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Mercury bioaccumulation and biomagnification in a small Arctic polynya ecosystem

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HIGHLIGHTS

- Polynyas are recurring sites of open water in polar marine areas
- Mercury (Hg) biomagnification was studied in a small polynya near Nasaruvaalik Island, NU, Canada
- Hg biomagnification estimates for invertebrates to fish were low compared to other Arctic systems
- Factors underlying this result are unknown but may relate to primary productivity in small polynyas

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ABSTRACT

Recurring polynyas are important areas of biological productivity and feeding grounds for seabirds and mammals in the Arctic marine environment. In this study, we examined food web structure (using carbon and nitrogen isotopes, $\delta^{13}C$ and $\delta^{15}N$) and mercury (Hg) bioaccumulation and biomagnification in a small recurring polynya ecosystem near Nasaruvaalik Island (Nunavut, Canada). Methyl Hg (MeHg) concentrations increased by more than 50-fold from copepods (*Calanus hyperboreus*) to Arctic terns (*Sterna paradisaea*), the abundant predators at this site. The biomagnification of MeHg through members of the food web – using the slope of log MeHg versus $\delta^{15}N$ – was 0.157 from copepods (*C. hyperboreus*) to fish. This slope was higher (0.267) when seabird chicks were included in the analyses. Collectively, our results indicate that MeHg biomagnification is occurring in this small polynya and that its trophic transfer is at the lower end of the range of estimates from other Arctic marine ecosystems. In addition, we measured Hg concentrations in some poorly studied members of Arctic marine food webs [e.g. Arctic alligatorfish (*Ulcina olrikii*) and jellyfish, Medusozoa], and found that MeHg concentrations in jellyfish were lower than expected given their trophic position. Overall, these findings provide fundamental information about food web structure and mercury contamination in a small Arctic polynya, which will inform future research in such ecosystems and provide a baseline against which to assess changes over time resulting from environmental disturbance.

1. Introduction

Polynyas are ice-free areas of the polar oceans, which typically occur at the same location and time each year (Stirling, 1980). They are created by physical processes in the ocean and overlying atmosphere (e.g., currents, tidal action, wind), and are key zones of biological productivity in the Arctic marine environment (Stirling, 1997). As such, they are critical feeding grounds for seabirds and large mammals (Gilchrist and Robertson, 2000; Mallory and Gilchrist, 2005; Karnovsky et al., 2007). Because polynyas are highly productive, they are also important zones of contaminant transfer from the physical environment (e.g., atmosphere, water column, and seabed) into marine food webs. Indeed, bioaccumulation and biomagnification of mercury (Hg) and other pollutants have been documented in the large Northwater Polynya (NOW) of Baffin Bay (Fisk et al., 2001; Hobson et al., 2002; Campbell et al., 2005). However, little is known about contaminant uptake and trophic transfer through food webs in the multitude of small polynyas that occur throughout the high Arctic. This is a significant knowledge gap given the productivity of these areas, and uncertainty about how the occurrence and distribution of polynyas will be affected by changing sea ice conditions and sea level rise resulting from climate change.

Contaminants such as Hg can biomagnify to potentially harmful levels in Arctic marine food webs. Concentrations of methyl Hg

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(MeHg, the organic, biomagnifying form) may be exceptionally high in some wildlife (Braune et al., 2006), and often exceed toxicity thresholds in human inhabitants of the Arctic, whose traditional diets include top predators of these food webs (Kirk et al., 2012). Therefore, understanding the processes that affect the accumulation and biomagnification of Hg in Arctic marine ecosystems is essential. Biomagnification of this contaminant is studied in a variety of ways, including trophic magnification slopes (TMSs), that is, slopes of regressions of $\log_{10}$-Hg concentrations versus raw or baseline-corrected nitrogen isotope ratios, expressed as $\delta^{15}N$ (Kidd et al., 2012a; Lavoie et al., 2013). TMS values for MeHg in Arctic marine systems range from 0.13 in the eastern Canadian Arctic (van der Velden et al., 2013) to 0.34 in waters of the lower west coast of Greenland (Rigét et al., 2007). Extending from the TMS, trophic magnification factors (TMFs) are another means of assessing food web transfer of Hg, and are calculated as the antilog of the slope of $\log_{10}$-Hg concentrations regressed against discrete trophic levels (calculated from $\delta^{15}N$ assuming an average trophic enrichment factor, $\Delta^{15}N$, through the food web; Borgå et al., 2012; Kidd et al., 2012a). Both TMS and TMF estimates in the literature vary considerably in terms of the organisms on which calculations are based. For instance, some studies include only fish and seabirds in their estimates (e.g., Jæger et al., 2009), whereas others looked at particulate organic matter through to apex predators such as polar bears (*Ursus maritimus*; Atwell et al., 1998). In addition, the inclusion of large-bodied animals (e.g. birds, mammals) typically requires that Hg analyses be conducted on muscle (or other individual tissues such as liver, as in Jæger et al., 2009) rather than on whole-body homogenates, which are more easily analyzed for smaller fishes and invertebrates. As such, estimates of Hg biomagnification often rely on a mix of muscle and whole-body Hg concentrations for organisms of different trophic positions.

In this study, we collected components of the seabird food web at a small polynya in the Canadian high Arctic to determine Hg concentrations and food web structure using stable carbon ($\delta^{13}C$) and nitrogen isotope ($\delta^{15}N$) analyses. Our goal was to determine whether Hg bioaccumulation and biomagnification (as indicated by TMSs and TMFs) in this polynya differed from larger polynyas or open water regions at high latitudes. As productive marine sites at high latitudes (Hoppema and Anderson, 2007; Lavoie et al., 2013), we predicted that the food

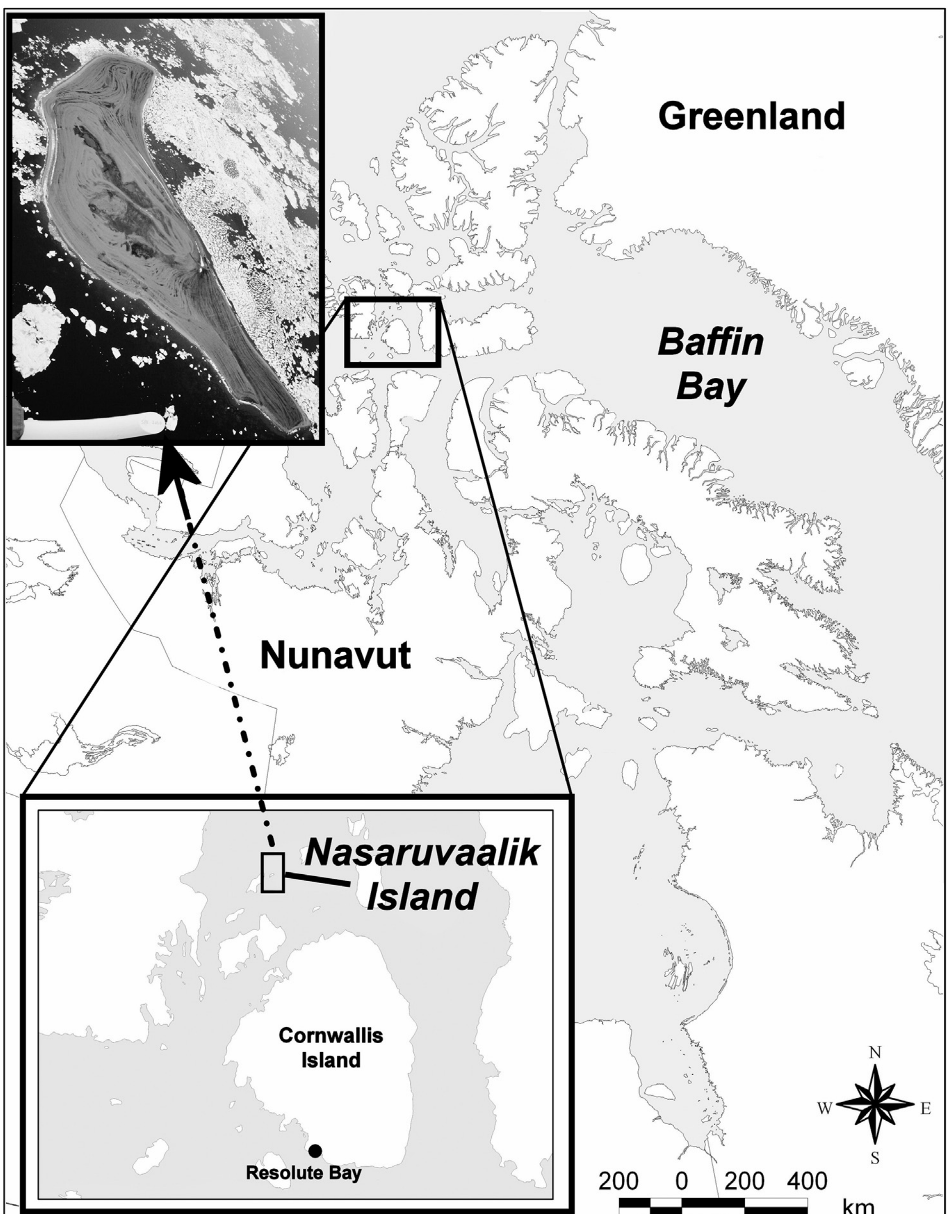

Fig. 1. Location of Nasaruvaalik Island (Nunavut, Canada) and recurring polynya (visible dark open water area immediately west of the gray island in the inset photograph).