

Oceanographic assessment of the planktonic communities in the Klondike and Burger prospect regions of the Chukchi Sea

Report for Survey year 2008

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Executive Summary

Surveys of the planktonic communities over both the Klondike and Burger prospects were completed 3 times over the majority of the ice-free period in 2008. Chlorophyll and nutrient concentrations suggest the phytoplankton spring bloom was observed at Burger on the first cruise, while all Klondike sampling appears to have occurred post-bloom. Surface concentrations of nutrients and chlorophyll remained low for the remainder of the season at both prospects. In total, 76 taxonomic categories of zooplankton, including 12 meroplanktonic larval categories, were observed during the 2008 field year. The greatest taxonomic diversity was observed within the copepods (20 species, plus juvenile categories), followed by the cnidarians (9 species), with all species typical for the region and largely of Pacific origin. An average abundance of 3330 individuals m^{-3} and 18.5 mg DW m^{-3} was captured by the 150 μm net and an average of 189 individuals m^{-3} and 11.4 mg DW m^{-3} captured by the 505 μm net. The contribution by meroplankton forms to both abundance and biomass was substantial. Abundance and biomass estimates of the zooplankton community appear lower than typical for the region, perhaps due to relatively cold oceanographic conditions experienced during 2008, which slowed the normal growth and development of the zooplankton. Despite the relative proximity of the prospects, they could generally be separated based on community structure. Not surprisingly, a temporal evolution of the community structure was apparent over both prospects. Although both temperature and chlorophyll influenced the observed community structure, the amount of variation attributed to them within this study was relatively low.

INTRODUCTION

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). This 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). The influx of the "rich" Pacific water 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 Schnack-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, 2009) 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.*, 2009).

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) and SBI (Shelf-Basin Interactions) programs. Within the Chukchi Sea there is considerable diversity of both small and large jellyfish, hydromedusae and ctenophores that are often overlooked: more than a dozen species were encountered in RUSALCA 2004 (Hopcroft *et al.*, 2009), and more are reported from the nearby deep basins (Raskoff *et al.* 2005, 2009). 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, 2009; 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, 2009; 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. 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.*, 2009).

In terms of mechanisms, planktonic communities of the Chukchi Sea could undergo climate related changes either through shifts in the absolute transport rate, and thus penetration, of Pacific species into the Arctic, or by environmental changes that ultimately effect their survival. 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). In the summer the southern Chukchi zooplankton fauna is primarily Pacific in character, and there were clear signs that Pacific species were carried northward as far as the eastern side of Wrangel Island Herald Canyon (Hopcroft *et al.*, 2009), while in the north-eastern Chukchi transitions to fully Arctic communities did not occur until the shelf break (Lane *et al.*, 2008). Future increases in transport could carry even more Pacific zooplankton through Bering Strait with even further penetration into the Arctic. In contrast, a reduction in transport of Bering Sea water would not only decrease the overall productivity of the Chukchi Sea, but give it a more Arctic Ocean faunal character. Thus, changes in the transport rates ultimately effect the species composition of this region as well as the absolute zooplankton biomass, and such shifts may result in changes in the size structure of zooplankton communities. Since most higher trophic levels select their prey based on size, the consequences of size-structure shifts could be more important than changes in zooplankton biomass.

Purpose of Study and Rationale

Chukchi Lease Sale 193 occurred in February 2008. Multiple years of data are planned to aid in the preparation of a defensible NEPA document to support exploratory drilling. Pelagic biological oceanography forms one aspect of these baseline studies, 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 inter-annual variability, long-term climate change or human activity, could therefore have direct impact on the ecosystem, including the more visible vertebrates. Long-term studies with direct observations of community composition and biomass are 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. The study area is near the historical transition between Alaska Coastal waters and Bering Shelf waters, both of which have unique assemblages of zooplankton. It is therefore critical to have assessment of typical communities in both these locations, concurrent with physical and chemical (i.e. nutrients) oceanographic measurements to ensure appropriate baselines are available because it is unclear that both sites are under identical oceanographic influences. A secondary goal, sampling of zooplankton in areas of observed bowhead whales feeding was not exercised due to the absence of such situations.

METHODS

Survey Design

The 2008 schedule consisted of three 25-day cruises occurring between late July and mid October collecting data and samples at 2 survey areas around the historic Klondike and Burger wells (Fig. 1). Sampling conducted during 2008 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 prospects was similar and relatively constant, varying between approximately 35 and 45 m. Inorganic macronutrients, phytoplankton (as chlorophyll) and zooplankton were sampled on each cruise. During the first survey of Burger, ice cover prevented sampling at 9 of the 25 stations.

Collection Procedures

Phytoplankton were assessed as chlorophyll *a* concentration from samples collected with a CTD rosette on upcasts at 6 depths per station: 0, 5, 10, 20, and 30 m, plus 1m above the sea floor. Samples were filtered under low pressure onto Whatman GFF filters and frozen for post-cruise analysis (Parsons *et al.*, 1984). Nutrient samples were taken from the same bottles as chlorophyll, were 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 net. The meters are rigged not to spin during descent. 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 net was 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 100% non-denatured ethanol (required for molecular identification). A subsample of fresh material from the sample to be preserved in ethanol, was made available to the contaminants team upon request.

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 conform 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 $505 \mu\text{m}$ 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.

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 Kiørboe 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 (4^{th} 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=0.0228·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 concentration was irregularly distributed across the sampling grids (Fig. 3), in part because of temporal offsets in sampling dates and the irregular pattern of the survey within each grid. In general, integral chlorophyll concentrations declined at each site from the first cruise to the final cruise, and integral chlorophyll concentrations were higher at the Burger prospect than Klondike within each cruise (Table 2). On all cruises, chlorophyll was generally low at the surface and near-bottom, with pronounced maximum measured at either 20 or 30 m depth at many, but not all stations (Fig. 3, 5, 7, 9, 11, 13).

Table 2. Average integral chlorophyll concentration (mg m^{-3}) at the Klondike and Burger survey grids during 2008

Cruise	Klondike	Burger
July/August	62.5	104.8
August/September	25.1	47.1
September/October	21.8	30.9

Nitrate, silicate and phosphate were virtually absent from surface waters even during the first cruise, generally increased toward the seafloor, and like chlorophyll, somewhat irregular in their profiles within each grid (Fig. 3-14). Nutrients concentrations at depth were generally higher at Burger than Klondike, with a notably large and undepleted deep pool of all nutrients present at Burger during the first cruise (Fig. 5, 6), while nutrients were already exhausted at all depths for the southern half of Klondike at that time (Fig. 3,4). The observed sub-surface chlorophyll maximums roughly corresponded to the depth where nutrient concentrations began to increase and are roughly collocated with the pycnocline observed by the CTD.

Zooplankton

In total, 76 taxonomic categories of zooplankton, including 12 meroplanktonic larval categories, were observed during the 2008 field year. An average abundance of 3330 individuals m^{-3} and 18.5 mg DW m^{-3} was captured by the 150 μm net and an average of 189 individuals m^{-3} and 11.4 mg DW m^{-3} captured by the 505 μm net. The greatest diversity was observed within the copepods (20 species, plus juvenile categories), followed by the cnidarians (9 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 *Pseudocalanus* copepods, barnacle larvae (nauplii and cyprids), calanoid copepod nauplii, the bivalve larvae, the copepod *Oithona similis*, polychaete larvae and the larvacean *Oikopleura vanhoeffeni*, 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 biomass, with barnacle larvae (nauplii and cyprids), the copepod *Calanus marshallae*, the chaetognath *Parasagitta elegans*, the *Pseudocalanus* copepod species, followed by polychaete larvae, the cnidarian *Aglantha digitale* and the larvacean *Oikopleura vanhoeffeni*. In contrast, abundance ranking for the 505 μm nets was led by barnacle larvae (nauplii and cyprids), the

Table 3. Zooplankton species observed during 2008, 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.

	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> spp.	8.624	0.003	1.068	0.003
<i>Acartia longiremis</i>	6.194	0.035	2.653	0.017
<i>Acartia hudsonica</i>	7.605	0.034	0.256	0.001
<i>Acartia tumida</i>	0.155	0.001	0.016	0.001
<i>Eurytemora</i> spp.	4.064	0.036	0.380	0.004
<i>Eurytemora pacifica</i>	0.018	0.000	0.132	0.002
<i>Calanus marshallae</i>	14.633	2.616	9.401	1.452
<i>Calanus glacialis</i>			0.015	0.011
<i>Centropages abdominalis</i>	37.987	0.093	4.400	0.023
<i>Epilabidocera amphitrites</i>	0.111	0.001		
<i>Eucalanus bungii</i>	0.385	0.042	0.110	0.014
<i>Metridia pacifica</i>	3.146	0.022	0.077	0.002
<i>Neocalanus flemingeri</i>	0.798	0.450	0.326	0.203
<i>Neocalanus plumchrus</i>	1.509	0.414	0.132	0.085
<i>Neocalanus cristatus</i>	0.052	0.347	0.047	0.361
<i>Pseudocalanus male</i>	6.676	0.067	1.696	0.010
<i>Pseudocalanus</i> spp.	555.602	1.324	19.693	0.109
<i>Pseudocalanus minutus</i>	7.684	0.107	1.811	0.039
<i>Pseudocalanus acuspes</i>	18.009	0.230	2.751	0.034
<i>Pseudocalanus newmani</i>	14.602	0.099	2.914	0.020
<i>Pseudocalanus mimus</i>	5.439	0.066	0.051	0.001
<i>Tortanus discaudata</i>			0.028	0.000
<i>Oithona similis</i>	223.071	0.306		
<i>Triconia (Oncaea) borealis</i>	3.939	0.003		
Harpacticoida	8.263	0.073	0.093	0.000
calanoid nauplius	294.970	0.179	0.104	0.000
cyclopoid nauplius	46.048	0.021		
calanoid nauplius (large)	0.077	0.000	0.049	0.000
Larvaceans				
<i>Oikopleura vanhoeffeni</i>	139.095	0.535	10.287	0.338
<i>Fritillaria borealis</i>	897.554	0.022	33.064	0.014
Pteropods				
<i>Limacina helicina</i>	5.045	0.014	0.246	0.002
<i>Clione limacina</i>	0.002	0.006	0.004	0.020
Euphausiids				
<i>Euphausiid nauplius</i>			0.069	0.000
<i>Euphausiid calyptopis</i>			0.236	0.006
<i>Euphausiid juvenile</i>	2.564	0.218	0.411	0.220
<i>Thysanoessa longipes</i>			0.000	0.001
<i>Thysanoessa inermis</i>			0.141	0.379
<i>Thysanoessa raschii</i>			0.024	0.045

Table 2 continued

	150 μm net		505 μm net	
	Abundance	Biomass	Abundance	Biomass
Shrimps and Mysids				
<i>Eualus gaimardii</i>			0.055	0.041
Hippolytidae (juveniles)			0.142	0.181
<i>Neomysis awatschensis</i>			0.000	0.006
Chaetognaths				
<i>Parasagitta elegans</i>	20.578	1.806	6.157	2.634
Cladocerans				
<i>Evadne nordmanni</i>			0.098	0.002
<i>Podon leuckartii</i>	0.306	0.001	0.048	0.120
Amphipods				
<i>Themisto pacifica</i>			0.009	0.081
<i>Themisto libellula</i>	0.001	0.031	0.003	0.026
<i>Hyperoche medusarum</i>			0.000	0.000
Gammaridae	0.078	0.002		
Hyperiididae			0.006	0.003
Amphipod (misc.)			0.019	0.007
Cumacea			0.001	0.000
Ostracoda			0.014	0.000
Cnidarians				
<i>Aglantha digitale</i>	35.056	0.630	5.342	0.806
<i>Rathkea octopunctata</i>	0.917	0.013	0.544	0.111
<i>Euphysa flammea</i>			0.004	0.001
<i>Sarsia tubulosa</i>			0.026	0.002
<i>Catablema vesicarium</i>	0.017	0.003	0.033	0.021
<i>Ptychogena</i> spp.			0.000	0.334
<i>Obelia</i> spp.	1.906	0.354	0.420	0.340
<i>Cyanea capillata</i>			0.041	0.000
<i>Chrysaora melanaster</i>			observed	
Unidentified medusoid	7.811	0.499	0.011	0.056
Ctenophores				
<i>Beroe cucumis</i>	0.449	0.008	0.034	0.132
TOTAL Holozooplankton	2381	10.7	106	8.3
Bivalve larvae	235.460	0.750	5.527	0.003
Decapod zoea			0.105	0.001
Pagurid zoea			0.219	0.000
Barnacle cyprius	291.386	5.234	34.330	0.673
Barnacle nauplius	185.864	0.783	36.109	0.041
Zoea (unspecified)	0.645	0.102		
Megalops			0.000	0.000
Polychaete larvae	197.344	0.882	7.192	0.095
Ophiuroid larvae	6.191	0.006		
Asteroid bipinnaria	5.840	0.014	0.035	0.000
Echinoid larvae	24.851	0.013	0.061	0.000
TOTAL Meroplankton	948	7.8	84	0.8
Fish larvae	0.078	0.045	0.050	2.264
TOTAL Zooplankton	3329	18.5	189	11.4

larvacean *Fritillaria borealis*, the *Pseudocalanus* copepod species, the larvacean *Oikopleura vanhoeffeni*, the copepod *Calanus marshallae*, polychaete larvae, the chaetognath *Parasagitta elegans*, bivalve larvae, and the cnidarian *Aglantha digitale*, all averaging more than 5 m⁻³. Biomass in the 505 µm nets was substantially different, dominated by fish larvae, the chaetognath *Parasagitta elegans*, the copepod *Calanus marshallae*, the cnidarian *Aglantha digitale*, barnacle larvae (primarily cyprid stage), the larvaceans *Oikopleura vanhoeffeni*, the euphausiid *Thysanoessa inermis*, plus several other cnidarians.

Summarizing the averages for each cruise by major taxonomic groups, in terms of abundance larvaceans and copepod nauplii appear to decline over successive cruises, while copepod and meroplankton appear somewhat variable but stable in number (Fig. 15). In terms of biomass, there were pronounced differences for all groups between Klondike and Burger on the first cruise while the 2 survey sites appear more similar on the latter 2 cruises (Fig. 16). Chaetognaths, cnidarians 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 a number of larger larval fish contributed to the high biomass.

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 and meroplankton (Fig. 17). The survey grids appear to diverge on the second cruise, with larvaceans becoming less important at both, but copepods becoming of greater importance at Burger compared to Klondike. By the third cruise, the 2 sites appear very different. Klondike was generally dominated by meroplankton, larvaceans were greatly reduced, and copepods became more important than on the second cruise. Burger was generally dominated on the third cruise with relatively similar contributions by both larvaceans and meroplankton. In terms of biomass, in the 150 µm nets, copepods and meroplankton dominated overall, with typically greater contributions by copepods at Burger than Klondike (Fig. 18). Patterns observed for the 505 µm nets are relatively similar to those of the 150 µm nets for abundances, accepting that nauplii are missed by the 505 µm nets and that the relative contribution of copepods, chaetognaths and cnidarians is frequently greater (Fig. 19). In contrast, the distribution of biomass in the 505 µm nets was distinctly different from that of the 150 µm nets, with chaetognaths prominent on the first survey, while jellies, the “others” group (euphausiids, amphipods, larval fish) and/or copepods typically dominated the collections on the third survey (Fig. 20).

Looking more closely at the species and genus level, faunal differences become apparent between the cruises and prospects. For the 150 µm nets, the copepods, *Acartia*, *Calanus* and *Centropages* showed no showed limited pattern, other than a reduction at Klondike on the final cruise. The numerically dominant *Pseudocalanus* declined somewhat after the first cruise, the coastal *Eurytemora* increased noticeably at Burger on the last two cruises, and the oceanic *Neocalanus* was most noticeable at Klondike, and declined during later cruises (Fig. 21). The small *Oithona similis* increased steadily over successive cruises, while the copepod nauplii and the larvacean *Fritillaria borealis* declined and the predatory chaetognath *Parasagitta elegans* remained relatively stable (Fig. 22). The larvacean *Oikopleura vanhoeffeni* declined as cruises progressed at Klondike, but increased at Burger, and the predatory cnidarian *Aglantha digitale*, was typically more abundant at Klondike than Burger which developed a large population over

Klondike on the last cruise. Meroplankton patterns (Fig. 23) showed peak numbers of barnacle nauplii earlier in the season and notably few had metamorphosed yet into cyprids at Burger on the first cruise. Cyprids themselves began to set-out during the final cruise. In contrast, the echinoderm bipinnaria and urchin larvae became more abundant on each successive cruise, with sea urchin larvae very common over Klondike on the third cruise. Polychaete larvae also remained abundant on all cruises, and were typically more abundant at Klondike than Burger.

For the 505 μm net, abundances were lower for the 4 smaller copepods (*Acartia*, *Eurytemora*, *Centropages*, *Pseudocalanus*) than observed in the 150 μm net, but not for the larger *Calanus* and *Neocalanus* (Fig. 24). The more robust data on these larger species in the 505 μm nets shows the neritic *Calanus* to be more abundant at Burger and the oceanic *Neocalanus* to be more abundant at Klondike. The larvaceans *Fritillaria borealis* and *Oikopleura vanhoeffeni*, the chaetognaths *Parasagitta elegans* and the cnidarian *Aglantha digitale* all showed similar patterns to the 150 μm net, and the cnidarians *Rathkea octopunctata* and *Catablema vesicarium* occurred primarily on the first 2 cruises and more so at Klondike (Fig. 25). Meroplankton pattern in the 505 μm net are also similar to the 150 μm net, but no obvious patterns occur for fish larvae, euphausiids, mysids or shrimps (Fig. 26).

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 60-70% similarity level (Fig. 27). Multidimensional scaling of the data, coded by cruise, demonstrated that most collections are moving along a similar but slightly divergent temporal trajectory (Fig. 28), the cold water and ice condition at Burger on the first cruise placing it at one end of the trajectory, and the warmest water observed at Klondike on the third cruise placing it at the other end. Clustering analysis of the 505 μm zooplankton abundances produced less clear clustering (Fig. 29), but a similar overall presence of temporal and site-specific trajectories (Fig. 30). Primer's BEST routine indicated a combination of integral chlorophyll and surface water temperature were correlated to community composition captured by the 150 μm net (Spearman's $r=0.42$), with no improvement by incorporation of more variables. The overlap and divergence between survey grids is better appreciated by superimposing the clusters on the water temperatures observed in the upper 10m on each survey (Fig. 31), as well as integral chlorophyll (Fig. 32). A combination of chlorophyll and surface water temperature and surface water salinity were correlated to community composition captured by the 505 μm net (Spearman's $r=0.29$), with no notable improvement by incorporation of more variables.

DISCUSSION

Chlorophyll and Nutrients

Phytoplankton pigments and size-fractionated biomass in the Chukchi Sea show spatial and temporal variation 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 rapidly depleted 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. Low nutrient concentrations were persistent in surface waters, as were surface chlorophyll concentrations during the surveys conducted in 2008, consistent with such

observations. The higher chlorophyll and nutrient concentrations observed at Burger on the first cruise are consistent with the survey capturing the bloom period at that prospect, while Klondike sampling appears to have occurred post-bloom. Maximum chlorophyll concentrations typically occurred subsurface, between 20 and 30 m depth in association with the pycnocline where a corresponding increase in nutrient concentration began. Fluorescence data from the CTD confirms the location of the subsurface maxima and sometimes a near bottom peak due to resuspension (Danielson and Weingartner, *in prep.*).

Zooplankton composition

The Chukchi Sea displays a similar level of diversity, and high biomass compared to the adjoining East Siberian (Jaschnov, 1940; Pavshits, 1994) and Beaufort (e.g. Horner, 1981) seas, but less diversity than is present in the deep vertically-structured basins (e.g. Kosobokova and Hirche, 2000; Kosobokova and Hopcroft, 2009). It is also notable that with the exception of the few cases of *Calanus glacialis*, all 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). 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.*, 2009), or similar coarser nets are compared (e.g. Wing, 1974; English and Horner, 1977). It is notable that during the first cruise, the copepod community was highly dominated by younger developmental stages, likely due to the cold-water temperatures persistent throughout the region during 2008.

In contrast, our estimates 3330 individuals m^{-3} and 18.5 mg DW m^{-3} (~ 0.75 g DW m^{-2}) captured by the 150 μm net, and the average of 189 individuals m^{-3} and 11.4 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. In waters to the south and west of the Klondike and Burger prospects 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.*, 2009). 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 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} - Pavshits, 1984) for all mesozooplankton spanning the Chukchi Sea is also close, assuming DW is 10-15% of WW (Wiebe *et al.*, 1975). Our observations 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), and but lower than values typical for the upper 50m (42 mg DW m^{-3}) further into the adjoining basin (Kosobokova and Hopcroft, 2009).

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*, *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 vanhoeffeni* 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.*, 2009) at times reaching high biomass (Springer *et al.*, 1989; Shiga *et al.*, 1998, Hopcroft *et al.*, 2009).

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.*, 2009). Consistent with these studies there was considerable biomass in both small and large gelatinous organisms: *Aglantha digitale* and *Rathkea octupuncta* 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.*, 2009), 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.*, 2009).

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 both temperature and integral chlorophyll could be statistically correlated to the observed community structures, the amount of variation explained was relatively low, perhaps because the environmental gradients measured were relatively small and physical data were incomplete for the first Klondike survey when this report was prepared. A

strong Alaska Coastal Current signal was not obvious in the zooplankton communities compared other studies (i.e. Hopcroft *et al.*, 2009), but these species (i.e. *Podon* and *Evadne*, *Acartia hudsonica*, *Eurytemora* species) were observed in low numbers. There is suggestion that Klondike fauna was more characteristic of the shelf, with contributions from some oceanic fauna, while Burger had somewhat more contribution from near-shore species characteristic of the ACC, but data is currently weak in this regard. Clearly, some of the observed differences in community composition between the two prospects are related to the typically colder waters observed over the Burger prospect, and the more elevated chlorophyll concentrations compared to Klondike. A fuller 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.

Conclusions and Outlook

In the summer of 2008 although one would characterize the surveyed areas as primarily Pacific in faunal character, with abundance and biomass likely depressed by late melt-back of ice in the region and the sustained cold-water temperatures present through the sampling period. The 2009 sampling season will benefit greatly from the context to be provided by the RUSALCA program in September, and the possibility that the BASIS (Bering-Aleutian Salmon International Survey) program will expand northward into the Chukchi Sea either this season or next year. As with most observational programs, the challenge will be in understanding the range of year-to-year variability to be expected in this area and better understanding the linkages between the different trophic levels being studied in the current assessment program.

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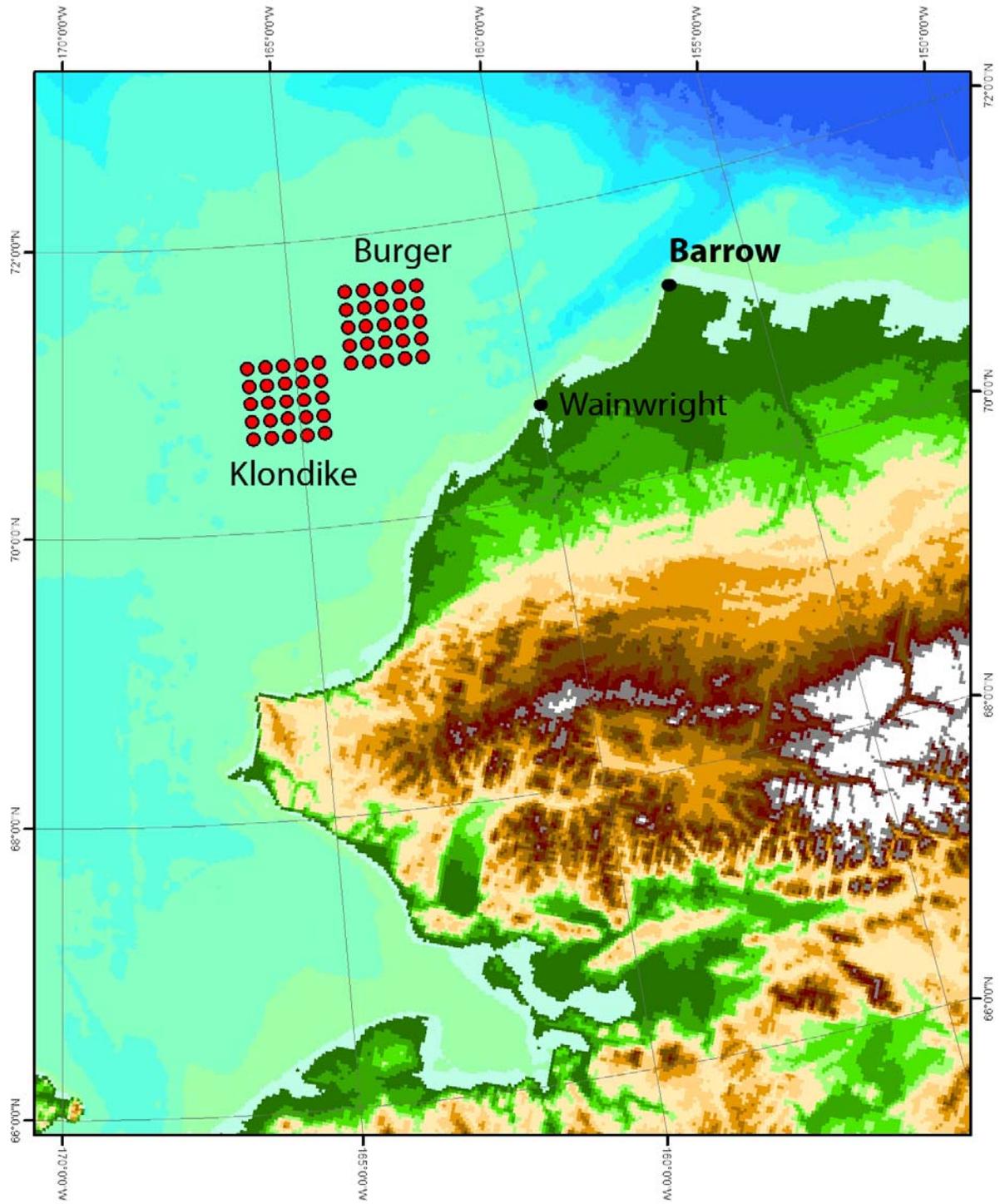


Fig.1. Locations of the Klondike and Burger prospect survey grids in the northeastern Chukchi Sea

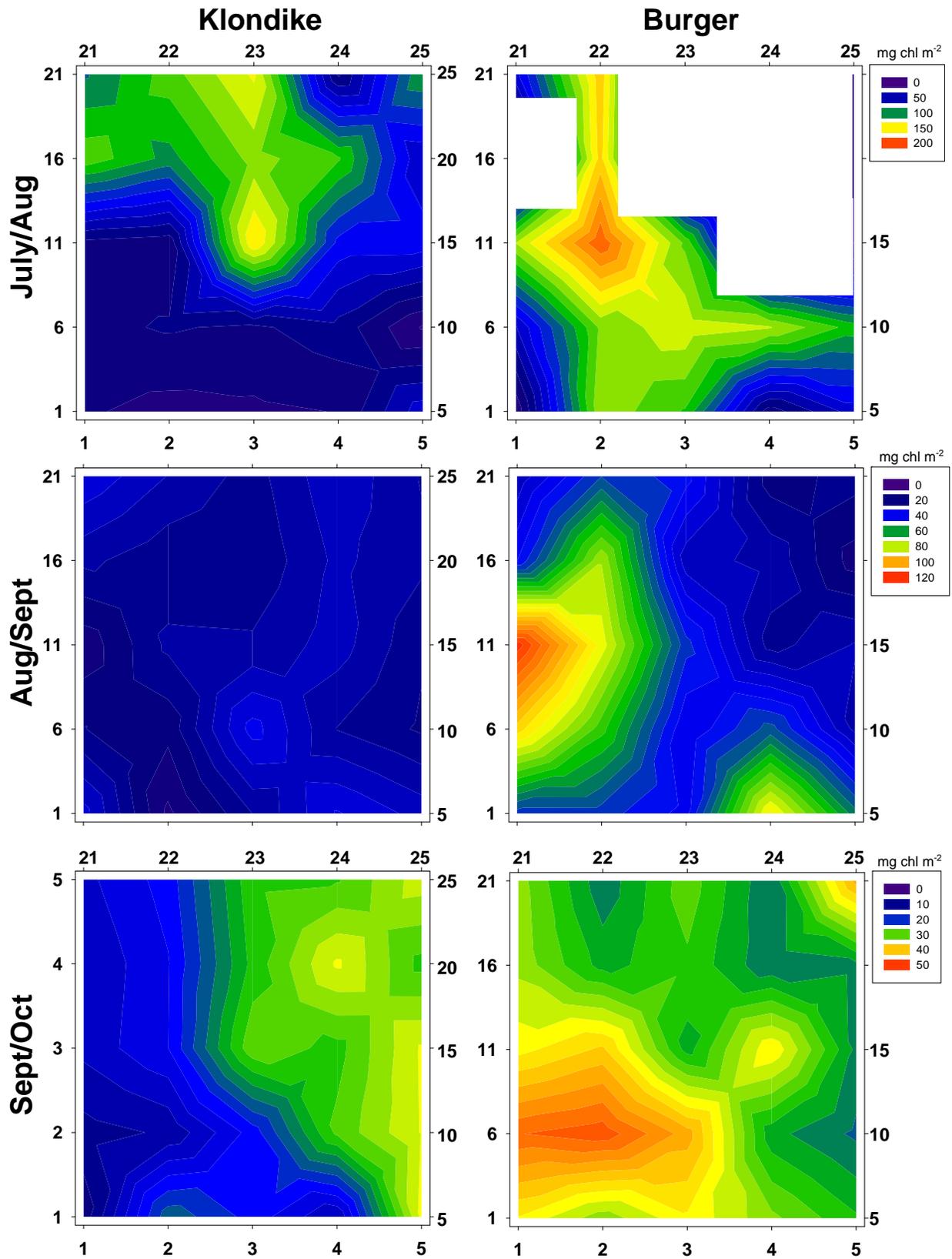


Fig. 2. Integrated chlorophyll *a* observed at the Klondike and Burger prospects during 2008.

Klondike July/Aug 2008

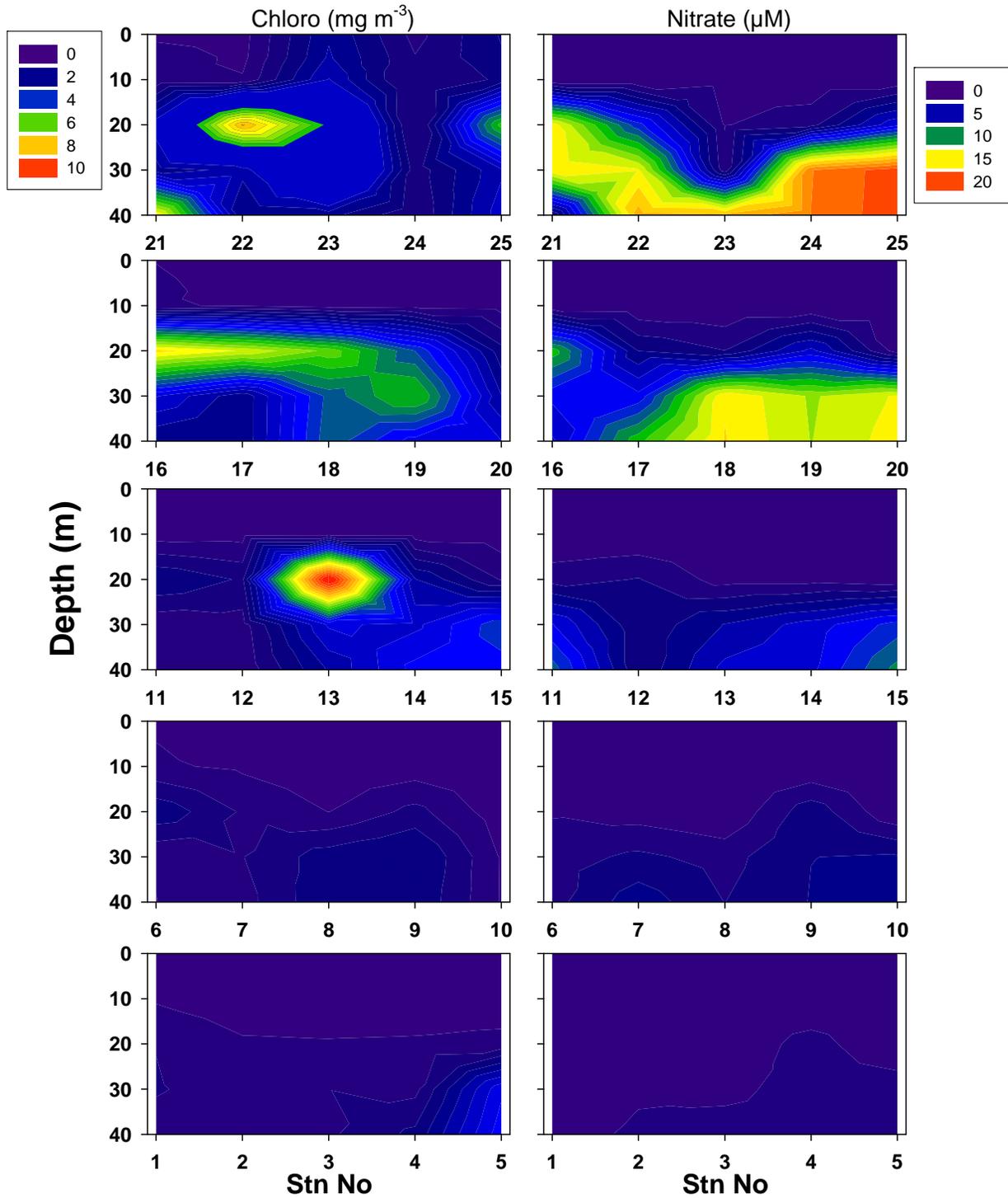


Fig. 3. Chlorophyll and nitrate profile concentrations observed at the Klondike prospect during the July/August cruise 2008 (BLF0802).

Klondike July/Aug 2008

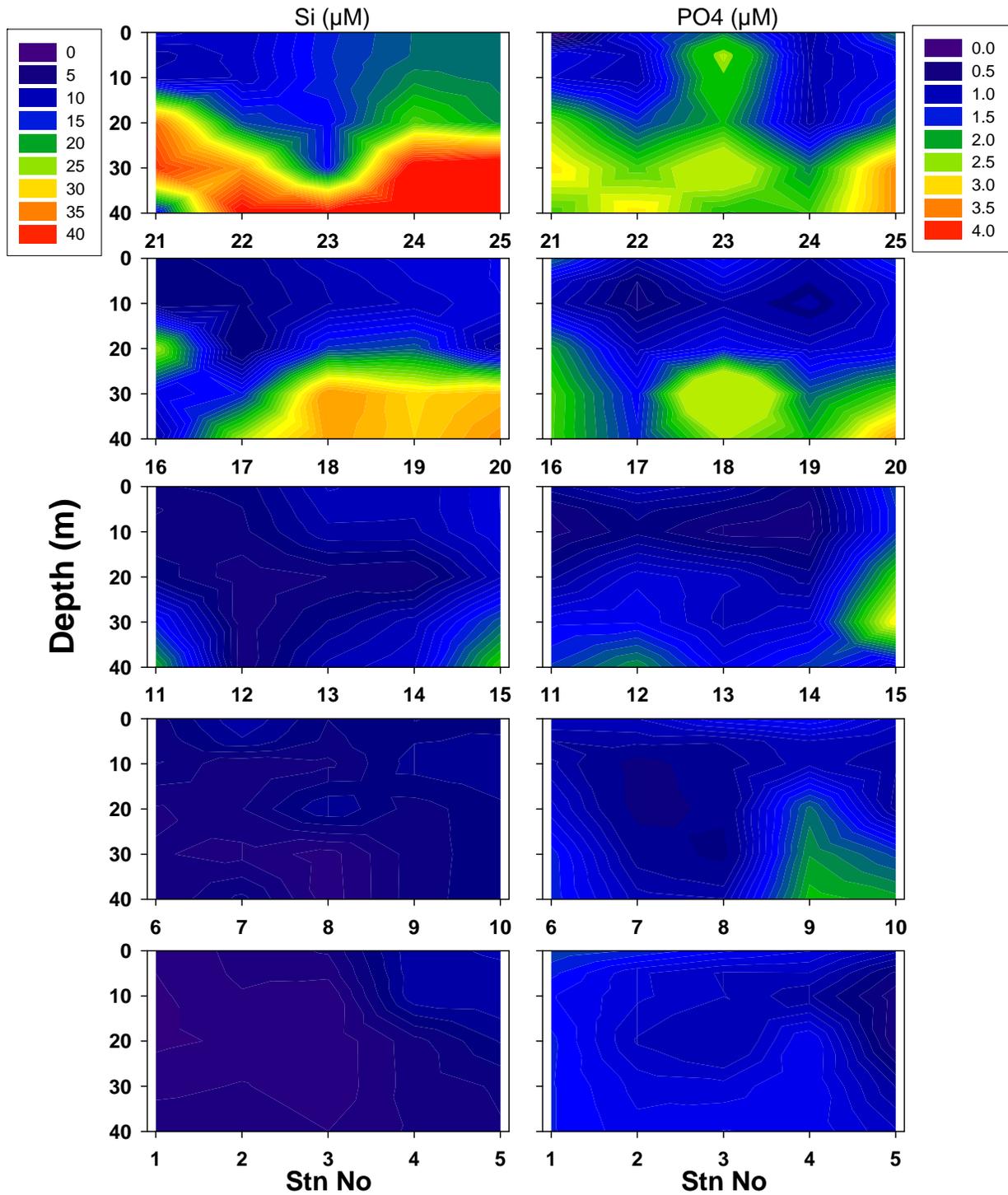


Fig. 4. Silicate and Phosphate profile concentrations observed at the Klondike prospect during the July/August cruise 2008 (BLF0802).

Burger July/Aug 2008

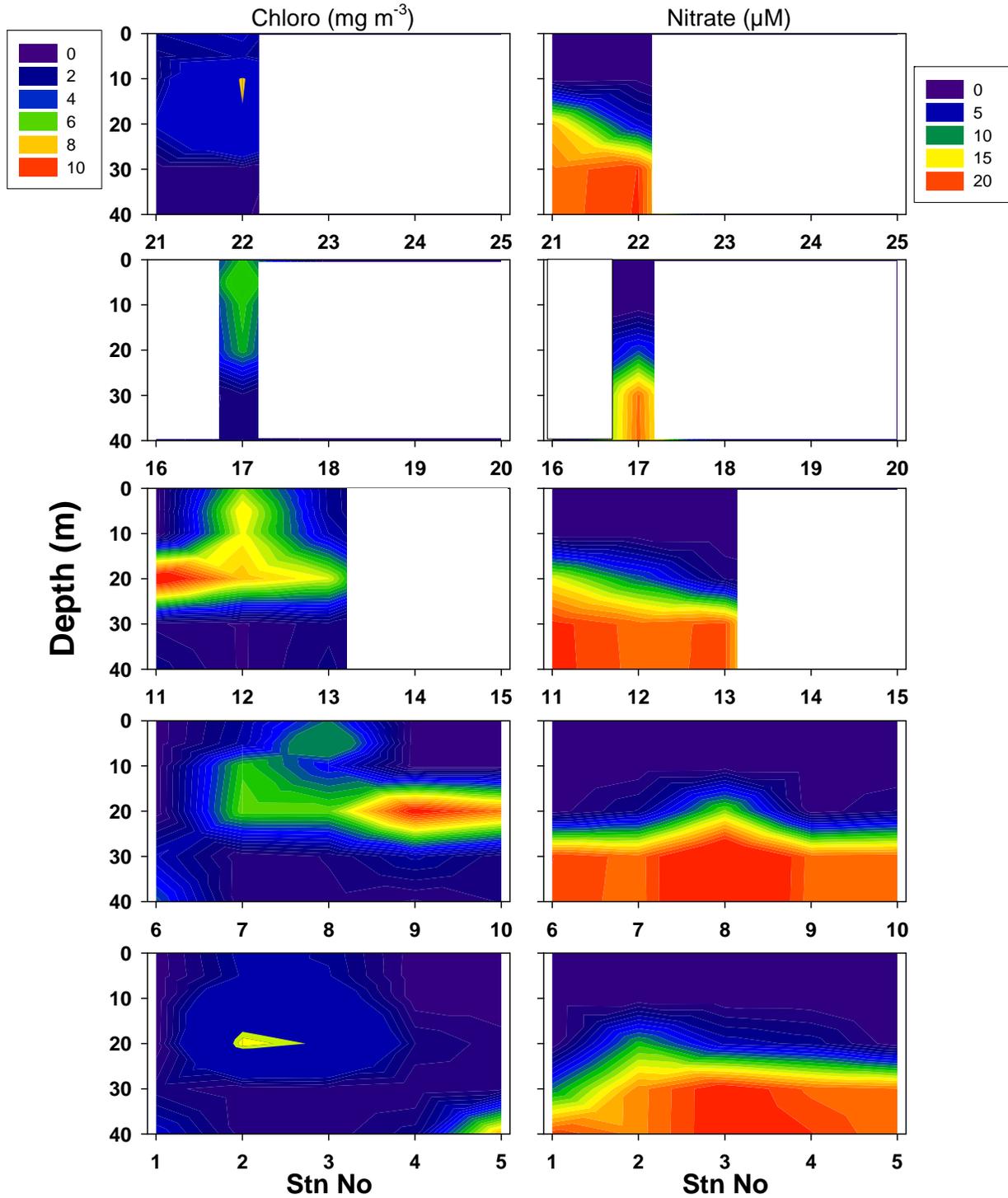


Fig. 5. Chlorophyll and nitrate profile concentrations observed at the Burger prospect during the July/August cruise 2008 (BLF0802).

Burger July/Aug 2008

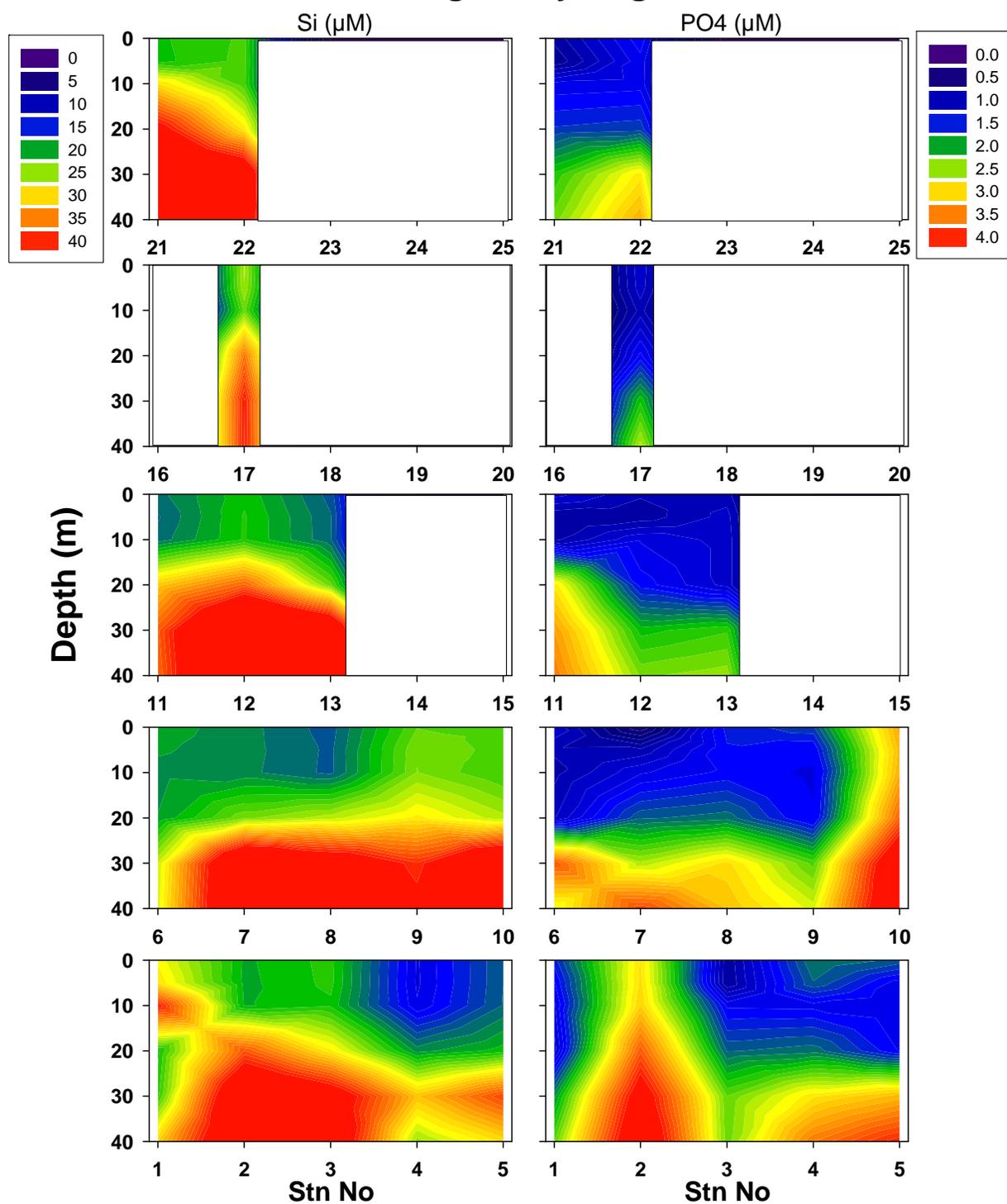


Fig. 6. Silicate and Phosphate profile concentrations observed at the Burger prospect during the July/August cruise 2008 (BLF0802).

Klondike Aug/Sept 2008

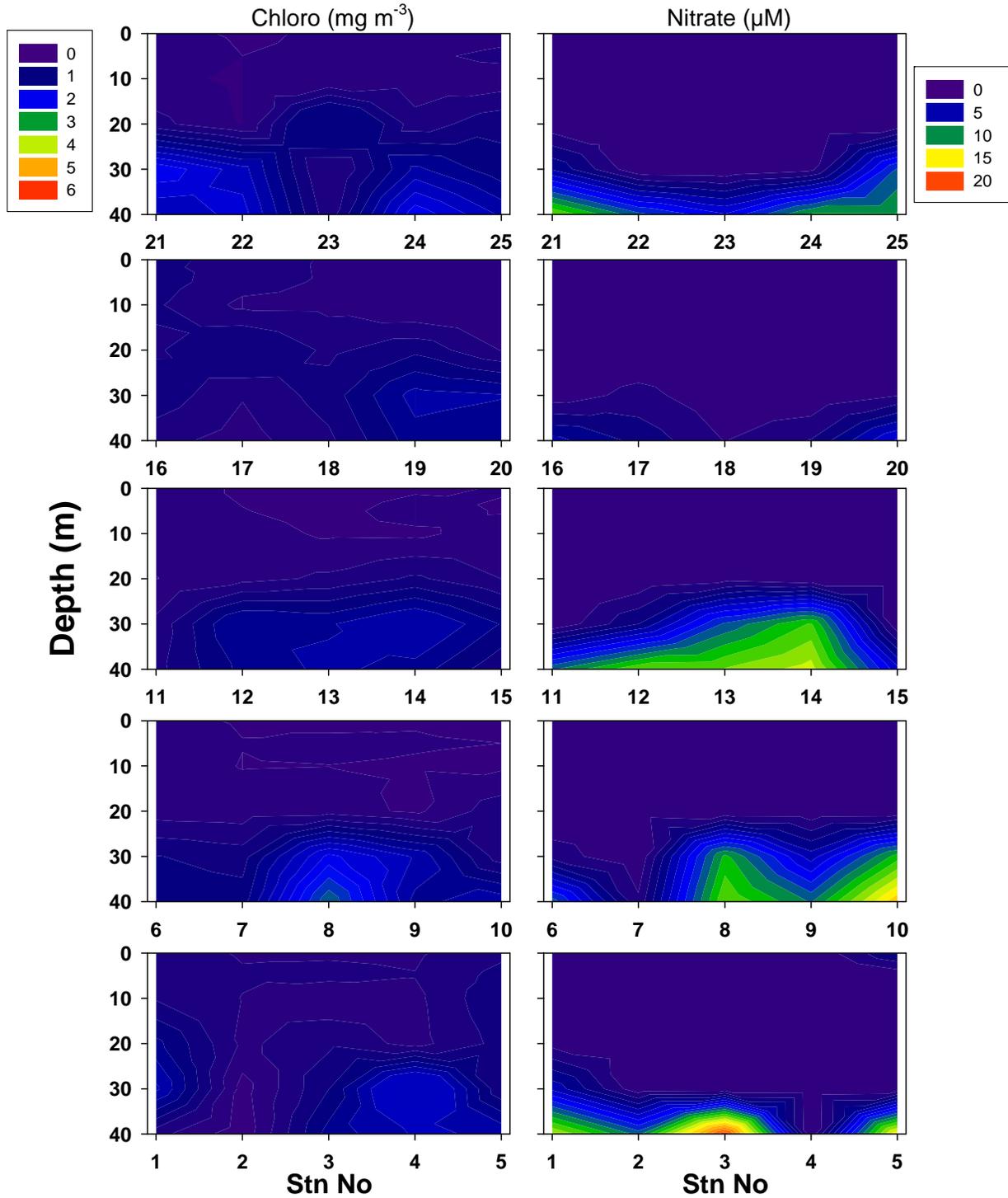


Fig. 7. Chlorophyll and nitrate profile concentrations observed at the Klondike prospect during the August/September cruise 2008 (BLF0803).

Klondike Aug/Sept 2008

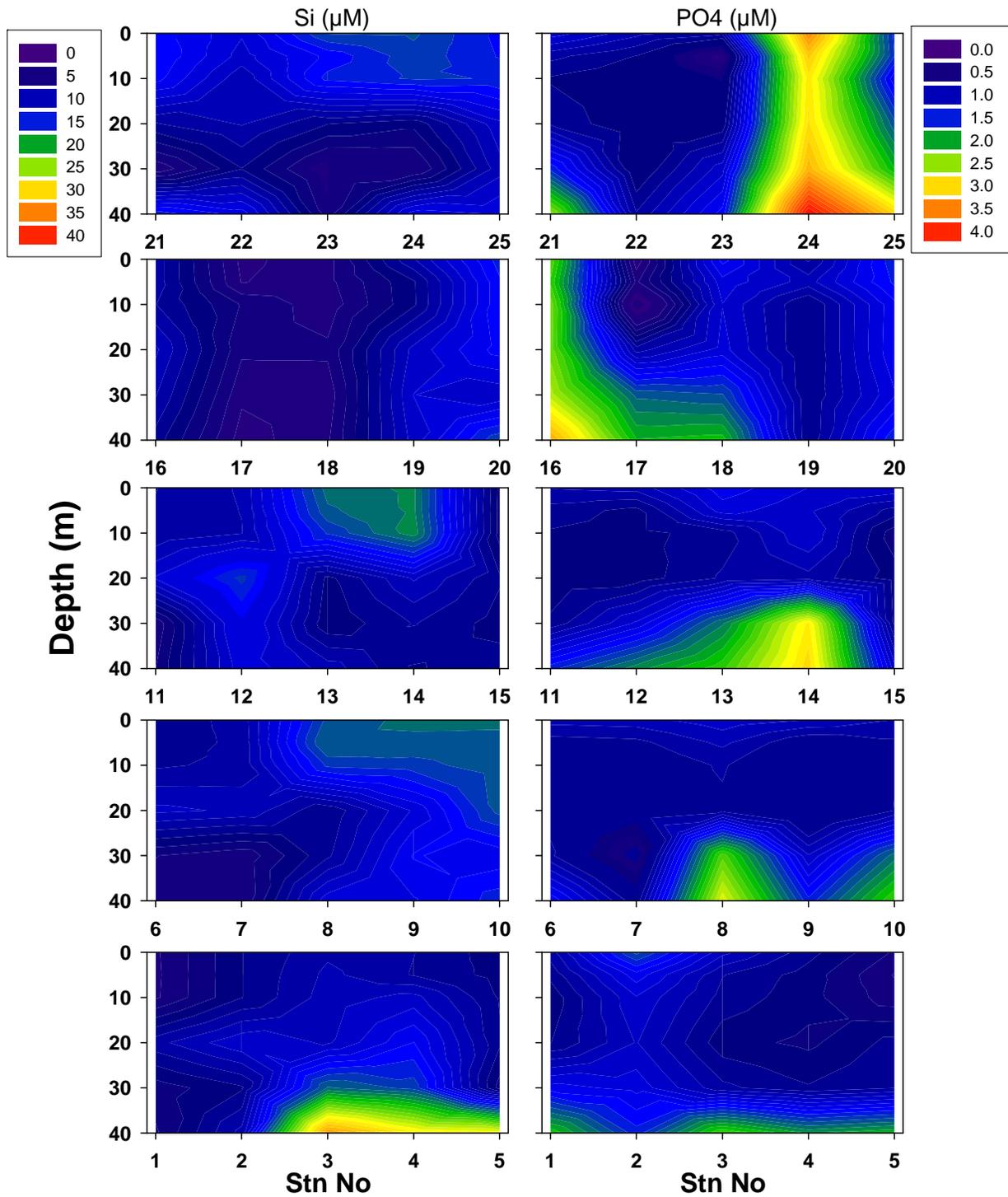


Fig. 8. Silicate and Phosphate profile concentrations observed at the Klondike prospect during the August/September cruise 2008 (BLF0803).

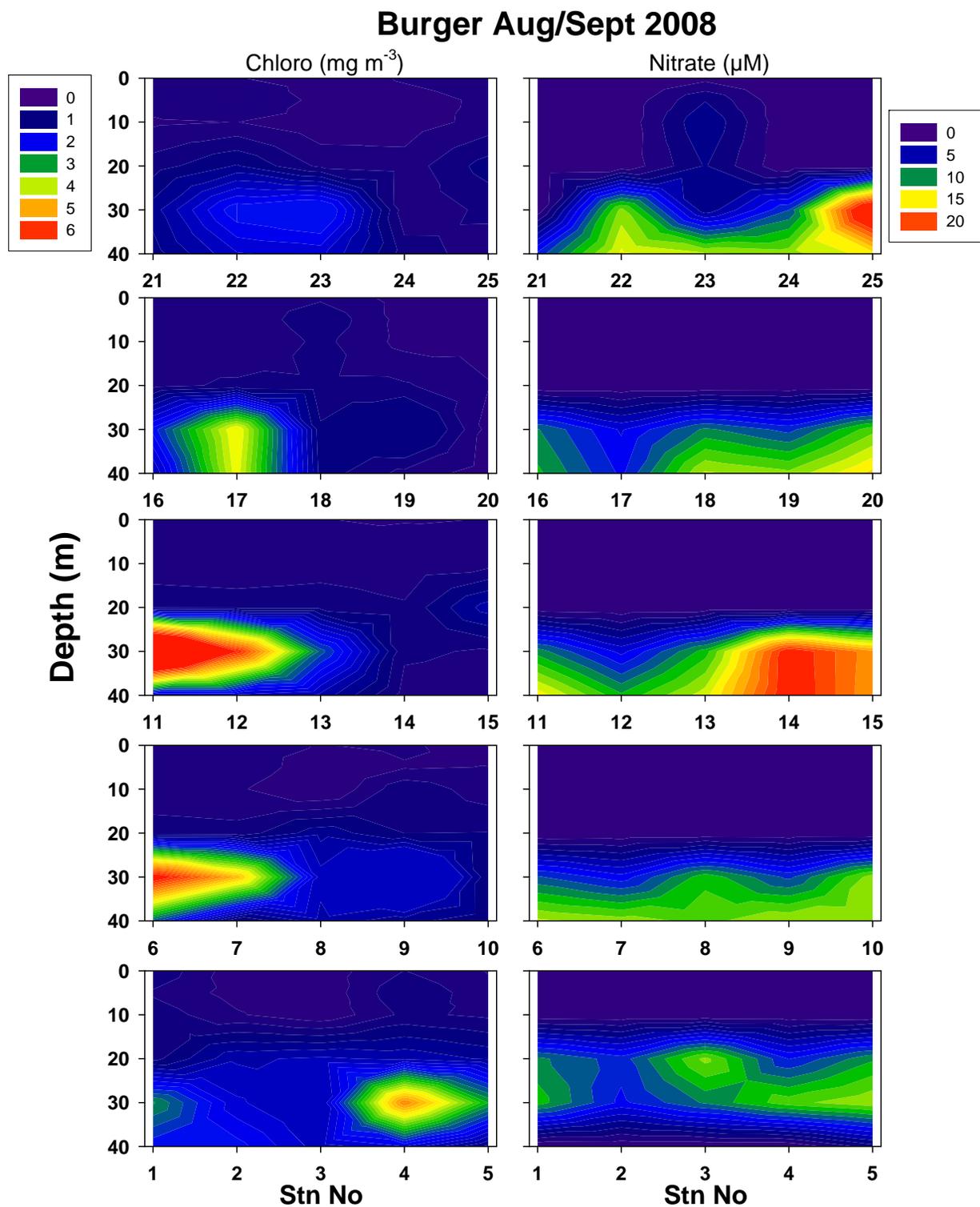


Fig. 9. Chlorophyll and nitrate profile concentrations observed at the Burger prospect during the August/September cruise 2008 (BLF0803).

Burger Aug/Sept 2008

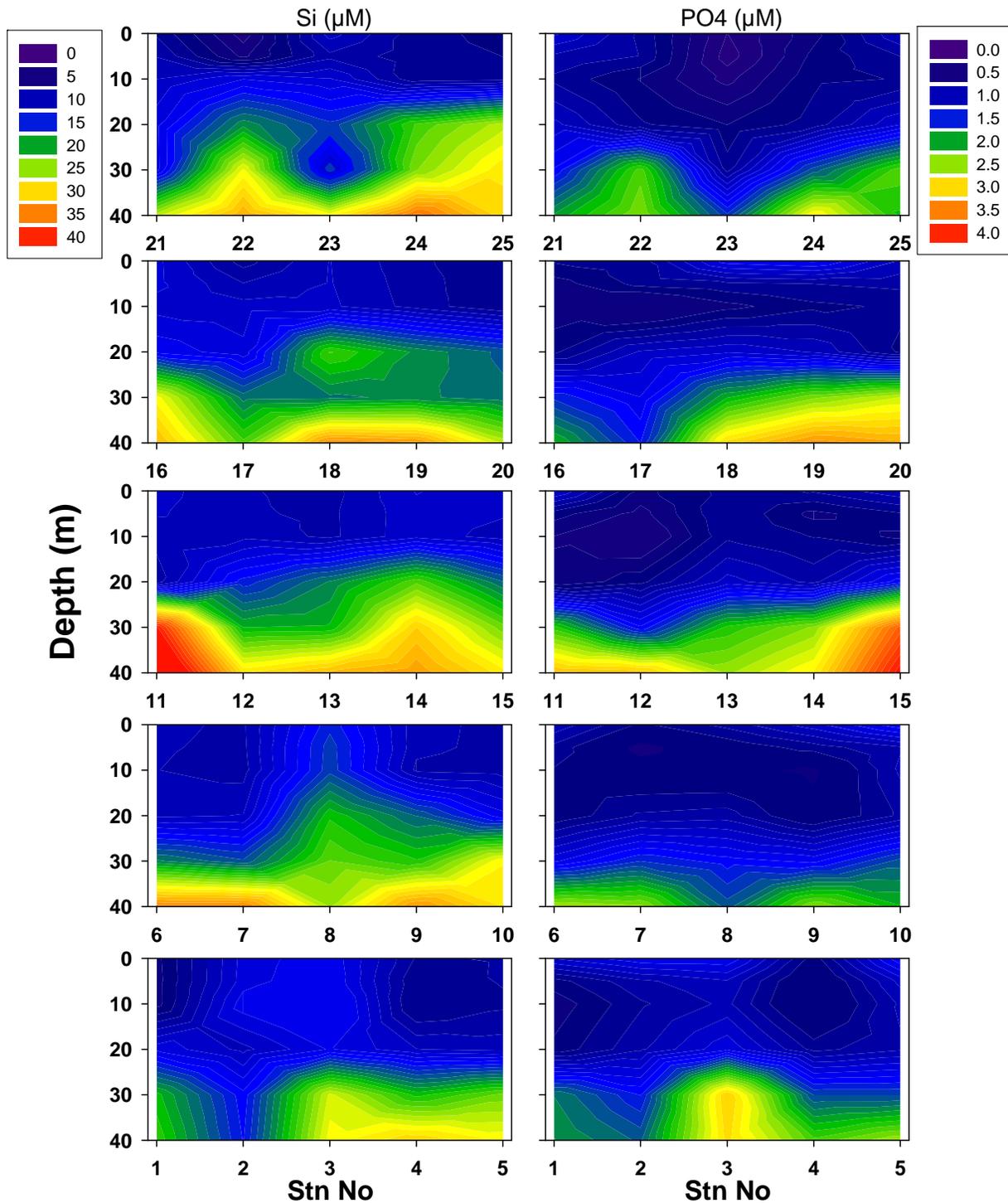


Fig. 10. Silicate and Phosphate profile concentrations observed at the Burger prospect during the August/September cruise 2008 (BLF0803).

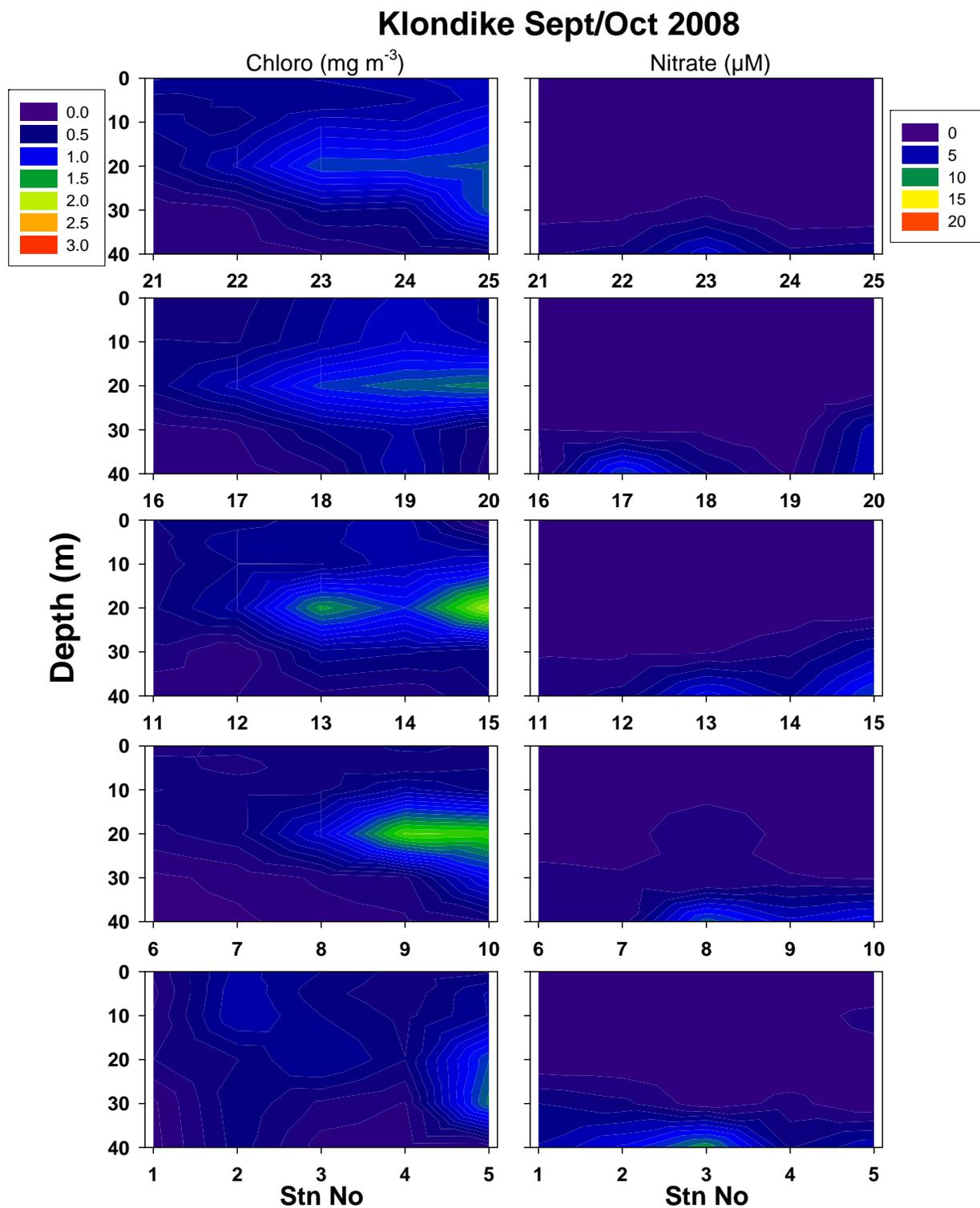


Fig. 11. Chlorophyll and nitrate profile concentrations observed at the Klondike prospect during the September/October cruise 2008 (BLF0805).

Klondike Sept/Oct 2008

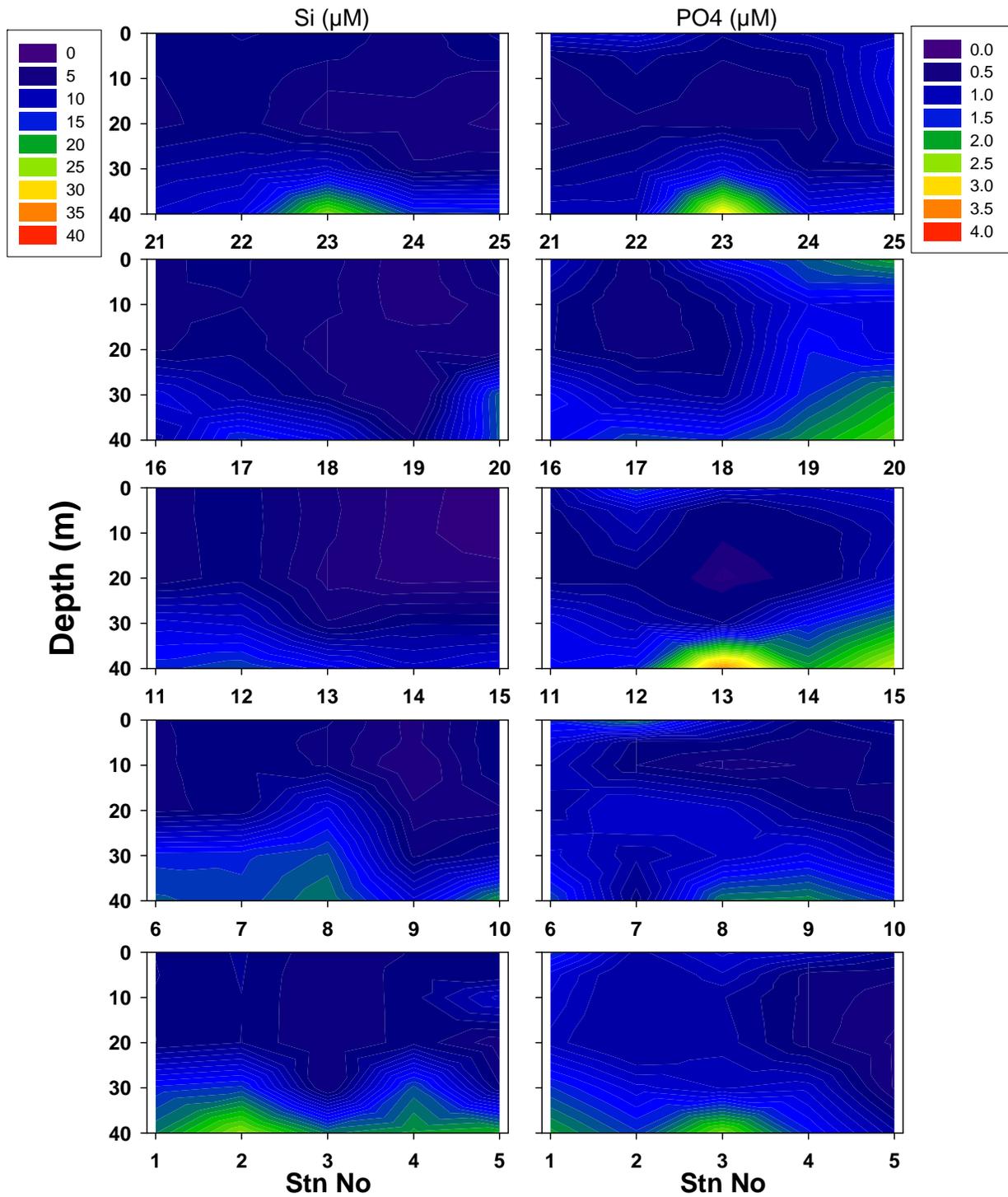


Fig. 12. Silicate and Phosphate profile concentrations observed at the Klondike prospect during the September/October cruise 2008 (BLF0805).

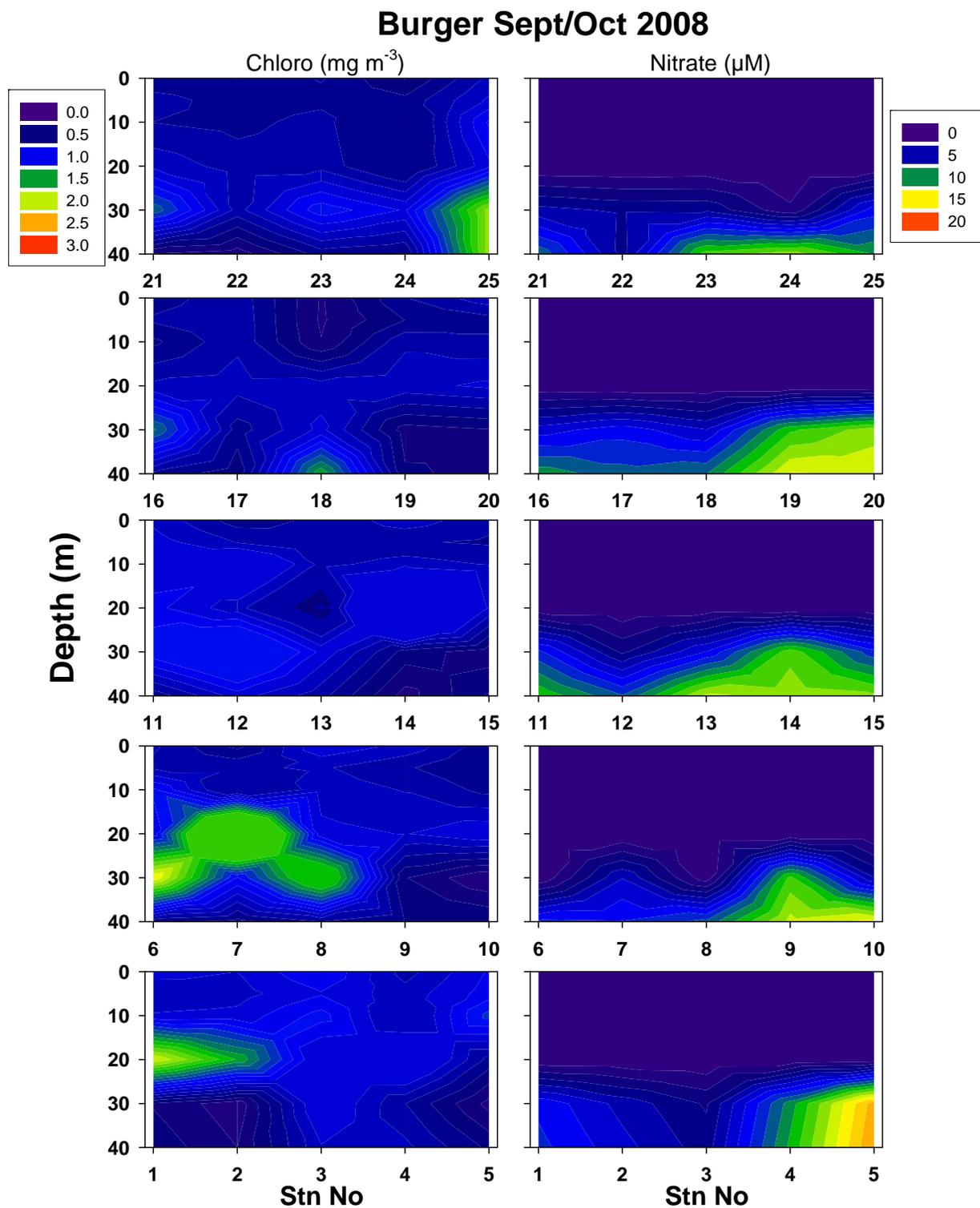


Fig. 13. Chlorophyll and nitrate profile concentrations observed at the Burger prospect during the September/October cruise 2008 (BLF0805).

Burger Sept/Oct 2008

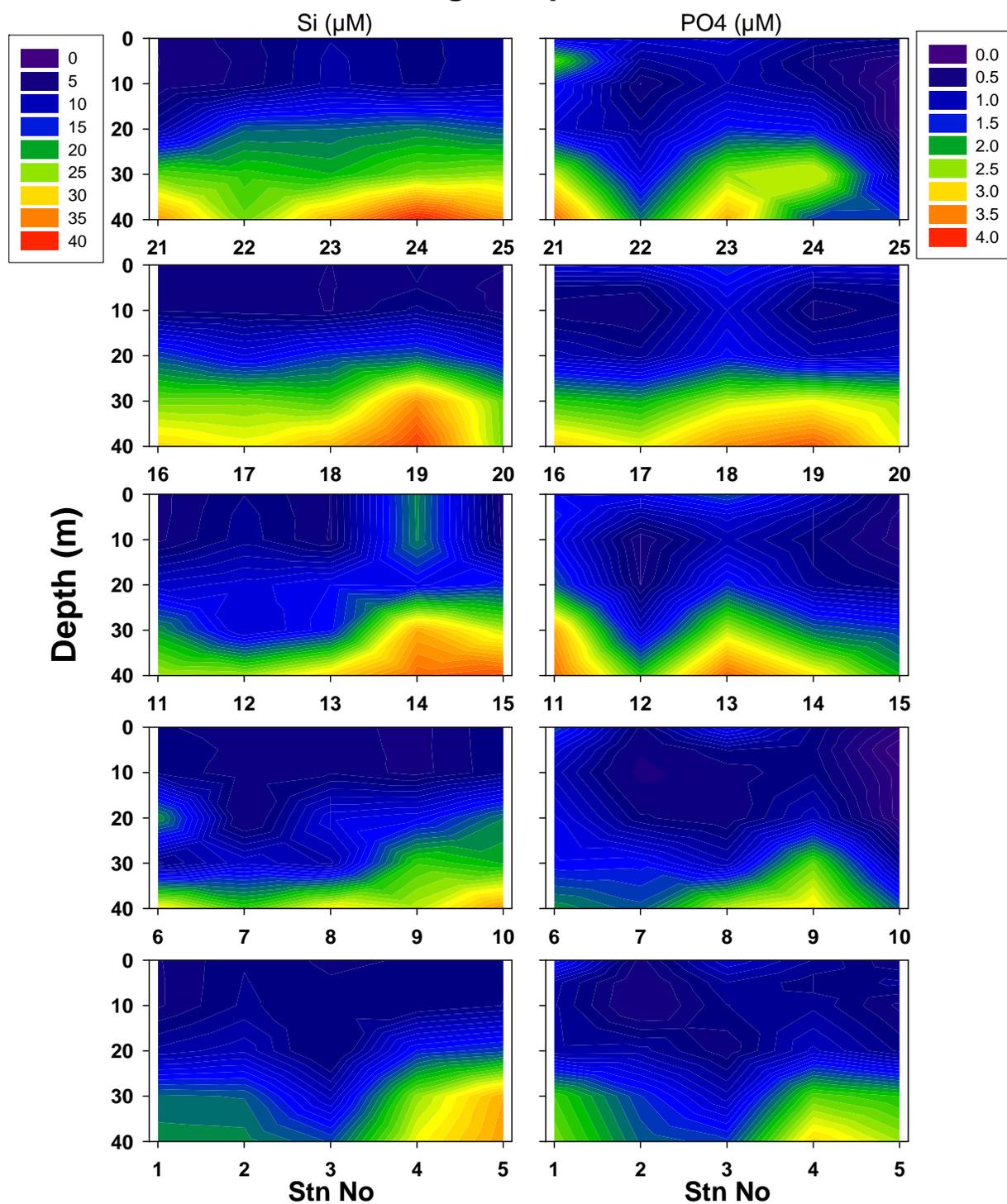


Fig. 14. Silicate and Phosphate profile concentrations observed at the Burger prospect during the September/October cruise 2008 (BLF0805).

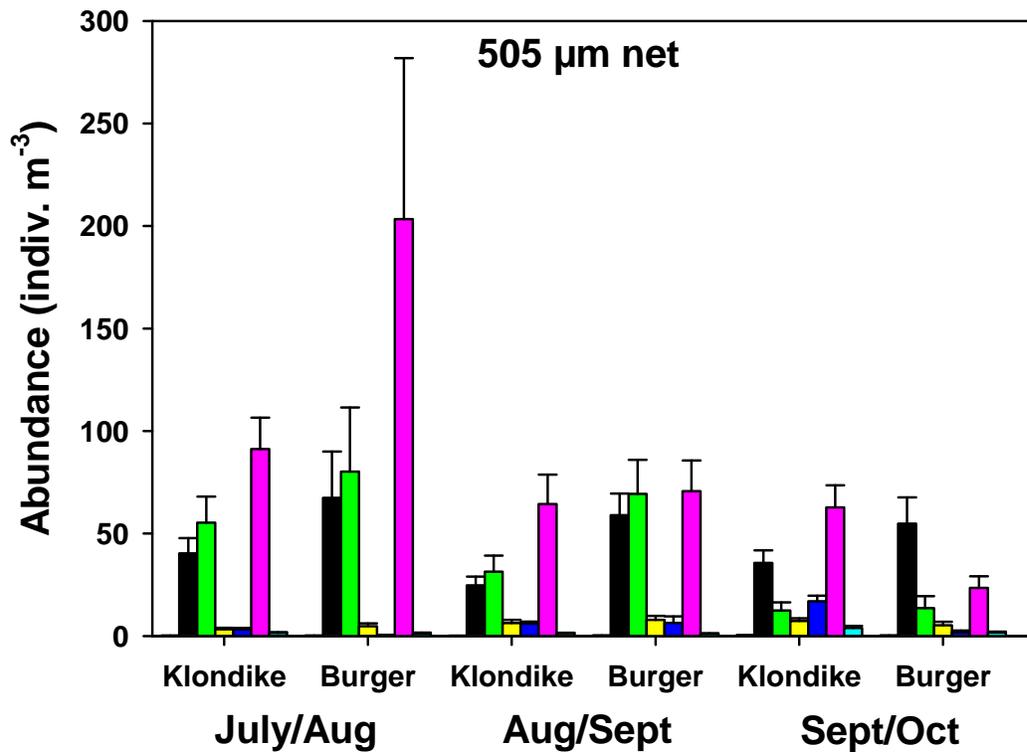
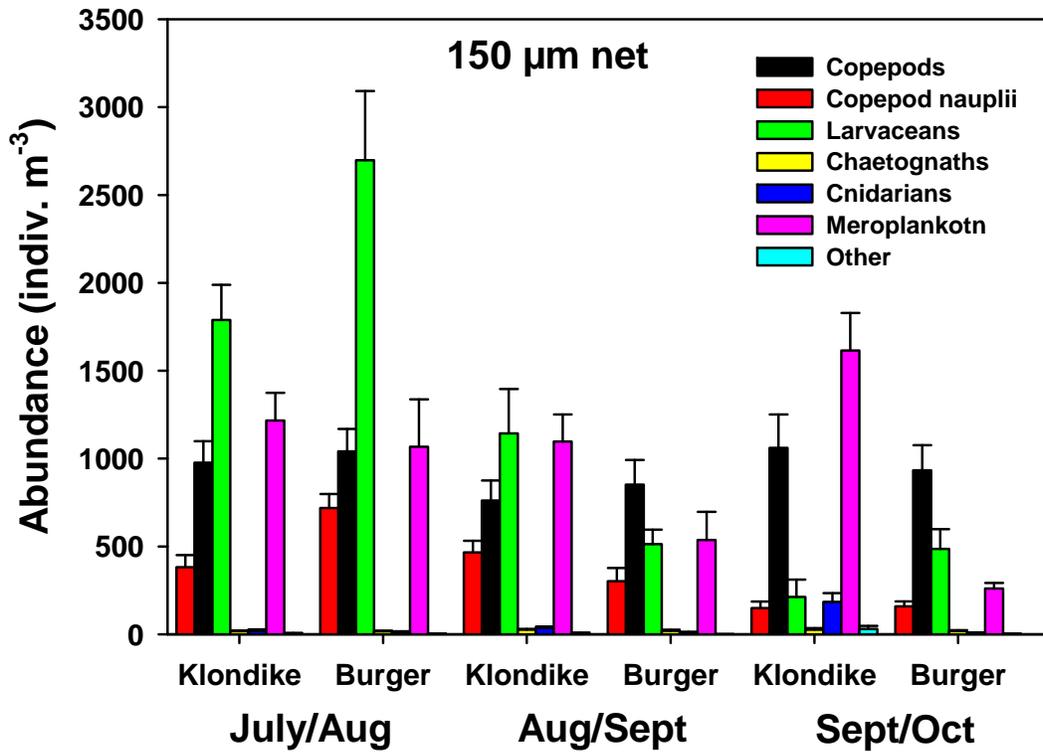


Fig. 15. Contribution of the major groups to the community abundance at each survey grid during 2008 as determined for both plankton nets. Error bars are standard error of the means.

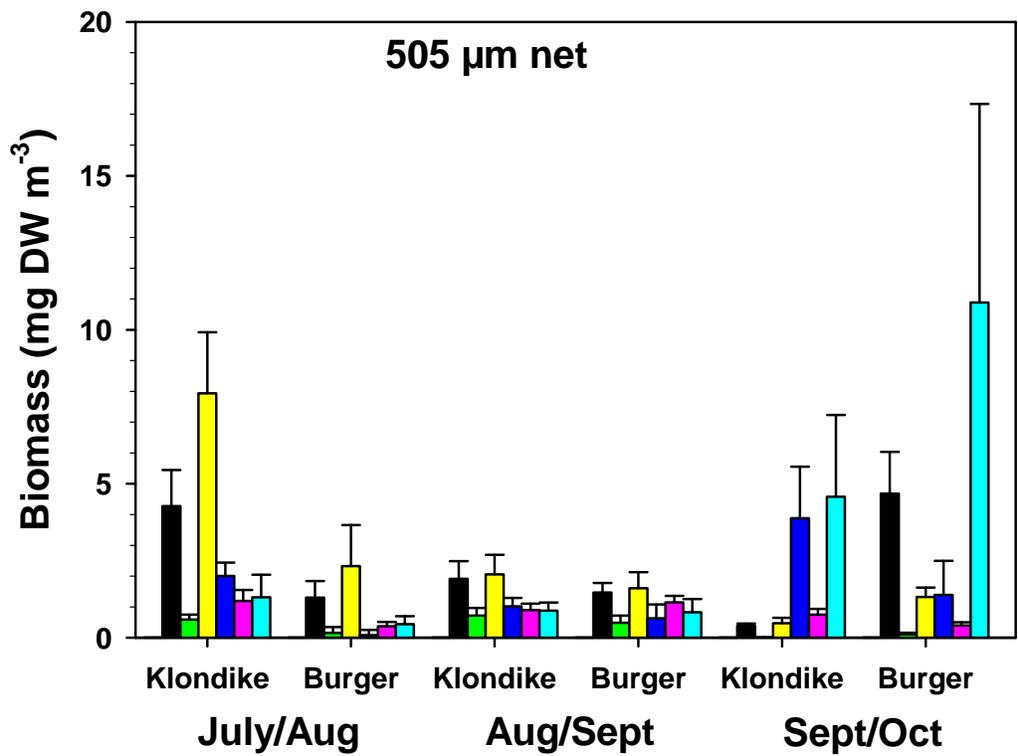
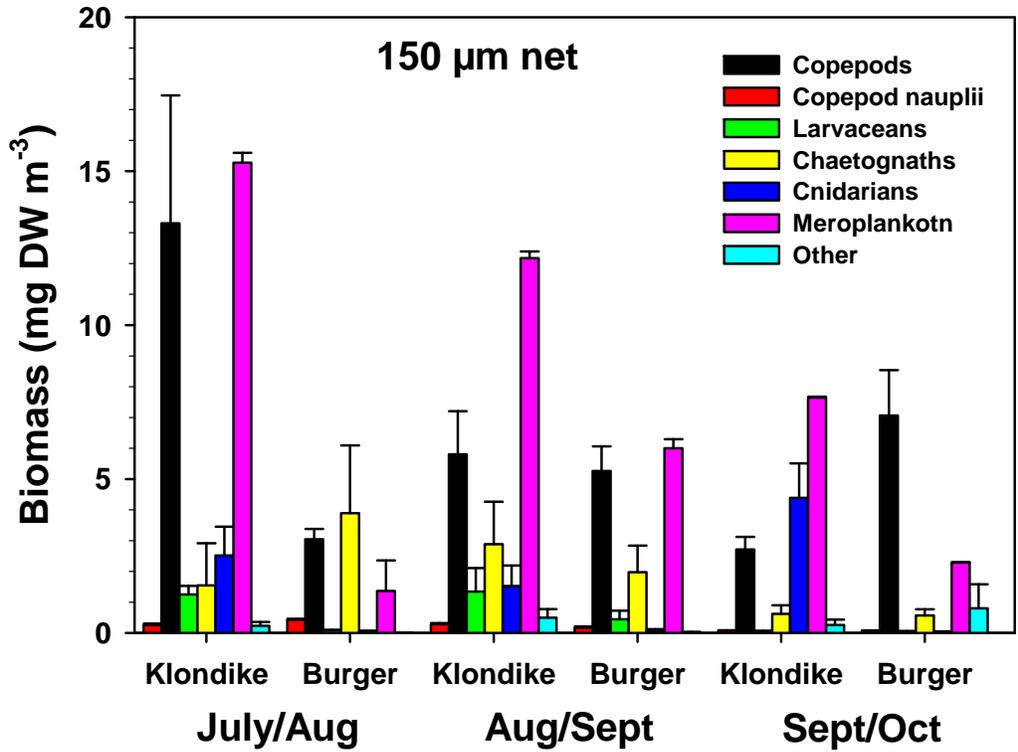


Fig. 16. Contribution of the major groups to the community biomass at each survey grid during 2008 as determined for both plankton nets. Error bars are standard error of the means.

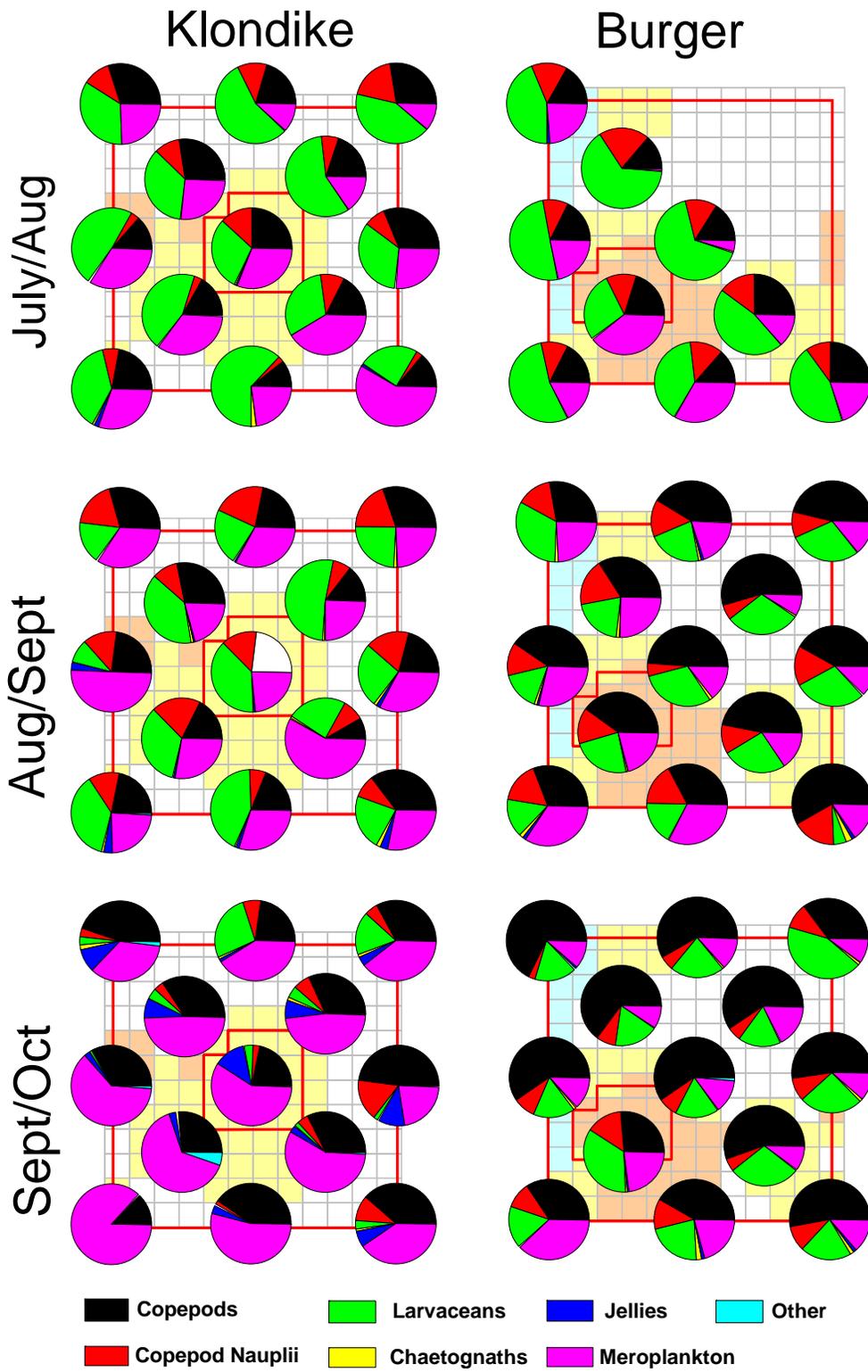


Fig. 17. Relative contribution of major taxonomic groups to the community abundance captured by the 150 μm net at each survey grid during 2008.

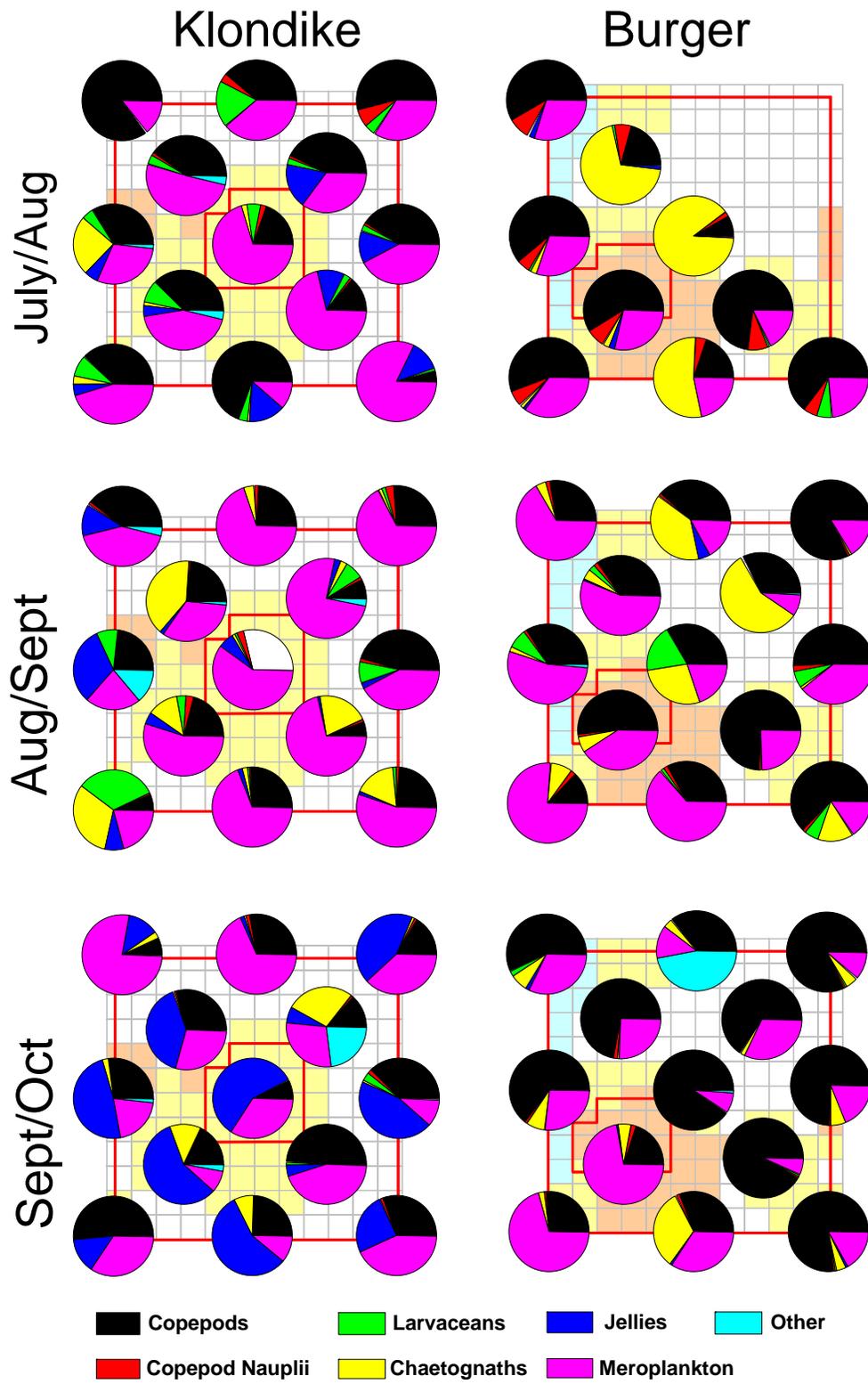


Fig. 18. Relative contribution of major taxonomic groups to the community biomass captured by the 150 µm net at each survey grid during 2008

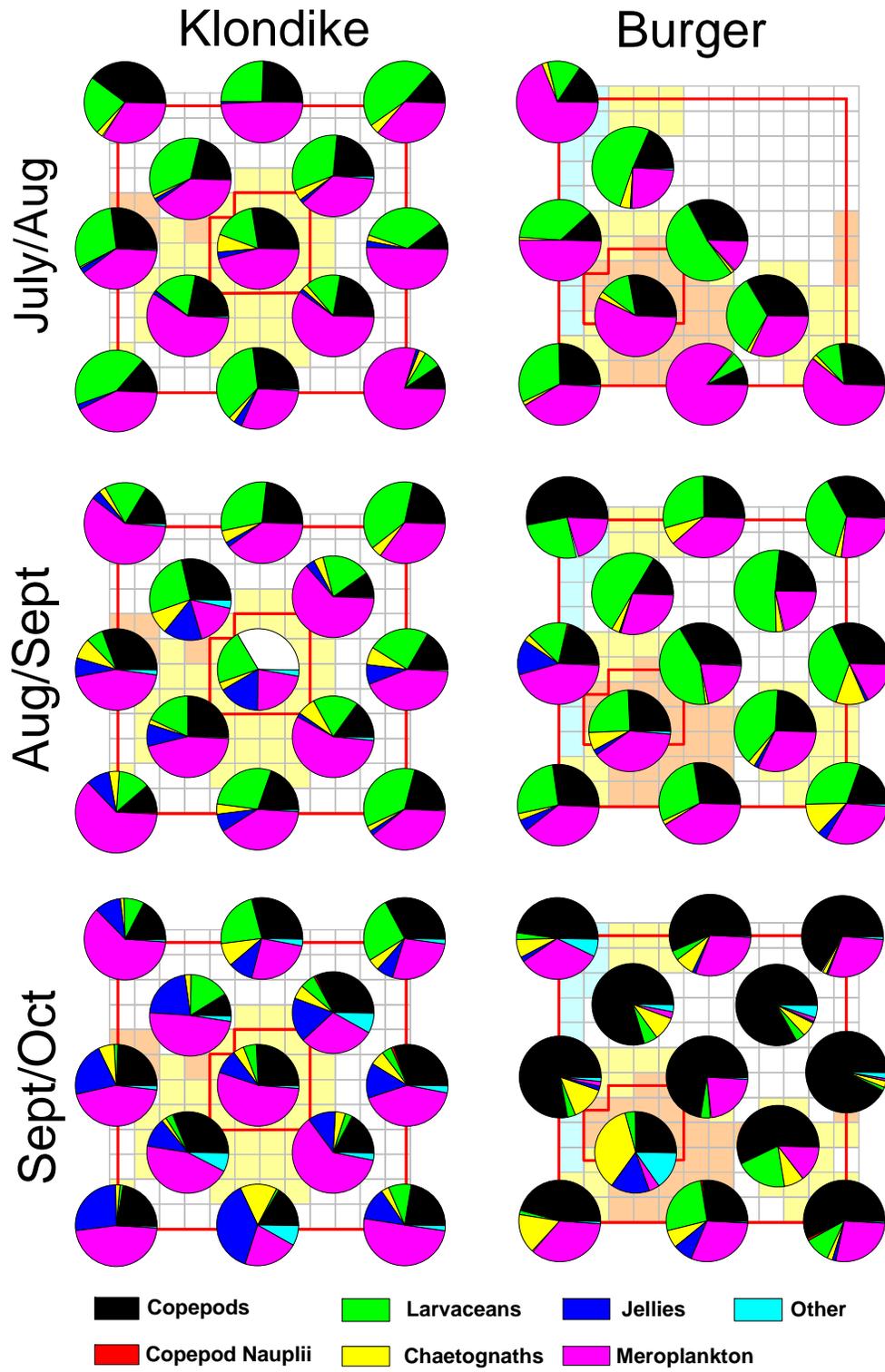


Fig. 19. Relative contribution of major taxonomic groups to the community abundance captured by the 505 μ m net at each survey grid during 2008.

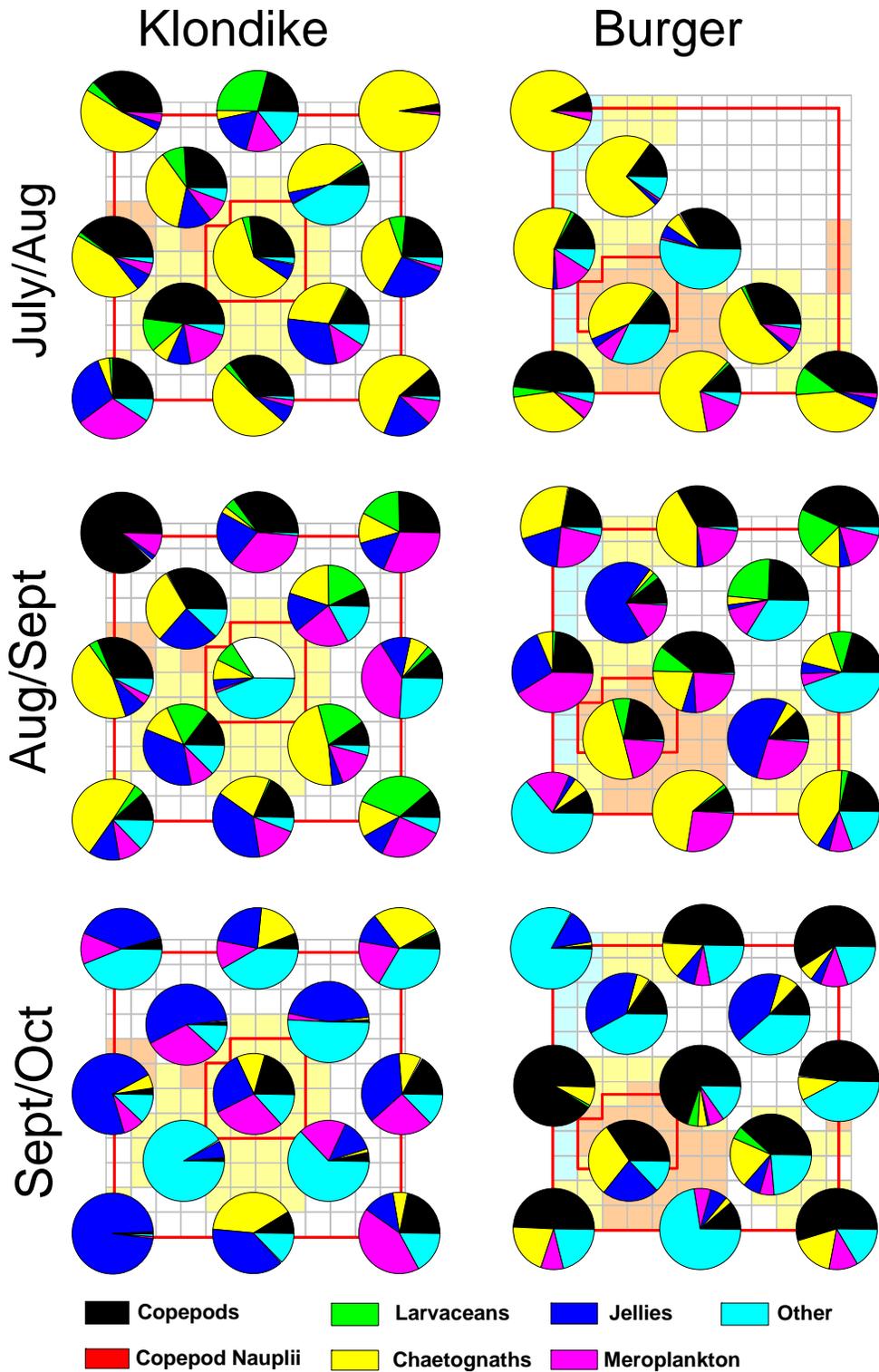


Fig. 20. Relative contribution of major taxonomic groups to the community biomass captured by the 505 μm net at each survey grid during 2008.

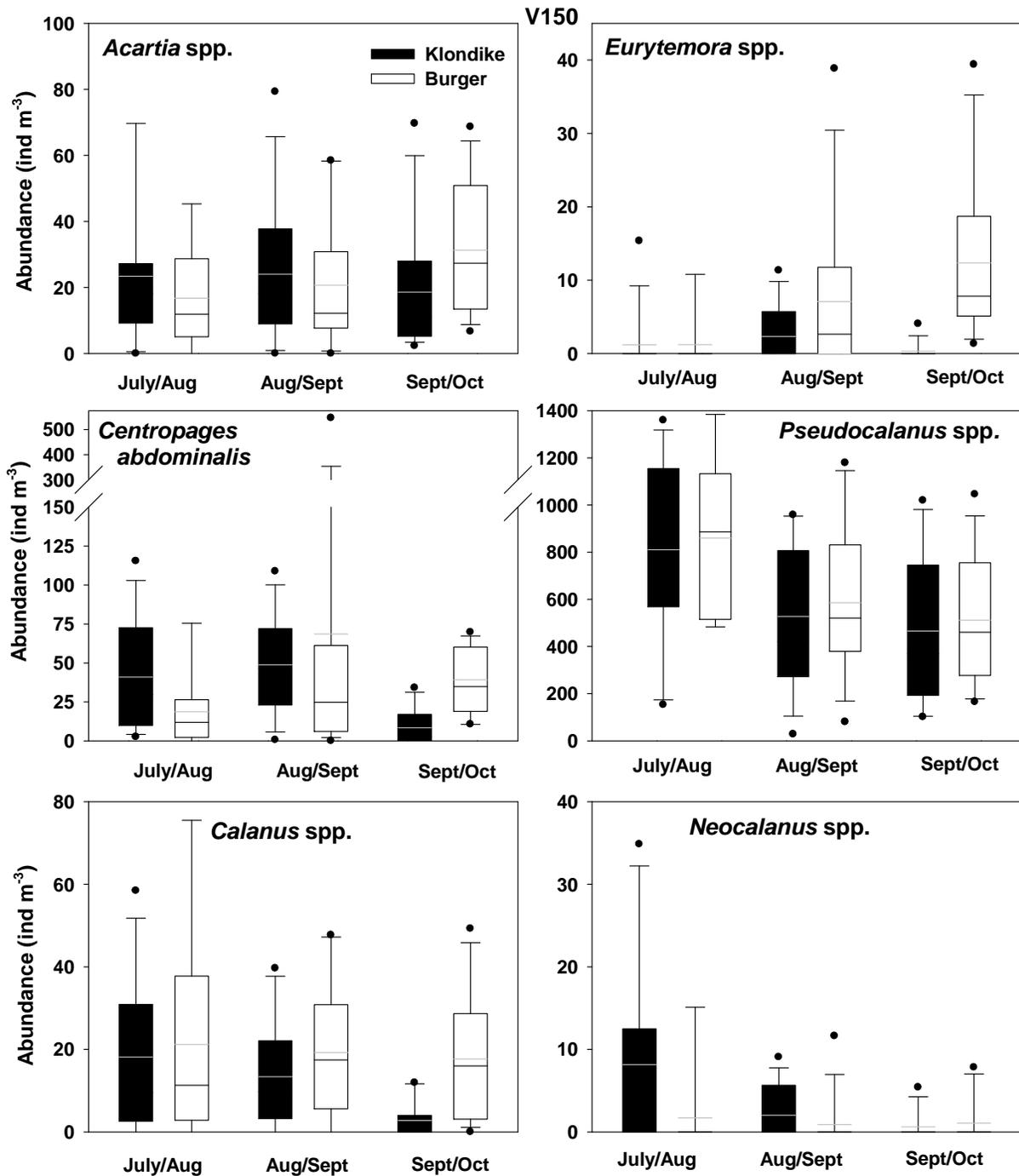


Fig. 21. Abundance of the dominant copepod species or genera during each survey grid in 2008 as captures by the 150 μ m net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low

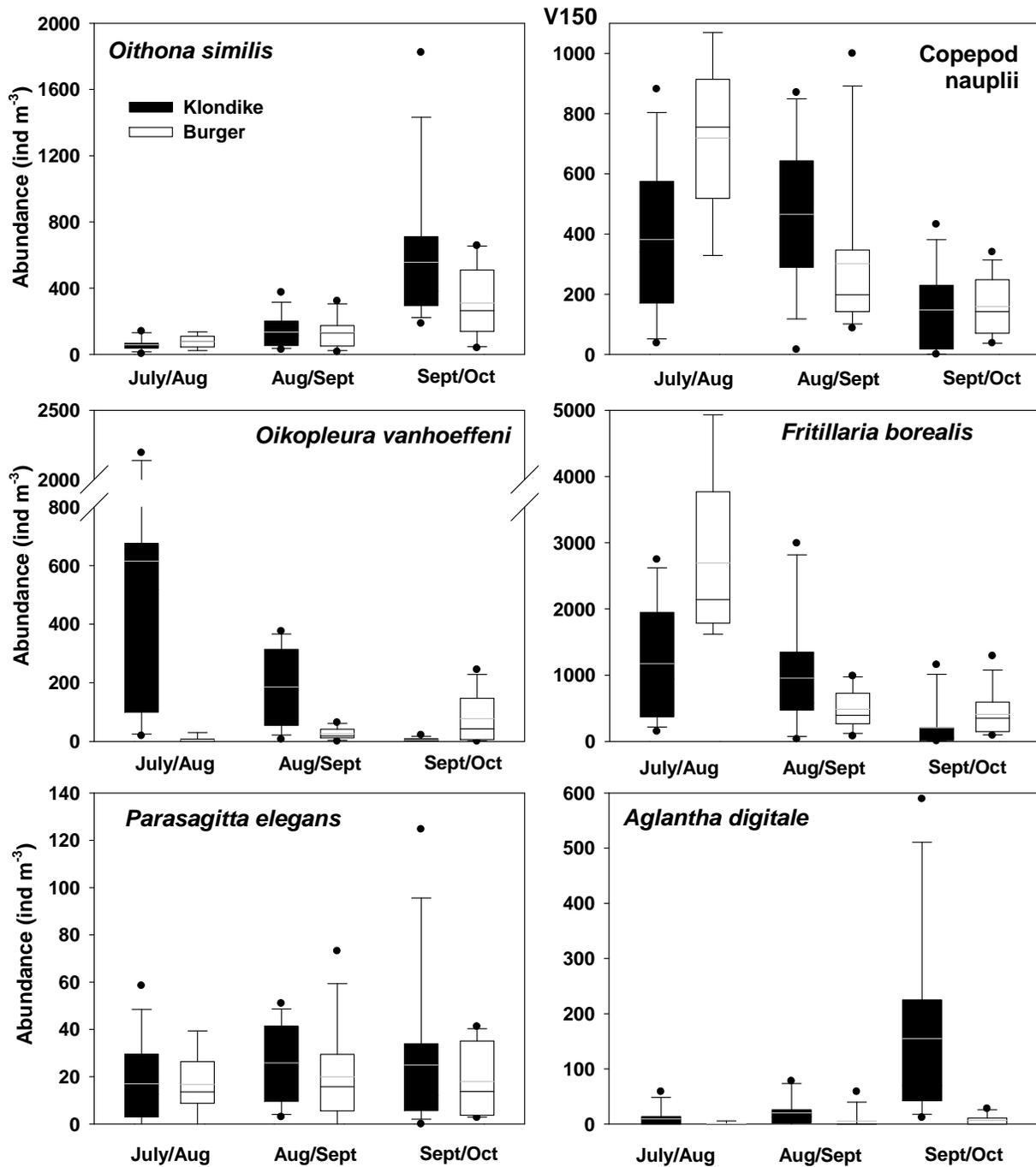


Fig. 22. Abundance of the dominant small copepod species/stages, larvaceans, chaetognaths and cnidarians during each survey grid in 2008 as captures by the 150 μm net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low

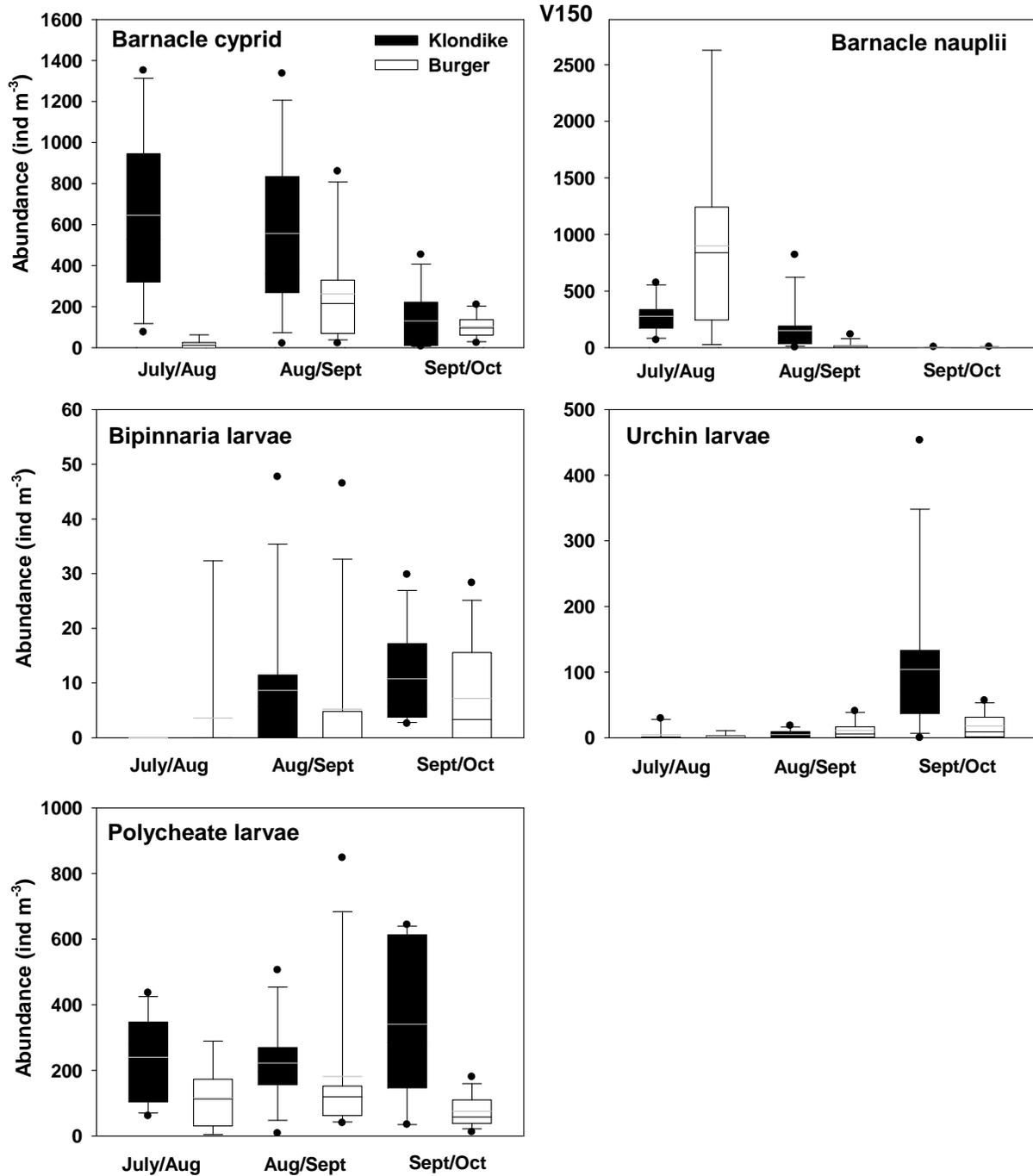


Fig. 23. Abundance of the dominant meroplankton during each survey grid in 2008 as captures by the 150 μ m net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low

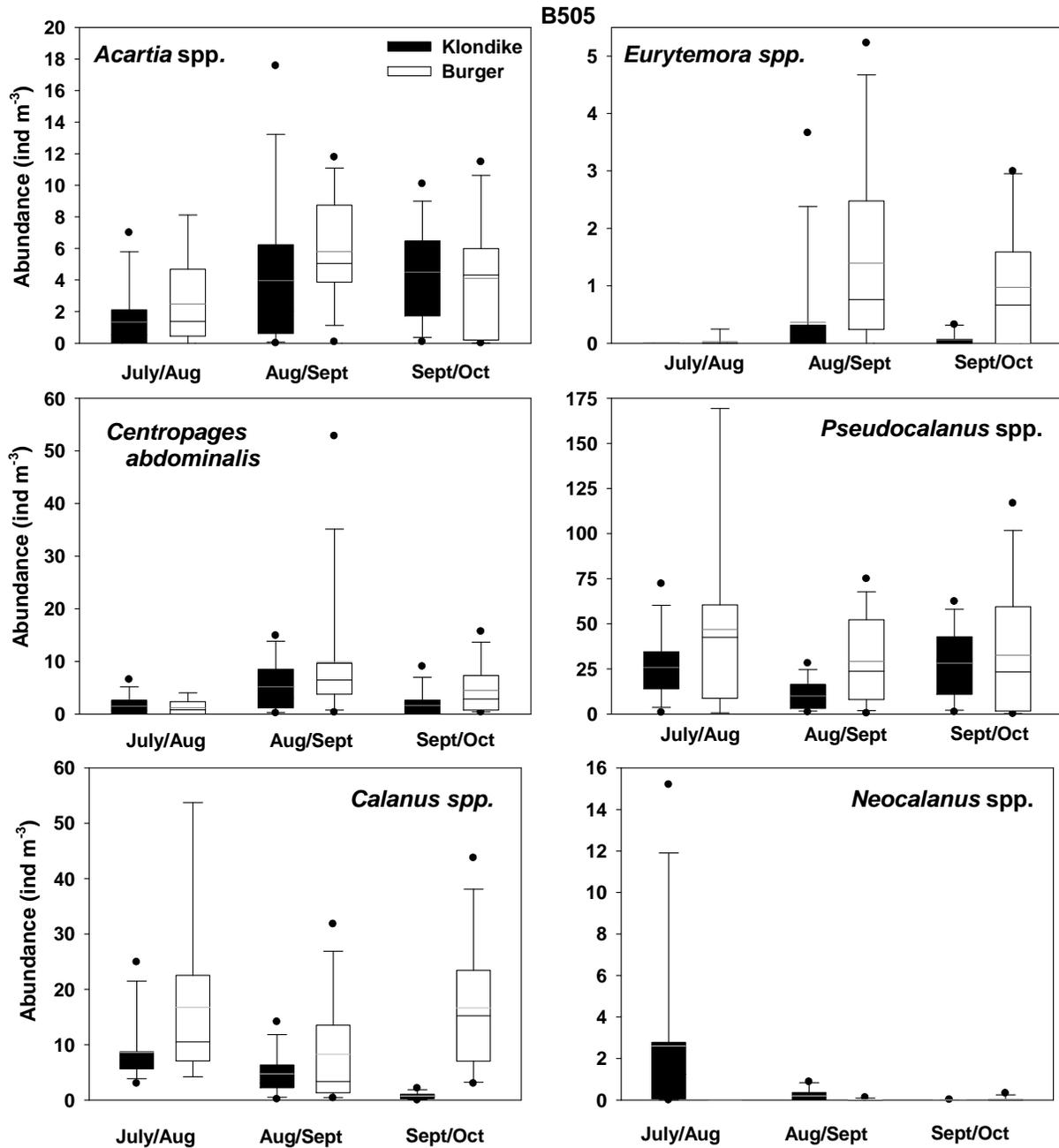


Fig. 24. Abundance of the dominant copepod species or genera during each survey grid in 2008 as captures by the 505 μ m net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low.

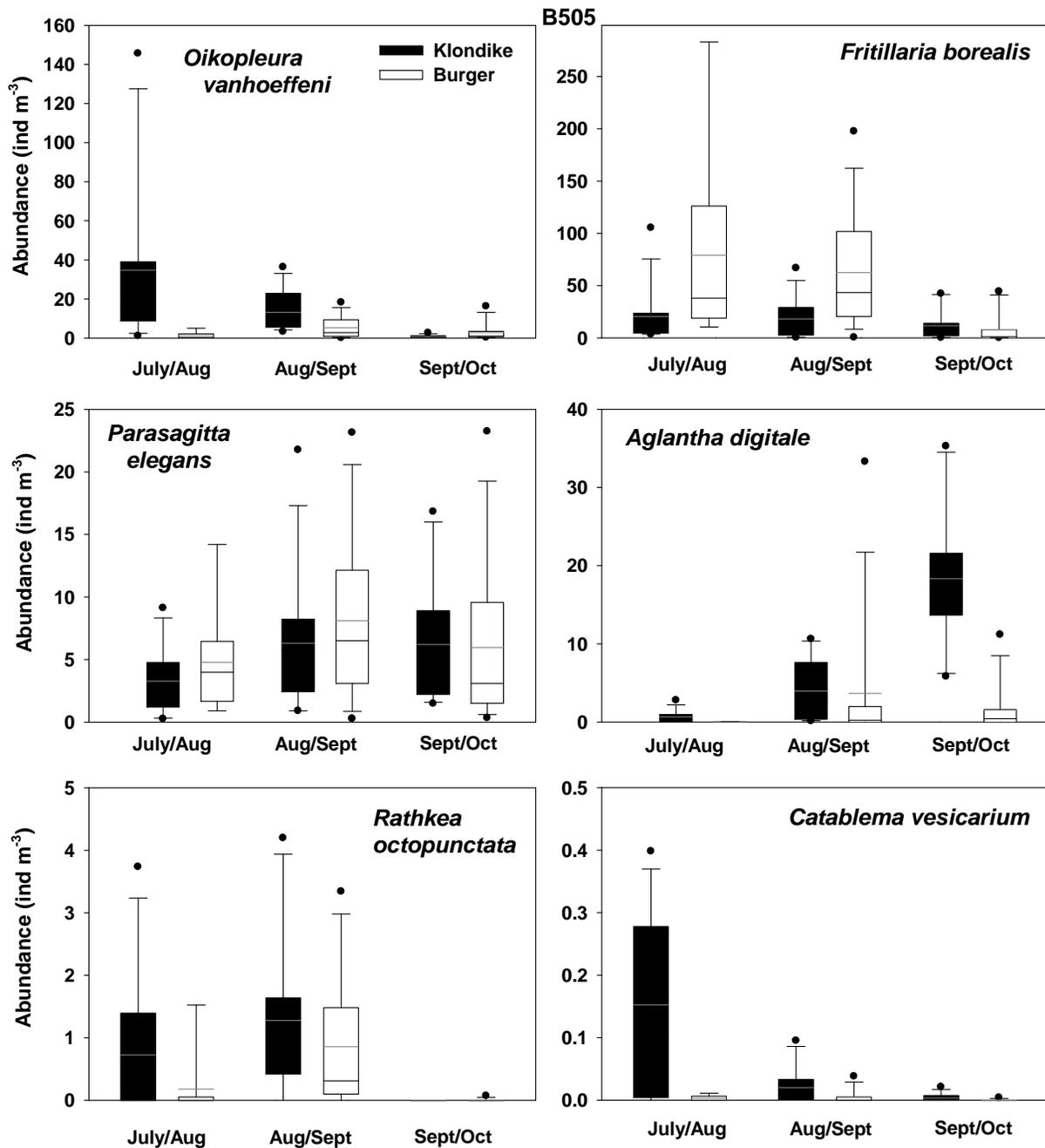


Fig. 25. Abundance of the dominant larvaceans, chaetognaths and cnidarians during each survey grid in 2008 as captures by the 505 μm net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low

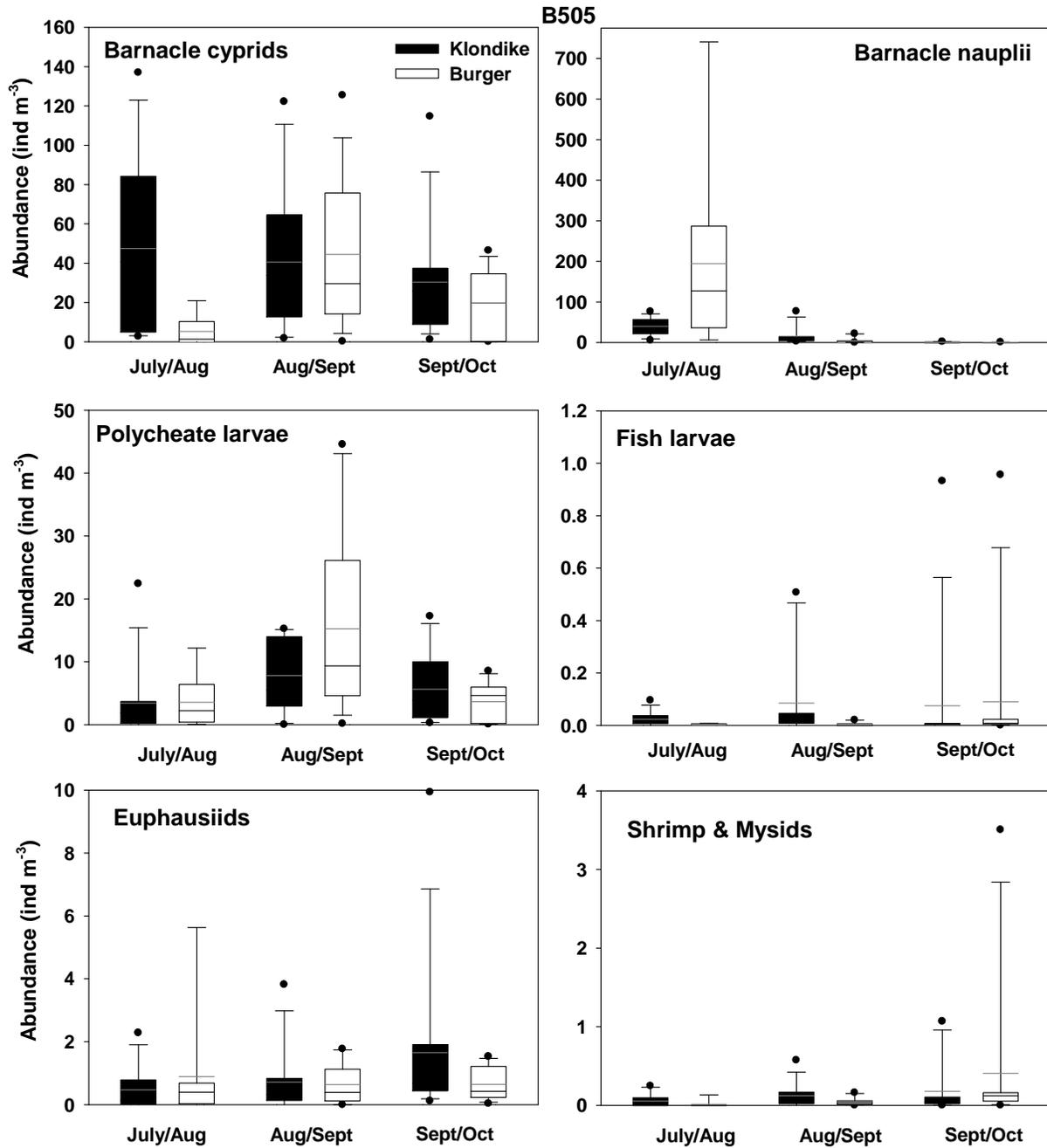


Fig. 26. Abundance of the dominant meroplankton, larval fish and shrimp-like crustaceans during each survey grid in 2008 as captures by the 505 μ m net. The black or white line through the box is the sample median; grey line is the mean, limits of the box are the 25th and 75th percentile. Whiskers are the 10th and 90th percentiles and the single points are the 5th and 95th percentiles. Features may be absent where number of samples with occurrence is low

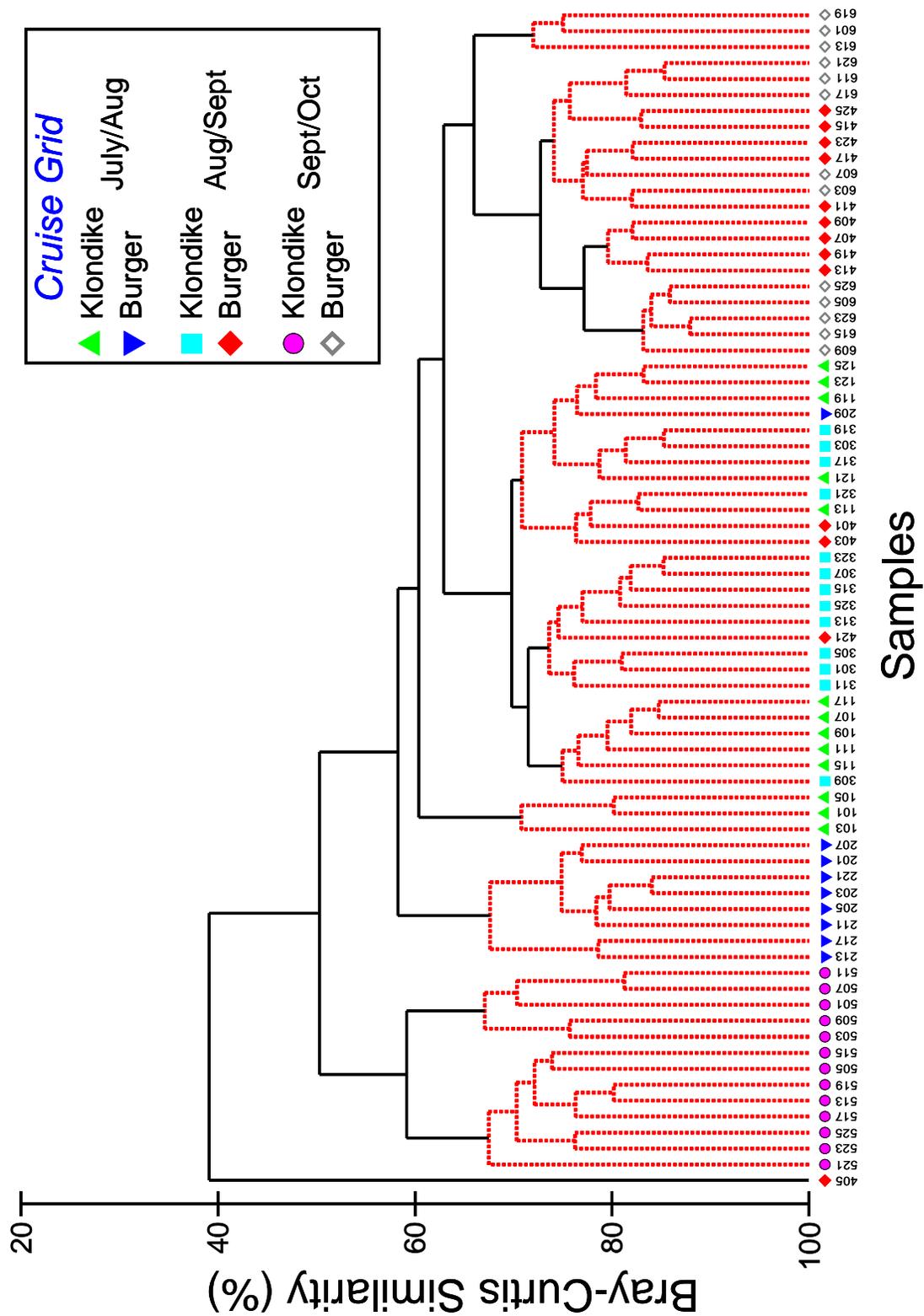


Fig. 27. Station similarity as determined by hierarchical clustering of fourth root-transformed zooplankton abundance for the 150 μ m net. Red lines connect stations that are not statistically unique ($P < 0.05$). Stations color-coded by survey grid to aid interpretation.

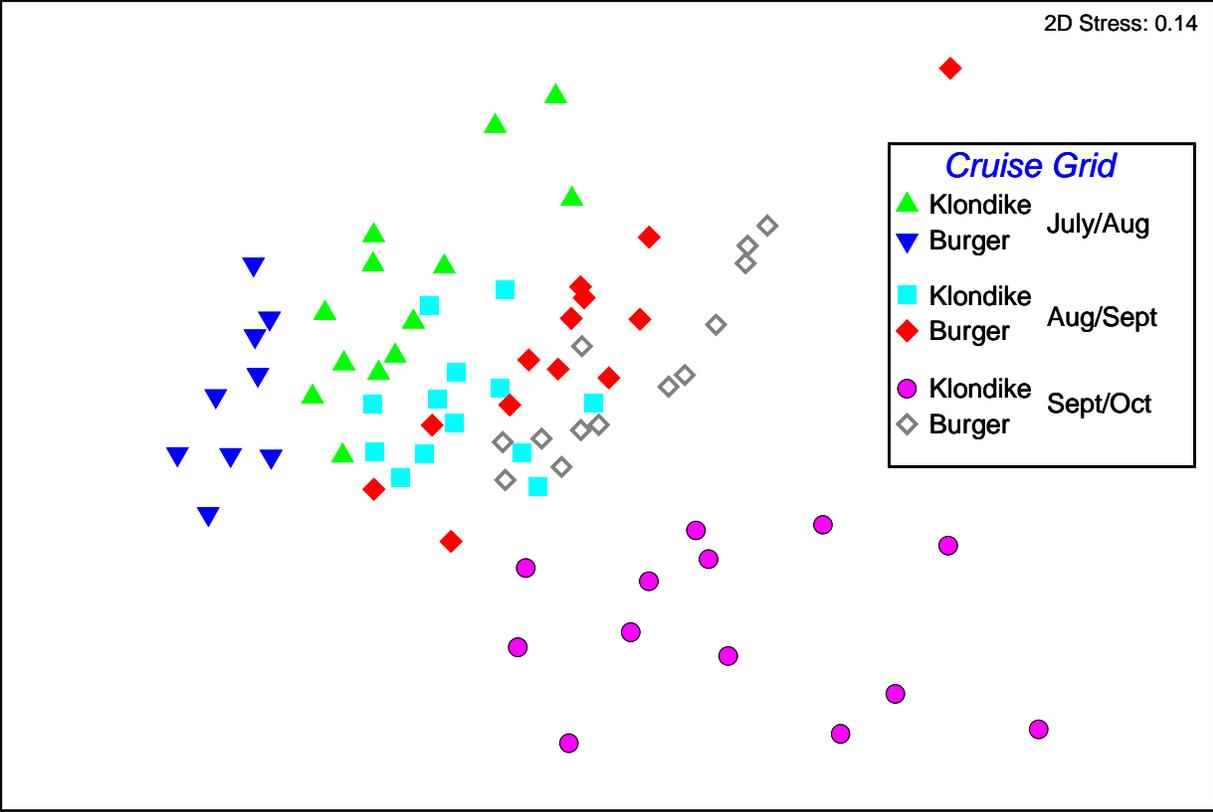


Fig. 28. Multidimensional scaling of zooplankton community abundances for the 150 μm net based on clustering performed in Fig. 26. Axes are arbitrary, spacing of samples represents the best 2-D projection of the distance in similarity between each sample. Stations color-coded by survey grid to aid interpretation.

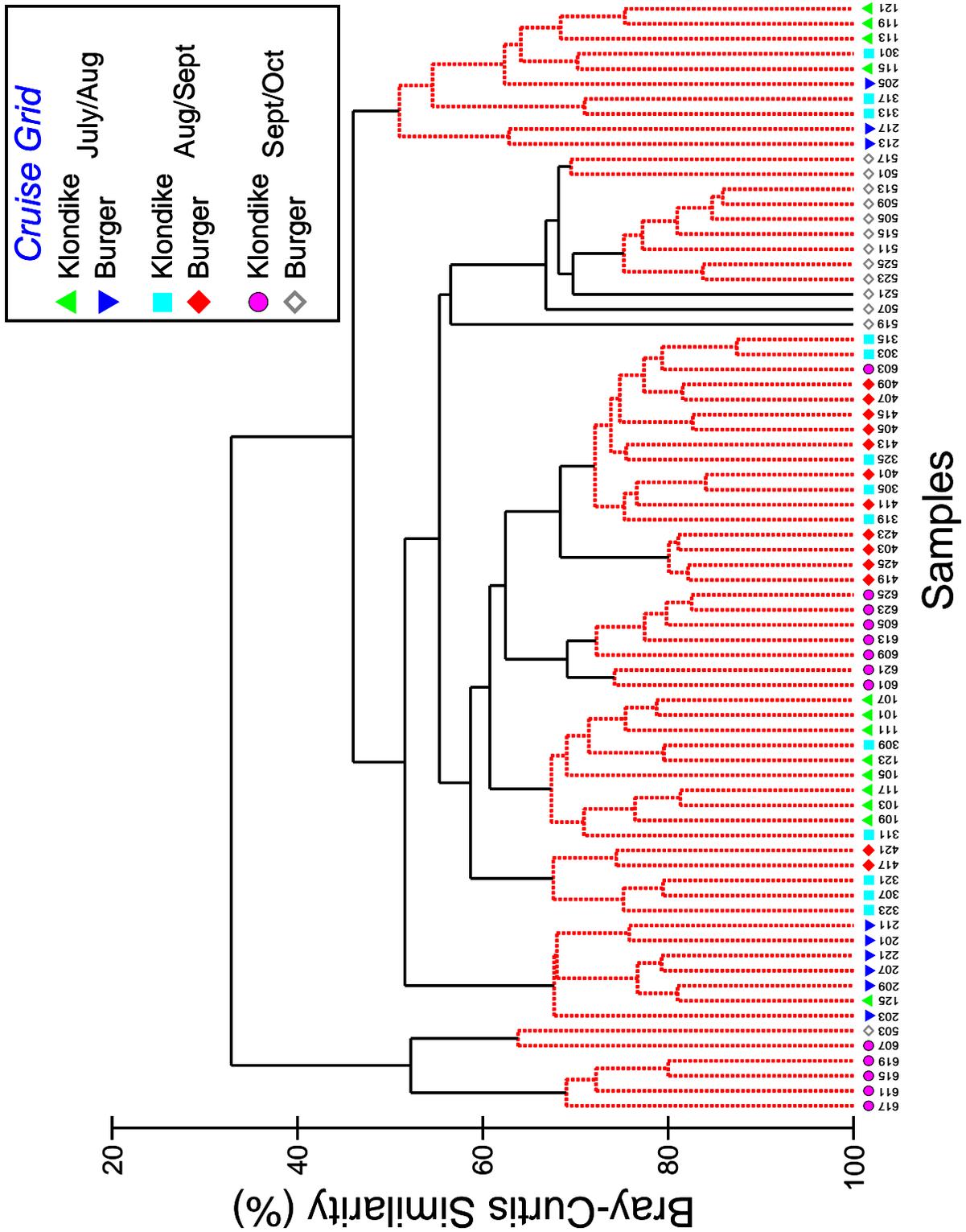


Fig. 29. Station similarity as determined by hierarchical clustering of fourth root-transformed zooplankton abundance for the 505 μ m net. Red lines connect stations that are not statistically unique ($P < 0.05$). Stations color-coded by survey grid to aid interpretation.

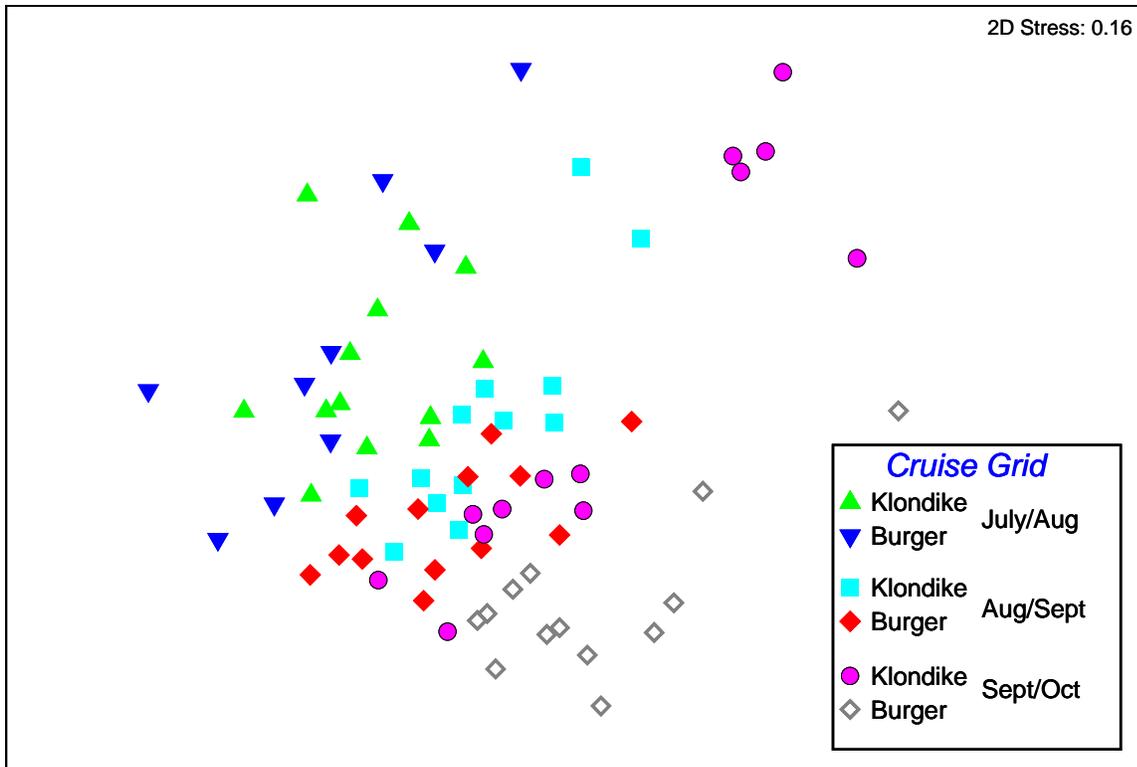


Fig. 30. Multidimensional scaling of zooplankton community abundances for the 150 μm net based on clustering performed in Fig. 26. Axes are arbitrary, spacing of samples represents the best 2-D projection of the distance in similarity between each sample. Stations color-coded by survey grid to aid interpretation.

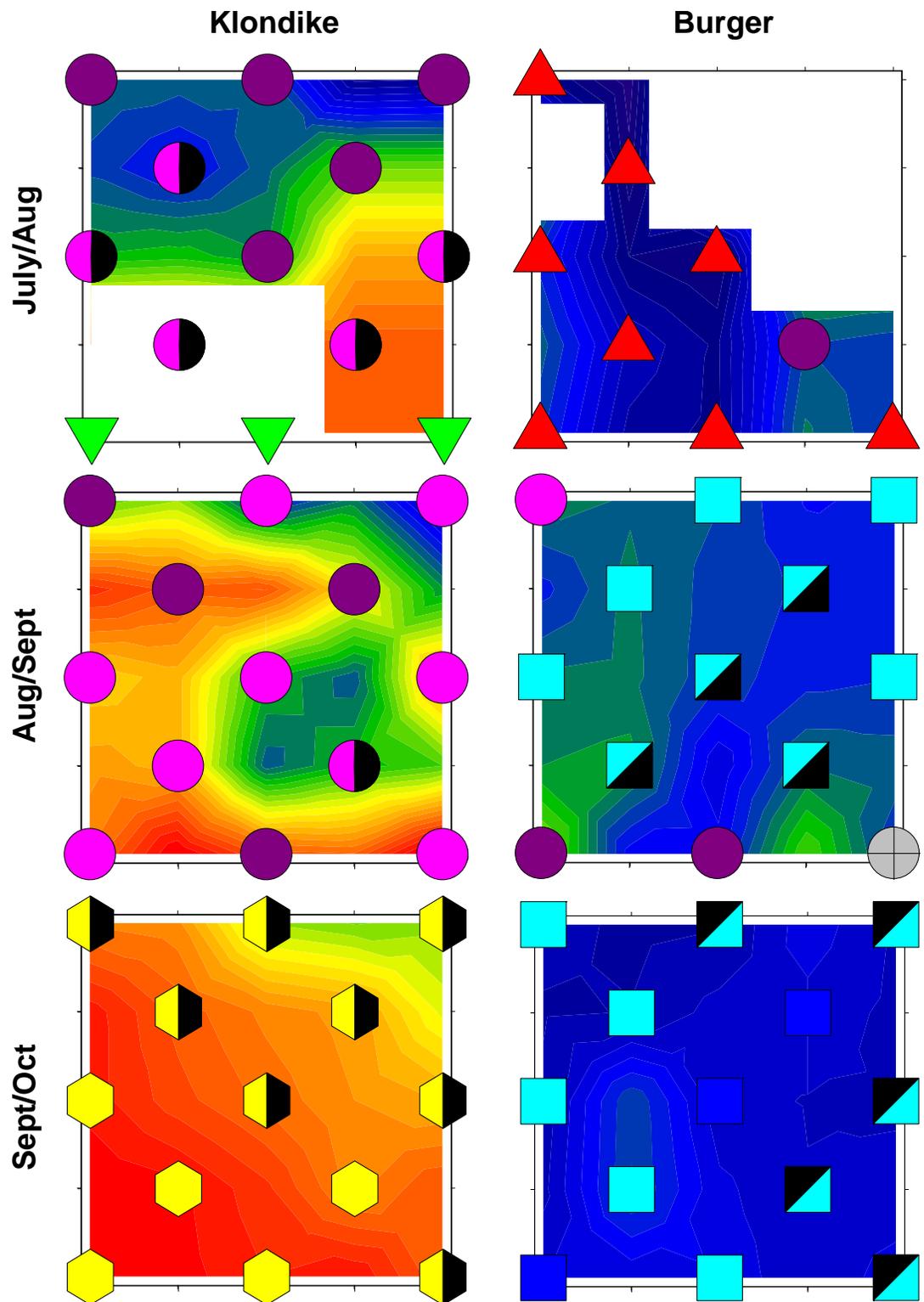


Fig. 31. Spatial distribution Bray-Curtis similarity clusters for the zooplankton communities collected by the 150 μm nets in 2008. Symbol shape reflects the major clusters, with different color-fills reflecting the sub-clusters. Distribution is superimposed over temperatures average for the upper 10m on the same absolute scale for all survey grids. Data missing for white boxes.

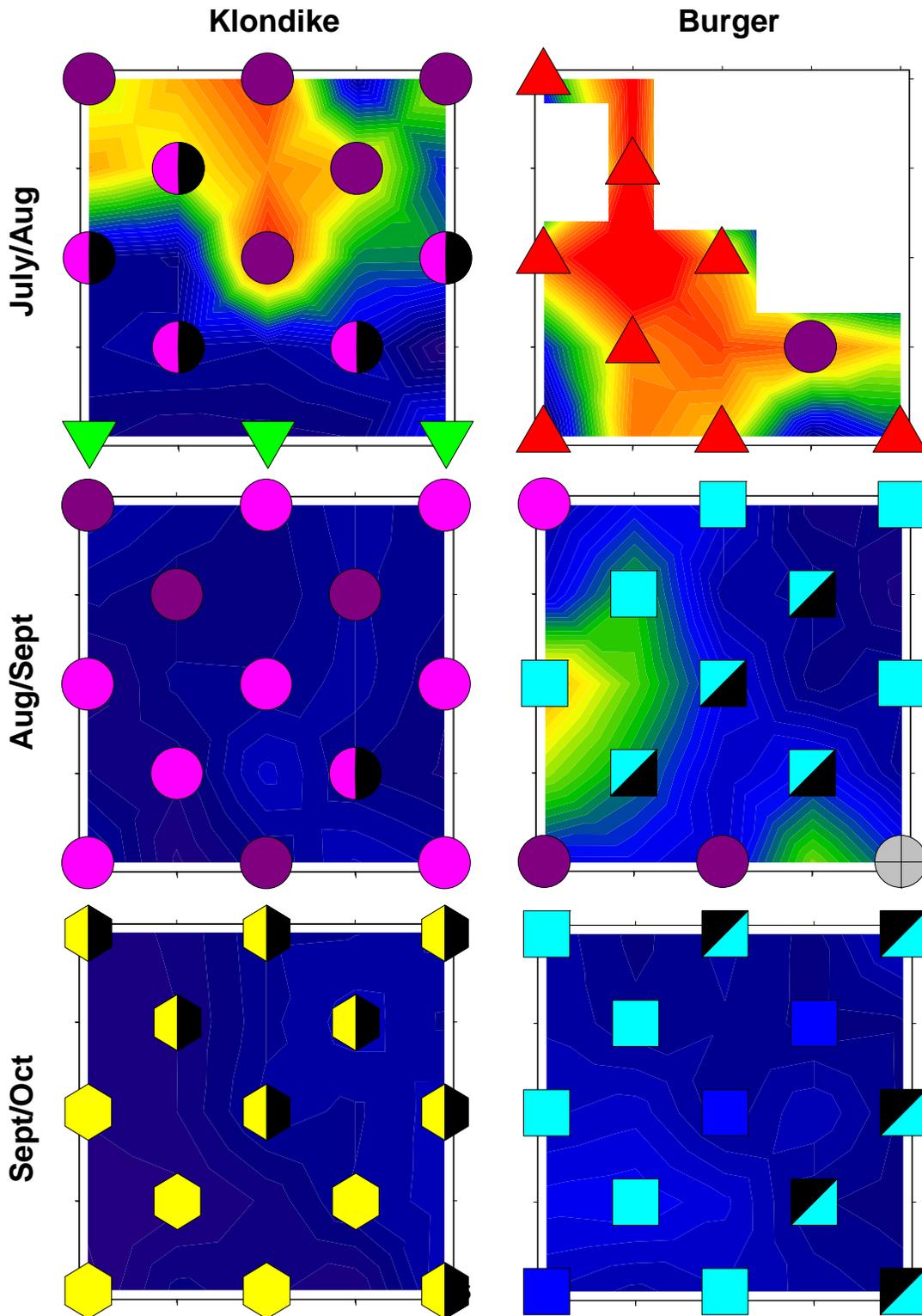


Fig. 32. Spatial distribution Bray-Curtis similarity clusters for the zooplankton communities collected by the 150 μm nets in 2008. Symbol shape reflects the major clusters, with different color-fills reflecting the sub-clusters. Distribution is superimposed over integral chlorophyll concentration presented on the same absolute scale for all survey grids.