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MERCURY LEVELS IN AN ARCTIC MARINE FOOD WEB

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Rapport
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Preface

In the present study, muscle and liver were sampled from the seabird species glaucous gull (*Larus hyperboreus*), northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), Brünnich's guillemot (*Uria lomvia*) and little auk (*Alle alle*) and the fish species polar cod (*Boreogadus saida*) and herring (*Clupea harengus*). In addition whole samples of capelin (*Mallotus villosus*), and the zooplankton species *Meganyctiphanes norvegica*, *Thysanoessa inermis*, *Themisto libellula* and *Calanus hyperboreus* were sampled. Total mercury (TotHg) were determined in all samples, whereas methyl mercury (MeHg) was determined in liver samples from all the seabirds, muscle samples from polar cod and pooled samples of *Themisto libellula* and *Calanus hyperboreus*. In addition, muscle samples from all bird and fish species and whole zooplankton species were analysed for stable isotopes of nitrogen to assess the trophic level of species.

This project was a collaboration between the Norwegian Polar Institute, Tromsø; Norwegian Veterinary Institute, Oslo; and University of Tromsø, Tromsø.

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Cover picture: Kittiwakes on an ice flow in Kongsfjorden, Svalbard (Geir W. Gabrielsen, Norwegian Polar Institute)

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Samandrag

Arktis vert rekna som eit viktig oppsamlingsområde for kvikksølv, der atmosfærisk langtransport står for mesteparten av kvikksølvtransporten til det relativt urørte Arktis. Dei totale menneskeskapte kvikksølvutsleppa har auka dei siste tiåra, i hovudsak på grunn av auka kolbrenning i Asia. Vidare har auka konsentrasjonar i ulike flora og fauna vorte tilskrive menneskeskapa kjelder i sørlege områder. Metylkvikksølv er den mest toksiske kvikksølvforbindelsen og den viktigaste når det gjeld biomagnifisering. Det er i samsvar med dette viktig å overvake metylkvikksølv i flora og fauna.

Denne studien rapporterar nivåa av total kvikksølv (TotHg) og metylkvikksølv (MeHg) i utvalde artar frå det marine arktiske økosystemet i Kongsfjorden på Svalbard. Artane som vart inkludert i studien var polarmåke (*Larus hyperboreus*), havhest (*Fulmarus glacialis*), krykkje (*Rissa tridactyla*), polarlomvi (*Uria lomvia*), alkekonge (*Alle alle*), polartorsk (*Boreogadus saida*), sild (*Clupea harengus*), lodde (*Mallotus villosus*) og zooplanktonartane *Themisto libellula*, *Meganyctiphanes norvegica*, *Thysanoessa inermis* og *Calanus hyperboreus*. Desse artane representerer ulike trofiske nivå i det marine næringsnettet i Kongsfjorden, Svalbard. Denne studien er den fyrste som rapporterar MeHg nivå i sjøfuglartar frå Barentshavområdet.

Polarmåke hadde dei høgste muskelnivåa av TotHg, tett følgd av havhest og krykkje. Dei høgaste levernivåa av TotHg vart funne i havhest. Havhesten hadde òg dei høgste nivåa av MeHg i levra. Polartorsken var den arten som hadde dei lågaste detekterbare nivåa av MeHg. Når det gjeld sjøfuglane, hadde alkekongen dei lågaste MeHg-nivåa.

Det var ein generell trend blant sjøfuglartane at delen MeHg minka med aukande TotHg-nivå i levra. TotHg-nivåa var gjennomgåande høgare i lever frå sjøfugl enn i muskel. Havhest og måkane hadde generelt høgare kvikksølvnivå enn alkefuglane. Polartorsk, sild og lodde hadde låge eller ikkje detekterbare kvikksølvnivå. Vidare hadde zooplanktonartane både TotHg- og MeHg-nivå under deteksjonsgrensa. Variasjonane i kvikksølvnivå mellom artane var større i lever enn i muskel. Denne studien viste at det ikkje ser ut til å vere ein auke i kvikksølvnivå i marine artar frå Svalbardområdet sidan 1990-talet.

Trofiske nivå og overføring av kvikksølv gjennom næringsnettet vart bestemt ved hjelp av stabile nitrogenisotop analyser ($\delta^{15}N$). Havhest og polarmåke ligg på det høgaste trofiske nivået av artane i denne studien. Den zooplanktonetande alkekongen ligg på det lågaste trofiske nivået av sjøfuglartane. Fiskeartane polartorsk, sild og lodde ligg på eit litt høgare trofisk nivå enn alkekongen. Den herbivore zooplanktonarten *Calanus hyperboreus* innehar det lågaste trofiske nivået av artane i denne studien. Det vart ikkje avdekka nokon samanheng mellom trofisk nivå og verken TotHg eller MeHg innan kvar enkelt art. Når alle sjøfuglartane vart inkludert i regresjonen vart det funne ein lineær samanheng mellom trofisk nivå og både MeHg og TotHg. Trofiske magnifikasjonsfaktorar (TMFs) og biomagnifikasjonsfaktorar (BMFs), for både TotHg og MeHg, viste verdiar > 1. Dette tyder på biomagnifikasjon av TotHg og MeHg i artane frå Kongsfjorden, Svalbard.

Summary

The Arctic is considered as an important sink for mercury, where long range atmospheric transport is considered as the main transport route for mercury to the pristine Arctic environment. The total anthropological mercury release has increased the last decades, mainly due to increased coal burning in Asia. Also, elevated concentrations found in various biota across the Arctic have been attributed to anthropogenic sources in southern regions. Methyl mercury is the main biomagnifying agent and the most toxic form of mercury and accordingly important to monitor in biota.

The present study reports total mercury (TotHg) and methyl mercury (MeHg) levels in selected species from the Arctic marine ecosystem in Kongsfjorden, Svalbard. Species included in the study were glaucous gull (*Larus hyperboreus*), northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), Brünnich's guillemot (*Uria lomvia*), little auk (*Alle alle*), polar cod (*Boreogadus saida*), herring (*Clupea harengus*), capelin (*Mallotus villosus*), the zooplankton species *Themisto libellula*, *Meganyctiphanes norvegica*, *Thysanoessa inermis* and *Calanus hyperboreus*. These species represent different trophic levels in the food web in Kongsfjorden, Svalbard. The present study is the first to report on MeHg levels in seabirds from the Barents Sea region.

Larger variation in mercury levels between species was found in liver than in muscle. The highest MeHg levels were found in liver of northern fulmar. This species also displayed the highest level of TotHg in liver. The lowest detectable MeHg levels were found in muscle of polar cod. With regards to seabird liver, little auk had the lowest MeHg levels. There was a general trend among the seabird species of decreasing proportion of MeHg with increasing level of TotHg in liver. TotHg levels were consistently higher in seabird liver than in muscle. Northern fulmar and gulls had generally higher concentrations of both TotHg and MeHg in the liver than the auks. Polar cod, herring and capelin had low to not detectable levels of mercury. Furthermore, all zooplankton species had both TotHg and MeHg levels below detection limit. The present study, showed no increase in mercury levels in marine species in the Svalbard area since the 1990s. Furthermore, none of the species sampled in the present study show mercury levels above threshold values for effects.

Trophic levels and transfer of mercury through the food web were determined using stable isotopes of nitrogen ($\delta^{15}N$). Northern fulmar and glaucous gull had the highest trophic level among the species in the present study. The zooplankton eating little auk had the lowest trophic level among the seabirds, while the fish species; polar cod, herring and capelin were at a somewhat higher trophic level than the little auk. The herbivore zooplankton species *Calanus hyperboreus* have the lowest trophic position among the species in the study. No correlation was found between trophic level and TotHg or MeHg within species. In seabirds, a linear relationship was found between the trophic level and TotHg or MeHg. Trophic magnification factors (TMFs) and biomagnification factors (BMFs), for both TotHg and MeHg, show values >1, which indicate biomagnification in marine species sampled in Kongsfjorden.

1. Introduction

Despite the limited anthropogenic activity in Arctic regions, the levels of heavy metals are of concern and the Arctic is considered as an important global sink for mercury depletion (Ariya et al. 2004). Long-range atmospheric transport are considered as the main transport route for mercury and source for increasing concentrations in the Arctic (Berg et al. 2003; Ariya et al. 2004; Barkay and Poulain 2007). Atmospheric Mercury Depletion Events (AMDEs) is an important process in cycling of mercury in the polar environment. During the polar sunrise, atmospheric mercury is deposited on the snow pack (Schroeder et al. 1998). Subsequently, the snow bound mercury ends up in the run-off and contributes to increased concentrations of mercury in the Arctic ecosystem (Berg et al. 2003). AMDE occurs in springtime, a sensitive time of the year when plants and animals become active and reproductive (Brooks et al. 2005).

The most important anthropological sources of mercury emission to the atmosphere are coal burning, waste incineration and industrial processes (Pacyna 2005). Elevated concentrations found in various biota across the Arctic have been attributed to anthropogenic sources in southern regions (Muir et al. 1999). Although emissions from the Western Europe and North America have decreased, the total global mercury release has increased during the last decades, mainly due to increased coal-burning in Asia (Pacyna 2005). Trend analysis for Hg in aerosols at the Zeppelin station in Ny-Ålesund from 1994 to 2002 showed no trend change during this period (Berg et al. 2004).

Mercury has been detected in various biota and varies geographically throughout the Arctic (Dietz et al. 1996; Wagemann et al. 1996; Braune et al. 2005b; Borgå et al. 2006). Mercury levels in seabird species are generally found to be lower in the Barents Sea area than in e.g. Greenland and the Canadian Arctic (Savinov et al. 2003; Borgå et al. 2006). A number of long-term studies from the Arctic and North Atlantic (e.g. Canadian Arctic and West Greenland) have reported increasing levels of mercury concentrations in piscivorous wildlife over the past decades, whereas there has been no such increase shown in the European Arctic (Barrett et al. 1996; Muir et al. 1999; Braune et al. 2005a).

Mercury is not readily available to the food web in its natural form. However, inorganic mercury are converted to organic mercury compounds (e.g. MeHg) by microbial processes of anaerobic organisms (Wolfe and Daniel 1998; Clark 2001; Derome et al. 2005). MeHg is more lipophilic, highly bioaccumulative and the most toxic form of mercury (Thompson and Furness 1989; Lee et al. 1994). Mercury is associated with damaging effects on the nervous system, weight loss, altered behaviours and negative impact on excretory, immune and reproductive systems in piscivorous birds, mammals and humans (Wolfe and Daniel 1998; Chan et al. 2003; Webster 2005). Clear effects in Arctic and other ecosystems are yet to be demonstrated. Demethylation, moulting and maternal transfer are all routes of body loss of MeHg in addition to excreta.

Analysis of stable isotopes of nitrogen is a commonly used method to determine the trophic relationships and the proportion of biomagnification of contaminants in the Arctic (Fisk et al. 2001; Hobson et al. 2002; Hop et al. 2002). MeHg, the main biomagnifying agent for TotHg, is found to biomagnify through a variety of food webs, with trophic levels determined from $\delta^{15}N$ values (Atwell et al. 1998; Thompson et al. 1998; Power et al. 2002; Campbell et al. 2005) and the concentrations are known to increase towards higher trophic levels in all tissues (liver, muscle, kidney) (Dietz et al. 1996).

The main objective of the present study was to assess the levels of total mercury (TotHg) and methyl mercury (MeHg) in species from different trophic levels of the Norwegian Arctic marine ecosystem in Kongsfjorden, Svalbard. Biomagnification and trophic magnification factors were calculated. There are few studies concerning MeHg levels in birds and lower trophic organisms in the Barents Sea region. This study contributes with recently measured levels of TotHg and MeHg levels in the following species: copepod (*Calanus hyperboreus*), krill (*Meganychtiphanes norvegica* and *Thysanoessa inermis*), hyperiid amphipod (*Themisto libellula*), capelin (*Mallotus villosus*), herring (*Clupea harengus*), polar cod (*Boreogadus saida*), little auk (*Alle alle*), Brünnich's guillemot (*Uria lomvia*), black-legged kittiwake (*Rissa tridactyla*), glaucous gull (*Larus hyperboreus*) and northern fulmar (*Fulmarus glacialis*). These species represent different trophic levels (TL 2-4) in the marine pelagic ecosystem of Kongsfjorden, Svalbard, from the herbivorous zooplankton *Calanus hyperboreus* to the top predator glaucous gull (Table 2). This was used to calculate the rate of biomagnification and trophic magnification factors in the food web. Mercury data from the 1990s, from the same area, were also compared to data obtained in the present study.

2. Materials and Methods

2.1 Sampling procedures

All sampling was performed in Kongsfjorden in the Svalbard archipelago (Figure 1) during summer 2005 and spring/summer 2006. Glaucous gull (n = 10), northern fulmar (n = 10), black-legged kittiwake (n = 10), Brünnich's guillemot (n = 10) and little auk (n = 11) were shot opportunistically using stainless steel ammunition. Polar cod (n = 10), herring (n = 10) and capelin (n = 10) were sampled using a Campelen 1800 bottom trawl. The zooplankton species *Meganychtiphanes norvegica*, *Thysanoessa inermis*, *Themisto libellula* and *Calanus hyperboreus* were sampled with Methode Isaac Kid (MIK) net and WP-3 net. Prior to analyses, all samples were wrapped in aluminium foil and stored at minimum -20^{o}C. The seabirds were weighed, sexed and size measured (wing, bill, head, tars), while fish were weighed and length measured. Muscle and liver were sampled from all seabirds, polar cod and herring. Capelin and zooplankton were homogenised before analysis.

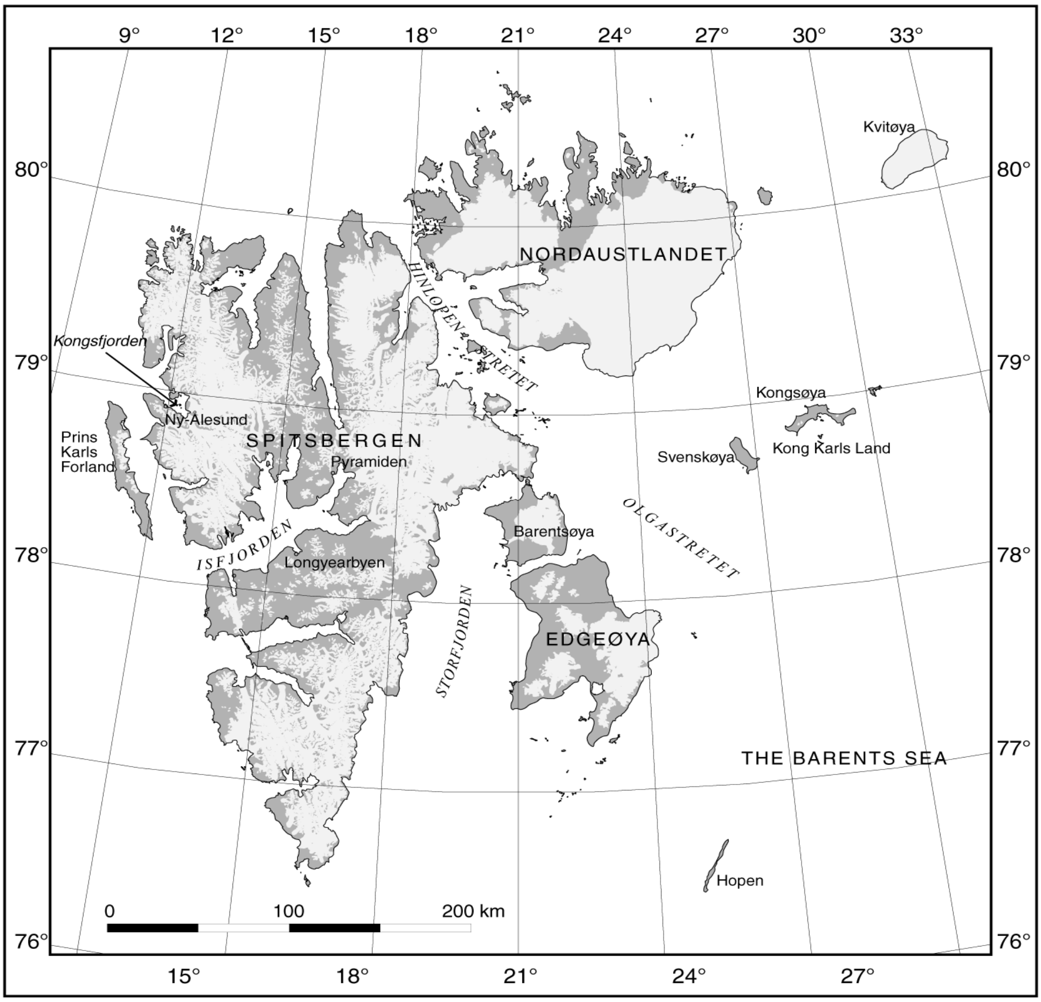


Figure 1: Map of Svalbard with the sampling site, Kongsfjorden.

2.2 Analyses

TotHg was determined in muscle and liver from all seabirds and polar cod, in muscle samples from herring, homogenized capelin and pooled samples of whole specimens of *Themisto libellula*, *Meganyctiphanes norvegica*, *Thysanoessa inermis* and *Calanus hyperboreus*. MeHg levels were determined in liver samples from all seabirds, muscle samples from polar cod and pooled samples of whole specimens of *Themisto libellula* and *Calanus hyperboreus*. Muscle samples from all seabirds and fish species, and pooled samples of all zooplankton species were analysed were analysed for $\delta^{15}N$.

2.2.1 Determination of total mercury

Determination of TotHg was performed at the Laboratory of Chemistry at the National Veterinary Institute (Oslo, Norway). The biological samples were digested (EN14084:2003E) by a mixture of nitric acid and hydrogen peroxide in a closed aqueous system in a microwave oven (Ethos Plus Microwave Labstation, Milestone Inc., Bergamo, Italy). After pressure digestion, the biological sample was supplied with stannous chloride ($SnCl_2$) and hydrochloric acid (HCl) to reduce the Hg in the sample to atomic Hg. The formed gaseous Hg was lead through a quartzcell by nitrogen gas (purity 99.99%). The amount of atomic mercury was determined, under steady state conditions, by cold vapour atomic absorption spectrometry (CVAAS) with tin(II)chloride (Merck) reduction at 253.7 nm wavelength with D_2-background correction against an external standard curve using a SpectrAA 600 (Varian SpectrAA 600, Varian Inc., Paolo Alto, CA, USA). The method is described in detail in Sturman (1985).

2.2.2 Quality assurance of mercury determination

Certified reference materials; TORT-2, LUTS-1, DORM-2 (NRC) and BCR 186 (IRMM), were used for comparison in agreement with certified values (Table 1). In addition a reagent blank, quality control (QC) and reslope were used to ensure quality. The laboratory's analytical method (VarianInc.; Sturman 1985; Welz and Sperling 1999) is accredited after NS-EN ISO/IEC 17025 by the Norwegian Accreditation. The laboratory's accredited analytical quality has been approved in several international calibration tests. Detection limits (3 x standard deviation of blank samples) were 0.01mg/kg. The measurement uncertainty is in level 0.01-0.03 mg/kg 60%, in level 0.04-0.29 mg/kg 30% and in level 0.30-24 mg/kg 20% (wet weight).

Table 1: Certified values ± 95% confidence interval and quantified values ± STDV of Hg, for four reference materials. n indicates the number of samples analysed.

Reference materials	n	Certified value (μg g^{-1})	Quantified value (μg g^{-1})
TORT-2	8	0.27 ± 0.06	0.29 ± 0.01
LUTS-1	8	0.0167 ± 0.0022	0.02 ± 0.003
DORM-2	5	4.64 ± 0.26	4.7 ± 0.2
BCR 186	3	1.97 ± 0.04	2.1 ± 0.1

2.2.3 Determination of methyl mercury

Determination of MeHg was conducted by IVL Swedish Environmental Institute AB (Gothenburg, Sweden). The samples were digested by an alkaline methanol solution (KOH-methanol). The sample became ethylated in a closed purge vessel by adding sodium tetraethyl borate ($NaBEt_4$) to generate the volatile derivate, methylethylmercury ($CH_3CH_3CH_2Hg$), from the MeHg present in the sample. The methylethylmercury vaporised from the water solution and became trapped at a graphitic carbon trap (Carbotrap®). In the following step, the trapped methylethylmercury became thermally desorbed from the carbon trap and got carried by an inert gas through a pyrolytic decomposition column where the liberated gasses got separated by isothermal gaschromatography. This decomposition column converted the methylethylmercury pyrolytically to elemental mercury (Hg^0). The elemental mercury is carried into the cell of the cold vapour atomic fluorescence spectrometer (CVAFS) and became detected by the fluorescence detector. The quality of the determination was ensured by calibration and testing of the digestion, ethylation, purging and detection systems.

2.2.4 Analyses of stable isotopes

Analyses of stable isotopes ($\delta^{15}N$) were conducted at the Institute for Energy Technology (Kjeller, Norway). Lipids were removed by Soxhlet extraction with dichloromethane (DCM) added 7% methanol. Traces of carbonates were removed by rinsing with 2 N HCl. The samples were combusted with O_2 and Cr_2O_3 at about 1700 ^oC in a Carlo Erba NCS Elemental Analyser (Carlo Erba Instruments, Milan, Italy). NO_x were reduced with Cu at 650 ^oC. The combustion products N_2, CO_2 and H_2O were separated on a Poraplot Q column and the $^{15}N/^{14}N$ isotope ratio were determined on a Micromass Optima Isotope Ratio Mass Spectrometer (IRMS) (Micromass, Manchester, UK). A detailed description of the method is given in Søreide et al. (2006). International standards (IAEA-N-1 and 2) are run for each 10 samples.

Enrichment of the stable isotope is expressed as

$$\delta^{15}N = (R_{sample} / R_{standard}) \times 1000$$

where $\delta^{15}N$ is expressed in (‰), R is the corresponding ratio of $^{15}N/^{14}N$ related to the $R_{standard}$ values based on international standards.

2.2.5 Trophic level and biomagnification calculations

Calanus copepods are assumed to represent the primary herbivores at the trophic level TL = 2. For the individual samples of the species investigated, modified relationship by Fisk et al. (2001):

$$TL_{consumer} = 2 + ((\delta^{15}N_{consumer} - \delta^{15}N_{Calanus}) / 3.4)$$

where $TL_{consumer}$ is the trophic level of an organism. For $\delta^{15}N_{Calanus}$ a mean (7.3) calculated from spring values in Søreide et al. (2006) was used. The trophic enrichment factor used is 3.4, determined for the Barents Sea region (Søreide et al. 2006). $\delta^{15}N$ values from *Calanus hyperboreus* sampled for this study were abnormally low (4.6 ± 0.2), and accordingly not used for trophic level calculations. For seabirds, a diet-tissue isotopic enrichment factor of 2.4 ‰ were used according to Hobson et al. (2002). The trophic level calculation was then modified by the relationship

$TL_{seabird} = TL_{consumer} + 1$ and

$\delta^{15}N_{seabird} = \delta^{15}N_{consumer} + 2.4$,

given that the trophic level of a seabird prey is $TL_{consumer}$, to modify the first equation according to (Hop et al. 2002) to:

$TL_{seabird} = 3 + ((\delta^{15}N_{seabird} - 9.7) / 3.4)$

The ability of a contaminant to biomagnify can be expressed in the terms of biomagnification factors (BMFs) or trophic magnification factors (TMFs), where BMF and TMF values > 1 indicate biomagnification. The BMF calculations are based on predator-prey relationship from the literature, and corrected to unity for trophic level differences since the trophic level of the predator in most cases is not a full trophic level above its prey (Hop et al. 2002).

The biomagnification of a contaminant can be expressed as a biomagnification factor (BMF) calculated as:

$$BMF = ([CONT_{predator}]/[CONT_{prey}]) / (TL_{predator} - TL_{prey}) \qquad (8)$$

where $[CONT_{predator}]$ and $[CONT_{prey}]$ are the concentration of mercury in the predator and prey respectively (Hop et al. 2002). Mean mercury level (µg g^{-1} ww) and mean trophic level (as quantified by $\delta^{15}N$) were applied in the BMF calculations.

Trophic magnification factors (TMFs) are based on the trophic level parameter in the linear regression model. It is derived from the slope of the linear relationship between contaminant concentrations and trophic level as shown by the equations:

$$TMF = 10^{bTL} \qquad (9)$$

$$\log [\text{Contaminant}] = a + bTL + e \qquad (10)$$

where a is the intercept, b is the slope and e is the error estimate. The trophic magnification factor provides the mean rate of increase per trophic level in the food chain and assumes that uptake from the diet is the main exposure route (Hop et al. 2002).

2.3 Statistical analyses

Analysis of variance (ANOVA) and Tukey's honestly significant difference test (Tukey's HSD) were conducted in order to analyze for differences in respectively TotHg, MeHg and trophic levels between species. In order to analyse for differences in contaminant levels between sexes when taking into account the species, the interaction term sex x species was included in the models. No differences between sexes were found in mercury levels in neither muscle nor liver when taking into account the seabird species. Accordingly, both sexes were treated as one group. It was not tested for between-year variation in seabirds due to low and varying sample size in the two sampling years, and the birds were accordingly treated as one group. Linear regression model was used to test the relationship between muscle and liver concentrations of TotHg. In addition, it was used to explore the possible effect of trophic level on mercury concentrations. Diagnostic plots were visually inspected to assess normality and homogeneity of variance assumptions in all models, and the data was log transformed in accordance to this. Exploratory and univariate statistics were computed in R 2.4.1 for Windows. Statistical significance level was set to $\alpha = 0.05$. All results are reported on a wet weight basis. To compare results with earlier studies giving mercury concentrations on a dry weight basis, conversion-factors from Dietz et al. (1996) were used.

3. Results and Discussion

3.1 TotHg concentration in lower trophic level species

Capelin and the zooplankton species *Meganychtiphanes norvegica*, *Thysanoessa inermis*, *Themisto libellula* and *Calanus hyperboreus* all had non-detectable levels of TotHg (Table 2). The concentrations of TotHg in zooplankton from previous studies in the Arctic (0.006 – 0.25 µg g-1 ww; Campbell et al. 2005) are comparable to the present study's detection limit. TotHg levels in zooplankton from the Barents Sea (median 0.09 – 0.12 µg g^{-1} dw) have earlier been found to be two times lower than e.g. levels in zooplankton from the North Sea (mean 0.32 µg g-1 dw; Joiris et al. 1997). Polar cod and herring did not differ in TotHg concentration in muscle and had lower concentrations than the seabirds. Polar cod concentrations were generally somewhat lower than found in Greenland (Dietz et al. 1996) and the Canadian Arctic (Atwell et al. 1998; Campbell et al. 2005). Only one polar cod liver sample was above the detection limit and supports the general trend of lower mercury concentrations in liver than muscle of fish.

3.2 TotHg concentration in seabird muscle

In muscle samples analysed for TotHg, glaucous gull had the highest mean concentrations of TotHg (0.32±0.06 µg g^{-1} wet weight, table 2) followed by black-legged kittiwake > northern fulmar > Brünnich's guillemot > little auk > polar cod > herring (Table 2).

Species differed significantly with regard to TotHg in muscle (ANOVA, $F_{6, 64} = 99.906$, $p<0.001$). Significant differences were found in all pairwise species comparisons derived from Tukey's honestly significant difference (Tukey's HSD, $p<0.05$) test, except between the following pairs: polar cod and herring, little auk and Brünnich's guillemot, northern fulmar and black-legged kittiwake, northern fulmar and glaucous gull, black-legged kittiwake and glaucous gull.

Little auk displayed the lowest TotHg concentration in muscle among the birds analysed. The levels are in line with findings from Franz Josef Land (0.03-0.09 µg g^{-1} ww) in the early nineties (Savinov et al. 2003). Higher TotHg-concentrations in liver have been found in central East Greenland (Dietz et al. 1996) and in Baffin Bay, Canadian Arctic (Campbell et al. 2005).

The mean concentrations found in muscle of Brünnich's guillemot (Table 2) are lower than both those reported from Baffin Bay (Campbell et al. 2005), Northwest Greenland (Dietz et al. 1996) and Lancaster Sound (Atwell et al. 1998), as well as off the coast of Spitsbergen in the 1980s (Norheim and Kjos-Hanssen 1984). Similar concentrations, although somewhat higher (0.167 µg g^{-1} ww), were found in muscle samples from Ny-Ålesund (Kongsfjorden) in 1991 (Savinov et al. 2003).

Black-legged kittiwake had, according to Tukey's HSD test ($p<0.05$), muscle concentration similar to both northern fulmar and glaucous gull. Studies from Baffin Bay (Campbell et al. 2005), Northwest Greenland (Dietz et al. 1996) and Lancaster Sound (Atwell et al. 1998) have reported mercury concentrations in muscle (0.25 – 0.54 µg g^{-1} ww) higher than or similar to those reported in the present study.

Table 2: Concentrations in µg g^{-1} wet weight of TotHg and MeHg (mean ± SE, range, median) for liver and muscle of five seabird species and polar cod, and TotHg in muscle of herring and whole samples of capelin and the four zooplankton species. MeHg concentrations were derived from pooled samples of *T. libellula* and *C. hyperboreus*. Mean and median concentrations are only given where ≥40% of the samples had mercury levels above detection limit, n is number of samples above detection limit relative to samples analysed, and - denotes not measured. MeHg level in liver is given with three decimals due to its detection limit.

Total Hg Muscle				
Species	n	Mean±SE	Range	Median
Glaucous gull	10/10	0.32 ± 0.06	0.15 - 0.66	0.28
Northern fulmar	10/10	0.21 ± 0.02	0.13 - 0.33	0.22
Black-legged kittiwake	10/10	0.22 ± 0.02	0.15 - 0.29	0.22
Brünnich's guillemot	10/10	0.11 ± 0.01	0.06 - 0.20	0.11
Little auk	11/11	0.06 ± 0.01	0.01 - 0.11	0.06
Polar cod	4/10	0.01± 0.00	n.d. - 0.02	0.01
Herring	7/10	0.01± 0.00	n.d. - 0.02	0.01
Capelin	0/10	n.d.	n.d.	n.d.
Meganyctiphanes norvegica	0/1	n.d.	n.d.	n.d.
Thysanoessa inermis	0/1	n.d.	n.d.	n.d.
Themisto libellula	0/1	n.d.	n.d.	n.d.
Calanus hyperboreus	0/1	n.d.	n.d.	n.d.
Total Hg Liver				
Species	n	Mean±SE	Range	Median
Glaucous gull	10/10	1.17 ± 0.16	0.40 - 2.00	1.04
Northern fulmar	10/10	2.57 ± 0.17	1.64 - 3.36	2.54
Black-legged kittiwake	10/10	0.94 ± 0.08	0.53 - 1.35	0.97
Brünnich's guillemot	10/10	0.37 ± 0.04	0.26 - 0.62	0.34
Little auk	11/11	0.26 ± 0.04	0.02 - 0.51	0.22
Polar cod	1/10	-	n.d. - 0.01	-
MeHg Liver				
Species	n	Mean±SE	Range	Median
Glaucous gull	10/10	0.737 ± 0.109	0.340 - 1.300	0.660
Northern fulmar	10/10	0.832 ± 0.102	0.450 - 1.600	0.805
Black-legged kittiwake	10/10	0.675 ± 0.055	0.420 - 0.900	0.580
Brünnich's guillemot	10/10	0.303 ± 0.026	0.200 - 0.480	0.290
Little auk	11/11	0.229 ± 0.033	0.023 - 0.380	0.210
Polar cod (muscle)	10/10	0.009 ± 0.004	0.004 - 0.017	0.014
Themisto libellula	0/1	n.d.	n.d.	n.d.
Calanus hyperboreus	0/1	n.d.	n.d.	n.d.

Contrary to this, concentrations in adult black-legged kittiwake reported from Hornøya, in the south-western Barents Sea, were lower (0.16 µg g^{-1} ww; Wenzel and Gabrielsen 1995) than the TotHg concentrations in muscle of black-legged kittiwake from the present study. Compared to earlier reported concentrations in muscle (0.12 µg g^{-1} ww) from the Barents Sea (Savinov et al. 2003), concentrations in muscle of black-legged kittiwakes from Kongsfjorden in the present study were higher. However this can be a result of natural variation based on the data available for comparison. Muscle and liver values in glaucous gull reported from Greenland and the

Canadian Arctic are above the concentrations detected in this study (Dietz et al. 1996; Campbell et al. 2005; Borgå et al. 2006). However, concentrations in glaucous gull from the present study were higher than what has been reported from Kongsfjorden earlier (0.20 µg g^{-1} ww; Savinov et al. 2003). Muscle concentrations of mercury in northern fulmar were comparable to those found in other studies in the Arctic (Dietz et al. 1996; Atwell et al. 1998; Savinov et al. 2003).

3.3 TotHg concentrations in liver

The highest TotHg concentrations were found in liver of northern fulmar and decreased in the order of glaucous gull > black-legged kittiwake > Brünnich's guillemot > little auk. Only one sample of polar cod was above detection limit (Table 2). Mercury concentrations were typically higher in liver than in muscle for seabirds. Nevertheless, a positive linear relationship was established between muscle and liver TotHg-concentrations in seabirds (Slope = 0.631, adjusted $r^2 = 0.713$, $F_{1, 49} = 125.3$, $p<0.001$). Highest overall mean concentration of TotHg was found in liver of northern fulmar followed by liver of glaucous gull (Figure 2). Species also differed in liver TotHg-concentrations (ANOVA, $F_{4, 46} = 43.151$, $p<0.001$). All species comparisons were significantly different, according to Tukey's HSD test, except between little auk and Brünnich's guillemot, black-legged kittiwake and glaucous gull. TotHg concentrations in liver did not differ significantly between little auk and Brünnich's guillemot; although the mean concentration in little auk was lower (Table 2). Little auks caught off the west coast of Spitsbergen in the late 1970s had a mean TotHg concentration in liver of 0.5 µg g^{-1} ww (Norheim and Kjos-Hanssen 1984), and similar values were found in central East Greenland (Dietz et al. 1996). Liver TotHg-concentrations in little auks from Franz Josef Land were lower (mean 0.07 - 0.15 µg g^{-1} ww; Savinov et al. 2003) than the present levels from Kongsfjorden.

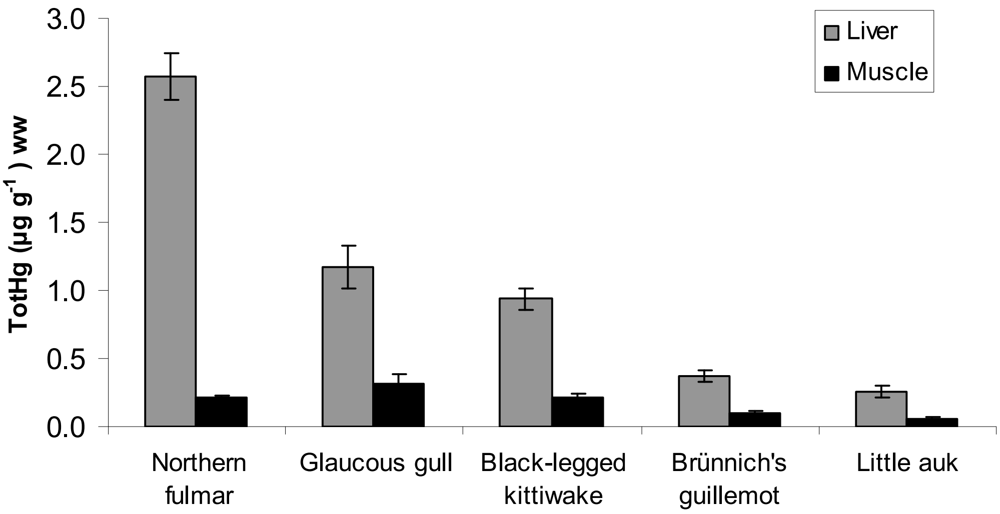


Figure 1: Mean concentrations (µg g^{-1} wet weight) of total mercury (TotHg) levels in liver and muscle from northern fulmar, glaucous gull, black-legged kittiwake, Brünnich's guillemot and little auk. Error bars are ± standard error (SE).

Similar to muscle TotHg-concentrations, the liver TotHg-concentrations of Brünnich's guillemot were lower in the present study than in studies from Baffin Bay (Campbell et al. 2005), north western Greenland (Dietz et al. 1996) and off the coast of Spitsbergen (Norheim and Kjos-Hanssen 1984). Brünnich's guillemot sampled in Kongsfjorden in the early 1990s had liver concentrations of TotHg comparable to, although somewhat higher than the concentrations found in the present study (0.479 µg g^{-1} ww; Savinov et al. 2003).

Black-legged kittiwake did not differ significantly from glaucous gull in liver TotHg-concentrations. Altough, black-legged kittiwake had a lower mean level than glaucous gull. Previously reported levels from Kongsfjorden (0.58 µg g^{-1} ww; Savinov et al. 2003), are lower than liver TotHg-concentrations found in black-legged kittiwake in the present study. As for muscle, liver TotHg-concentrations in black-legged kittiwake are generally lower than TotHg-concentrations in liver (0.97 – 1.05 µg g^{-1} ww) reported from Canadian and Greenland Arctic areas (Dietz et al. 1996; Campbell et al. 2005).

TotHg-concentrations in liver of glaucous gull reported from Greenland and the Canadian Arctic are above the concentrations detected in this study (Dietz et al. 1996; Campbell et al. 2005; Borgå et al. 2006). Glaucous gull caught off the west coast of Spitsbergen in 1980s were found to have a mean level of 1.6 µg g^{-1} ww in liver (Norheim and Kjos-Hanssen 1984). In contrast, liver TotHg-concentrations in the present study was notably higher than what has been reported from Kongsfjorden earlier (0.46 µg g^{-1} ww; Savinov et al. 2003).

Northern fulmar had the highest concentration of TotHg in liver among the species in the present study (Figure 2), although these levels were intermediate with regards to other Arctic areas (Dietz et al. 1996; Campbell et al. 2005; Knudsen et al. 2007). Liver TotHg-concentrations reported earlier from Kongsfjorden were lower (1.7 µg g^{-1} ww; Savinov et al. 2003) than those reported here (Table 2).

None of the bird species in the present study displayed significant differences in mercury levels between females and males. However, significant differences in muscle load of mercury between male and female of black-legged kittiwake have been found (Savinov et al. 2000) and significant differences in liver have been found for males and females of common eider (*Somateria mollissima*) (Nielsen and Dietz 1989). Other studies have revealed no contaminant load differences between sexes in Arctic seabirds (Borgå et al. 2006).

Linear regressions were conducted in order to test the relationship between different size measurements (weight, wing, bill, head, tarsus and caudal length) and mercury concentrations in the tissues. There was for most of the bird and fish species found no correlation between size measurements and mercury levels. Mercury has been found to increase with size or age in fish (Riget et al. 2000). The positive correlation between weight and wing length and mercury in little auks indicates higher levels in larger individuals of the species. The opposite was the case for northern fulmars where wing and tarsus length were negatively correlated to TotHg concentration in muscle. In addition, wing length was negatively correlated to muscle TotHg-concentrations in black-legged kittiwakes.

Thus, the mercury levels revealed in the present study are generally lower than mercury levels reported in biota from other Arctic areas such as the Canadian Arctic and Greenland (e.g. Dietz et al. 1996; Campbell et al. 2005; Borgå et al. 2006). Levels earlier reported from Kongsfjorden are generally comparable to the levels found in the present study (Savinov et al. 2003).

3.4 Concentrations and contribution of MeHg

The mean concentration of MeHg in liver was highest in northern fulmar followed by glaucous gull > black-legged kittiwake > Brünnich's guillemot > little auk > polar cod (Table 2). MeHg concentrations in *Themisto libellula* and *Calanus hyperboreus* were below detection limit (<0.0015 µg g^{-1} wet weight) (Table 2). Species differed significantly in MeHg levels (ANOVA, $F_{5, 55} = 134.6$, $p<0.001$), except for little auk and Brünnich's guillemot; black-legged kittiwake, glaucous gull and northern fulmar (Appendix C).

No detectable levels of MeHg were found when analysing *C. hyperboreus* and *T. libellula*. MeHg levels in *C. hyperboreus* and *T. libellula* from the Canadian Arctic have been reported to be 0.001 µg g^{-1} ww and 0.007 µg g^{-1} ww, respectively (Campbell et al. 2005).

The concentration of organic mercury in muscle relative to both diet and sea water can be high in fish (Riisgard and Hansen 1990). MeHg concentration in muscle of polar cod (Table 2) were comparable to levels found in whole specimens of polar cod (0.008 µg g^{-1} ww) in the Canadian Arctic (Campbell et al. 2005). Not surprisingly, it was lower in MeHg concentration than all the bird species. Although it should be noted that MeHg was measured in polar cod muscle.

As for TotHg level, MeHg levels between little auk and Brünnich's guillemot did not differ significantly according to Tukey's HSD test. Again, little auk had lower mean level of MeHg than Brünnich's guillemot. This is in line with their similar feeding ecology as well as the fact that the little auk is more of a planktonic feeder. Few studies from the Arctic have reported on MeHg levels in liver of seabirds. MeHg levels from 0.105 to 1.458 µg g^{-1} ww were reported in birds from Greenland (Dietz et al. 1990), where little auk displayed the lowest level. The three gull species did not differ in MeHg levels. Northern fulmar, however, had highest mean MeHg and black-legged kittiwake the lowest. Concentrations of MeHg in liver of glaucous gull and northern fulmar from Greenland were similar to the levels found in the present study (Dietz et al. 1990). Contrary to this, organic mercury in black-legged kittiwake was lower (0.311 µg g^{-1} ww; Dietz et al. 1990) than found in the present study from Kongsfjorden. However it should be noted that the values from Dietz et al. (1990) are based on only one individual per species.

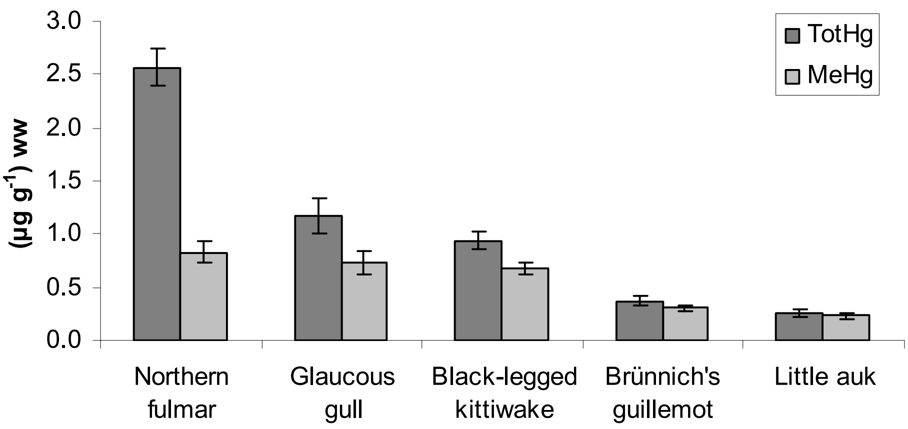


Figure 2: Mean concentrations (µg g^{-1} wet weight) of total mercury (TotHg) and methyl mercury (MeHg) in liver from northern fulmar, glaucous gull, black-legged kittiwake, Brünnich's guillemot and little auk. Error bars are ± standard error (SE).

3.5 Proportion of MeHg

The MeHg proportion differed among species (ANOVA, $F_{4, 46} = 31.944$, $p < 0.001$). In polar cod muscle, virtually all mercury was present in the methylated form. The high proportion of MeHg is typical for fish in general (Bloom 1992) and for polar cod in particular (Campbell et al. 2005). The proportion of MeHg did not differ between little auk and Brünnich's guillemot. These two auk species had both low TotHg levels and accordingly the proportion of MeHg in the liver was high in both species (89.5% and 81.2%, respectively) (Figure 4). Little auk had the lowest TotHg level among the seabirds but the highest proportion of MeHg (89.5%). Black-legged kittiwake had a higher level of TotHg than Brünnich's guillemot and little auk. It had a lower proportion of MeHg (71.9%; Figure 4) although not significantly different from Brünnich's guillemot. Glaucous gull had an intermediate proportion of MeHg (62.9%; Figure 4) and a relatively high level of TotHg in the liver. The general trend was decreasing proportions of MeHg with increasing levels of TotHg measured in the tissue. A similar trend has been found in other seabirds (Norheim et al. 1982; Thompson and Furness 1989; Kim et al. 1996).

When comparing the liver MeHg proportions in this study with studies reporting MeHg relative to TotHg concentrations in muscle, a similar relationship occurs for most seabirds (Campbell et al. 2005). The northern fulmar, however, represents a special case, as it differed significantly from all other seabirds in this study with regards to MeHg proportion. While Campbell et al. (2005) found a proportion of 81.3% MeHg in muscle of northern fulmar, this study revealed a proportion of 32.4% in liver tissue (Figure 4). Long lived seabird species with relatively low moulting rate have been proposed to use demethylation to a larger extent than birds with higher moulting rate (Thompson and Furness 1989). MeHg levels in Arctic seabirds have not been previously reported from the Barents Sea area. The overall relatively high level of MeHg compared to TotHg in tissues, is similar to other studies reporting MeHg levels in Arctic seabirds (Dietz et al. 1990; Campbell et al. 2005).

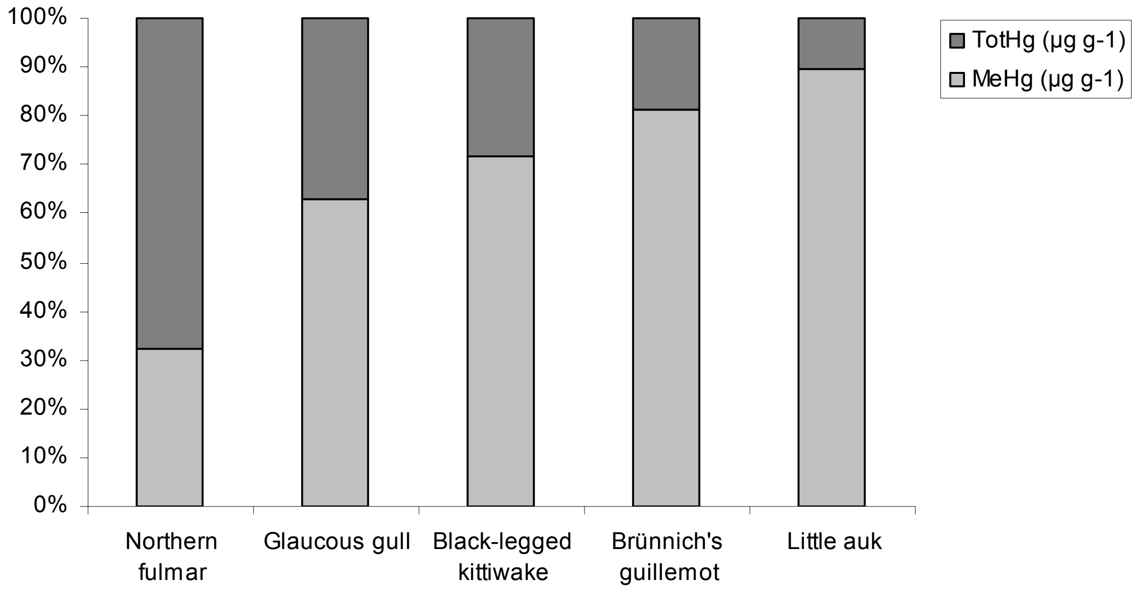


Figure 3: Methyl mercury in % of TotHg in liver from northern fulmar, glaucous gull, black-legged kittiwake, Brünnich's guillemot and little auk.

3.6 Mercury concentration related to trophic level

3.6.1 Stable isotopes of nitrogen and trophic level

A wide range of $\delta^{15}N$ was found in the investigated species (3.9 - 15.4‰) (Table 3). The $\delta^{15}N$ measurements illustrate the continuous enrichment of the heavier stable isotope ^{15}N through the food web from the herbivorous *C. hyperboreus* to the avian predator glaucous gull. With trophic level 2 set for *Calanus* spp., the trophic positions calculated for this study ranged from 1.00 to 4.68 (Table 3). There was a significant difference in TL between species (ANOVA, $F_{12,\ 78}$ = 144.69, $p<0.001$).

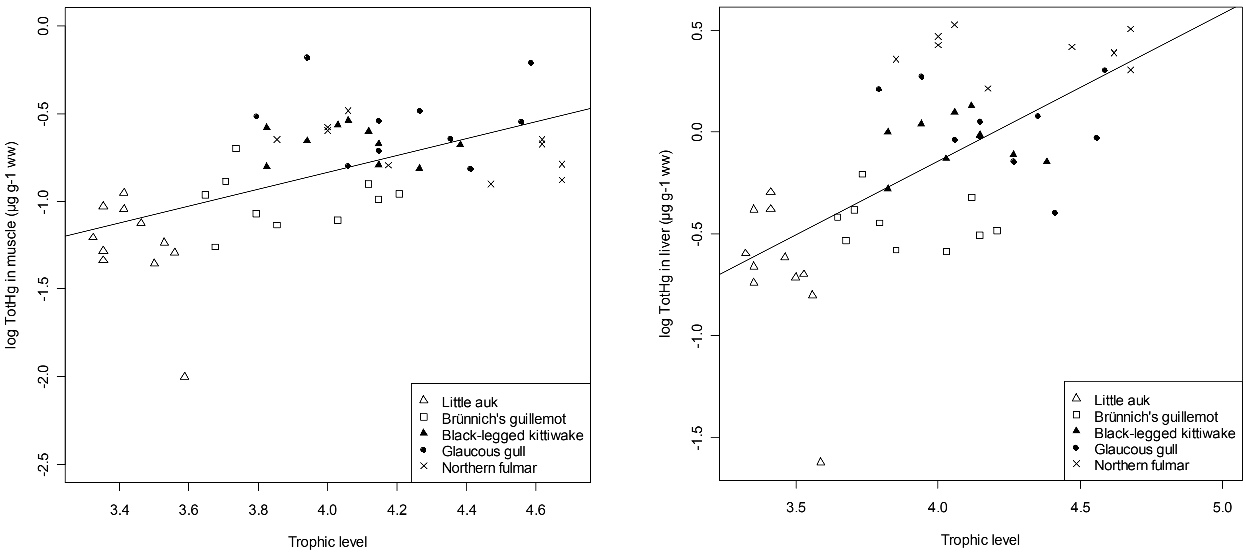
Table 2: Stable isotopes of nitrogen ($\delta^{15}N$) and trophic level (TL) calculated from $\delta^{15}N$ values, given as mean ± SE, range and median for all species analysed.

		$\delta^{15}N$		
Species	n	Mean ± SE	Range	Median
Northern fulmar	10	14.2 ± 0.4	12.6 - 15.4	14.2
Glaucous gull	10	13.9 ± 0.3	12.4 - 15.1	13.8
Black-legged kittiwake	10	13.4 ± 0.2	12.5 - 14.4	13.4
Brünnich's guillemot	10	12.7 ± 0.2	11.9 - 13.8	12.5
Little auk	11	11.2 ± 0.1	10.8 - 11.7	11.1
Herring	4	14.2 ± 1.0	12.6 - 18.2	13.6
Polar cod	5	13.5 ± 0.4	12.2 - 14.4	13.7
Capelin	6	12.8 ± 0.3	12.0 - 13.9	12.7
Thysanoessa inermis	5	9.4 ± 0.3	8.4 - 9.8	9.7
Meganychtiphanes norvegica	4	9.1 ± 0.3	8.6 - 10.0	8.8
Themisto libellula	7	8.3 ± 0.1	7.9 - 9.1	8.2
Calanus spp.	3	7.3 ± 0.1	7.1 - 7.5	7.4
Calanus hyperboreus	6	4.6 ± 0.3	3.9 - 5.4	4.55

		TL		
	n	Mean ± SE	Range	Median
Northern fulmar	10	4.31 ± 0.10	3.85 - 4.68	4.32
Glaucous gull	10	4.23 ± 0.08	3.79 - 4.59	4.21
Black-legged kittiwake	10	4.07 ± 0.06	3.82 - 4.38	4.09
Brünnich's guillemot	10	3.89 ± 0.07	3.65 - 4.21	3.82
Little auk	11	3.44 ± 0.03	3.32 - 3.58	3.41
Herring	4	3.73 ± 0.08	3.56 - 3.88	3.75
Polar cod	5	3.82 ± 0.11	3.44 - 4.09	3.88
Capelin	6	3.62 ± 0.08	3.38 - 3.94	3.58
Thysanoessa inermis	5	2.61 ± 0.08	2.32 - 2.74	2.71
Meganychtiphanes norvegica	4	2.51 ± 0.09	2.38 - 2.79	2.44
Themisto libellula	7	2.29 ± 0.04	2.18 - 2.53	2.26
Calanus spp.	3	2.01 ± 0.04	1.94 - 2.06	2.03
Calanus hyperboreus	6	1.2 ± 0.1	1.0 - 1.4	1.2

3.6.2 Trophic transfer of mercury

Mercury concentration did not correlate with trophic level within species. Contrary to this, TotHg concentration in muscle and trophic level were significantly positively correlated considering all birds (slope = 0.480, adjusted r^2 = 0.316, $F_{1, 49}$ = 24.05, p<0.001: Fig. 5), indicating that TotHg in muscle tissue biomagnifies with trophic level. TotHg in seabird livers and trophic level were also positively correlated (slope = 0.723, adjusted r^2 = 0.403, $F_{1, 49}$ = 34.69, p< 0.001: Fig. 5). Additionally, MeHg concentration in liver of seabirds was positively correlated to trophic level (slope = 0.471, adjusted r^2 = 0.318, $F_{1, 49}$ = 24.31, p< 0.001: Fig. 5). Mercury has been shown to increase with trophic position in a wide range of food webs (Atwell et al. 1998; Campbell et al. 2005).



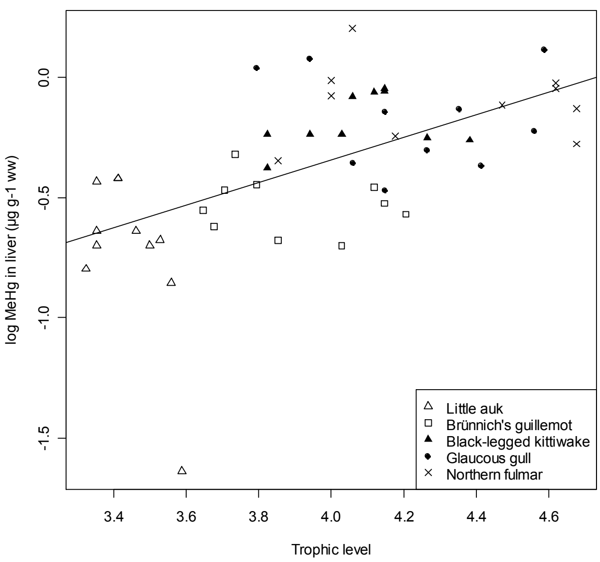


Figure 5: Regression relationship between respectively total mercury (TotHg) concentration in muscle, TotHg in liver, methyl mercury (MeHg) and trophic level for a part of the marine food web in Kongsfjorden, Svalbard consisting of northern fulmar, glaucous gull, black-legged kittiwake, Brünnich's guillemot and little auk. All mercury values were log-transformed. Solid line indicates the regression line.

The positive linear relationships between mercury in muscle of seabird and trophic levels are a sign of biomagnification of mercury in the food web. However, due to the non-detectable mercury levels in many of the lower trophic species, only a limited picture can be given. The seabird with the lowest trophic level, little auk, had accordingly the lowest measurable levels of both TotHg in muscle and liver as well as MeHg in liver. The Brünnich's guillemot, which in accordance with its diet is at a higher trophic level than the above mentioned auk, also has higher both TotHg and MeHg levels. The gulls, black-legged kittiwake and glaucous gull did not differ neither in trophic position nor mercury levels according to the Tukey's HSD tests. Again, the glaucous gull which has a mean trophic level higher than the black-legged kittiwake also had mean levels of both TotHg and MeHg higher than this species. This reflects the feeding strategy of glaucous gull, known as a generalist in addition to its ecological function as a bird of prey (Anker-Nilssen et al. 2000). The northern fulmar with a trophic level similar to the above mentioned gulls displayed the highest total and MeHg levels in liver in the current study. However, glaucous gull had higher TotHg-concentrations in muscle than the northern fulmar.

Although, MeHg is considered the main biomagnifying agent of mercury, the slope derived from liver MeHg was lower than that of TotHg in liver. This might be linked to the birds' ability to demethylate mercury in the liver and hence accumulate inorganic mercury in the liver.

3.6.3 Biomagnification of mercury

As no zooplankton had detectable levels of mercury, biomagnification calculations could only be performed on fish and birds. Biomagnification factors were based on predator-prey relationships inferred from literature. Highest BMF's were found in TotHg and MeHg in liver. All predator-prey relationships had BMF > 1, indicating biomagnification in all predator – prey relationships.

Biomagnification factors (BMFs) from this study, calculated by presumed predator-prey relationships, are summarized in Table 4. BMF calculated from the predator-prey relationship between concentrations of TotHg in liver of ringed seal (*Phoca hispida*) and TotHg levels in whole polar cod has been found to be 381 in Alaskan areas (Dehn et al. 2006). In the same study, the relationship between polar cod and zooplankton was found to be 3.3. BMFs calculated in this study are highest between the seabirds and fish in TotHg level in liver. These values might be somewhat misleading. Seabirds accumulate highest mercury levels in liver (Dietz et al. 1996), while many marine fishes tend to accumulate most of their mercury burden in muscle tissue (AMAP 2005). In addition, liver tissue represents very little of the total body mass of the fish. Thus, the BMFs calculated for MeHg in liver tissue of seabirds and muscle tissue of fish might be more representative for the actual biomagnification of mercury between fish and seabird species. The trophic magnification factors (TMFs) represent an average rate of mercury increase over multiple trophic levels in the food web, whereas BMFs only show the increase from prey to predator, corrected for trophic level ratio differences, and thereby only involves two trophic levels. Additionally, BMFs assume a complete consumption of the prey by the predator and, unless based on a mixed diet, and thus assume a simple predator-prey relationship. TMFs might be advantageous when comparing the degree of biomagnification between different food webs and ecosystems.

Figure 4: Biomagnification factors (BMF) for selected species from the Barents Sea food web, Kongsfjorden.

Predator	Glaucous gull					Northern fulmar		Black-legged kittiwake		Brünnich's guillemot	
Prey	Black-legged kittiwake	Brünnich's guillemot	Little auk	Polar cod	Herring	Polar cod	Herring	Polar cod	Herring	Polar cod	Herring
TotHg (muscle)	9.1	8.8	6.4	54.6	45.2	29.8	25.4	61.5	45.7	107.3	47.4
TotHg (liver)	7.8	9.2	5.8	285.9	-*	523.9	-	375.6	-	532.9	-
MeHg (liver)	6.8	7.2	4.1	191.2	-	180.6	-	287.2	-	460.5	-

* denotes not analysed

The trophic magnification factors (TMFs) for TotHg were 3.02 and 5.28 derived from regressions in seabird muscle and liver respectively. The TMFs derived from MeHg in seabird liver was calculated to 2.96. This reveals that mercury biomagnifies through the trophic levels in the food chain. TMFs when including both seabird and fish were; for TotHg in muscle 4.87; for TotHg in liver 5.29 and for MeHg in liver 4.26.

The slopes obtained regarding only seabirds are somewhat lower than slopes observed for whole food webs (Atwell et al. 1998; Power et al. 2002; Campbell et al. 2005). This difference is influenced by the differences in poikilotherm and homeotherm physiology. While poikilotherm species can be at a trophic level similar to homeotherm species, their physiology and energy demands are lower. The biomagnification of mercury will thus be lower if only considering poikilotherm species.

All together BMFs, TMFs provide evidence for biomagnification of mercury with trophic level in the Barents Sea food web.

3.7 Toxicological evaluation

Despite relatively high amounts of data available on tissue concentrations of heavy metals in Arctic biota, there are few reports available on toxic effects of heavy metals in relation to actual tissue concentrations. Seabird species at high trophic level are most at risk from organic and metal contamination exposure, although there is generally little evidence of toxicological effects in Arctic seabird species (Fisk et al. 2005). Threshold toxicity data can be used to identify levels of exposure that can be expected to result in biotic effects although not as evidence of toxic effects. Extrapolating toxicity threshold data across species and from non-Arctic species to Arctic species living under different environmental conditions introduces further uncertainties. Based on the guidelines of toxicity thresholds from Arctic Monitoring and Assessment Programme (AMAP) (Derome et al. 2005), none of the seabird species from Kongsfjorden, Barents Sea displayed hepatic mercury levels above threshold levels for biological effects in birds (Thompson 1996). Seabirds are known to tolerate higher mercury levels than terrestrial birds, and consequently tissue threshold levels are an order of magnitude higher for seabirds (Thompson 1996). Regarding mercury levels in fish species considered in the present study, they were also below toxicity thresholds summarised in Derome et al. (2005) based on (Wiener and Spry 1996).

4. Conclusions

Levels of both TotHg and MeHg were too low in zooplankton to be detected, whereas significant amounts were found in fish and seabirds. Levels of TotHg in muscle were highest in glaucous gull followed by black-legged kittiwake and northern fulmar. TotHg levels in liver were highest in northern fulmar followed by glaucous gull and black-legged kittiwake. MeHg levels in liver were highest in northern fulmar followed by glaucous gull and black-legged kittiwake. Little auk and Brünnich's guillemot had the lowest levels of both TotHg and MeHg in muscle and liver. In addition, the proportions of MeHg to TotHg in the liver of seabird species indicate differences in the accumulation and ability to demethylate mercury between the species. Northern fulmar has a lower proportion of MeHg than the glaucous gull. This indicates that the northern fulmar is better adapted to demethylate MeHg than the glaucous gull, which has a similar TotHg concentration in liver.

The present study describes the Arctic marine species trophic position quantitatively on a continuous scale. Subsequently, this allowed for a more detailed account of the relationship between mercury, the species and their trophic position. The present study reveals a pattern of biomagnification of TotHg with trophic level in species from Kongsfjorden, Svalbard, where MeHg is the main biomagnifying agent.

Present mercury levels detected in species from this study were generally low and are below what is thought to cause toxic effects. Although, due to the toxicity and potential of biomagnification, it is important to include levels of MeHg when monitoring mercury levels in the marine food web. Due especially to increasing release of mercury by anthropogenic sources in south-east Asia, there seem to be no evident reduction in emission on a global scale. As the Arctic is considered as an important sink for mercury depletion, it further provides a reason for monitoring the future levels of mercury in biota from the Arctic. However, there seem to be no significant changes in mercury levels in marine species from the Barents Sea area. In concert with this, it would be advisable to continue monitoring mercury levels in the Barents Sea area.

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Tittel - norsk og engelsk

Kivkksølv i eit Arktisk marint næringsnett
Mercury levels in an Arctic marine food web

Samandrag – summary
Tolv ulike artar frå det marine næringsnettet i Kongsfjorden, Svalbard, vart samla inn og analysert for total kvikksølv, metylkvikksølv og stabile nitrogen isotopar. Både total kvikksølv og metylkvikksølv vert biomagnifisert i dette næringsnettet. Kvikksølv nivåa i sjøfugl frå Kongsfjorden, Svalbard ser ikkje ut til å vorte endra sidan 1990-talet.

In the present study twelve species from different trophic levels of the marine food web in Kongsfjorden, Svalbard, were sampled and analyzed for total mercury, methyl mercury and stable isotopes of nitrogen. Both total mercury and methyl mercury were found to biomagnify. Mercury levels in seabirds from Kongsfjorden did not show any obvious change since the 1990s.

4 emneord	4 subject words
Kvikksølv, metylkvikksølv, næringsnett, Svalbard	Mercury, methyl mercury, food web, Svalbard

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Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, vassdrag, fjorder og havområder.
Overvåkingsprogrammet dekker langsiktige undersøkelser av:

- overgjødsling
- forsuring (sur nedbør)
- ozon (ved bakken og i stratosfæren)
- klimagasser
- miljøgifter

Overvåkingsprogrammmet skal gi informasjon om tilstanden og utviklingen av forurensningssituasjonen, og påvise eventuell uheldig utvikling på et tidlig tidspunkt.
Programmet skal dekke myndighetenes informasjonsbehov om forurensningsforholdene, registrere virkningen av iverksatte tiltak for å redusere forurensningen, og danne grunnlag for vurdering av nye tiltak. SFT er ansvarlig for gjennomføringen av overvåkningsprogrammet.

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