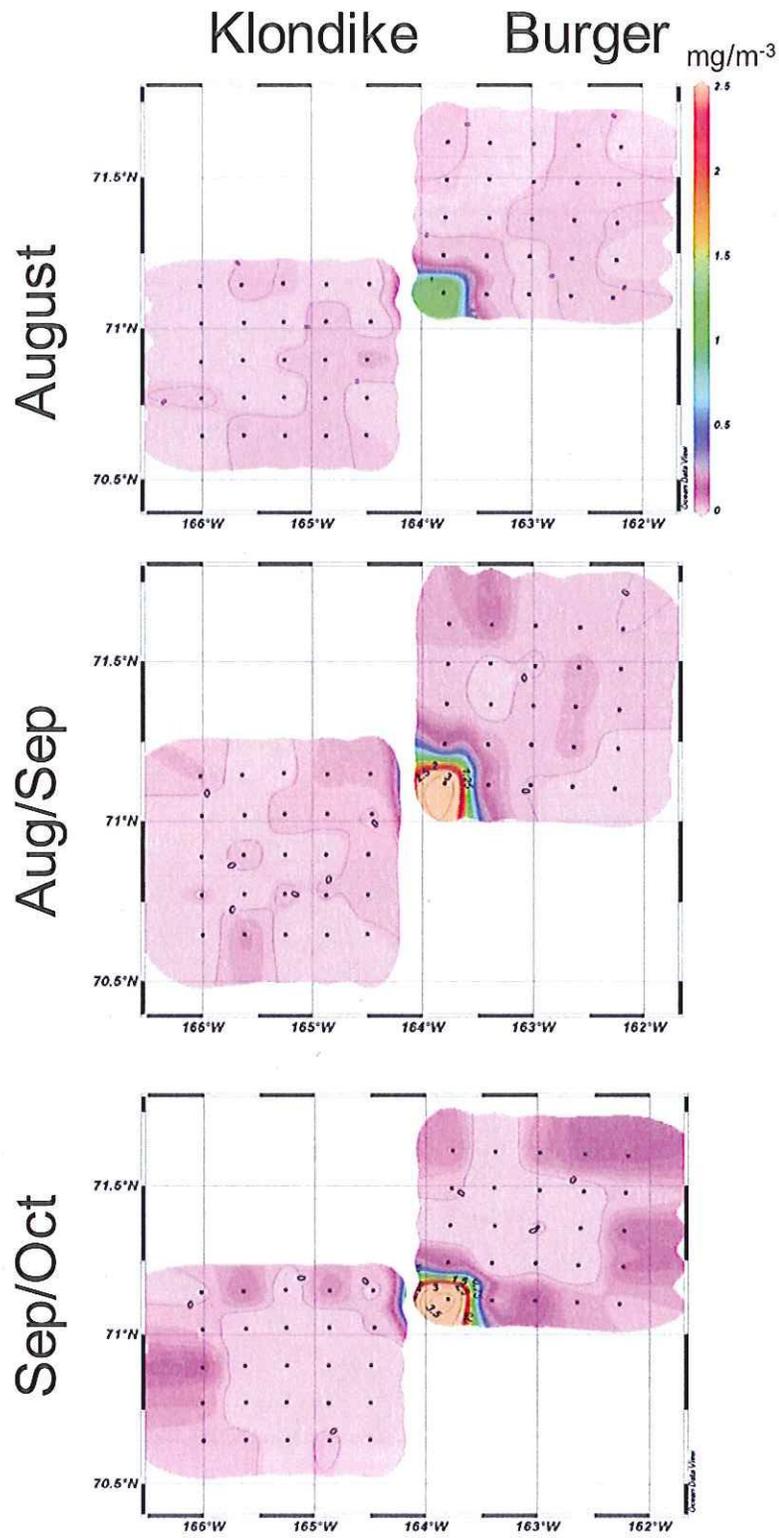


Fig. 2. Integrated chlorophyll *a* observed at the Klondike and Burger areas during 2009.

Klondike August 2009

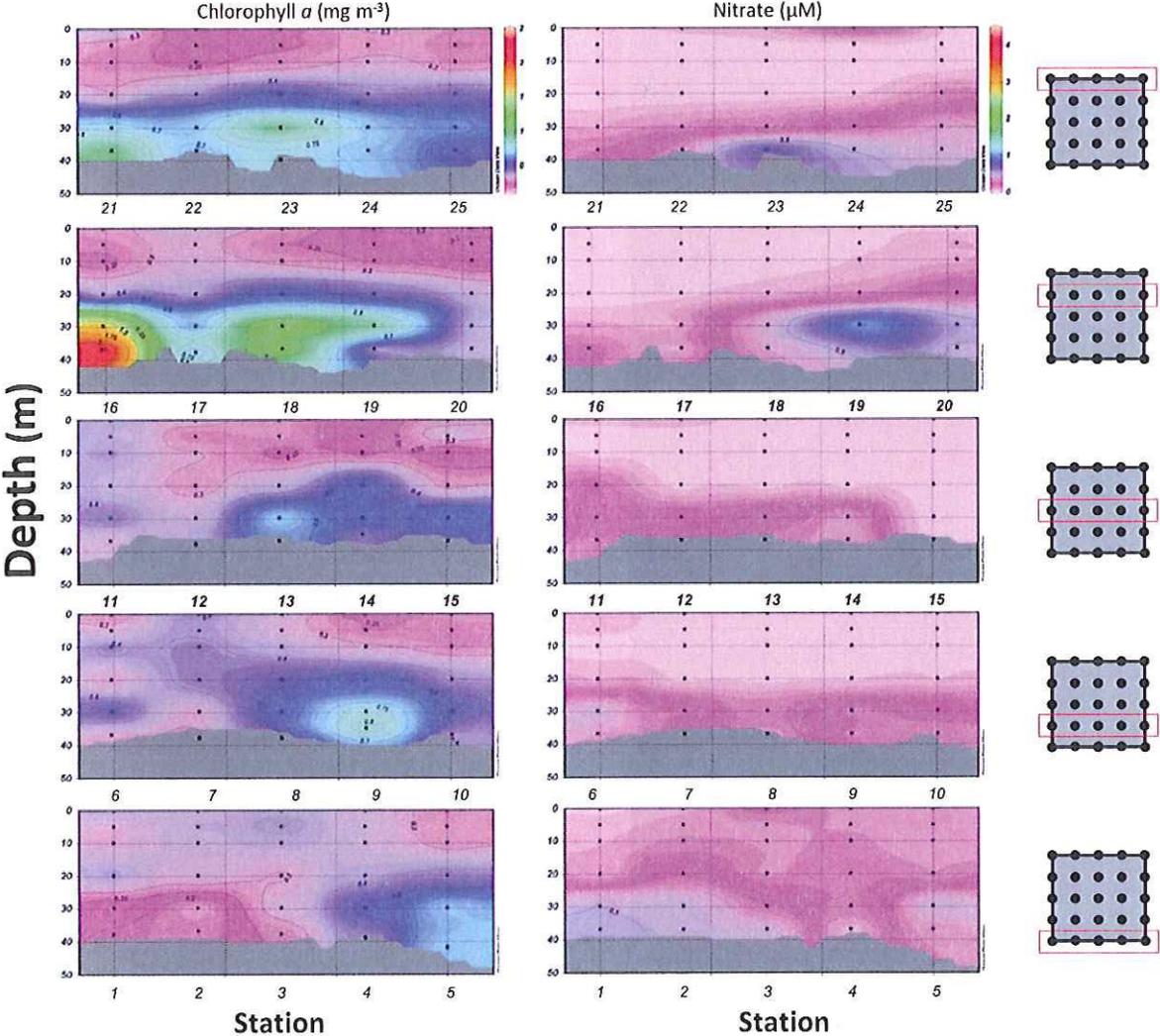


Fig. 3. Chlorophyll and nitrate profile concentrations observed at the Klondike survey area during the August cruise 2009 (WWW0902).