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Macrofaunal biomass distribution on the Canadian Beaufort Shelf

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ABSTRACT

Macrofaunal biomass on the Canadian Beaufort Shelf (CBS) was mapped for major taxa and all showed increased biomass under the upwelling region on the eastern shelf. Stations having elevated biomass were defined as those in the top three of five biomass groups defined by the Jenks criterion of natural breaks, determined as biomass $\geq$143.2 g shell-free wet wt (ww) m^{-2}. Elevated macrofaunal biomass was estimated to cover 4550 km^2 of the CBS, spreading west from Cape Bathurst. Maximum macrofaunal biomass found was 1016.0 $\pm$ 332.2 g ww m^{-2}, of which up to 307.3 $\pm$ 51.2 g ww m^{-2} was due to ampeliscid amphipods of the genera *Ampelisca*, *Byblis* and *Haploops*. Since ampeliscids form beds where pelagic–benthic coupling is high, we use the area of elevated ampeliscid biomass (2550 km^2) to indicate the area of strongest upwelling effect on the benthos. Low macrofaunal biomass (<50 g ww m^2) was observed on the shelf close to the Mackenzie River inflow and on the continental slope in the Beaufort Sea and Amundsen Gulf. Mackenzie Trough, also where upwelling occurs, had an observed maximal biomass of 364.8 $\pm$ 101.8 g ww m^{-2} at its head but this was due to the polychaete *Maldane sarsi* and the brittle star *Ophiocten sericeum* rather than ampeliscid amphipods. We suggest that the ampeliscid bed under the Cape Bathurst upwelling region could be a resource for summer visiting Pacific gray whales (*Eschrichtius robustus*), which intensively forage on ampeliscid beds elsewhere.

1. Introduction

Nutrient-rich Pacific water and strong pelagic–benthic coupling support high benthic macrofaunal biomass on the arctic shelves of the Bering and Chukchi Seas where biomass of up to 150 g C m^{-2} has been recorded (Grebmeier, 2012). The high biomass areas support summering Eastern Pacific gray whales (*Eschrichtius robustus*), benthic feeding walrus (*Odobenus rosmarus*) and spectacled eider (*Somateria fischeri*) (Grebmeier, 2012). Eastwards of the Chukchi Sea, macrofaunal biomass declines along the Alaskan Beaufort shelf to near zero under the effects of the Mackenzie River plume (Wacasey, 1975; Wacasey et al., 1977). East of the Mackenzie River, macrofaunal biomass increases, recorded up to 28.3 g C m^{-2} off the tip of the Tuktoyaktuk Peninsula. Inshore of the Tuktoyaktuk Peninsula, biomass is much higher (recorded up to 119 g C m^{-2} (Wacasey, 1974[1])).

While Wacasey (1974) and Wacasey et al. (1977) extensively sampled the western Canadian Beaufort Shelf (CBS) for macrofauna, the eastern CBS was not sampled with similar intensity until this decade, spurred by the Canadian Arctic Shelf Exchange Study (CASES) (2002–2004) and the *Nahidik* Program (2003–2009). Based on the CASES work, Conlan et al. (2008) discovered a 10-fold greater macrofaunal abundance (up to 17,950 ind m^{-2}) on the northeastern shelf edge at Cape Bathurst, relative to other parts of the CBS sampled, a level as high as in parts of the Bering and Chukchi Seas (Feder et al., 2007; Grebmeier and Cooper, 1995), but did not report biomass. Renaud et al. (2007) reported a sediment carbon demand (8.0 $\pm$ 4.3 mmol C m^{-2} d^{-1}) that was nearly twice as high at Cape Bathurst as other shelf edge areas on the CBS. Conlan et al. (2008) also found that community composition was different at Cape Bathurst than elsewhere on the shelf or slope, being dominated in abundance by ampeliscid amphipods rather than polychaetes, which dominated the rest of the CBS. Similar ampeliscid beds also occur in the Bering and Chukchi Seas and have high caloric value to their gray whale predators (Highsmith and Coyle, 1990).

Williams and Carmack (2008) describe the mechanism for nutrient enrichment at Cape Bathurst, which is due to the combined effects of episodic wind-driven upwelling, which brings nutrient-rich Pacific water onto the shelf here and isobath convergence from the shelf to the cape, which alters the along-shelf flow. Sampei et al. (2011) measured high annual particulate organic carbon and biogenic silica fluxes at Cape Bathurst relative to other parts of the CBS in 2003–4.

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[1] Converted from reported dry weight, where C/DW = 0.399, based on an average of 75 records for various macrofaunal taxa in Brey et al. (2010).

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Tremblay et al. (2011) noted 2–6× increases in ice algal, phytoplankton, zooplankton and benthic production at Cape Bathurst in 2007–8 which lagged closely (<2 weeks) behind upwelling-favorable wind events.

Walkusz et al. (2012) linked an upwelling event at Cape Bathurst in 2008 to the delivery of entrained, Pacific-water zooplankton to bowhead whales (*Balaena mysticetus*), which were so numerous at Cape Bathurst as to comprise an estimated 33% of the population. Gray whale sightings, some including evidence of feeding, have been recorded with increasing frequency near Cape Bathurst and in the offshore Beaufort shelf in recent years (ADF&G, Alaska Department of Fish and Game, 2013; Harris et al., 2008; Renaud and Davis, 1981; Rugh and Fraker, 1981). The Cape Bathurst area is also a prime staging area for spring migrating king eider (*Somateria spectabilis*), common eider (*S. mollissima*) and long-tailed ducks (*Clangula hyemalis*) (Dickson and Gilchrist, 2002).

Benthic macrofauna integrate events in the water column and may reflect the Cape Bathurst upwelling as long as productivity enhancement reaches the seafloor. The purpose of this paper is to map macrofaunal biomass collected during the CASES and *Nahidik* Programs, focusing on different taxonomic components. In particular, we examine ampeliscid amphipod distributions since these were previously found to constitute a large part of benthic abundance on the shelf edge at Cape Bathurst where the upwelling occurs (Conlan et al., 2008). Ampeliscids are tube-dwelling suspension and surface deposit feeders that can form dense beds where pelagic–benthic coupling is high and can be an important food resource for higher trophic levels (Coyle and Highsmith, 1994; Feder et al., 1994; Franz and Tanacredi, 1992; Grebmeier and McRoy, 1989; Grebmeier et al., 1989; Sudo and Azeta, 1996).

2. Materials and methods

2.1. Sampling

A total of 540 samples of macrofauna at 225 stations were collected over 2002–9 from four Canadian Coast Guard ships within the sampling program of the Institute of Ocean Sciences (Humfrey Melling program on the CCGS *Laurier*), the CASES program (CCGS *Radisson* and *Amundsen*) and the *Nahidik* program (CCGS *Nahidik*). This latter program enabled access to 88% (176) of the stations. At 90% (n = 202) of these stations, a 0.25 m^2 box corer was used while at the other 23, a 0.1 m^2 van Veen grab was used (Table 1). The grab sampler was used when the box corer was unavailable (e.g., aboard the CCGS *Laurier*) or could not penetrate the sediment >10 cm depth (some *Nahidik* stations, where the sediment had a high sand content). Samples that penetrated <10 cm were discarded. The number of stations sampled per year depended on logistic opportunity and varied from 11 in 2005 to 44 in 2008. The majority of the samples (99%) were collected over July–November, with 64% being in August. Most stations were replicated in triplicate (71%). All replicates per station were taken within 24 h of each other. The average standard deviation at each of the 162 replicated sites was 0.00237 ± 0.00160 (SD) decimal degrees latitude, 0.05031 ± 0.31964 decimal degrees longitude and 0.61 ± 1.09 m depth. Sixty-three stations (28%) were not replicated due to logistic limitations. However, these were stations that were located near others that were replicate sampled. The purpose of the single sampling was to map small scale change, such as for the ampeliscid amphipods at Cape Bathurst.

2.2. Biota

Each sample was partitioned for macrofaunal and sediment analyses. Area sampled for macrofauna averaged 0.14 ± 0.04 m^2. Macrofauna were elutriated from the sediment onto 0.4 mm mesh screens and fixed in 5% buffered formalin–seawater. In the lab, they were rewashed on 0.5 mm mesh (erroneously reported as 0.4 mm mesh in Conlan et al., 2008) and separated into 13 groups (amphipods, isopods, tanaids, ostracods, cumaceans, barnacles, polychaetes, bivalves, gastropods, holothuroids, ophiuroids + crinoids, brachiopods and others). The "others" category contained mostly nemerteans, with priapulids, sipunculids, bryozoans, hydroids, sponges, tunicates, soft corals, flatworms, pycnogonids, mites and echiuroids occasionally present. Shells of molluscs, barnacles and brachiopods and tubes of polychaetes were removed (except for molluscs <0.5 cm and small polychaetes). All groups were weighed damp dry to the nearest 0.1 g. Organisms traditionally considered as meiofauna (i.e., harpacticoid copepods and nematodes) were excluded.

In order to maintain accuracy, these measured wet weights (ww) are reported rather than carbon (C) conversions since, unlike e.g. Grebmeier et al. (1988) and Feder et al. (1994) the relationship between the two biomass measures is unknown for the CBS. However, for comparison of results with dry (dw) and carbon (C) biomass values reported in the literature, the ww/dw and dw/C conversions of Brey et al. (2010) were used.

For the total fauna, ww/dw conversions were available in Brey et al. (2010) for each of the major taxa. The "others" category was converted using the nemertean conversion since nemerteans constituted a consistently large portion of the biomass of this group. For dw/C, conversions were available only for isopods, ostracods, amphipods, tanaids, holothurians and polychaetes. Therefore, the average of the reported values was used (0.397 ± 0.023, n = 6).

Table 1
Number of the 225 stations sampled by different cruises and equipment and in different months and years, number of replicates per station and number of stations measured for surface sediment and bottom water characteristics. Each column is one of the above variables and each row is a state for that variable. The states are described below the table.

Variable state	Ship cruise[a]	Sampler[b]	Month sampled[c]	Year sampled[d]	Replication[e]	Surface sediment descriptor[f]	Bottom water descriptor[g]
A	20	202	1	26	63	156	74
B	6	23	0	34	13	182	74
C	23		2	37	146	59	74
D	176		42	11	2	189	71
E			144	20	1	189	
F			23	40		189	
G			12	44			
H				13			

[a] A = CCGS *Laurier* (September 2002); B = CCGS *Radisson* (October 2002); C = CCGS *Amundsen* (September–November 2003, April 2004, July 2004); D = CCGS *Nahidik* (August–September 2002–9)
[b] A = box corer; B = van Veen grab
[c] A = April; B = May; C = June; D = July; E = August; F = September; G = October; H = November; no samples were taken in December-March
[d] A = 2002; B = 2003; C = 2004; D = 2005; E = 2006; F = 2007; G = 2008; H = 2009
[e] A = 1 replicate; B = 2 replicates; C = 3 replicates; D = 4 replicates; 5 = 5 replicates
[f] A = % N; B = % C; C = $\delta^{13}C$; D = % clay; E = % silt; F = % sand
[g] A = fluorescence; B = temperature; C = salinity; D = dissolved oxygen