Food baseline study on the quality of narwhal, ringed seal and Arctic char in Eclipse Sound and Milne Inlet, Nunavut

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Executive Summary

This study provides quantitative information on the quality of marine country foods used by residents of Mittimatalik; Narwhal, ringed seal and Arctic char. Thanks to the contribution of a community-based monitoring approach run in the community in 2022 and 2023, the study is the first to provide a catalog of results on narwhal based on a large sample size in Eclipse Sound. The study considers the possible impact of by-products of Baffinland's mining, transportation, and shipping of iron ore on the marine environment and the species examined in this study. We compared our results from Eclipse sound with results collected in the neighbor narwhal population of Admiralty Inlet, situated beyond the zone of influence of the mining activities. We also compared our narwhal results with resident species; ringed seal and Arctic char harvested in Milne Inlet.

Concentrations of trace metals were measured in the tissues of the three country food species. Persistent organic pollutants (POPs) were measured in the blubber of narwhal, despite the fact that they are not necessarily related to the activities of Baffinland. The general health condition of narwhal was also determined. We accounted for several covariables including the region, tissue, age, season and year.

Our comparative results show that narwhal from Eclipse Sound had higher levels of mercury and POPs than narwhal from Admiralty Inlet. Inter-individual variation in trace metals concentrations were obvious in Eclipse Sound, with some showing extreme concentrations (outliers). However, some specific metals like cadmium were higher in narwhal from Admiralty Inlet and inter-individual variation was noticeable for several metals. Concentrations of essential trace metals in some particular individuals were sometimes a hundred times the average concentrations observed. Results suggest that narwhal from Eclipse Sound could be impacted by the release of trace metals that can bioaccumulate throughout the food chain from a source release in Milne Bay (Qingua).

Results have to be interpreted with care because trace metals intake in a migratory species like narwhal can originate from different sources. In ringed seal residing in Milne Inlet, mean concentrations of copper, arsenic, manganese and zinc were higher than in narwhal from Eclipse Sound, but mean concentration of total mercury were in the range of concentrations observed in ringed seal from Eclipse Sound in previous years, or in other areas of the Northeastern Arctic. Extreme concentrations of trace metals (outliers) were also observed in several ringed seal from Milne Inlet. In Arctic char from Qurluqtuuq lake (Milne Inlet), the concentration of certain metals (As, Cu, Fe and Al) was worrisome in individual fish, despite mercury levels that were comparable to the average of the Canadian Arctic. Our study also demonstrated the effect of covariables such as tissue, age, season and year on the variance of trace metals concentrations.

In general, levels of stress hormone (cortisol) and body condition indicators were higher and lower, respectively, in narwhal from Eclipse Sound and Admiralty Inlet. Individual ringed seal had cortisol levels in the range of the narwhal. Results suggest that narwhal from Eclipse Sound and ringed seal are likely impacted by the shipping activities of the mine, which can disrupt their behavior and increase stress levels. However, a few individuals from Admiralty Inlet have clearly demonstrated evidence of lowered body condition even in the context of 'natural' conditions and environment. Seasonal variations related to a number of other variables may account for this.

The concentration of trace metals was typically higher in the liver of species studied, revealing greater exposure risk for one consuming this tissue. We simulated the intake risk of trace metals for the local residents of Mittimatalik. Results suggest that residents could be at risk when eating ringed seal liver or narwhal meat. According to our model, we also expect higher estimated daily intake for a high Arctic community like Mittimatalik where people depend heavily on country foods, especially ringed seal. We also expect higher estimated daily intake for consumers unlucky enough to consume for weeks or months, a large whale with extreme concentrations of trace metals (outliers).

The focus of this report is on matters with significant implications for the health and well-being of Inuit of Mittimatalik. The Qikiqtani Inuit Association has a stated mission of “advanc(ing) the rights and benefits of Qikiqtani Inuit, protect(ing) and promot(ing) their social, political, economic, and cultural interests, and safeguard(ing) the land, waters, and resources that sustain their communities”. This report, and the research behind it, honours and give substance to this mission statement.

This report is ‘exploratory’. It is suggestive of relationships that need further research and exploration. This report is important as it is based on tissue samples from the species noted.

ᓯᕗᓪᓕᖅᑎᓂᑦ ᓇᐃᓈᖅᓯᒪᔪᑦ ᐅᓂᒃᑳᑦ

ᑖᓐᓇ ᖃᐅᔨᓴᕐᓂᖅ ᑐᕌᖓᔪᖅ ᓴᖅᑭᑦᑎᓗᓂ ᐆᒃᑐᖅᓯᒪᔪᑎᒍᑦ (ᓇᐃᓴᖅᓯᒪᔪᑎᒍᑦ) ᖃᐅᔨᓴᐅᔪᓂᒃ ᐱᐅᓂᖏᓐᓄᑦ ᑕᕆᐅᕐᒥᐅᓂᑦ ᓂᕿᒋᔭᐅᔪᑦ ᒥᑦᑎᒪᓕᖕᒥᐅᓂᑦ; ᕿᓚᓗᒐᑦ, ᓇᑦᑏᑦ ᐃᖃᓗᐃᑦᓗ: ᖁᔭᓐᓇᒦᒃ ᐃᑲᔪᓚᐅᖅᑐᓄᑦ ᓄᓇᓕᖕᒧᑦ ᑐᙵᔪᓄᑦ ᖃᐅᔨᓴᕈᓯᕐᓄᑦ ᐊᐅᓚᑕᐅᔪᓄᑦ ᓄᓇᓕᖕᓂ 2022ᒥ 2023ᒥᓗ, ᖃᐅᔨᓴᕐᓂᖅ ᓯᕗᓪᓕᖅᐸᐅᔪᖅ ᓴᖅᑭᑦᑎᔪᖅ ᑲᑎᓯᒪᔪᓂᒃ ᖃᐅᔨᓴᐅᔪᓂᒃ ᕿᓚᓗᒐᓂᑦ ᑐᙵᑦᑐᑎᒃ ᐃᒪᒐᓚᖕᓂᑦ ᖃᐅᔨᓴᕐᕕᖕᓂᑦ ᑕᓯᐅᔭᕐᒥᑦ. ᖃᐅᔨᓴᕐᓂᖅ ᐃᓱᒪᒋᔭᖃᖅᐳᖅ ᐊᒃᑐᐃᓂᐅᑐᐃᓐᓇᕆᐊᓕᖕᓂᒃ ᐱᔮᖅᑰᖏᑦᑐᒃᑯᑦ ᓴᖅᑭᑦᑐᓂᑦ ᐸᕙᓐᓇᓐᑯᑦ ᐅᔭᕋᖕᓂᐊᕐᓂᖏᓐᓂᑦ, ᐅᓯᑲᖅᑕᕐᓂᖏᓐᓂᑦ ᐅᒥᐊᕐᔪᐊᒃᑯᓪᓗ ᐅᓯᑲᖅᑕᕐᓂᖏᓐᓂᑦ ᓴᕕᕋᔭᒃᓴᓂᒃ ᑕᕆᐅᕐᓂ ᐊᕙᑎᓂ ᐆᒪᔪᓄᓪᓗ ᑕᑯᓇᒃᑕᐅᔪᓄᑦ ᑕᕝᕙᓂ ᖃᐅᔨᓴᕐᓂᕐᒥ. ᓴᓂᓕᓅᒃᑎᕐᓗᒋᑦ ᑕᑯᓇᓚᐅᖅᑕᕗᑦ ᖃᐅᔨᓴᕗᑦ ᑕᓯᐅᔭᕐᒥᑦ (Eclipse sound) ᖃᐅᔨᓴᐅᔪᓄᑦ ᑲᑎᖅᓱᖅᑕᐅᔪᓂᑦ ᓴᓂᐊᓃᑦᑐᓂᑦ ᕿᓚᓗᒐᖅᑎᒌᓂᑦ ᐊᑯᓕᐊᖃᑦᑕᖕᒥᑦ ᐅᖓᑖᓃᑦᑐᒥᑦ ᐊᒃᑐᐃᓂᖏᑕ ᐅᔭᕋᖕᓂᐊᕐᓂᓕᕆᔨᓂᑦ. ᑕᑯᓇᓚᐅᕐᒥᔭᕗᑦ ᓴᓂᓕᓅᒃᑐᑦ ᕿᓚᓗᒐᓂᑦ ᖃᐅᔨᓴᕗᑦ ᑕᒫᓂᕐᒥᐅᓄᑦ ᐆᒪᔪᓂᑦ: ᓇᑦᑏᑦ ᐃᖃᓗᐃᑦᓗ ᐊᖑᔭᐅᔪᓂᑦ ᕿᙳᐊᓂᑦ.

ᐱᑕᖃᕐᓃᑦ ᓴᕕᕋᔭᕋᓛᓂᑦ ᐆᒃᑐᖅᑕᐅᓚᐅᖅᑐᑦ (ᓇᐃᓴᖅᑕᐅᔪᑦ) ᓂᕿᖏᓐᓂ ᐱᖓᓱᓂᑦ ᐊᖑᓇᓱᒃᑕᓂᑦ ᓂᕿᒋᔭᐅᔪᓂᑦ. ᑕᕝᕙᐅᖏᓐᓇᓲᑦ ᑎᒥᓂ ᓱᕈᐃᑦ (POPs) ᐆᒃᑐᖅᑕᐅᓚᐅᖅᑐᑦ (ᓇᐃᓴᖅᑕᐅᔪᑦ) ᐅᖅᓱᖏᓐᓂ ᕿᓚᓗᒐᑦ ᐊᒃᑐᐊᓗᐊᖏᒃᑲᓗᐊᕐᓗᑎᒃ ᐸᕙᓐᓇᓐᑯᑦ ᐱᓕᕆᔭᖏᓐᓄᑦ. ᖃᓄᐃᔾᔪᓯᑦᑐᐊᑕᑦ ᑎᒥᒃᑯᑦ ᕿᓚᓗᓂᑦ ᖃᐅᔨᓴᐅᓚᐅᓇᓐᑐᑎᒃ. ᐱᖃᓯᐅᑎᓚᐅᕐᒥᔭᕗᑦ ᖃᔅᓯᑦ ᐊᓯᔾᔭᓯᑦ ᐱᖃᓯᐅᔾᔪᒋᑦ ᓇᓃᙱᖏᑦ, ᓂᕿᖏᑦ, ᐊᕐᓲᒍᖏᑦ, ᖃᖓᒥ ᐊᕐᓲᒍᐊᓗ.

ᓴᓂᓕᓅᒃᑐᓂ ᖃᐅᔨᓴᕗᑦ ᓴᖅᑭᑦᑎᕗᑦ ᕿᓚᓗᒐᑦ ᑕᓯᐅᔭᕐᒥᑦ ᐱᖃᕐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᒨᑯᓇᓂᒃ ᑕᕝᕙᐅᖏᓐᓇᓲᓂᒃ ᑎᒥᓂ ᓱᕈᓂᓪᓗ ᕿᓚᓗᒐᓂᑦ ᐊᑯᓕᐊᖃᑦᑕᖕᒥᐅᓂᑦ. ᐊᑐᓂᓂᑦ ᕿᓚᓗᒐᓂᑦ ᐊᔾᔨᒌᙱᓐᓃᑦ ᓴᕕᕋᔭᕋᓛᓂ ᑲᑎᖓᓂᓯᓂ ᓇᑐᓇᓚᐅᖏᑦᑐᑦ ᑕᓯᐅᔭᕐᒥ ᐃᓚᖏᑦ ᐱᖃᓗᐊᖅᑐᑎᒃ (ᐱᖃᓗᐊᖅᑐᑦ). ᑭᓯᐊᓂ, ᓇᓕᐊᑦᑐᐊᑕᑦ ᓴᕕᕋᔭᑦ ᑲᑦᒥᐊᓪᑎᑐᑦ ᐱᑕᖃᕐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᕿᓚᓗᒐᓂ ᐊᑯᓕᐊᖃᑦᑕᖕᒥᑦ ᐊᑐᓂᓂᓗ ᕿᓚᓗᒐᐅᖅᑎᒌᓂ ᐊᔾᔨᒌᙱᓐᓃᑦ ᐅᔾᔨᕐᓇᓚᐅᖅᑐᑦ ᖃᔅᓯᑲᓪᓚᓄᑦ ᓴᕕᕋᔭᓄᑦ. ᐱᑕᖃᕐᓃᑦ ᐊᑐᓗᐊᖅᑐᓄᑦ ᓴᕕᕋᔭᓄᑦ ᓇᓕᐊᑦᑐᐊᑕᓂᑦ ᕿᓚᓗᒐᓂᑦ 100ᓄᑦ ᐱᑕᖃᖃᕐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᐱᖃᑕᐅᓪᓗᐊᖅᑐᓂᑦ ᖃᐅᔨᓴᐅᔪᓂᑦ. ᖃᐅᔨᐊᔪᑦ ᐅᖅᑯᐃᓯᕗᑦ ᕿᓚᓗᒐᑦ ᑕᓯᐅᔭᕐᒥᑦ ᐊᒃᑐᖅᑕᐅᓯᒪᑐᐃᓐᓇᕆᐊᓖᑦ ᑯᕕᓴᐅᔪᓄᑦ ᓴᕕᕋᔭᓐᓂᑦ ᑎᒥᒃᑯᑦ ᑲᑎᑉᐸᓚᐊᔪᓐᓇᖅᑐᓂᒃ ᓂᕿᑮᒃᑎᒋᑎᒍᑦ ᖁᕕᐊᕕᐅᔪᒥᑦ ᕿᙳᐊᓂ.

ᖃᐅᔨᓴᐅᔪᑦ ᑐᑭᓯᔭᐅᑦᑎᐊᕙᓯᒋᐊᖃᖅᐳᑦ ᓴᕕᕋᔭᑲᑦᑐᕐᓃᑦ ᐊᓯᓇᐊᓯᓂ ᐆᒪᔪᓂ ᕿᓚᓗᒃᑎᑦ ᓇᑭᖕᒪᖕᒪᓂ ᐊᓯᓂᑦ ᐱᕝᕙᓂᑦ. ᓇᑦᑎᓂ ᕿᙳᐊᒥᐅᓂᑦ, ᐱᑕᖃᕐᓂᐅᒪᕚᒃᑐᑦ ᑲᐳᓂᑦ, ᐊᕐᓴᓂᒃ, ᒪᖓᓂᔅ ᓯᖕᒥᓪᓗ ᐱᑕᖃᕐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᕿᓚᓗᒐᓂᑦ ᑕᓯᐅᔭᕐᒥᑦ, ᑭᓯᐊᓂ ᐱᑕᖃᕐᓂᐅᓚᐅᖅᑐᑦ ᑲᑎᑦᑐᓂᑦ ᒧᑯᓇᓂᑦ ᓇᓚᒧᓂᖏᓐᓃᑕᐅᖅᑐᑦ ᐱᑕᖃᕐᓂ ᖃᐅᔨᓴᐅᔪᓂᑦ ᓇᑦᑎᓂᑦ ᑕᓯᐅᔭᕐᒥᑦ ᕿᒪᒃᑕᑦᑎᓐᓂᑦ ᐊᕐᓲᒍᓂᑦ, ᐊᓯᓂᑦ ᐅᐊᖕᓇᒥ ᑭᓇᖕᓇᖓᓂ ᐅᑭᐅᖅᑕᖅᑑᑉ.

ᐱᖃᓗᐊᖅᑐᑦ (ᐱᖃᓗᐊᖅᑐᑦ) ᓴᕕᕋᔭᕋᓛᓂᒃ ᖃᐅᔨᓴᐅᓚᐅᕐᒥᔭᕗᑦ ᓇᑦᑎᕐᓂ ᕿᒪᖑᐊᓂᑦ. ᐃᖃᓗᖕᓂ ᖁᔅᓗᖅᑑᑉ ᑕᓯᖑᓂᑦ (ᕿᙳᐊᓂ), ᐱᑕᖃᕐᓃᑦ ᓇᓕᐊᑦᑐᐊᑕᓂᑦ ᓴᕕᕋᔭᓂᑦ (ᐊᕐᓴᓂᒃ, ᑲᐳ, ᓴᕕᕋᔭᒃᓴᖅ ᒧᑯᓇᓗ) ᐱᖏᖕᓇᓚᐅᖅᑐᑦ ᐊᑐᓂᓂ ᐃᖃᓗᖕᓂ ᒨᑯᓇᖃᕐᓃᑦ ᓇᓚᒧᒃᑲᑐᐊᖅᑎᑦᑐᒋᑦ ᒨᒃᑯᕈᓇᖅᕈᓯᓄᑦ ᑲᓇᑕᒥ ᐃᖃᓗᖕᓂ. ᖃᐅᔨᓴᕐᓂᕗᑦᑕᐅᖅ ᓴᖅᑭᑦᑎᑕᐅᖅᑐᖅ ᐊᒃᑐᐃᓂᖏᓐᓂᒃ ᐊᓯᔾᔨᕈᓐᓇᖅᑐᓂ ᓱᕈᓂ ᓂᕿᓂ, ᐊᕐᓲᒍᓂ, ᖃᖓᓂ ᐊᕐᓲᒍᓂᓗ ᐊᓯᔾᔨᕈᓐᓇᖅᑐᑎᒍᑦ ᓴᕕᕋᔭᐃᑦ ᐱᑕᖃᕐᓂᖏᓐᓂ.

ᑕᐃᒪᐃᒐᔪᖕᓂᖅᑎᒍᑦ, ᐱᑕᖃᕐᓃᑦ ᐊᒃᓯᕈᕐᓂᕐᓂᑦ ᐃᔅᓯᓂᒃ (ᑯᐊᑎᓯᐊᑦ) ᑎᒥᐅᑦᑐ ᖃᓄᐃᓐᓂᖏᓐᓄᑦ ᓇᓗᓇᐃᒃᑯᑕᐃᑦ ᐱᑕᖃᕐᓂᖅᓴᐅᓚᐅᖅᑐᑦ ᐱᑕᖃᖏᓐᓂᖅᓴᐅᓪᓗᑎᓪᓗ, ᐊᑐᓂᓄᑦ, ᕿᓚᓗᒐᓂ ᑕᓯᐅᔭᕐᒥ ᐊᑯᓕᐊᖃᑦᑕᖕᒥᐅᓂᑦ. ᐊᑐᓂ ᓇᑦᑏᑦ ᐊᒃᓯᕈᕐᓂᕐᓂᑦ ᐃᔅᓯᖅᓯᐅᖏᓐᓇᐅᓪᓗᑦ ᕿᓚᓗᒐᓂᑦ ᐱᑕᖃᕐᓂᕐᓂᑦ. ᖃᐅᔨᓴᐅᔪᑦ ᐅᖅᑯᐃᓯᕗᑦ ᕿᓚᓗᒐᑦ ᑕᓯᐅᔭᕐᒥᑦ ᓇᑦᑎᓂᓗ ᐊᒃᑐᖅᑕᐅᔪᒃᓴᐅᔪᑦ ᐅᒥᐊᕐᔪᐊᒃᑯᑦ ᐅᓯᑲᖅᑕᕐᓂᕐᓂᑦ ᐅᔭᕋᖕᓂᐊᕐᕕᖕᒥᑦ ᐊᓯᔾᔨᕈᓐᓇᖅᑐᑎᒃ ᖃᓄᐃᓕᐅᕈᓯᖏᓐᓂᒃ

ᐊᒃᓱᕈᓕᖅᑎᒃᑲᓐᓂᕐᓗᑎᑦᓗ. ᑭᓯᐊᓂ, ᐊᑐᓃᑦ ᕿᓚᓗᒐᑦ ᐊᑯᓕᐊᖅᑲᑦᑕᖕᒥᑦ ᓴᖅᑭᔮᖅᑎᑦᑎᑦᑎᐊᖅᓯᒪᕗᑦ ᑎᒥᒃᑯᑦ ᖃᕗᖕᓂᖅᓴᐅᓂᕐᓂᒃ ᑕᕝᕙᐅᒐᓗᐊᖅᑎᑦᓗᑎᑦ ‘ᐃᓕᖅᑯᓯᑐᖃᑦ’ ᑎᒥᒃᑯᑦ ᐊᕙᑎᓂᓗ. ᓇᓕᐊᖕᓂ ᑕᖅᑭᓂ ᐊᓯᔾᔨᕈᓐᓇᖅᑐᑦ ᐊᒃᑐᐊᔪᑦ ᐅᓄᕐᓂᕐᓄᑦ ᖃᔅᓯᓄᑦ ᐊᓯᔾᔨᕈᓐᓇᖅᑐᓄᑦ ᖃᐅᔨᓴᐅᔾᔪᑎᐅᔪᓐᓇᖅᐳᑦ.

ᐱᑕᖃᕐᓃᑦ ᓴᕕᕋᔭᕋᓛᓂ ᐱᑕᖃᕐᓂᖅᓴᐅᒐᔪᓚᐅᖅᑐᑦ ᑎᖕᒍᖕᒋᓐᓂ ᐆᒪᔪᓂ ᖃᐅᔨᓴᖅᑕᐅᔪᓂᑦ ᓴᖅᑭᑦᑎᑦᓗᑎᒃ ᑲᑉᐱᐊᓇᕐᓂᖅᓴᐅᓂᖕᒐᓂᒃ ᓂᕆᔪᒧᑦ ᑖᔅᓱᒥᖕᒐ ᓂᕿᒥᒃ. ᐋᕿᖖᒍᐊᖅᓯᓚᐅᖅᑐᒍᑦ ᓂᕆᔭᓄᑦ ᓴᕕᕋᔭᕋᓛᓄᑦ ᒥᑦᑎᒪᑕᓕᖕᒥᐅᓄᑦ. ᖃᐅᔨᓴᐅᔪᑦ ᐅᖃᖅᑰᔨᕗᑦ ᓄᓇᓕᖕᒥᐅᑦ ᑲᑉᐱᐊᓇᖅᑐᒦᑦᑐᓐᓇᖅᑐᑦ ᓂᕆᒍᑎᒃ ᓇᑦᑏᑦ ᑎᖕᒍᖕᒋᓐᓂᒃ ᓂᕿᑦᑕᓐᓇᖕᓂᒡᓗ. ᒪᓕᒡᓗᒍ ᐋᖅᑭᖖᒍᐊᖅᓯᒪᔭᕗᑦ, ᓂᕆᐅᒃᑭᕗᒍᑦ ᐱᑕᖃᕐᓂᖅᓴᓂᒃ ᖃᐅᑕᒫᓂ ᓂᕆᔭᐅᔪᓂᑦ ᐃᖃᓗᖕᓂᑦ ᓄᓇᓕᖕᓂ ᒥᑦᑎᒪᑕᓕᒃᑎᑐᑦ ᓂᕿᖃᑦᓚᒃᑐᓂ ᐊᖑᓇᓱᒃᑕᐅᔪᓂᑦ ᓂᕿᓂᒃ ᓇᑦᑎᓗᐊᑕᖅᑎᑐᑦ. ᓂᕆᐅᒃᑭᕗᒍᑦ ᐱᖃᑦᑕᕐᓂᖅᓴᓂᒃ ᐅᑦᓗᒥ ᐱᔭᐅᔪᓂ ᓂᕆᔭᓄᑦ ᓂᕆᔭᕆᐊᖃᖅᑐᓄᑦ ᐱᓇᓱᐊᕈᓯᓄᑦ ᑕᖅᑭᓄᑦᓗᓐᓃᑦ ᐊᖏᔪᒥᒃ ᕿᓚᓗᒐᒥᒃ ᓴᕕᕋᔭᕋᓛᖃᑦᓚᒃᑐᓂᑦ (ᐱᖃᓗᐊᖅᑐᑦ).

ᑐᓵᖕᒐᔭᖕᒐ ᑖᔅᓱᒪᐅᑉ ᐅᓂᒃᑳᑉ ᖃᓄᐃᑦᑐᓄᑦ ᐊᒃᑐᐃᓂᖃᑦᓚᒃᑐᓄᑦ ᖃᓄᐃᖏᓐᓂᖏᓐᓄᑦ ᐃᓅᓯᖃᑦᑎᐊᕐᓂᖏᓐᓄᑦᓗ ᒥᑦᑎᒪᑕᓕᖕᒥᐅᓄᑦ ᐃᓄᖕᓄᑦ. ᕿᑭᖅᑕᓂ ᐃᓄᐃᑦ ᑲᑐᔾᔨᖅᑎᑮᖏᑦ ᐅᖃᖅᓯᒪᔭᕐᒥᓄᑦ ᐱᓕᕆᐊᒃᓴᖅᓯᒪᑕ “ᓯᕗᒧᐊᖅᑎᑦᓗᒋᑦ ᐱᔪᓐᓇᐅᑎᖏᑦ ᐃᑲᔫᑎᖏᑦᓗ ᕿᑭᖅᑕᓂᒥᐅᑉ ᐃᓄᐃᑦ, ᓴᐳᑎᓗᒋᑦ ᑐᓴᐅᒪᔭᐅᑎᑦᓗᒋᑦ, ᐃᓅᓯᖅᑎᑮᖕᓂᒃᑯᑦ, ᐃᓱᒪᒋᔭᕐᒥᒍᑦ, ᑮᓇᐅᔭᓕᐅᕐᓂᒃᑯᑦ ᐃᓕᖅᑯᓯᑐᖃᒃᑯᑦ ᐱᔪᒪᔭᕐᒥᓂᒃ, ᓴᐳᑎᓗᒋᑦᓗ ᓄᓇᐃᑦ, ᐃᒪᐃᑦ ᐊᑐᒐᒃᓴᓗ ᑲᔪᓯᔾᔭᑕᐅᔪᑦ ᓄᓇᓕᖏᓐᓄᑦ’. ᑖᓐᓇ ᐅᓂᒃᑳᖅ ᖃᐅᔨᓴᖅᑕᑦᓗ ᓯᕗᓂᐊᓂᑦ, ᐅᐱᒍᓱᒃᐳᑦ ᑕᖏᖃᖅᑎᑦᑎᑦᓗᑎᑦᓗ ᑖᔅᓱᒥᖕᒐ ᐱᓕᕆᐊᒃᓴᓗᑦ ᐅᖃᖅᑐᒥᒃ.

ᑖᓐᓇ ᐅᓂᒃᑳᖅ ‘ᖃᐅᔨᓴᕆᐊᕐᓂᐅᔪᖅ’. ᐅᖃᖅᑰᔨᔭᖅ ᐆᒪᔫᖅᑎᑮᖕᓂᕐᓂᒃ ᖃᐅᔨᓴᖅᑕᐅᒃᑲᓐᓂᕆᐊᓕᖕᓂᒃ ᑐᑭᓯᓇᓱᒃᑲᓐᓂᕐᓂᑦᓗ. ᑖᓐᓇ ᐅᓂᒃᑳᖅ ᐱᕐᔭᐊᖑᔪᖅ ᑐᙵᕕᒥ ᑎᒥᓂᑦ ᖃᐅᔨᓴᒐᒃᓴᓂᑦ ᐆᒪᔪᓂᑦ ᐅᖃᐅᓯᐅᔪᓂᑦ.

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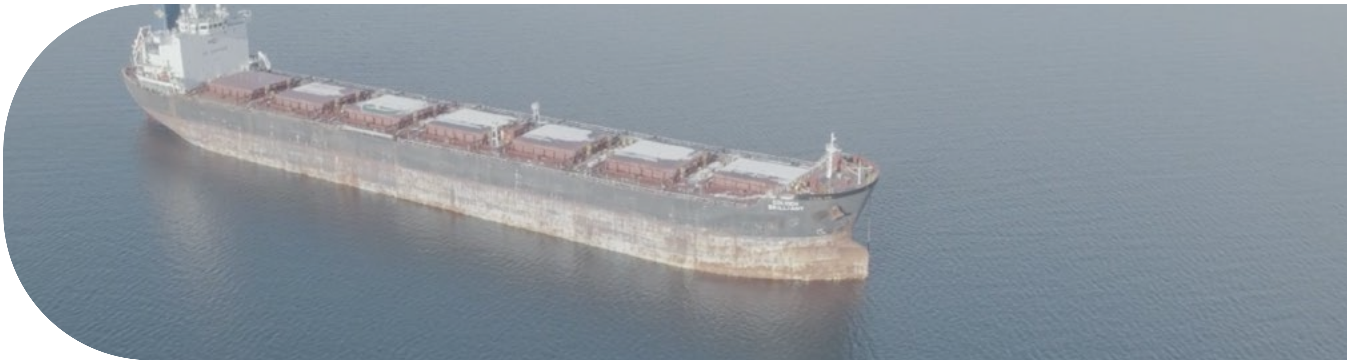
1. Introduction



Trace metal contamination has beings studied in Arctic wildlife and fish (Sonne et al. 2018; Rune Dietz et al. 2019) and, to a lesser extent, in humans (Chan et al. 1995; Johansen et al. 2004; Lemire et al. 2015). Nonessential heavy metals, such as mercury and cadmium, are especially of concern as they can be assimilated by living organisms, with potential toxic effects on their organs and metabolism (Lavery et al. 2009; Rawson et al. 1993; Sonne et al. 2007; 2018). Heavy metals can bioaccumulate and biomagnify throughout food webs. Even essential metals such as Zn, Cu or As can be toxic at high concentrations. Persistent Organic Pollutants are another source of contamination that is important to monitor in country foods (B. M. Braune et al. 2005). Emerging POPs, such as the PBDEs, have been more recently added to the Stockholm Convention because of their exponential increase in recent decades, including tissues of Arctic marine mammals (Hoguet et al. 2013; Rotander et al. 2012).

However, sources of metals or POPs contamination in the Arctic are often diffuse and hard to pinpoint. If they can originate from a particular source like a mine, they can also originate from industrial areas all over the world. They can be transported through ocean circulation or through the atmosphere to reach Arctic latitudes.

The activities of the Baffinland Iron Mines' Mary River project can impact wildlife and aquatic life in several ways. Shipping activities in Milne Inlet and Eclipse Sound are a stressful source of noise and disturbance for marine mammals, altering their behavior and body condition (Watt et al. 2021). The ore crushing, stacking and transport along the 100 km-long tote road from the Mary River Mine to the Milne Inlet Port release notable quantities of red iron-ore dust containing other metals. This fugitive red dust is carried away by strong winds, and settles in the terrestrial, marine and aquatic environments (Coupel et L'Herault 2023).

As part of the Inuit Certainty Agreement (ICA) negotiated between the Qikiqtani Inuit Association (QIA) and BIMC, ArctiConnexion was asked to conduct a Country Food Baseline Study (CFBS) in the community of Pond Inlet (Mittimatalik). In the past decade, residents of Mittimatalik have been affected in different ways by Baffinland's activities and initiatives, and have reported declining access to their country foods. Country foods are critical for Inuit food security and sovereignty. Country foods are known to be highly nutritious, meeting the dietary requirements of an Arctic climate and meeting the food preferences of Inuit culture. The CFBS aimed to document data on country food consumption patterns and country food quality. The consumption of country food has been treated independently from this report. The objective of this study was to determine the quality of different country food being consumed by Inuit living in Mittimatalik. We noted and recorded the condition of the species in question. We also undertook to explore the possible and most likely origins of contaminants.

2. Methods

2.1 Sample collection

We studied narwhal specimens harvested by local hunters in the Eclipse Sound in 2022 and 2023 (Figure 1). For purposes of comparison, we also studied narwhal from Admiralty Inlet, a neighbor ecosystem outside the influence of BIM activities. Hunters from the local community of Ikpiarjuk provided specimens from Admiralty Inlet in 2022 and 2023. Ringed seal were harvested in 2023 in Milne Inlet; a branch of Eclipse Sound leading to the Milne Port (Figure 1). Arctic char were also collected from the Milne Inlet area, specifically in Qurluqtuuq lake, located approx. 10km from the Milne Port (Figure 1). Qurluqtuuq lake is a place of great importance for Mittimatalik fishers.

2.1.1 Narwhal & Ringed seal

In 2022 and 2023, in collaboration with the Mittimatalik Hunters and Trappers Organization (Pond Inlet) and the Ikajutit Hunters and Trappers Association (Arctic Bay), local hunters were distributed sampling kits to collect tissues; liver, muscle, blubber and skin from narwhal and ringed seal harvested from subsistence hunts.

Board members at the local HTAs in Mittimatalik and Ikpiarjuk, who are themselves hunters and regularly meet and chat with other hunters in the community, and the local HTA managers were trained in the right sampling procedures to follow to fill the sampling kits. Local managers at the HTAs had the responsibility to provide clear instructions when they handed out sample kits to the hunters. More information on sample kits is provided in Appendix 2. Sample kits collected on the field by local hunters were kept fresh in a cooler and stored frozen at −20 °C at the local HTA. All samples were shipped in coolers by plane and kept at −20 °C during transit time all the way to ArctiConnexion's Laboratory where they were sorted. All samples were analysed at certified laboratories within a five-month time period.

Sixty-five narwhal sample kits were collected in Eclipse Sound and 33 in Admiralty Inlet (Figure 1). In the fall of 2023, narwhal samples could not be collected because the community had reached its hunting quota over the summer. Seven seals were harvested in Milne Inlet (Figure 1). Information of the sex, length, age and fat thickness of the narwhal and seal were recorded in the field (Appendix 2). The general body condition / health of narwhal and seal was determined by the hunters as a result of conducting a visual inspection and assessment of the animal based on Inuit Qaujimajatuqngit (historical knowledge and experience). Whales were classified into one of the following categories: “Healthy / Fat”, “Below Average” or “Unhealthy / Skinny”. Adults were discriminated from subadults using size as a proxy, or through visual observations. Whales over 350 cm were considered adults (Sonne et al. 2018a). In the few instances when size was not recorded on the site, we determined the age of the whale by measuring the change in the ratio of D- and L-enantiomers of aspartic acid in the eye lens nucleus (aspartic acid racemization [AAR]) at the Freshwater Institute laboratory, University of Winnipeg (Watt et al. 2021). Narwhal over 10 years old were considered adults.

The age of ringed seal was determined by the count of cementum annuli analysis (CAA) in the canine tooth at Matson’s Laboratory (Manhattan, MT, USA). Seals over 5 years were considered adults (Brown et al. 2016).

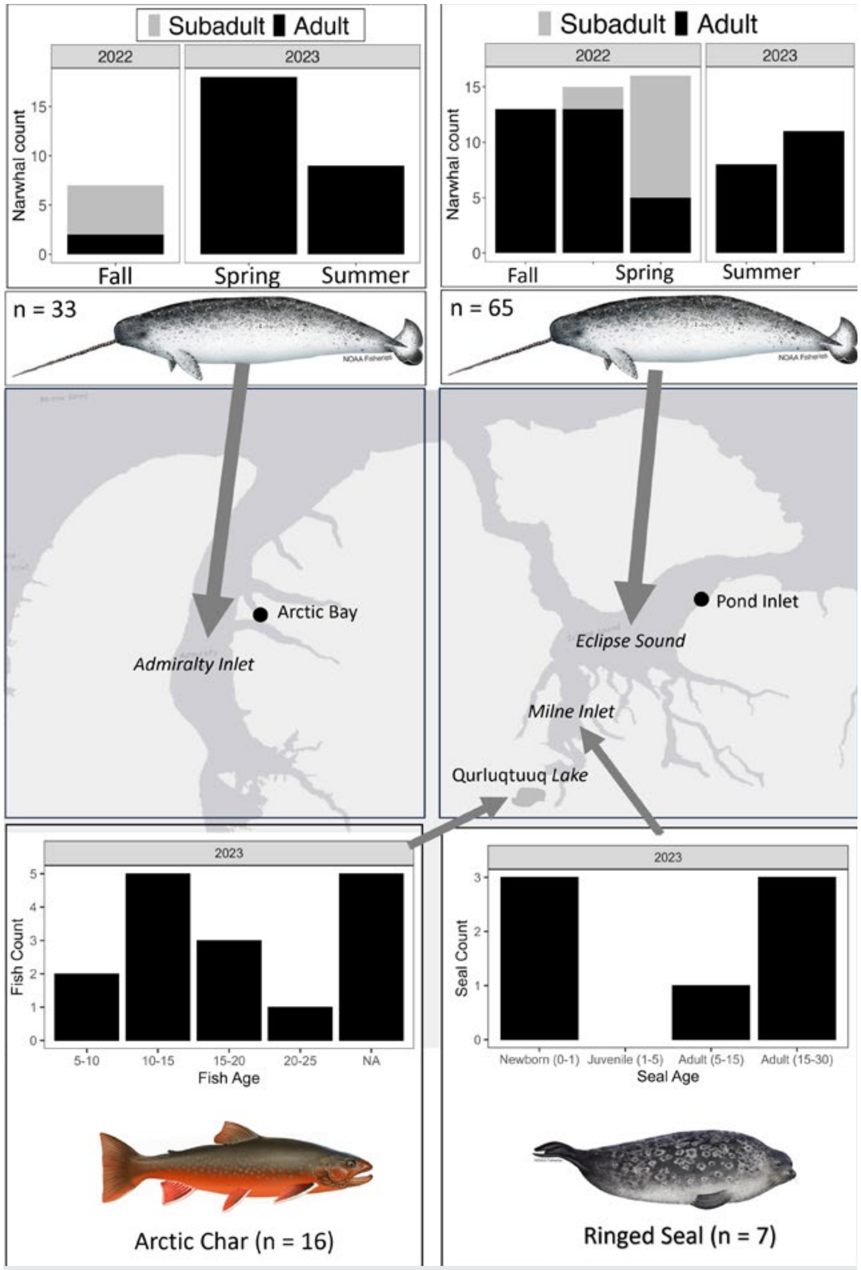


Figure 1 – Number of narwhal, ringed seal and Arctic Char harvested in the greater Eclipse Sound region and in Admiralty Inlet (narwhal) in 2022 and 2023. Histograms break down the numbers per age group (narwhal, seal, fish) and season (narwhal).

Meat, liver and skin (maktaaq) tissues were sampled on whales and seals to measure the concentration of trace metals. Blubber samples were collected on narwhal and seal to measure the concentration of Persistent Organic Pollutants (POPs) and cortisol.

2.1.2 Arctic Char

Local fishers were distributed sampling kits to collect tissues – liver, muscle, blubber and skin – on Arctic char harvested for subsistence. Sixteen Arctic char were harvested at spring 2023 in Qurluqtuuq Lake located 10km North of the Milne Inlet port across Qingua (Milne Bay) (Figure 1). Information of the sex and length of the fish were recorded in the field. Based on Inuit Qaujimajatuqangit, local fishers confirmed that all fish harvested were sea-run Arctic char. We determined the age of fish by counting the cementum annuli on otoliths at Aquatic, Agricultural and Environmental Tech Services Inc, University of Western Ontario. All samples were stored frozen at -18°C before lab analyses.

2.2 Laboratory analysis

2.2.1 Trace metals

We tested for 34 trace metals in the tissues of narwhal, ringed seal and Arctic char. Samples were digested using a closed vessel microwave digestion technique with nitric and hydrochloric acids, and hydrogen peroxide as a digesting reagent (EPA M3052 procedure). Instrumental analysis of the digestate was performed via CVAA (EPA M7470A) for mercury and via collision-reaction cell Inductively Coupled Plasma Mass Spectrometry (ICPMS) for all of the other trace metals. Analyses were run at the ALS national laboratory for Environment Testing in Burlington, Ontario. Trace metal concentrations are provided in ug/kg of wet weight. We focus on 13 trace metals that are more of concern (underlined in yellow in the Tables of this report). These include non-essential heavy metals (Hg, Cd, Pb, As) that are highly toxic even at low concentrations with a potential to bioaccumulate and biomagnify. We tested for other non-essential metals (Cr, Al) and essential metals (Ni, Cu, Zn, Mn, Fe, Ag, Se) that can be toxic, but only at high concentration. We also focus on Fe, Al, Mn, and Cr that have been observed at high concentration in the fugitive ore dust released by Baffinland's project activities (EDI 2016).

2.2.2 Persistent Organic Pollutants (POPs)

We tested 95 analytes of polychlorinated biphenyls (PCBs) and 24 analytes of Organochlorine Pesticides (OCPs) in the blubber of 12 narwhal from fall 2022 (6 from Eclipse Sound and 6 from Admiralty Inlet). PCBs were analyzed via selected ion monitoring (SIM) gas chromatography/low resolution mass spectrometry (GC/LRMS) using isotope dilution technique. OCPs were analyzed by Soxhlet extraction of the samples, prepared by gel-permeation chromatography, followed by column chromatography, and analyzed by gas chromatography coupled with high resolution mass spectrometry (GC-HRMS). We tested 21 analytes of Perfluoroalkyl Substances (PFAS) in the liver of 10 narwhal; 6 from Admiralty Inlet and 4 from Eclipse Sound (2 liver samples were unavailable). Samples were first extracted with alkaline organic solvent, diluted with water then passed through solid-phase extraction. Final extract of PFAS compounds was analyzed by liquid chromatography coupled with mass spectrometry (LC-MS/MS).

All POPs analyses were run at ALS Global Laboratory in Burlington, Ontario. The analytical methods used by ALS are developed using internationally recognized reference methods such as those published by US EPA, APHA Standard Methods, ASTM, ISO, Environment Canada, BC MOE, and Ontario MOE.

2.2.3 Cortisol

Cortisol levels in sub-dermal blubber are an integrated measure of stress in whales *(Delphinapterus leucas)* (Loseto et al. 2017; Watt et al. 2021). Cortisol concentrations were measured in the blubber of all narwhal samples collected in 2022-2023 and on four ringed seal harvested in 2023. Blubber samples were loaded onto a solid phase extraction cartridge, eluded with 60% MeOH, centrifuged and then loaded for LC-MS analysis. Complete information about the chemical, instrument, calibration, sample preparation and LC-MS analysis are described in (Watt et al. 2021). Analyses were run at the Health Sciences Centre at the University of Calgary, AB.

2.3 Statistical analysis

T-TESTS

We tested the homogeneity of the variance (Levene test) and the normality of the data (Shapiro-Wilcoxon test) prior to running statistical tests. We ran parametric Student tests on data sets with homogeneous variance and that were normally distributed. We used a Welsh test if the variance was not homogeneous but the data normally distributed and non-parametric. We used a Wilcoxon-Mann-Whitney test if the data were not normally distributed. We used the non-parametric Kruskal Wallis test and post hoc Dunn test to compare more than two groups (e.g. tissues in narwhal, seasons, years and species). Levels of significance are presented as follow: $p > 0.05$: non-significant (ns); $0.01 < p \leq 0.05$: significant (*) ; $0.001 < p \leq 0.01$: very significant (**); $0.0001 < p \leq 0.001$; highly significant (***) or $0.00001 < p \leq 0.0001$: very highly significant (****). Boxplots presented in the results section show the 25th percentile (first quartile; Q1), 50th percentile (median; Q2) and 75th percentile (third quartile; Q3). The 5th and 95th percentiles are represented by the whiskers below and above the boxplot, respectively. Dots represent the extreme values above the 95th percentile (outliers).

OUTLIERS

Extreme concentrations of trace metals (outliers) in narwhal, ringed seal and Arctic char were determined using the interquartile range (IQR = Q3 – Q1) or «Tukey's fences» method (Tukey 1977). In narwhal and Arctic char, we defined outlier values falling above the third quartile (Q3) plus 3 times the IQR for metals with potential toxicity at low concentration (Hg, Cd, Pb, As).

$$\text{Outlier}_{[\text{Low}]} > Q3 + 3 \times (Q3 - Q1)$$

For trace metals with a potential toxicity at high concentration (Zn, Al, Mn, Fe, Se, Cu, Ni, Ag, Cr) we defined as outlier values falling above the third quartile (Q3) plus 5 times the IQR.

$$\text{Outlier}_{[\text{High}]} > Q3 + 5 \times (Q3 - Q1)$$

For ringed seal, the sample size was small, and consequently we defined as outlier values, those falling above the third quartile (Q3) plus 1.5 times the IQR which corresponds to the more classic definition of outliers. For:

$$\text{Outlier} > Q3 + 1.5 \times (Q3 - Q1)$$

METHYL MERCURY

We estimated the average concentrations of Methyl Mercury (MeHg), the toxic fraction of Total mercury, in the liver of ringed seal using a normalized equation developed by examining the correlation between Hg and MeHg as part of a previous study conducted in 2018 on ringed seal of Eclipse Sound (Coupel et al., unpublished). For

$$[\text{MeHg}_{\text{estimated}}] = 1.1173 + 0.7437 * \log[\text{Hg}]$$

In the muscle, it is known that a fraction of 80% to 100% of the Total Hg is in its methylated form (Wagemann et al. 1998). In this report, we consider that MeHg equals 80% of Total Hg.

2.4 Guidelines for human health

We calculated the Estimated Daily Intake (EDI) to assess trace metal adsorption by someone consuming Arctic char, seal, and narwhal. The EDI was calculated using methods similar to those described by Lemire et al. (2015), following the guidelines provided by the United Nations' Food and Agriculture Organization and World Health Organization for assessing the dietary exposure to contaminants (FAO/WHO, 2011; Lemire et al. 2015).

For:

$$EDI = \frac{\text{Portion+F+[C]}}{\text{Body Weight}} \quad (1)$$

EDI *(Estimated Daily Intake) - in µg/person/day*

Portion *– the weight of the country food portion eaten (kg)*

F *– Nb of day of consumption (d)*

[C] *– mean concentration of trace metals in country food* ($\mu g\ kg^{-1}$)

Body weight *– of the person eating the country food (kg)*

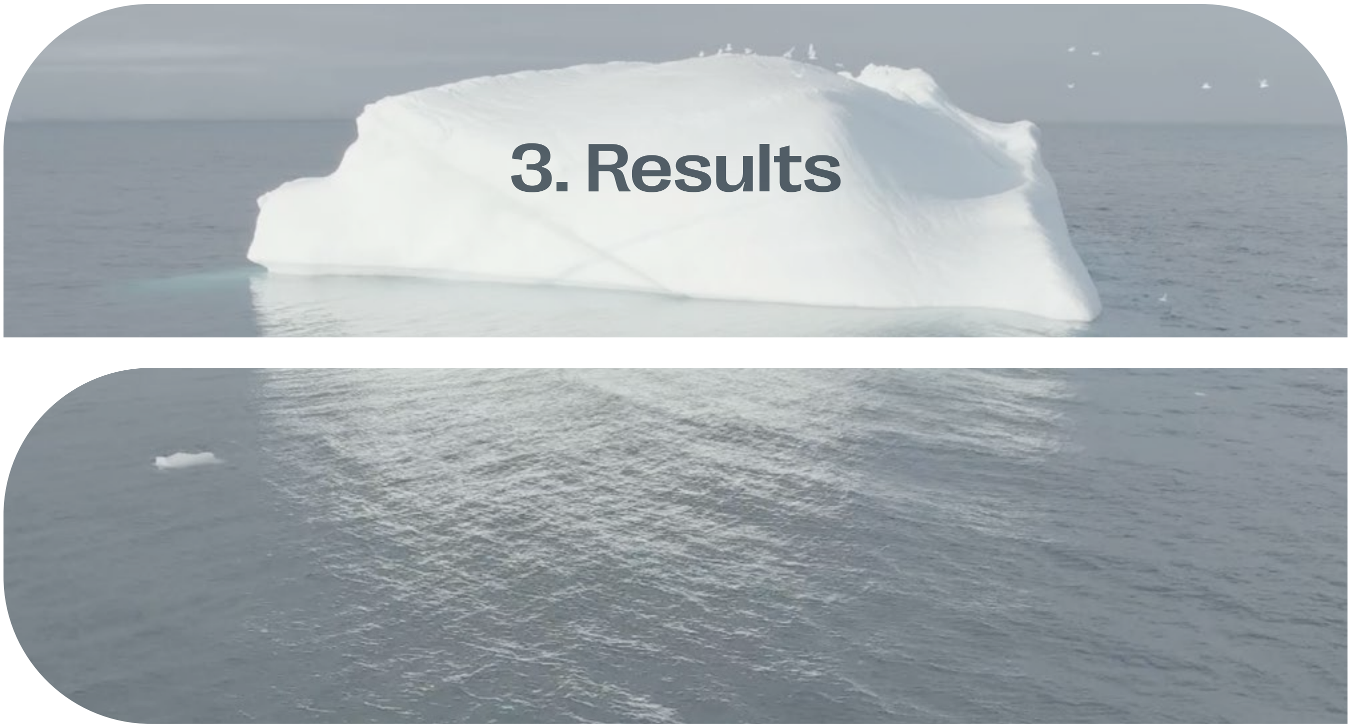
For example, the EDI of an adult of 60 kg consuming a portion of 300g of country food with a given trace metal concentration of 3µg kg^{-1} is:

$$EDI = \frac{0.300 \times 1 \times 3}{60} = 0.015\ \mu g\ d^{-1} \text{ of trace metal}$$

People's consumption habits are not consistent throughout the year. Consumption varies according to the availability of country foods, the type of consumer or the social context. In this study, the estimated daily intake rate accounts for an average daily portion size calculated based on the annual consumption of Inuit men from Nunavik; 0.0274 kg a day^{-1} of fish and seafood and 0.0127 kg a day^{-1} of marine mammals. (Lemire et al. 2015). To address the exposure risk, we compared the EDI of trace metals to the maximum daily intake guideline for safe consumption established for Fe, Hg, Zn, Cu and Ni by Health Canada, 2009).

For Cd, As and Pb we referred to the upper tolerable thresholds provided by the World Health Organizations (WHO 2017).

3. Results



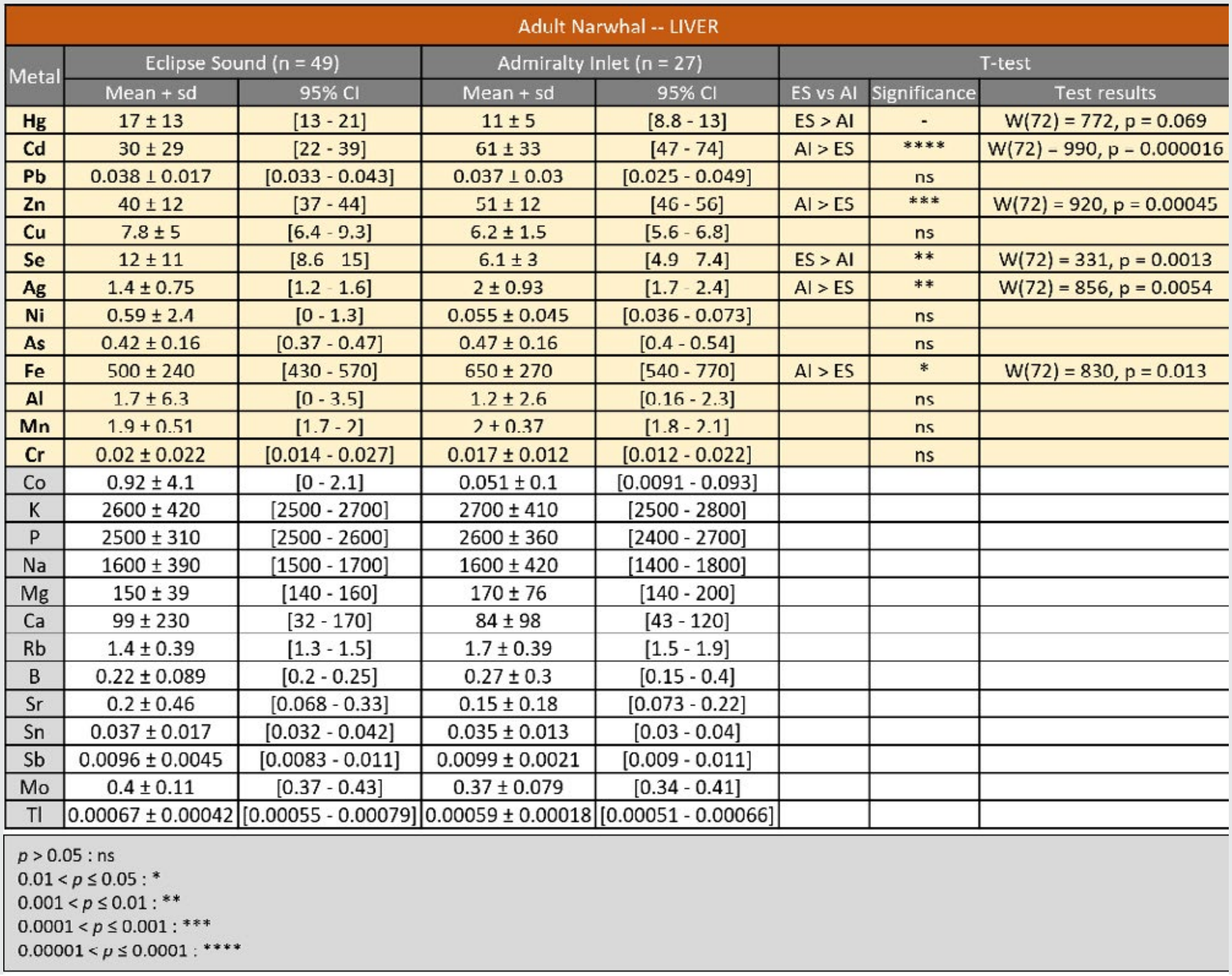
3.1 Narwhals

3.1.1 Trace metals

Tables 1, 2 and 3 show trace metal concentrations in the liver, meat and skin of adult narwhal harvested in Eclipse Sound and Admiralty Inlet. Trace metals for which concentrations were below the limit of detection (LOD) were excluded from the report.

Trace metals concentrations were compared between narwhal from Eclipse Sound and Admiralty Inlet. The mean concentration of total Hg in meat (1.5 ± 0.7 mg kg^{-1}) and skin (0.76 ± 0.39 mg kg^{-1}) was significantly higher in narwhal from Eclipse Sound than narwhal from Admiralty Inlet (Table 1-3, Figure 2). The mean concentration of total Se in liver (12 ± 11mg kg^{-1}), Pb in meat (0.39 ± 2.6 mg kg^{-1}), Cr in skin (0.052 ± 0.073 mg kg^{-1}) and Zn in skin (65 ± 13 mg kg^{-1}) were significantly higher in narwhal from Eclipse Sound than narwhal from Admiralty Inlet (Table 1-3, Figure 2). In contrast, the mean concentration of total Cd in liver (61 ± 33 mg kg^{-1}), Cd in meat (0.41 ± 0.38 mg kg^{-1}), Cd in skin (0.05 ± 0.04 mg kg^{-1}), Fe in liver (650 ± 270 mg kg^{-1}), Ag in liver (2 ± 0.93 mg kg^{-1}), Zn in liver (51 ± 12 mg kg^{-1}) and As in skin (1.2 ± 0.27 mg kg^{-1}) were significantly higher in narwhal from Admiralty Inlet than narwhal from Eclipse Sound (Table 1-3, Figure 2).

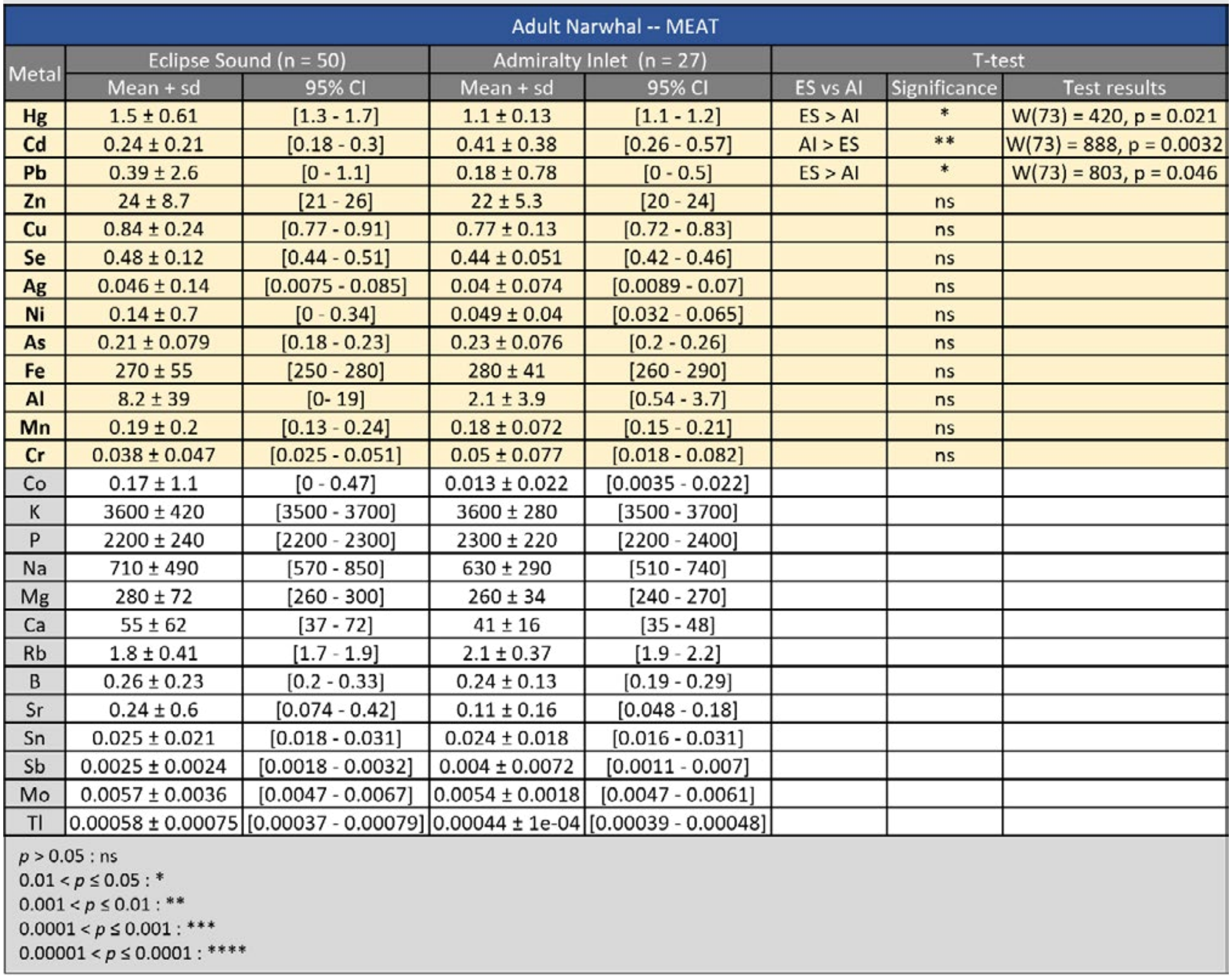
Table 1 – Mean concentration (mg kg^{-1}) of total trace metals in the liver of adult narwhal (> 350cm) harvested in Eclipse Sound and Admiralty Inlet in 2022 and 2023. Standard deviation and 95% confidence intervals are provided. Results of Wilcoxon-Mann-Whitney tests (W) compare concentrations among regions. Statistical significance is determined by p-value.



Adult Narwhal -- LIVER							
Metal	Eclipse Sound (n = 49)		Admiralty Inlet (n = 27)		T-test		
	Mean + sd	95% CI	Mean + sd	95% CI	ES vs AI	Significance	Test results
Hg	17 ± 13	[13 - 21]	11 ± 5	[8.8 - 13]	ES > AI	-	W(72) = 772, p = 0.069
Cd	30 ± 29	[22 - 39]	61 ± 33	[47 - 74]	AI > ES	****	W(72) = 990, p = 0.000016
Pb	0.038 ± 0.017	[0.033 - 0.043]	0.037 ± 0.03	[0.025 - 0.049]		ns	
Zn	40 ± 12	[37 - 44]	51 ± 12	[46 - 56]	AI > ES	***	W(72) = 920, p = 0.00045
Cu	7.8 ± 5	[6.4 - 9.3]	6.2 ± 1.5	[5.6 - 6.8]		ns	
Se	12 ± 11	[8.6 - 15]	6.1 ± 3	[4.9 - 7.4]	ES > AI	**	W(72) = 331, p = 0.0013
Ag	1.4 ± 0.75	[1.2 - 1.6]	2 ± 0.93	[1.7 - 2.4]	AI > ES	**	W(72) = 856, p = 0.0054
Ni	0.59 ± 2.4	[0 - 1.3]	0.055 ± 0.045	[0.036 - 0.073]		ns	
As	0.42 ± 0.16	[0.37 - 0.47]	0.47 ± 0.16	[0.4 - 0.54]		ns	
Fe	500 ± 240	[430 - 570]	650 ± 270	[540 - 770]	AI > ES	*	W(72) = 830, p = 0.013
Al	1.7 ± 6.3	[0 - 3.5]	1.2 ± 2.6	[0.16 - 2.3]		ns	
Mn	1.9 ± 0.51	[1.7 - 2]	2 ± 0.37	[1.8 - 2.1]		ns	
Cr	0.02 ± 0.022	[0.014 - 0.027]	0.017 ± 0.012	[0.012 - 0.022]		ns	
Co	0.92 ± 4.1	[0 - 2.1]	0.051 ± 0.1	[0.0091 - 0.093]			
K	2600 ± 420	[2500 - 2700]	2700 ± 410	[2500 - 2800]			
P	2500 ± 310	[2500 - 2600]	2600 ± 360	[2400 - 2700]			
Na	1600 ± 390	[1500 - 1700]	1600 ± 420	[1400 - 1800]			
Mg	150 ± 39	[140 - 160]	170 ± 76	[140 - 200]			
Ca	99 ± 230	[32 - 170]	84 ± 98	[43 - 120]			
Rb	1.4 ± 0.39	[1.3 - 1.5]	1.7 ± 0.39	[1.5 - 1.9]			
B	0.22 ± 0.089	[0.2 - 0.25]	0.27 ± 0.3	[0.15 - 0.4]			
Sr	0.2 ± 0.46	[0.068 - 0.33]	0.15 ± 0.18	[0.073 - 0.22]			
Sn	0.037 ± 0.017	[0.032 - 0.042]	0.035 ± 0.013	[0.03 - 0.04]			
Sb	0.0096 ± 0.0045	[0.0083 - 0.011]	0.0099 ± 0.0021	[0.009 - 0.011]			
Mo	0.4 ± 0.11	[0.37 - 0.43]	0.37 ± 0.079	[0.34 - 0.41]			
Tl	0.00067 ± 0.00042	[0.00055 - 0.00079]	0.00059 ± 0.00018	[0.00051 - 0.00066]			

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

Table 2 - Mean concentration (mg kg^{-1}) of total trace metals in the meat of adult narwhal (> 350cm) harvested in Eclipse Sound and Admiralty Inlet in 2022 and 2023. Standard deviation and 95% confidence interval are provided. Results of Wilcoxon-Mann-Whitney tests (W) compare concentrations among regions. Statistical significance is determined by p-value.

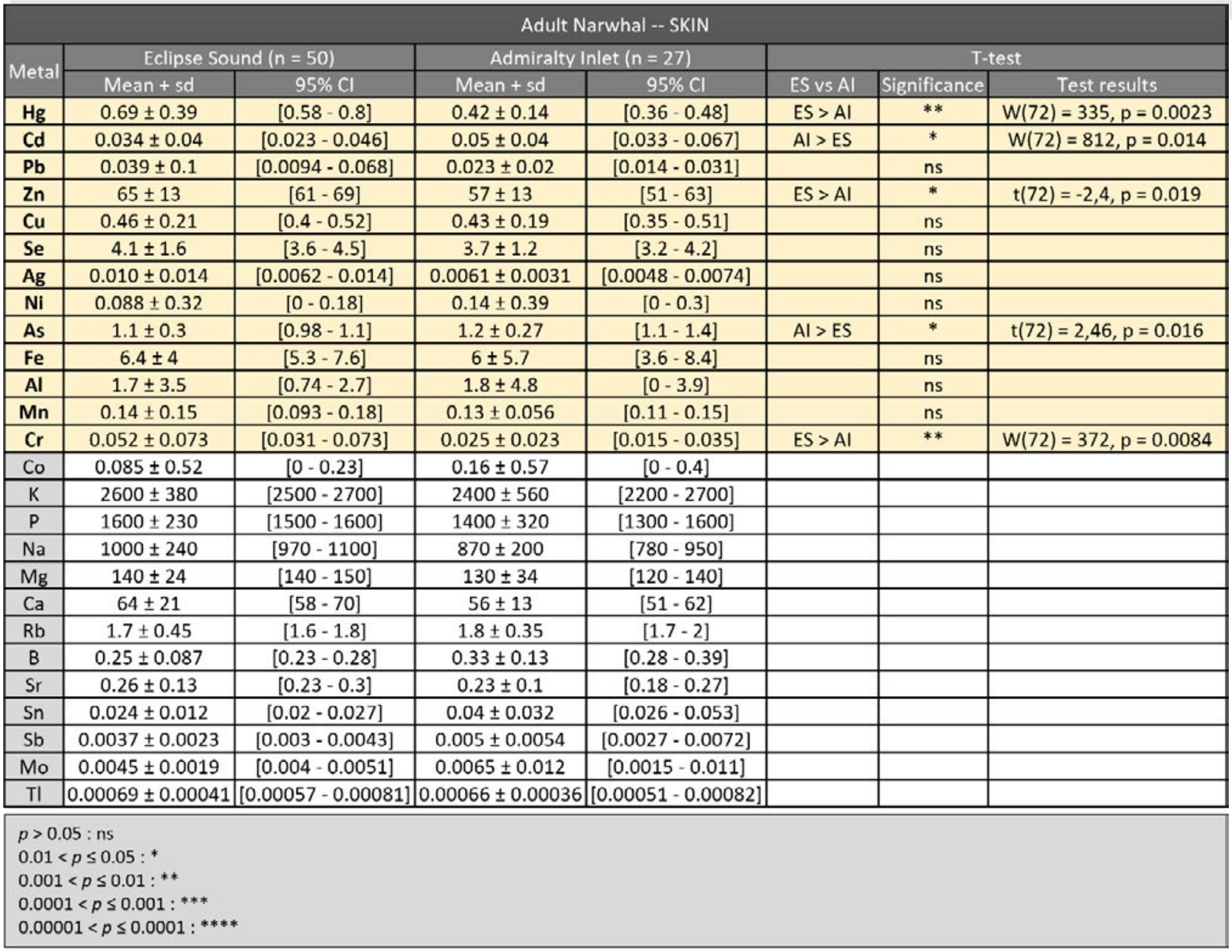


Adult Narwhal -- MEAT

Metal	Eclipse Sound (n = 50)		Admiralty Inlet (n = 27)		T-test		
	Mean + sd	95% CI	Mean + sd	95% CI	ES vs AI	Significance	Test results
Hg	1.5 ± 0.61	[1.3 - 1.7]	1.1 ± 0.13	[1.1 - 1.2]	ES > AI	*	W(73) = 420, p = 0.021
Cd	0.24 ± 0.21	[0.18 - 0.3]	0.41 ± 0.38	[0.26 - 0.57]	AI > ES	**	W(73) = 888, p = 0.0032
Pb	0.39 ± 2.6	[0 - 1.1]	0.18 ± 0.78	[0 - 0.5]	ES > AI	*	W(73) = 803, p = 0.046
Zn	24 ± 8.7	[21 - 26]	22 ± 5.3	[20 - 24]		ns	
Cu	0.84 ± 0.24	[0.77 - 0.91]	0.77 ± 0.13	[0.72 - 0.83]		ns	
Se	0.48 ± 0.12	[0.44 - 0.51]	0.44 ± 0.051	[0.42 - 0.46]		ns	
Ag	0.046 ± 0.14	[0.0075 - 0.085]	0.04 ± 0.074	[0.0089 - 0.07]		ns	
Ni	0.14 ± 0.7	[0 - 0.34]	0.049 ± 0.04	[0.032 - 0.065]		ns	
As	0.21 ± 0.079	[0.18 - 0.23]	0.23 ± 0.076	[0.2 - 0.26]		ns	
Fe	270 ± 55	[250 - 280]	280 ± 41	[260 - 290]		ns	
Al	8.2 ± 39	[0- 19]	2.1 ± 3.9	[0.54 - 3.7]		ns	
Mn	0.19 ± 0.2	[0.13 - 0.24]	0.18 ± 0.072	[0.15 - 0.21]		ns	
Cr	0.038 ± 0.047	[0.025 - 0.051]	0.05 ± 0.077	[0.018 - 0.082]		ns	
Co	0.17 ± 1.1	[0 - 0.47]	0.013 ± 0.022	[0.0035 - 0.022]			
K	3600 ± 420	[3500 - 3700]	3600 ± 280	[3500 - 3700]			
P	2200 ± 240	[2200 - 2300]	2300 ± 220	[2200 - 2400]			
Na	710 ± 490	[570 - 850]	630 ± 290	[510 - 740]			
Mg	280 ± 72	[260 - 300]	260 ± 34	[240 - 270]			
Ca	55 ± 62	[37 - 72]	41 ± 16	[35 - 48]			
Rb	1.8 ± 0.41	[1.7 - 1.9]	2.1 ± 0.37	[1.9 - 2.2]			
B	0.26 ± 0.23	[0.2 - 0.33]	0.24 ± 0.13	[0.19 - 0.29]			
Sr	0.24 ± 0.6	[0.074 - 0.42]	0.11 ± 0.16	[0.048 - 0.18]			
Sn	0.025 ± 0.021	[0.018 - 0.031]	0.024 ± 0.018	[0.016 - 0.031]			
Sb	0.0025 ± 0.0024	[0.0018 - 0.0032]	0.004 ± 0.0072	[0.0011 - 0.007]			
Mo	0.0057 ± 0.0036	[0.0047 - 0.0067]	0.0054 ± 0.0018	[0.0047 - 0.0061]			
Tl	0.00058 ± 0.00075	[0.00037 - 0.00079]	0.00044 ± 1e-04	[0.00039 - 0.00048]			

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

Table 3 - Mean concentration (mg kg^{-1}) of total trace metals in the skin of adult narwhal (> 350cm) harvested in Eclipse Sound and Admiralty Inlet in 2022 and 2023. Standard deviation and 95% confidence interval are provided. Results of Wilcoxon-Mann-Whitney tests (W) or Student t-tests (t) compare concentrations among regions. Statistical significance is determined by p-value.



Adult Narwhal -- SKIN

Metal	Eclipse Sound (n = 50)		Admiralty Inlet (n = 27)		T-test		
	Mean + sd	95% CI	Mean + sd	95% CI	ES vs AI	Significance	Test results
Hg	0.69 ± 0.39	[0.58 - 0.8]	0.42 ± 0.14	[0.36 - 0.48]	ES > AI	**	W(72) = 335, p = 0.0023
Cd	0.034 ± 0.04	[0.023 - 0.046]	0.05 ± 0.04	[0.033 - 0.067]	AI > ES	*	W(72) = 812, p = 0.014
Pb	0.039 ± 0.1	[0.0094 - 0.068]	0.023 ± 0.02	[0.014 - 0.031]		ns	
Zn	65 ± 13	[61 - 69]	57 ± 13	[51 - 63]	ES > AI	*	t(72) = -2,4, p = 0.019
Cu	0.46 ± 0.21	[0.4 - 0.52]	0.43 ± 0.19	[0.35 - 0.51]		ns	
Se	4.1 ± 1.6	[3.6 - 4.5]	3.7 ± 1.2	[3.2 - 4.2]		ns	
Ag	0.010 ± 0.014	[0.0062 - 0.014]	0.0061 ± 0.0031	[0.0048 - 0.0074]		ns	
Ni	0.088 ± 0.32	[0 - 0.18]	0.14 ± 0.39	[0 - 0.3]		ns	
As	1.1 ± 0.3	[0.98 - 1.1]	1.2 ± 0.27	[1.1 - 1.4]	AI > ES	*	t(72) = 2,46, p = 0.016
Fe	6.4 ± 4	[5.3 - 7.6]	6 ± 5.7	[3.6 - 8.4]		ns	
Al	1.7 ± 3.5	[0.74 - 2.7]	1.8 ± 4.8	[0 - 3.9]		ns	
Mn	0.14 ± 0.15	[0.093 - 0.18]	0.13 ± 0.056	[0.11 - 0.15]		ns	
Cr	0.052 ± 0.073	[0.031 - 0.073]	0.025 ± 0.023	[0.015 - 0.035]	ES > AI	**	W(72) = 372, p = 0.0084
Co	0.085 ± 0.52	[0 - 0.23]	0.16 ± 0.57	[0 - 0.4]			
K	2600 ± 380	[2500 - 2700]	2400 ± 560	[2200 - 2700]			
P	1600 ± 230	[1500 - 1600]	1400 ± 320	[1300 - 1600]			
Na	1000 ± 240	[970 - 1100]	870 ± 200	[780 - 950]			
Mg	140 ± 24	[140 - 150]	130 ± 34	[120 - 140]			
Ca	64 ± 21	[58 - 70]	56 ± 13	[51 - 62]			
Rb	1.7 ± 0.45	[1.6 - 1.8]	1.8 ± 0.35	[1.7 - 2]			
B	0.25 ± 0.087	[0.23 - 0.28]	0.33 ± 0.13	[0.28 - 0.39]			
Sr	0.26 ± 0.13	[0.23 - 0.3]	0.23 ± 0.1	[0.18 - 0.27]			
Sn	0.024 ± 0.012	[0.02 - 0.027]	0.04 ± 0.032	[0.026 - 0.053]			
Sb	0.0037 ± 0.0023	[0.003 - 0.0043]	0.005 ± 0.0054	[0.0027 - 0.0072]			
Mo	0.0045 ± 0.0019	[0.004 - 0.0051]	0.0065 ± 0.012	[0.0015 - 0.011]			
Tl	0.00069 ± 0.00041	[0.00057 - 0.00081]	0.00066 ± 0.00036	[0.00051 - 0.00082]			

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

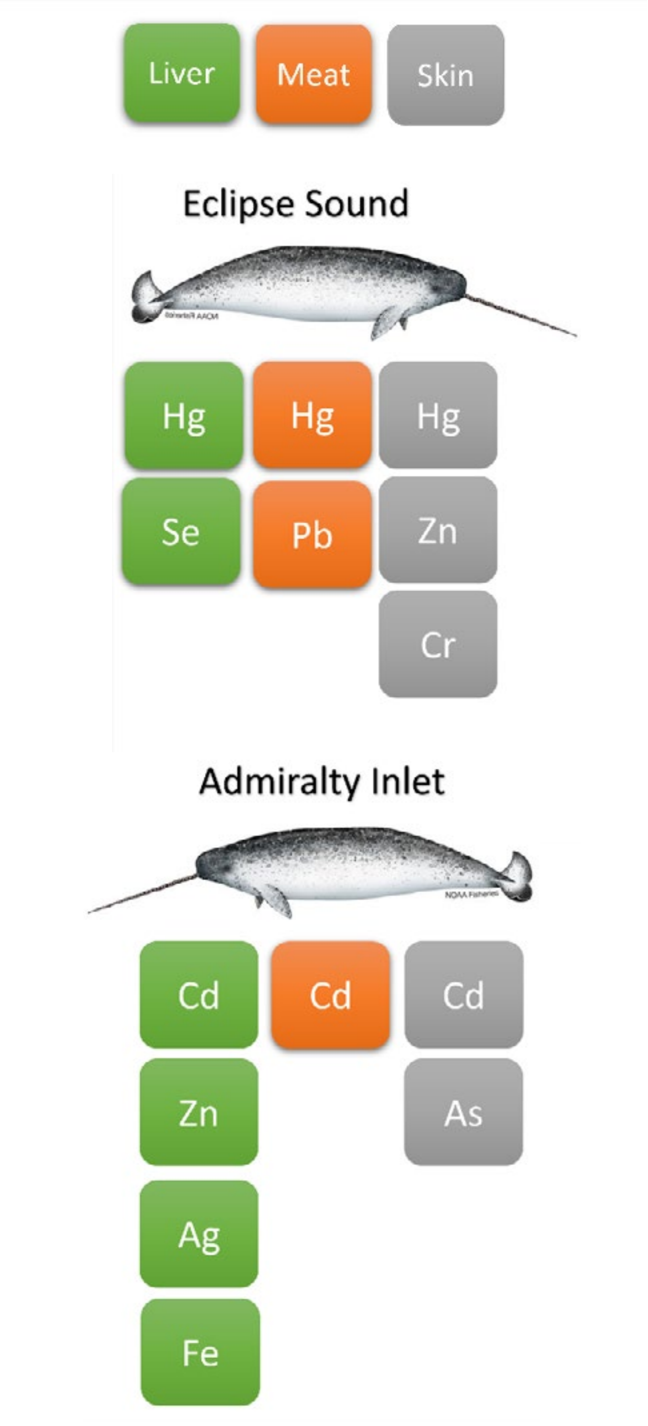


Figure 2 – Graphical illustration of the significant differences observed in the concentration of trace metals in liver (green), muscle (orange) and skin (gray) among narwhal harvested in Eclipse Sound and Admiralty Inlet in 2022-23. Trace metal icons illustrated under Eclipse Sound indicate that concentrations were significantly higher in narwhal from that region vs Admiralty Inlet, and vice-versa. See Table 1-3 for details.

EXTREME CONCENTRATIONS OF TRACE METALS

In some narwhal, concentrations of trace metals fell far outside ranges displayed in Table 1, 2 and 3.

MERCURY (HG)

Hepatic concentrations of total Hg in most narwhal from Eclipse Sound ranged from 13 to 21 mg kg^{-1}, but the liver of an adult female (#72) harvested in fall 2022 in Tremblay Sound showed an abnormally high concentration of total Hg of 73 mg kg^{-1} (Figure 3). The same animal exhibited a high level of total Se (63 mg kg^{-1}); a metal known to neutralize the toxicity of Hg in the liver.

CADMIUM (CD)

Hepatic concentrations of total Cd in most narwhal from Eclipse Sound ranged from 22 to 39 mg kg^{-1} and from 47 to 74 mg kg^{-1} in Ikpiarjuk (Table 1). The meat of two adult males (#107 and #21) from Admiralty Inlet showed abnormally high concentrations of total Cd (45.7 mg/kg and 23 mg/kg, respectively); a hundred times the mean concentration observed in Admiralty Inlet (0.41 ± 0.38 mg kg^{-1}) (Table 2). In Eclipse Sound, the meat of a male narwhal (#80) harvested in the fall 2022 near Upirngivik showed an abnormally high concentration of total Cd (19.2 mg kg^{-1}); a hundred times the mean concentration observed in Eclipse Sound (0.24 ± 0.21 mg kg^{-1}). This individual was also reported as unhealthy by the harvester. Still, in Eclipse Sound, the skin of narwhal #63 exhibited a high concentration of total Cd (1.1 mg kg^{-1}); 50 times the mean concentration observed in Eclipse Sound (0.023 - 0.046 mg kg^{-1}).

LEAD (PB) AND ALUMINUM (AL)

Concentrations of total Pb in the meat of most narwhal from Eclipse Sound ranged from 0 to 1.1 mg kg^{-1}, but a female (#59) harvested at fall 2022 in the region showed abnormally high concentration of total Pb (18 mg kg^{-1}). The meat of the same female showed an elevated concentration of Al (272 mg kg^{-1}), 30 times the mean concentration observed in Eclipse Sound (8.2 ± 39 mg kg^{-1}). The skin of narwhal #27 and narwhal #66 from Eclipse Sound showed extreme concentrations of total Pb (0.61 mg kg^{-1} and 0.44 mg kg^{-1}, respectively); 10 times the mean concentration of the region (0.039 ± 0.1 mg kg^{-1}).

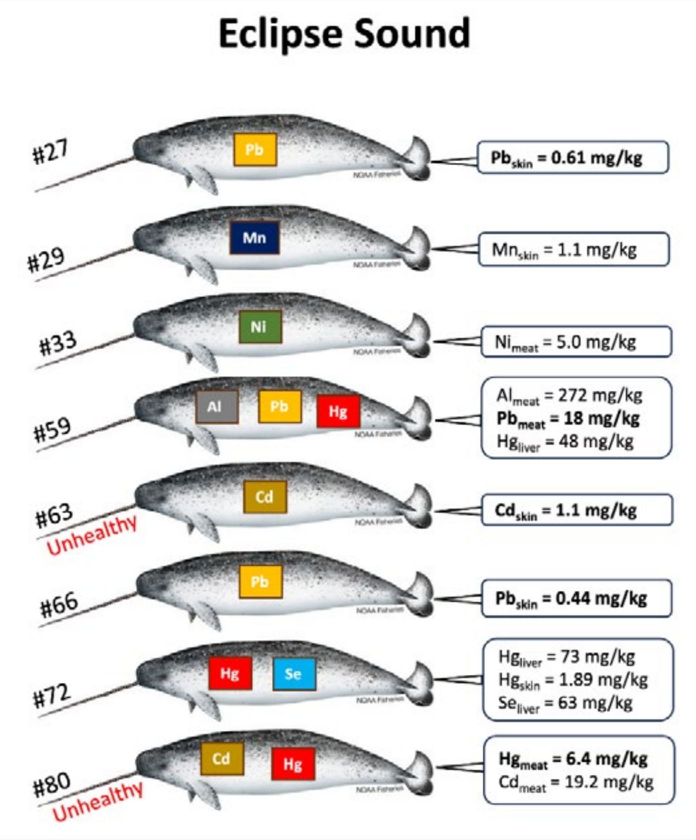


Figure 3 – Graphical list of narwhals harvested in Eclipse Sound in 2022-23 with elevated concentrations of trace metals (outliers). Characters in bold highlight extreme outliers for heavy metals (Hg, Cd, As, Pb). The statistical method used to determine the outliers is described in the methods.

OTHER METALS

The skin and meat of narwhal #107, harvested in the spring 2023 in Sinaavik, Admiralty Inlet, showed high concentrations of Ni (meat = 6.92 mg kg^{-1} ; skin = 13.3 mg kg^{-1}), Hg (meat = 9.22 mg kg^{-1}) and Fe (skin = 705 mg kg^{-1}), about ten times the mean concentrations observed in Admiralty Inlet. The liver of narwhal #105 harvested at spring 2023 in Admiralty Inlet showed an abnormally high concentration of Ni (359 mg kg^{-1}), 20 times the mean concentration observed in the region (14 ± 72 mg kg^{-1}).

Finally, the skin of narwhal #126, harvested in the spring 2023 in Admiralty Inlet, showed extreme concentrations of Mn (1.47 mg kg^{-1}), Cu (44.5 mg kg^{-1}), Ni (487 mg kg^{-1}), Al (184 mg kg^{-1}) and Fe (861 mg kg^{-1}); hundred times the mean concentrations observed in the region (0.13 ± 0.06 mg kg^{-1}, 0.61 ± 0.93 mg kg^{-1}, 0.66 ± 2.7 mg kg^{-1}, 2.1 ± 5.1 mg kg^{-1} and 6.6 ± 6.3 mg kg^{-1}, respectively).

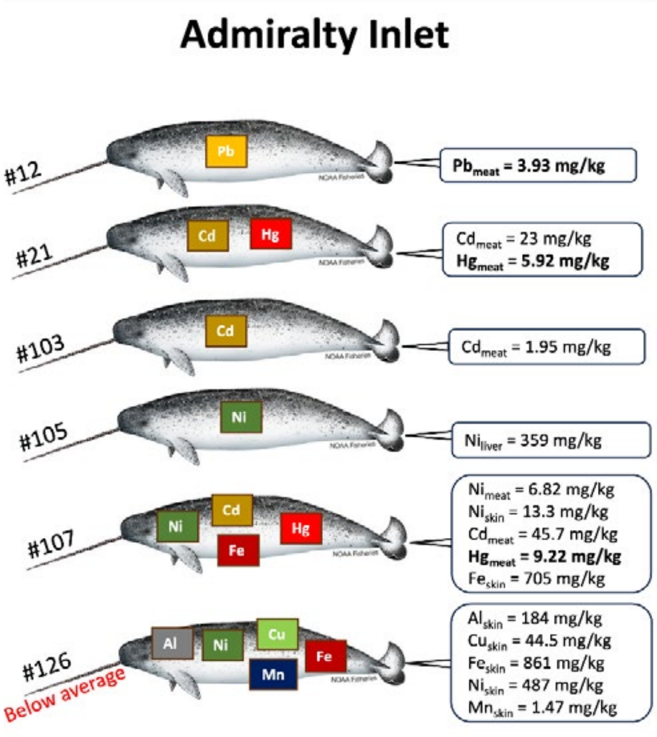
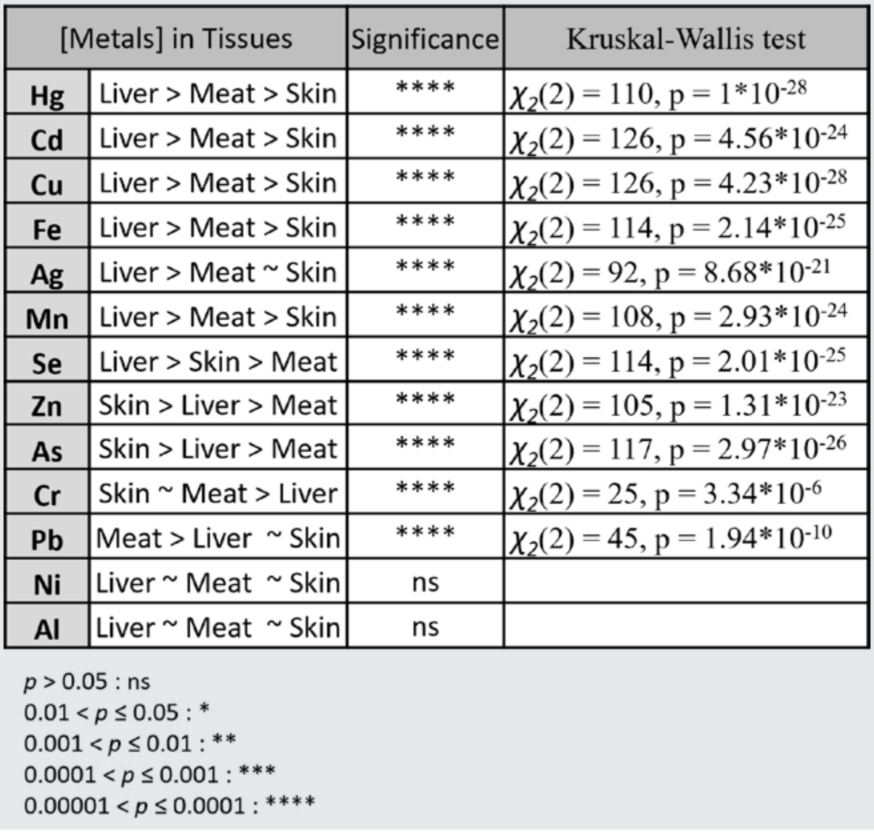


Figure 4 - Graphical list of narwhal harvested in Admiralty Inlet in 2022-23 with elevated concentrations of trace metals (outliers). Characters in bold highlight extreme outliers for heavy metals (Hg, Cd, As, Pb). The statistical method used to determine the outliers is described in the methods.

TISSUE

Hierarchical differences in the concentration of trace metals is typical among tissues and usually the highest in the liver of marine mammals (Rune Dietz et al. 2019; Sonne et al. 2018a; B. Braune et al. 2015; Dehn et al. 2005). Mean concentrations of Hg, Cd, Cu, Fe and Mn in narwhal were significantly more elevated in liver (Hg = 17 ± 13 mg kg^{-1} ; Cd = 30 ± 29 mg kg^{-1}; Cu = 7.8 ± 5 mg kg^{-1}; Fe = 500 ± 240 mg kg^{-1}; Mn = 1.9 ± 0.51 mg kg^{-1}) than in meat (Hg = 1.5 ± 0.6 mg kg^{-1} ; Cd = 0.24 ± 0.21 mg kg^{-1}; Cu = 0.84 ± 0.24 mg kg^{-1}; Fe = 270 ± 55 mg kg^{-1}; Mn = 0.19 ± 0.20 mg kg^{-1}) , and significantly more elevated in meat than in skin (Hg = 0.7 ± 0.4 mg kg^{-1} ; Cd = 0.034 ± 0.04 mg kg^{-1}; Cu = 0.46 ± 0.21 mg kg^{-1}; Fe = 6.4 ± 4.0 mg kg^{-1}; Mn = 0.14 ± 0.15 mg kg^{-1}) (Table 4). Mean concentrations of Ag were significantly higher in liver (Ag = 1.40 ± 0.75 mg kg^{-1}) than other tissues but were no different between meat (Ag = 0.046 ± 0.140 mg kg^{-1}) and skin (Ag = 0.010 ± 0.014 mg kg^{-1}). Interestingly, mean concentrations of Zn and As were more significantly higher in skin (65 ± 13 mg kg^{-1}; 1.1 ± 0.3 mg kg^{-1}, respectively) than in liver (40 ± 12 mg kg^{-1}; 0.42 ± 0.16 mg kg^{-1}, respectively) and meat (24 ± 8.7 mg kg^{-1}; 0.21 ± 0.08 mg kg^{-1}, respectively). Mean concentration of Se was higher in liver (12 ± 11 mg kg^{-1}) than in the skin (4.1 ± 1.6 mg kg^{-1}) and the meat (0.48 ± 0.12 mg kg^{-1}). Pb was significantly higher in the meat (0.39 ± 2.6 mg kg^{-1}) than in the skin (0.039 ± 0.100 mg kg^{-1}) and the liver (0.038 ± 0.017 mg kg^{-1}). Finally, the mean concentration of Cr was lower in liver (0.020 ± 0.020 mg kg^{-1}) than in meat (0.038 ± 0.047 mg kg^{-1}) and skin (0.052 ± 0.073 mg kg^{-1}).

Table 4 – Hierarchical differences in the concentration of trace metals among tissue in adult narwhal harvested in Eclipse Sound in 2022-23. Significance was determined by Kruskal Walis test and post hoc Dunn test Adjusted p-values (Benjamini-Hochberg) are provided.



[Metals] in Tissues		Significance	Kruskal-Wallis test
Hg	Liver > Meat > Skin	****	$\chi_2(2) = 110, p = 1*10^{-28}$
Cd	Liver > Meat > Skin	****	$\chi_2(2) = 126, p = 4.56*10^{-24}$
Cu	Liver > Meat > Skin	****	$\chi_2(2) = 126, p = 4.23*10^{-28}$
Fe	Liver > Meat > Skin	****	$\chi_2(2) = 114, p = 2.14*10^{-25}$
Ag	Liver > Meat ~ Skin	****	$\chi_2(2) = 92, p = 8.68*10^{-21}$
Mn	Liver > Meat > Skin	****	$\chi_2(2) = 108, p = 2.93*10^{-24}$
Se	Liver > Skin > Meat	****	$\chi_2(2) = 114, p = 2.01*10^{-25}$
Zn	Skin > Liver > Meat	****	$\chi_2(2) = 105, p = 1.31*10^{-23}$
As	Skin > Liver > Meat	****	$\chi_2(2) = 117, p = 2.97*10^{-26}$
Cr	Skin ~ Meat > Liver	****	$\chi_2(2) = 25, p = 3.34*10^{-6}$
Pb	Meat > Liver ~ Skin	****	$\chi_2(2) = 45, p = 1.94*10^{-10}$
Ni	Liver ~ Meat ~ Skin	ns	
Al	Liver ~ Meat ~ Skin	ns	

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

AGE

The age of an individual can influence the concentration of bioaccumulating and biomagnifying trace metals. Hepatic concentrations of three non-essential heavy metals; Hg, Pb and Cd, were higher in adults (16.9 ± 12.9 mg kg^{-1} ; 0.038 ± 0.017 mg kg^{-1} ; 30.2 ± 28.7 mg kg^{-1}, respectively) than subadults (3.5 ± 2.7 mg kg^{-1} ; 0.020 ± 0.011 mg kg^{-1} ; 11.9 ± 11.6 mg kg^{-1}, respectively) (*U*(59) = 34, p = 7*10^{-6} ; *U*(59) = 107, p = 0.002 ; *U*(59) = 137, p = 0.010 respectively for Hg, Pb and Cd) (Figure 5). The concentration of Se was also significantly higher in the liver of adults (11.6 ± 10.6 mg kg^{-1}) than in subadults (4.6 ± 4.5 mg kg^{-1}) (*U*(59) = 114, p = 0.0031). In contrast, concentrations of Cr and Mn were higher in the liver of subadults (0.043 ± 0.037 mg kg^{-1}; 2.52 ± 1.17 mg kg^{-1}, respectively) than adults (0.020 ± 0.022 mg kg^{-1}; 1.88 ± 0.51 mg kg^{-1}, respectively) (*U*(59) = 409, p = 0.0056; *U*(59) = 414, p = 0.0058, respectively for Cr and Mn).

Concentrations of Hg and As were more elevated in the skin of adults (0.69 ± 0.39 mg kg^{-1} ; 1.06 ± 0.29 mg kg^{-1}, respectively) compared to subadults (0.37 ± 0.32 mg kg^{-1}; 0.74 ± 0.31 mg kg^{-1}, respectively) (*U*(62) = 127, p = 0.0008; *U*(62) = 159, p = 0.005, respectively for Hg and As). However, concentrations of Cd and Mn were higher in the liver of subadults (0.097 ± 0.305 mg kg^{-1}; 0.21 ± 0.14 mg kg^{-1}, respectively) than in adults (0.034 ± 0.040 mg kg^{-1}; 0.13 ± 0.15 mg kg^{-1}, respectively) (*U*(62) = 145, p = 0.0023; *U*(62) = 464, p = 0.0050, respectively).

In the meat of narwhal, concentrations of Hg were more elevated in adults (1.50 ± 0.61 mg kg^{-1}) than in subadults (1.26 ± 1.70 mg kg^{-1}) (*U*(62) = 129, p = 0.0009). Concentrations of Cd and Cu were higher in the liver of subadults (1.59 ± 5.29 mg kg^{-1}; 1.46 ± 1.51 mg kg^{-1}, respectively) than in adults (0.238 ± 0.206 mg kg^{-1}; 0.84 ± 0.24 mg kg^{-1}, respectively) (*U*(62) = 161, p = 0.0055; *U*(62) = 493, p = 0.0044, respectively for Cd and Cu).

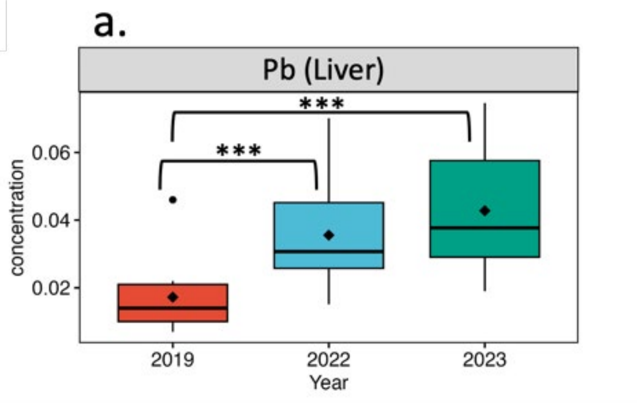
Figure 5 – Graphical illustration of the significant differences observed in the concentration of trace metals in liver (green), muscle (orange) and skin (gray) between adult and subadult narwhal harvested in Eclipse Sound in 2022-23. Trace metal icons illustrated under 'Adult' indicate that concentrations were significantly higher in adult narwhal vs 'subadult', and vice-versa.

SEASONAL AND INTERANNUAL

In adult narwhal from Eclipse Sound, seasonal differences in the concentration of trace metals were observed for total As and Cr. Mean concentrations of total As in the meat and liver of narwhal harvested at spring (0.238 ± 0.074 mg kg^{-1} and 0.485 ± 0.151 mg kg^{-1}, respectively) were significantly higher than in the meat and liver of narwhal harvested at summer (0.175 ± 0.073 mg kg^{-1} and 0.351 ± 0.150 mg kg^{-1}, respectively) ($U(44) = 2.85$, p = 0.007) and $U(44) = 2.97$, p = 0.005 respectively for meat and liver).

We compared adult narwhal harvested in the same season among years and using data collected in 2019 in the same region (Simonee et al. unpublished). The mean hepatic concentration of total Pb in 2019 (0.017 ± 0.012 mg kg^{-1}) was significantly lower than in 2022 (0.35 ± 0.015 mg kg^{-1}) or 2023 (0.043 ± 0.018 mg kg^{-1}) ($\chi_2(2) = 15.0$, p = 0.0005, *n = 53*) (Fig. 6a). The mean hepatic concentration of total Cu in 2022 (9.44 ± 6.35 mg kg^{-1}) was significantly higher than 2019 (5.34 ± 2.38 mg kg^{-1}) or 2023 (5.84 ± 1.85 mg kg^{-1}) ($\chi_2(2) = 9.4$, p = 0.009, *n = 53*) (Fig. 6b).

In the muscle tissue, the mean concentration of total Cr in 2023 (0.018 ± 0.011 mg kg^{-1}) was lower than in 2019 (0.046 ± 0.023 mg kg^{-1}) or 2022 (0.052 ± 0.059 mg kg^{-1}) ($\chi_2(2) = 15.7$, p = 0.0003, *n = 54*) (Fig.6c).



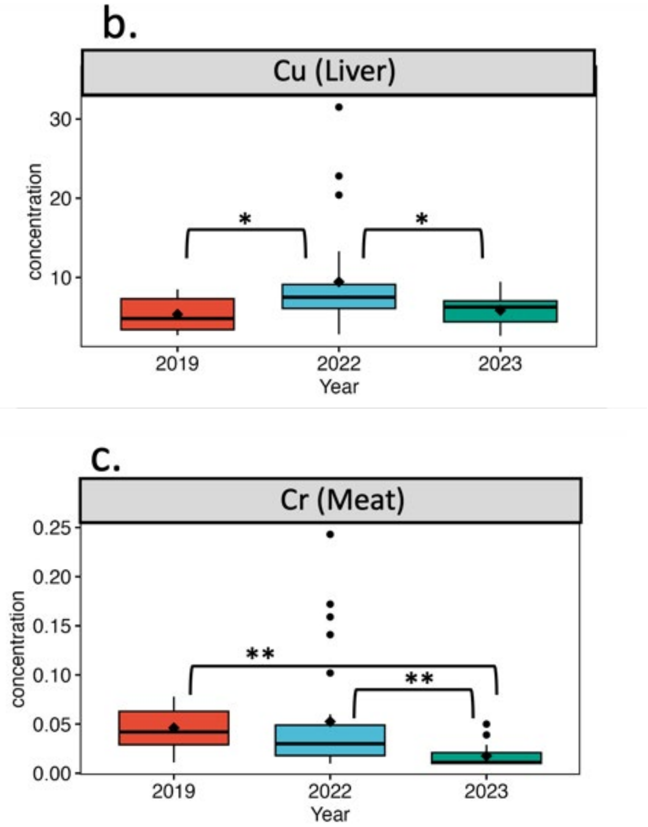
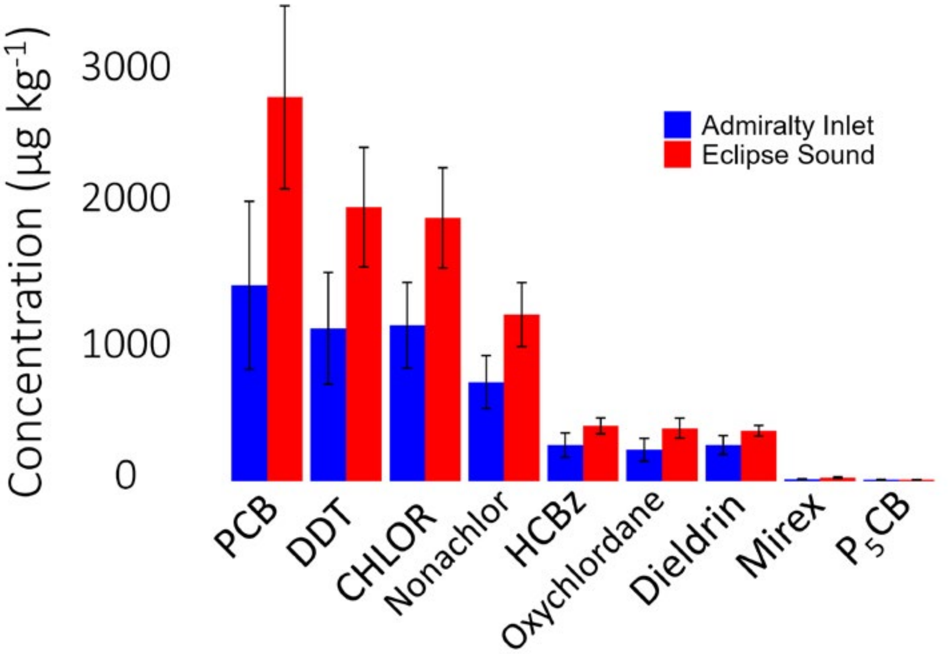


Figure 6 - Inter-annual differences in concentrations of trace metals determined by Student's t-test on adult narwhal harvested in Eclipse Sound in 2022 and 2023. Median concentrations are illustrated by the dark bar. For comparison purpose, we plot 2019 data collected on narwhal of the Eclipse Sound. Asterisks attest the significance (see method section).

3.1.2 Persistent Organic Pollutants (POPs)

Mean concentrations of POPs measured in narwhal harvested in fall 2022 in Eclipse Sound (n = 6) and Admiralty Inlet (n = 6) are summarized in Figure 7. Mean concentrations of DDT ($\Sigma_4$dichlorodiphenyltrichloroethanes: 2786 ± 1626 µg kg^{-1}), PCB (Σ_{95}polychlorinated biphenyl: 1989 ± 1063 µg kg^{-1}) and CHLOR ($\Sigma_6$chlordanes: 1911 ± 891 µg kg^{-1}) were higher in narwhal from Eclipse Sound than Admiralty Inlet. However, differences observed were not statistically significant (e.g. for Total DDT, t(10) = -1.48, p = 0.17) likely due to our small sample size, and large among-individual variability observed. For example, narwhal

#1 (Eclipse Sound) exhibited the highest level of DDT (5,148 µg kg^{-1}), PCB (3,600 µg kg^{-1}) and CHLOR (3,202 µg kg^{-1}) while narwhal **#23** (Eclipse Sound) had concentrations about ten times lower (338 µg kg^{-1}, 332 µg kg^{-1} and 452 µg kg^{-1} for DDT, PCB, and CHLOR, respectively). These notable differences suggest that some individuals can be exposed to localized sources of contaminants in the Eclipse Sound and/or in the wintering grounds, whereas others are not. Emerging POPs, such a Perfluoroalkyl Substances (PFAS = 23 ± 14 µg kg^{-1}) remained relatively low.



POPS	2019	2022	
	Eclipse Sound (n = 6)	Eclipse Sound (n = 6)	Admiralty Inlet (n = 6)
Total PCB	2722 ± 2261	1989 ± 1063	1110 ± 994
Total DDT	3010 ± 2782	2786 ± 1626	1422 ± 1491
Tot CHLOR	2098 ± 1722	1911 ± 891	1133 ± 760
Hexachlorobenzene (HCBz)	402 ± 263	403 ± 141	264 ± 214
Pentachlorobenzene (P_5CB)	9 ± 6	11 ± 4	11 ± 8
Mirex	33 ± 27	29 ± 14	17 ± 7
trans-Nonachlor	1428 ± 1218	1210 ± 566	720 ± 471
Oxychlordane	406 ± 339	387 ± 177	231 ± 199
Dieldrin	361 ± 202	368 ± 94	264 ± 168
Total 21 PFAS		23 ± 14	16 ± 1

Figure 7 – Histogram illustrating mean concentrations (µg kg^{-1} wet weight) of Persistent Organochlorine Pollutants in the blubber of narwhal from Eclipse Sound (blue) and Admiralty Inlet (red) in 2022. The table shows the details. For purposes of comparison, we present former results obtained from narwhal in Eclipse Sound in 2019. (Simonee et al., unpublished).

3.1.3 Cortisol

The mean concentration of cortisol in narwhal harvested in fall 2022 (1.20 ± 1.45 ng g^{-1}) was significantly higher than narwhal from Admiralty Inlet (0.38 ± 0.30 ng g^{-1}) ($U(19) = 70.5$, p value = 0.052) (Figure 8). However, the concentration of cortisol in narwhal from the two regions were in the same range in 2023. Lowest concentrations of cortisol in narwhal from Eclipse Sound were observed at spring 2022 (0.51 ± 0.73 ng g^{-1}) and summer 2022 (0.43 ± 0.31 ng g^{-1}). During fall 2022 and spring and summer 2023, six narwhal from Eclipse Sound had extreme concentrations of cortisol (outliers) against three narwhal from Admiralty Inlet (Figure 9). The three highest cortisol concentrations were observed in narwhal from Eclipse Sound (5.6 ng/g, 11.3 ng/g and 16.5 ng/g for narwhal #103, #100 and #79, respectively) (Figure 9).

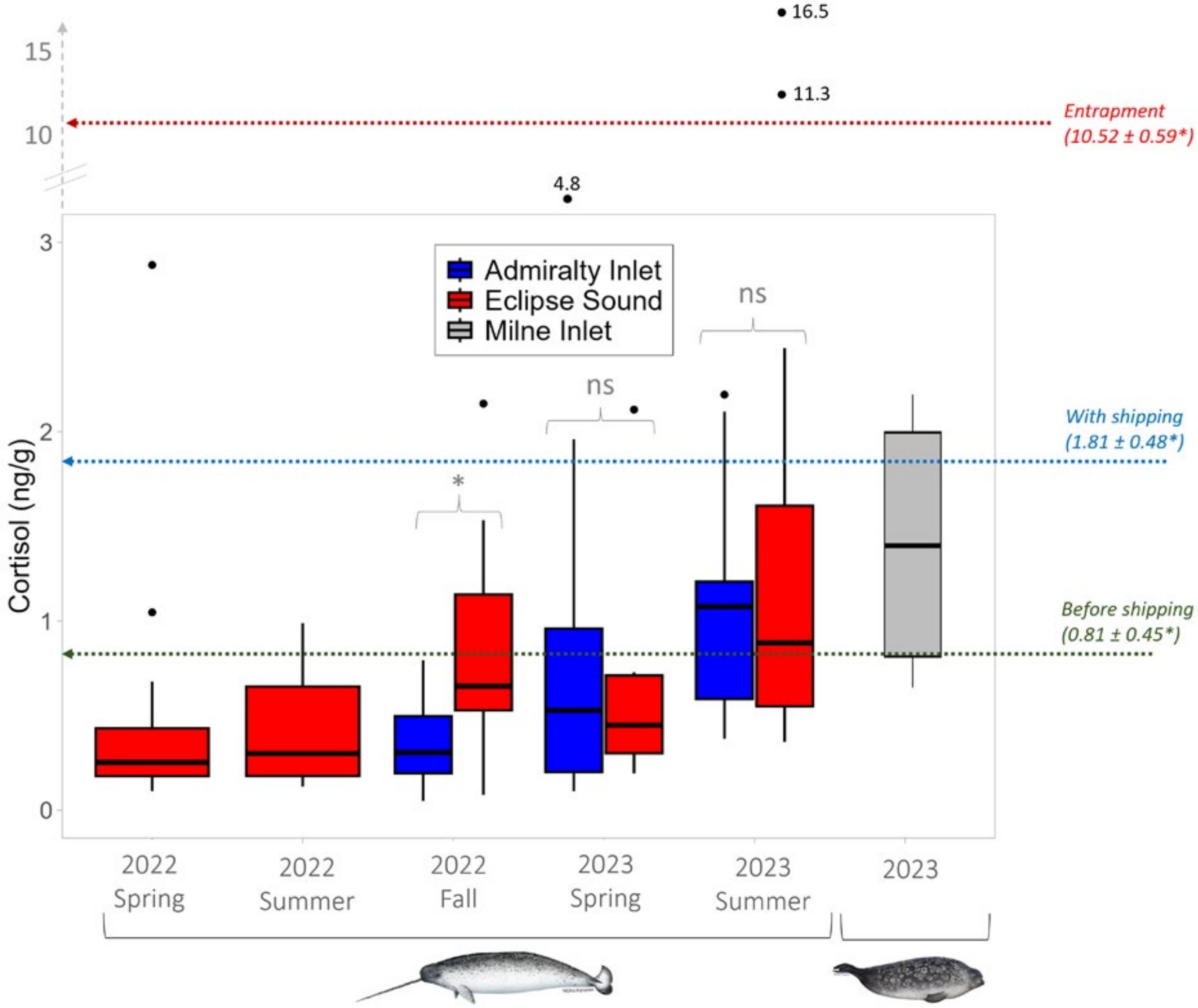


Figure 8 – Boxplots illustrating cortisol concentrations in the blubber of narwhal harvested in Eclipse Sound (red) and Admiralty Inlet (blue) from spring 2022 to summer 2023 and of ringed seal (grey) harvested in Milne Inlet in 2023. Median cortisol concentrations are illustrated by the dark bar. Extreme values are illustrated by the black dots. For comparison purpose, reference values/thresholds referring to the intensity of shipping traffic in Milne Inlet are provided in dotted lines (from Watt et al. 2022).

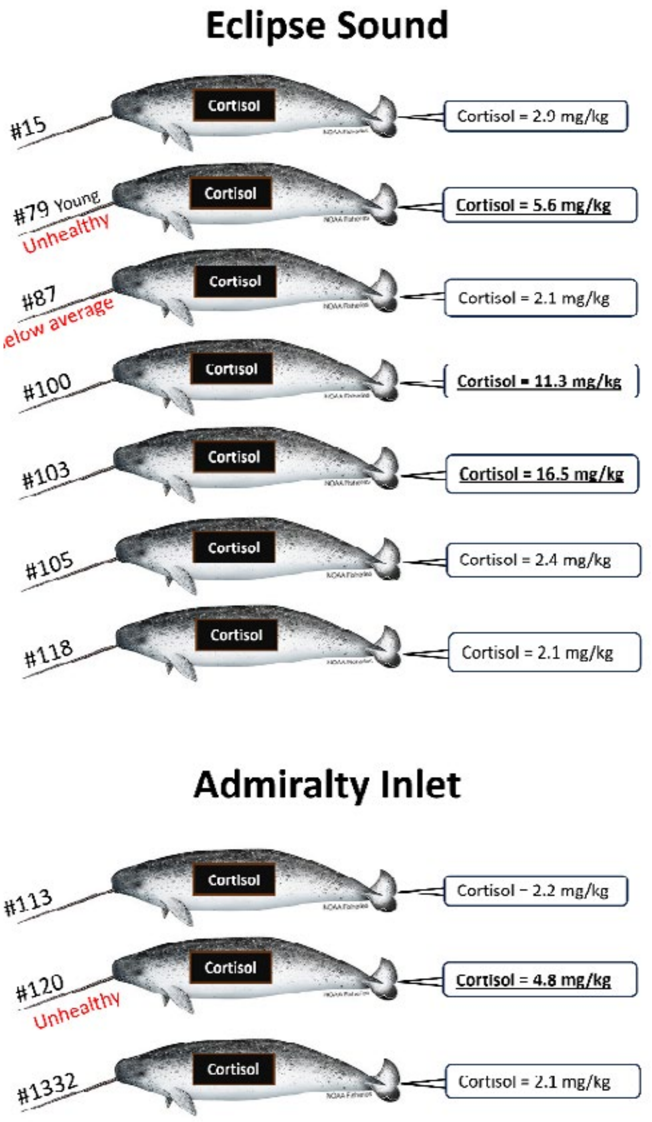


Figure 9 - Graphical list of narwhals harvested in Milne Inlet in 2022-23 with elevated concentrations of cortisol (outliers). Characters in bold highlight extreme outliers for cortisol. The statistical method used to determine the outliers and extreme outliers is described in the methods.

3.1.4 Body condition

3.1.4.1 VISUAL INSPECTION

Visual observations performed by the hunters on freshly harvested narwhal indicate that nearly 85% of the narwhal harvested in spring and summer were in good health in both Admiralty Inlet and Eclipse Sound, whereas 15% were deemed below average (Fig. 10). In Eclipse Sound in the fall, 40% of the narwhal harvested were deemed healthy, 40% below average, and 20% unhealthy. In Admiralty Inlet in the fall, 70% of the narwhal harvested were deemed healthy and 30% below average. None were deemed unhealthy. Interestingly, all the individuals reported as unhealthy in Eclipse Sound were subadults (**#79, #80, #81**).

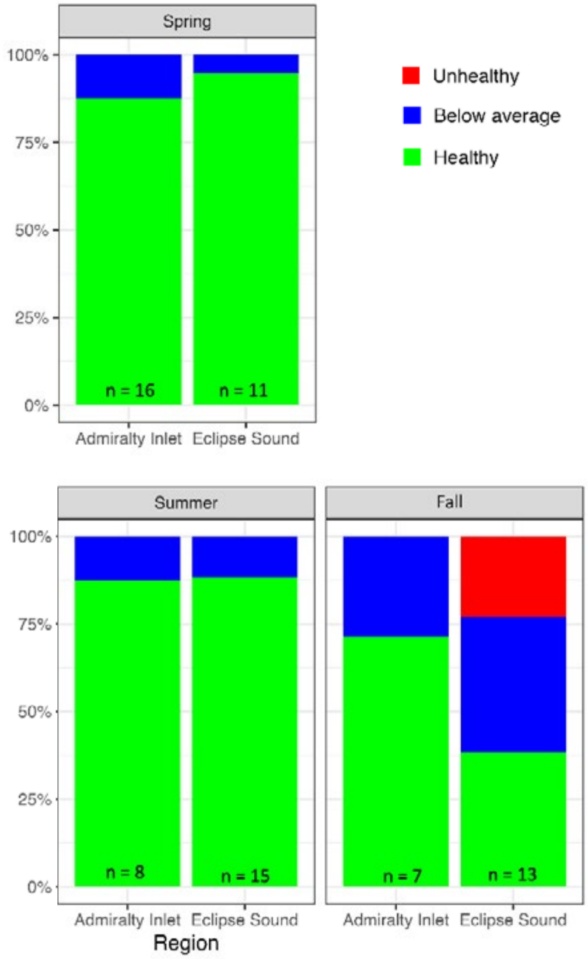


Figure 10 – Visual inspection depicting seasonal variation in the body condition of narwhal harvested in Eclipse Sound and Admiralty Inlet in 2022-23.

3.1.4.2 BLUBBER THICKNESS

The mean thickness of the blubber layer in the fall (5.8 ± 2.0 cm) was significantly lower than in spring (10.7 ± 4.8 cm) in narwhal from Admiralty Inlet ($\chi_2(2) = 7.9$, p = 0.019, *n = 38*) (Fig. 11). In the spring, mean blubber thickness in narwhal from Eclipse Sound (6.2 ± 0.9 cm) was significantly lower than narwhal from Admiralty Inlet (10.7 ± 4.8 cm) (*U*(36) = 24.5, p = 0.000017).

In Eclipse Sound, narwhal harvested in the spring of 2023 (4.8 ± 2.0 cm) were significantly leaner than in the spring of 2022 (6.2 ± 0.9 cm) (*t*(17) = 1.98, p = 0.06). Narwhal harvested in the summer of 2023 (7.2 ± 1.2 cm) were significantly fatter than the one harvested in the summer of 2022 (5.2 ± 1.7 cm) (*t*(22) = -3.35, p = 0.003).

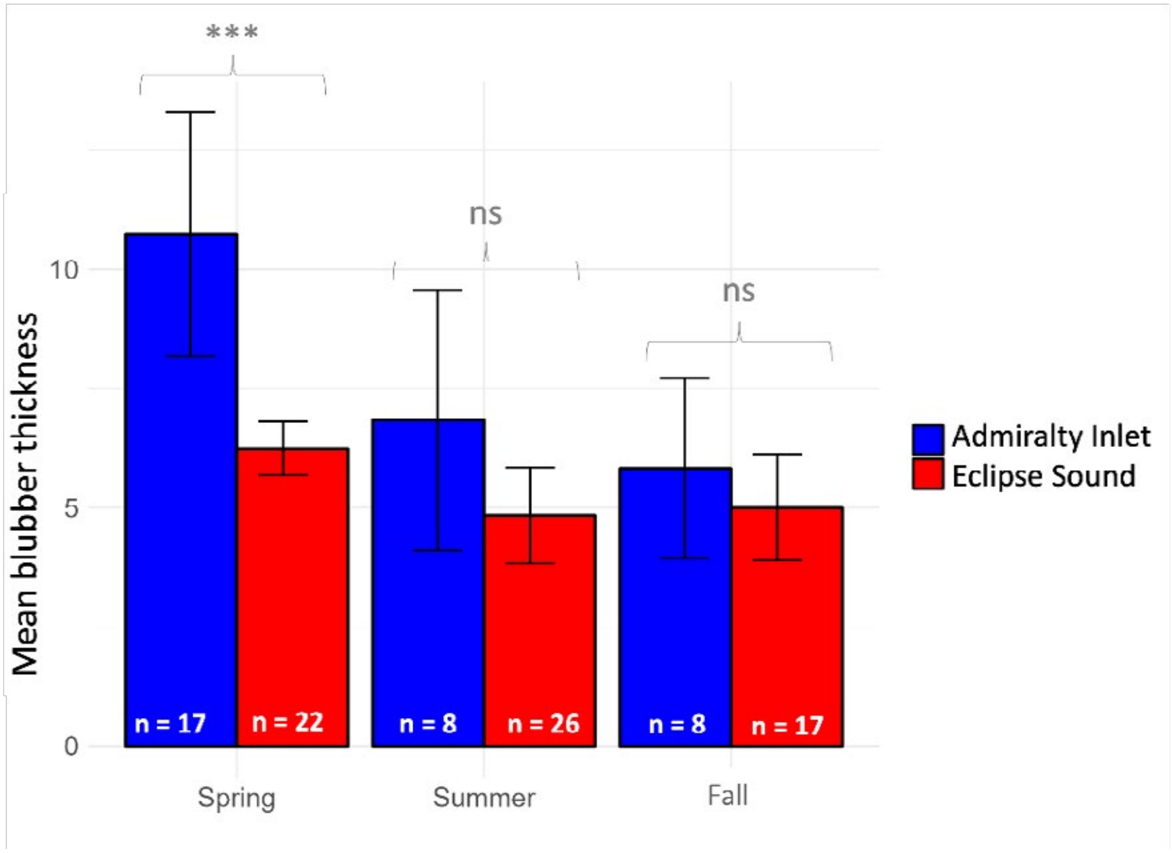


Figure 11 - Thickness of the blubber of narwhal harvested in Eclipse Sound and Admiralty Inlet in 2022 and 2023.

3.2 Ringed Seal

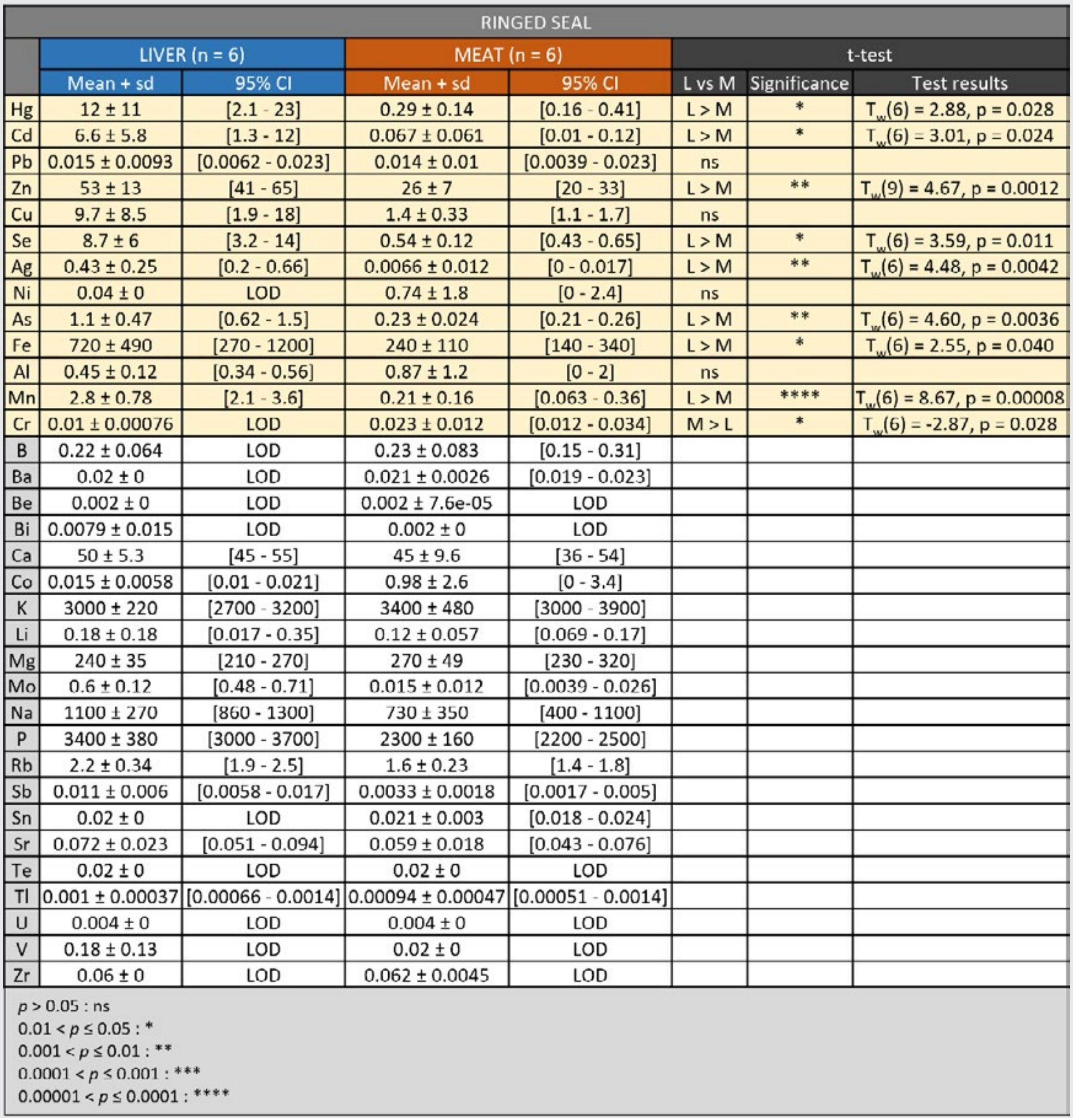
3.2.1 Age and body condition

Three of the seals sampled were newborns; two of them were deemed to be unhealthy (#9, #18). The four adult seals sampled (#7; 9 yr, #14; 5 yr, #21; 16 yr, and #8; 29 yr) had body conditions deemed below-average.

3.2.2 Trace metals

Fe and Zn were the most concentrated trace metals in liver (720 ± 490 mg kg^{-1} and 53 ± 13 mg kg^{-1}, respectively) and meat (240 ± 110 mg kg^{-1} and 26 ± 7 mg kg^{-1}, respectively, Table 5). Mean hepatic concentrations of non-essential metals Hg (12 ± 11 mg kg^{-1}) and Cd (6.6 ± 5.8 mg kg^{-1}) were relatively high in ringed seal.

Table 5 - Mean concentration (mg kg^{-1}) of total trace metals in the meat of adult ringed seal (>5-yo) harvested in Milne Inlet in the spring of 2023. Standard deviation and 95% confidence interval are provided. Non-parametric Welsh t-tests were used to compare concentrations among tissues. Results and statistical significance are provided.



RINGED SEAL							
	LIVER (n = 6)		MEAT (n = 6)		t-test		
	Mean + sd	95% CI	Mean + sd	95% CI	L vs M	Significance	Test results
Hg	12 ± 11	[2.1 - 23]	0.29 ± 0.14	[0.16 - 0.41]	L > M	*	T_w(6) = 2.88, p = 0.028
Cd	6.6 ± 5.8	[1.3 - 12]	0.067 ± 0.061	[0.01 - 0.12]	L > M	*	T_w(6) = 3.01, p = 0.024
Pb	0.015 ± 0.0093	[0.0062 - 0.023]	0.014 ± 0.01	[0.0039 - 0.023]	ns		
Zn	53 ± 13	[41 - 65]	26 ± 7	[20 - 33]	L > M	**	T_w(9) = 4.67, p = 0.0012
Cu	9.7 ± 8.5	[1.9 - 18]	1.4 ± 0.33	[1.1 - 1.7]	ns		
Se	8.7 ± 6	[3.2 - 14]	0.54 ± 0.12	[0.43 - 0.65]	L > M	*	T_w(6) = 3.59, p = 0.011
Ag	0.43 ± 0.25	[0.2 - 0.66]	0.0066 ± 0.012	[0 - 0.017]	L > M	**	T_w(6) = 4.48, p = 0.0042
Ni	0.04 ± 0	LOD	0.74 ± 1.8	[0 - 2.4]	ns		
As	1.1 ± 0.47	[0.62 - 1.5]	0.23 ± 0.024	[0.21 - 0.26]	L > M	**	T_w(6) = 4.60, p = 0.0036
Fe	720 ± 490	[270 - 1200]	240 ± 110	[140 - 340]	L > M	*	T_w(6) = 2.55, p = 0.040
Al	0.45 ± 0.12	[0.34 - 0.56]	0.87 ± 1.2	[0 - 2]	ns		
Mn	2.8 ± 0.78	[2.1 - 3.6]	0.21 ± 0.16	[0.063 - 0.36]	L > M	****	T_w(6) = 8.67, p = 0.00008
Cr	0.01 ± 0.00076	LOD	0.023 ± 0.012	[0.012 - 0.034]	M > L	*	T_w(6) = -2.87, p = 0.028
B	0.22 ± 0.064	LOD	0.23 ± 0.083	[0.15 - 0.31]			
Ba	0.02 ± 0	LOD	0.021 ± 0.0026	[0.019 - 0.023]			
Be	0.002 ± 0	LOD	0.002 ± 7.6e-05	LOD			
Bi	0.0079 ± 0.015	LOD	0.002 ± 0	LOD			
Ca	50 ± 5.3	[45 - 55]	45 ± 9.6	[36 - 54]			
Co	0.015 ± 0.0058	[0.01 - 0.021]	0.98 ± 2.6	[0 - 3.4]			
K	3000 ± 220	[2700 - 3200]	3400 ± 480	[3000 - 3900]			
Li	0.18 ± 0.18	[0.017 - 0.35]	0.12 ± 0.057	[0.069 - 0.17]			
Mg	240 ± 35	[210 - 270]	270 ± 49	[230 - 320]			
Mo	0.6 ± 0.12	[0.48 - 0.71]	0.015 ± 0.012	[0.0039 - 0.026]			
Na	1100 ± 270	[860 - 1300]	730 ± 350	[400 - 1100]			
P	3400 ± 380	[3000 - 3700]	2300 ± 160	[2200 - 2500]			
Rb	2.2 ± 0.34	[1.9 - 2.5]	1.6 ± 0.23	[1.4 - 1.8]			
Sb	0.011 ± 0.006	[0.0058 - 0.017]	0.0033 ± 0.0018	[0.0017 - 0.005]			
Sn	0.02 ± 0	LOD	0.021 ± 0.003	[0.018 - 0.024]			
Sr	0.072 ± 0.023	[0.051 - 0.094]	0.059 ± 0.018	[0.043 - 0.076]			
Te	0.02 ± 0	LOD	0.02 ± 0	LOD			
Tl	0.001 ± 0.00037	[0.00066 - 0.0014]	0.00094 ± 0.00047	[0.00051 - 0.0014]			
U	0.004 ± 0	LOD	0.004 ± 0	LOD			
V	0.18 ± 0.13	LOD	0.02 ± 0	LOD			
Zr	0.06 ± 0	LOD	0.062 ± 0.0045	LOD			

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

Seal **#7** had the highest concentration of Hg (0.53 mg kg^{-1}), Se (0.76 mg kg^{-1}) and Ag (0.033 mg kg^{-1}) in the meat. Seal **#14** the highest concentration of Al (3.58 mg kg^{-1}) and Ni (4.92 mg kg^{-1}) in the meat; ten times the average concentrations (Fig. 12). Seal **#18**, reported as unhealthy by local hunters, had elevated hepatic concentration of Cu (27.5 mg kg^{-1}) and Zn (81.2 mg kg^{-1}) compared to the group average. Newborn seal **#9** had the highest hepatic concentration of Pb (19.2 mg kg^{-1}), over 500 times the average, and of Mn (6.4 mg kg^{-1}).

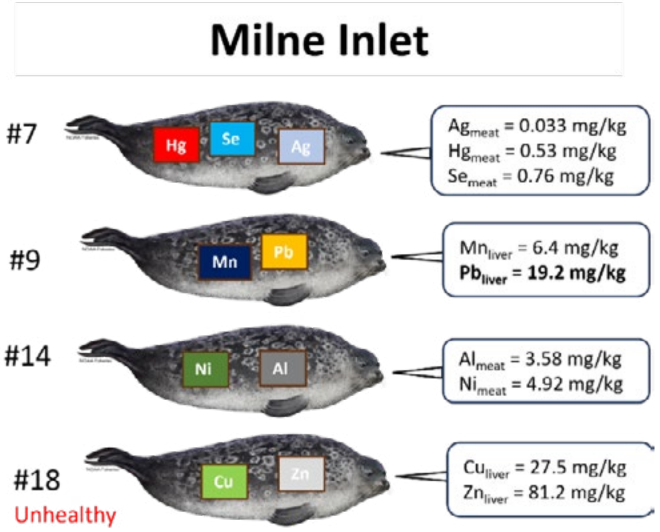


Figure 12 - Graphical list of ringed seal harvested in Milne Inlet in 2023 with elevated concentrations of trace metals (outliers). Characters in bold highlight extreme outliers for heavy metals (Hg, Cd, As, Pb). The statistical method used to determine the outliers is described in the methods.

Estimated mean concentration of MeHg in the liver and the muscle of ringed seal was 2.36 ± 0.90 mg kg^{-1} and 0.23 ± 0.14 mg kg^{-1}, respectively.

TISSUE

Trace metal concentrations were higher in the liver than in the meat, as observed for Hg, Cd, Zn, As, Fe, Se, Ag and Mn (see Table 5). However, Cr was less concentrated ($t(11) = -2.87$, p = 0.028) in the liver (0.010 ± 0.001 mg kg^{-1}) than in the meat (0.023 ± 0.012 mg kg^{-1}). Differences between tissues were not significative for Pb, Cu, Ni and Al, possibly due to the small sample size.

INTERANNUAL VARIATION

Mean concentrations of Hg and Cd in ringed seal harvested in Milne Inlet in 2023 were in the same range as seal harvested in 2017-2018 in Eclipse Sound and seal from the Northeastern Canadian Arctic. The concentration of Hg in ringed seal meat measured in 2023 (0.29 ± 0.14 mg kg^{-1}) was also in the range of ringed seal harvested in 2009 in Mittimatalik (0.20 ± 0.03 mg kg^{-1}, Brown et al. 2016).

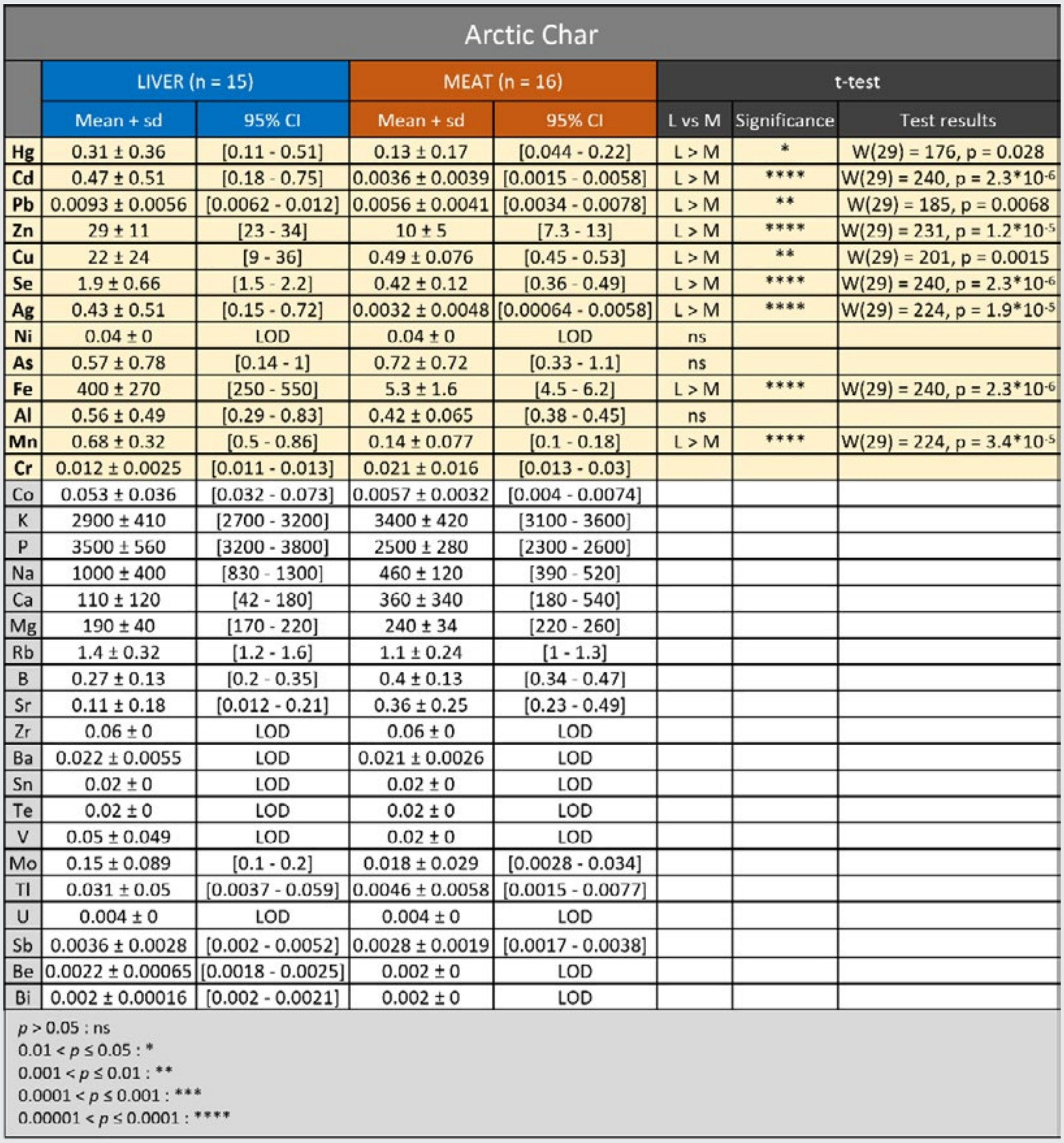
CORTISOL

Cortisol levels were measured in the blubber of four ringed seal from Milne Inlet and ranged from 0.65 to 2.20 ng g^{-1}. Highest cortisol levels observed (Figure 8) were in the range of stressed narwhal exposed to shipping traffic (Watt et al. 2022). Mean cortisol levels in ringed seal from Milne Inlet (1.42 ± 0.77 ng g^{-1}) were not statistically different than in narwhal from Eclipse Sound (1.18 ± 2.56 ng g^{-1}) or Admiralty Inlet (0.82 ± 0.90 ng g^{-1}). Small sample size was nonetheless limiting.

3.3 Arctic Char

Table 6 depicts trace metals concentration in the liver and meat of Arctic char harvested in Qurluqtuuq lake in the spring of 2023. Mean concentrations of Fe (400 ± 270 mg kg^{-1}) and Zn (29 ± 11 mg kg^{-1}) were the highest among the trace metals tested in Arctic Char (Table 6). Mean concentration of As was relatively high in the meat of Arctic char ranging from 0.33 to 1.1 mg kg^{-1} (95% CI). A few fish shown elevated concentrations of trace metals (outliers). Fish **#50** shown the highest concentration of Cd in the meat (0.016 mg kg^{-1}, Fig. 13) and fish **#72** had the highest concentrations of Pb in the meat (0.02 mg kg^{-1}). Fish **#69** and **#91**, show high Hg concentration in the meat (0.59 and 0.44 mg kg^{-1}, respectively) which is four times the average of the group and similar to the Canadian guidelines of 0.5ug/kg determined by Health Canada (2009).

Table 6 - Mean concentration (mg kg^{-1}) of total trace metals in the meat of Arctic char aged 8 to 25 years old harvested in Qurluqtuuq lake at spring 2023. Standard deviation and 95% confidence interval are provided. Non-parametric Wilcoxon-Mann-Whitney tests were used to compare concentrations among tissue. Results and statistical significance are provided.



Arctic Char

	LIVER (n = 15)		MEAT (n = 16)		t-test		
	Mean + sd	95% CI	Mean + sd	95% CI	L vs M	Significance	Test results
Hg	0.31 ± 0.36	[0.11 - 0.51]	0.13 ± 0.17	[0.044 - 0.22]	L > M	*	W(29) = 176, p = 0.028
Cd	0.47 ± 0.51	[0.18 - 0.75]	0.0036 ± 0.0039	[0.0015 - 0.0058]	L > M	****	W(29) = 240, $p = 2.3*10^{-6}$
Pb	0.0093 ± 0.0056	[0.0062 - 0.012]	0.0056 ± 0.0041	[0.0034 - 0.0078]	L > M	**	W(29) = 185, p = 0.0068
Zn	29 ± 11	[23 - 34]	10 ± 5	[7.3 - 13]	L > M	****	W(29) = 231, $p = 1.2*10^{-5}$
Cu	22 ± 24	[9 - 36]	0.49 ± 0.076	[0.45 - 0.53]	L > M	**	W(29) = 201, p = 0.0015
Se	1.9 ± 0.66	[1.5 - 2.2]	0.42 ± 0.12	[0.36 - 0.49]	L > M	****	W(29) = 240, $p = 2.3*10^{-6}$
Ag	0.43 ± 0.51	[0.15 - 0.72]	0.0032 ± 0.0048	[0.00064 - 0.0058]	L > M	****	W(29) = 224, $p = 1.9*10^{-5}$
Ni	0.04 ± 0	LOD	0.04 ± 0	LOD	ns		
As	0.57 ± 0.78	[0.14 - 1]	0.72 ± 0.72	[0.33 - 1.1]	ns		
Fe	400 ± 270	[250 - 550]	5.3 ± 1.6	[4.5 - 6.2]	L > M	****	W(29) = 240, $p = 2.3*10^{-6}$
Al	0.56 ± 0.49	[0.29 - 0.83]	0.42 ± 0.065	[0.38 - 0.45]	ns		
Mn	0.68 ± 0.32	[0.5 - 0.86]	0.14 ± 0.077	[0.1 - 0.18]	L > M	****	W(29) = 224, $p = 3.4*10^{-5}$
Cr	0.012 ± 0.0025	[0.011 - 0.013]	0.021 ± 0.016	[0.013 - 0.03]			
Co	0.053 ± 0.036	[0.032 - 0.073]	0.0057 ± 0.0032	[0.004 - 0.0074]			
K	2900 ± 410	[2700 - 3200]	3400 ± 420	[3100 - 3600]			
P	3500 ± 560	[3200 - 3800]	2500 ± 280	[2300 - 2600]			
Na	1000 ± 400	[830 - 1300]	460 ± 120	[390 - 520]			
Ca	110 ± 120	[42 - 180]	360 ± 340	[180 - 540]			
Mg	190 ± 40	[170 - 220]	240 ± 34	[220 - 260]			
Rb	1.4 ± 0.32	[1.2 - 1.6]	1.1 ± 0.24	[1 - 1.3]			
B	0.27 ± 0.13	[0.2 - 0.35]	0.4 ± 0.13	[0.34 - 0.47]			
Sr	0.11 ± 0.18	[0.012 - 0.21]	0.36 ± 0.25	[0.23 - 0.49]			
Zr	0.06 ± 0	LOD	0.06 ± 0	LOD			
Ba	0.022 ± 0.0055	LOD	0.021 ± 0.0026	LOD			
Sn	0.02 ± 0	LOD	0.02 ± 0	LOD			
Te	0.02 ± 0	LOD	0.02 ± 0	LOD			
V	0.05 ± 0.049	LOD	0.02 ± 0	LOD			
Mo	0.15 ± 0.089	[0.1 - 0.2]	0.018 ± 0.029	[0.0028 - 0.034]			
Tl	0.031 ± 0.05	[0.0037 - 0.059]	0.0046 ± 0.0058	[0.0015 - 0.0077]			
U	0.004 ± 0	LOD	0.004 ± 0	LOD			
Sb	0.0036 ± 0.0028	[0.002 - 0.0052]	0.0028 ± 0.0019	[0.0017 - 0.0038]			
Be	0.0022 ± 0.00065	[0.0018 - 0.0025]	0.002 ± 0	LOD			
Bi	0.002 ± 0.00016	[0.002 - 0.0021]	0.002 ± 0	LOD			

$p > 0.05$: ns
$0.01 < p \leq 0.05$: *
$0.001 < p \leq 0.01$: **
$0.0001 < p \leq 0.001$: ***
$0.00001 < p \leq 0.0001$: ****

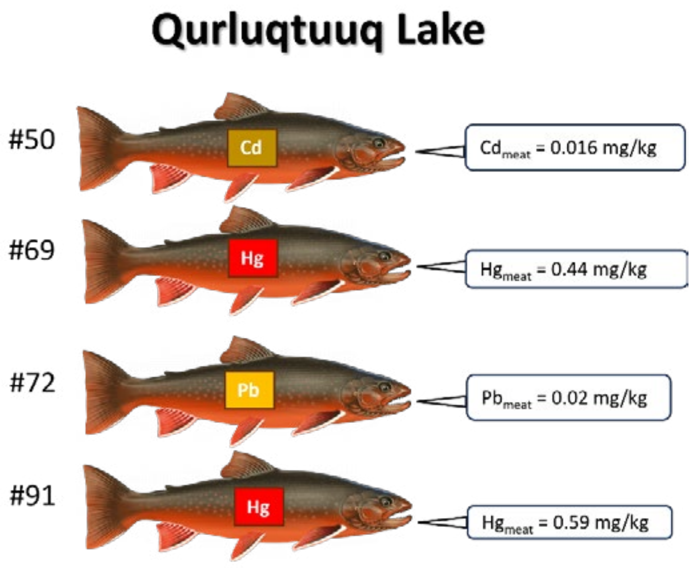


Figure 13 - Graphical list of Arctic char harvested in Qurluqtuuq Lake in 2023 with elevated concentrations of trace metals (outliers). The statistical method used to determine the outliers is described in the method sections.

TISSUES

Concentrations of trace metals in the liver of Arctic char were significantly higher than in the meat, with the exception of Al, As and Cr, which were in the same range (Table 6). Mean concentrations of Fe, Cd, Cu and Ag were two times higher in the liver than in the meat, and mean concentrations of Pb, Hg and Zn were in the same range in the liver and the meat.

INTERANNUAL

Mean concentrations of Hg in the meat of Arctic char harvested in 2023 in Qurluqtuuq lake (0.045 ± 0.027 mg kg^{-1}) were significantly lower than the mean concentrations of Hg in fish from the same age group collected in the same area in 2016 (0.097 ± 0.017 mg kg^{-1}) (Fig. 14). The mean concentration of Hg in Arctic Char harvested in 2023 was in the range of fish from the Canadian Arctic (0.05 ± 0.02 mg kg^{-1}, ranging from 0.01 to 0.08 mg kg^{-1} (Evans et al. 2015).

AGE

Arctic Char collected in Qurluqtuuq Lake in 2023 ranged from 8 to 25-years-old. Figure 14 depicts the relationship between age and trace metals concentration. Older fish (≥ 20 year) had higher concentrations of Hg and Se in the liver and meat (not shown) compared to young fish (Fig. 15). In contrast, concentrations of Cd and Zn were lower in old fish compared to young fish.

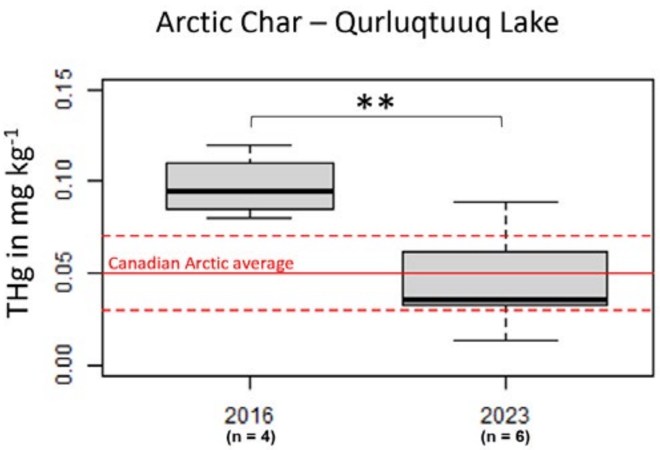


Figure 14 - Variation in total mercury (THg) concentrations in the meat of sea run Arctic char harvested in Qurluqtuuq Lake in 2016 and 2023 (see Fig. 1). We controlled for the confounding effect of age by comparing Arctic char from the same age group (10 to 15 years old). The 10-15 age group maximized sample size for each lake.

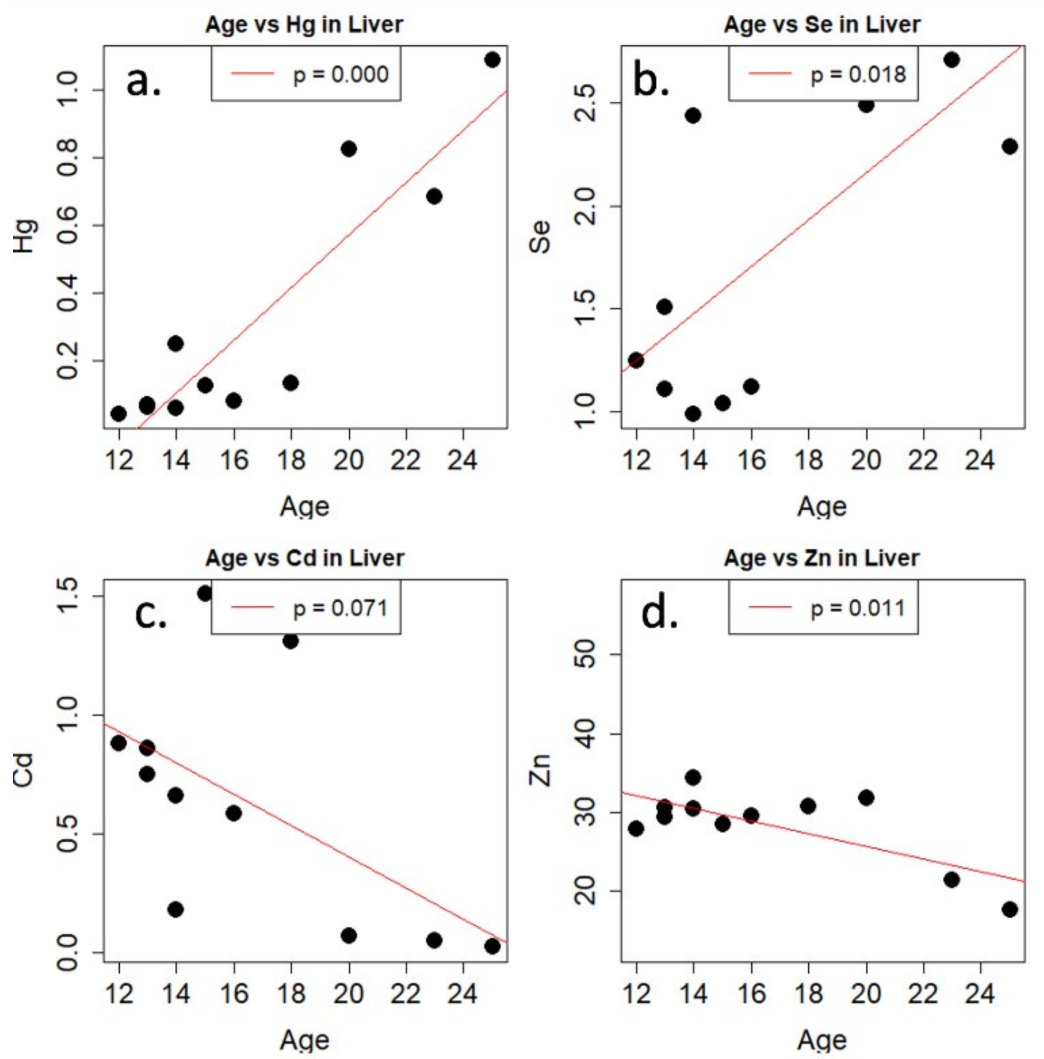


Figure 15 - Relationship between the age and the concentration of trace metals in the liver of sea-run Arctic Char collected in Qurluqtuuq Lake in the spring of 2023. The p-value of the linear regression (t-test) is indicated on each graph.

3.4 Trace metals among species

Trace metal concentration varied among species and tissues (Fig. 16). Mean hepatic concentrations of Cd, Pb, Ag and Cr in narwhal (27 ± 27 mg kg^{-1}, 0.035 ± 0.017 mg kg^{-1}, 1.32 ± 0.73 mg kg^{-1}, 0.024 ± 0.026 mg kg$^{-1,}$ respectively) were significantly higher than in ringed seal (6.6 ± 5.8 mg kg^{-1}, 0.015 ± 0.009 mg kg^{-1}, 0.43 ± 0.25 mg kg^{-1}, 0.010 ± 0.001 mg kg^{-1}, respectively) and Arctic char meat (0.47 ± 0.51 mg kg^{-1}, 0.009 ± 0.006 mg kg^{-1}, 0.43 ± 0.51 mg kg^{-1}, 0.012 ± 0.002 mg kg^{-1}, respectively)(Table 7). Concentrations of Cd and Hg in narwhal meat (0.52 ± 2.40 mg kg^{-1}, 1.43 ± 0.93 mg kg^{-1}, respectively) were also more elevated than in ringed seal meat (0.07 ± 0.06 mg kg^{-1} and 0.28 ± 0.14 mg kg^{-1}, respectively) and Arctic char meat (0.004 ± 0.004 mg kg^{-1}, 0.13 ± 0.17 mg kg^{-1}, respectively)(Table 7).

Interestingly, mean hepatic concentrations of As, Zn, Mn and meat concentration of Cu were significantly higher in ringed seal (1.05 ± 0.47 mg kg^{-1}, 53 ± 13 mg kg^{-1}, 2.83 ± 0.78 mg kg^{-1}, 1.36 ± 0.33 mg kg^{-1}, respectively) than in narwhal (0.20 ± 0.09 mg kg^{-1}, 24 ± 8 mg kg^{-1}, 0.20 ± 0.30 mg kg^{-1}, 0.97 ± 0.74 mg kg^{-1}, respectively) and Arctic char (0.71 ± 0.72 mg kg^{-1}, 10 ± 5 mg kg^{-1}, 0.14 ± 0.08 mg kg^{-1}, 0.49 ± 0.08 mg kg^{-1}, respectively) (Table 7). Mean hepatic concentrations of Hg and Se in narwhal liver (1.85 ± 0.65 mg kg^{-1} and 0.31 ± 0.36 mg kg^{-1}) were higher than in Arctic char (14.2 ± 12.5 mg kg^{-1}, 9.9 ± 9.5 mg kg^{-1}, respectively) but no different from ringed seal (Table 7).

Mean concentrations of Pb, Ag and Al in narwhal meat (0.029 ± 0.079 mg kg^{-1}, 0.052 ± 0.016 mg kg^{-1}, 2.55 ± 6.51 mg kg^{-1}, respectively) were significantly higher in narwhal compared with Arctic char (0.005 ± 0.004 mg kg^{-1}, 0.003 ± 0.005 mg kg^{-1}, 0.42 ± 0.06 mg kg^{-1}, respectively) but no different from ringed seal (Table 7). Mean concentrations of Zn and Fe in narwhal meat (24 ± 8 mg kg^{-1}, 262 ± 56 mg kg^{-1}) were significantly higher than in Arctic char (10 ± 5 mg kg^{-1}, 5 ± 2 mg kg^{-1}, respectively), but no different from ringed seal (Table 7).

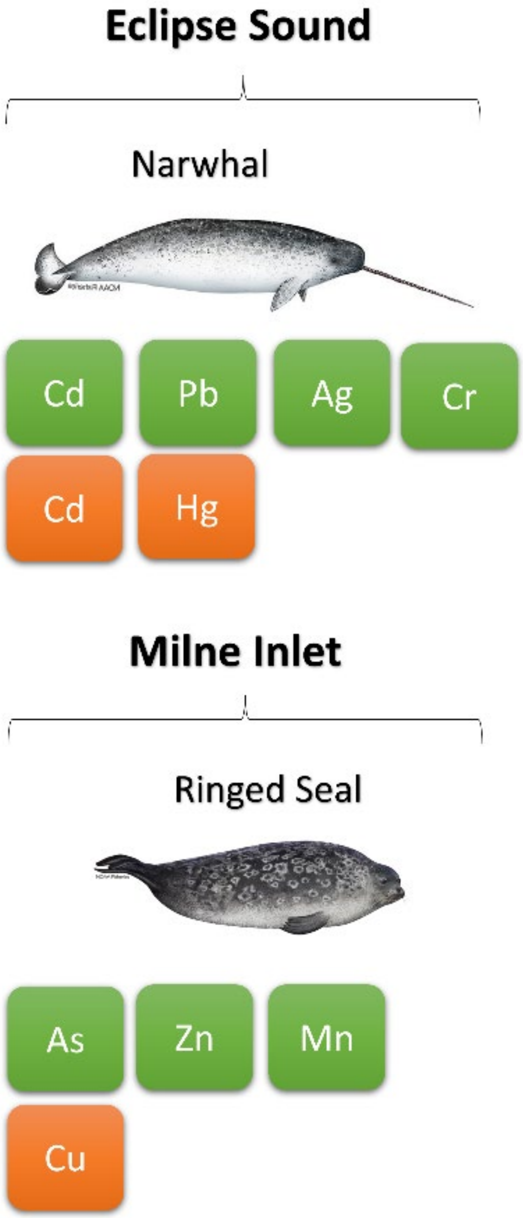
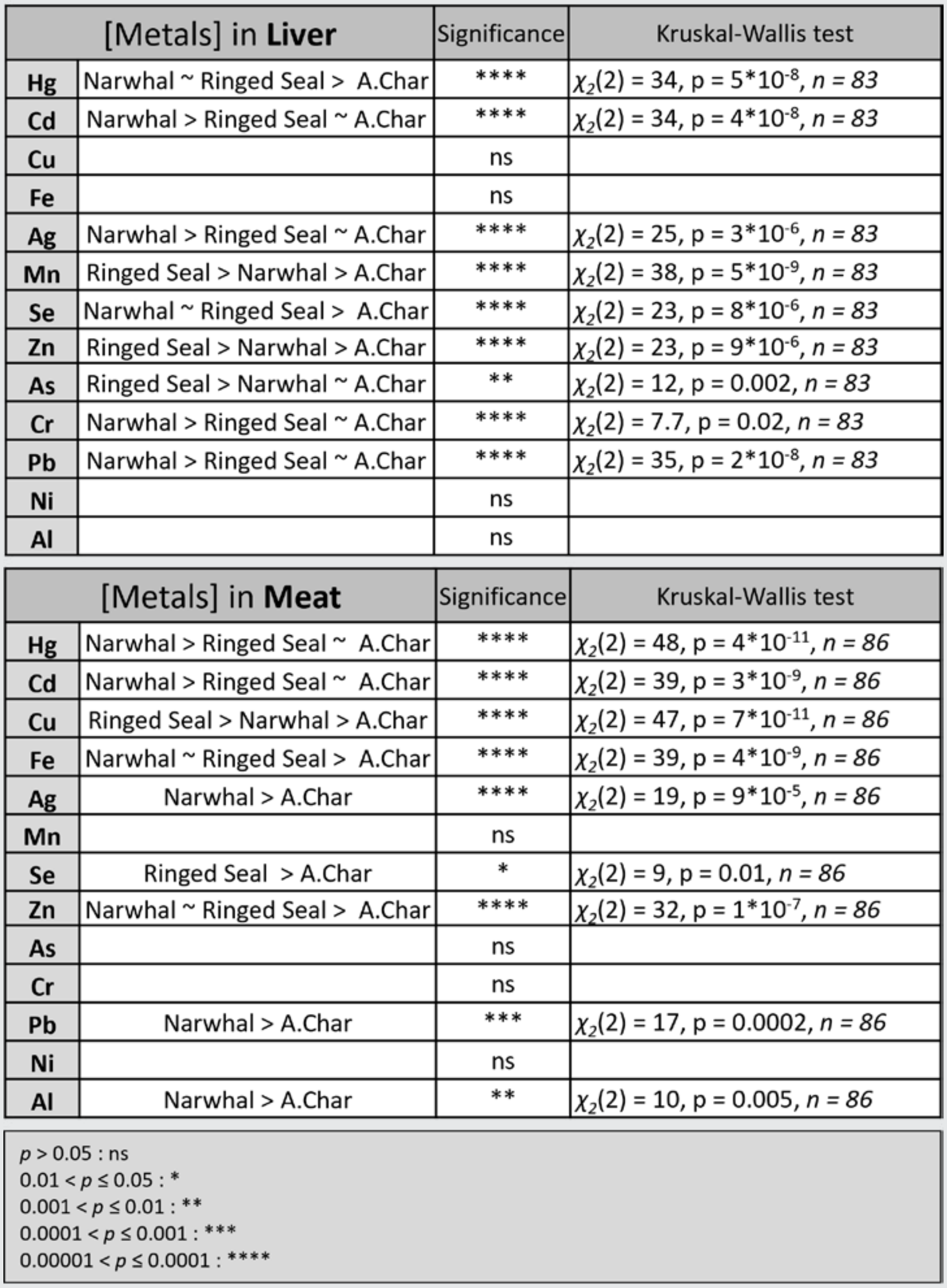


Figure 16 - Graphical illustration of the significant differences observed in the concentration of trace metals in liver (green) and muscle (orange) among three country food species harvested in Eclipse Sound region. Trace metal icons illustrated under a given species indicate that concentrations were significantly higher in that species vs others.

Table 7 – Hierarchical differences in the concentration of trace metals in narwhal, ringed seal and Arctic char liver (upper table) and meat (lower table). Statistical significance was determined by Kruskal Wallis test and post hoc Dunn test. p-values are provided.



[Metals] in **Liver**		Significance	Kruskal-Wallis test
Hg	Narwhal ~ Ringed Seal > A.Char	****	$\chi_2(2) = 34$, $p = 5*10^{-8}$, $n = 83$
Cd	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 34$, $p = 4*10^{-8}$, $n = 83$
Cu		ns	
Fe		ns	
Ag	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 25$, $p = 3*10^{-6}$, $n = 83$
Mn	Ringed Seal > Narwhal > A.Char	****	$\chi_2(2) = 38$, $p = 5*10^{-9}$, $n = 83$
Se	Narwhal ~ Ringed Seal > A.Char	****	$\chi_2(2) = 23$, $p = 8*10^{-6}$, $n = 83$
Zn	Ringed Seal > Narwhal > A.Char	****	$\chi_2(2) = 23$, $p = 9*10^{-6}$, $n = 83$
As	Ringed Seal > Narwhal ~ A.Char	**	$\chi_2(2) = 12$, $p = 0.002$, $n = 83$
Cr	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 7.7$, $p = 0.02$, $n = 83$
Pb	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 35$, $p = 2*10^{-8}$, $n = 83$
Ni		ns	
Al		ns	

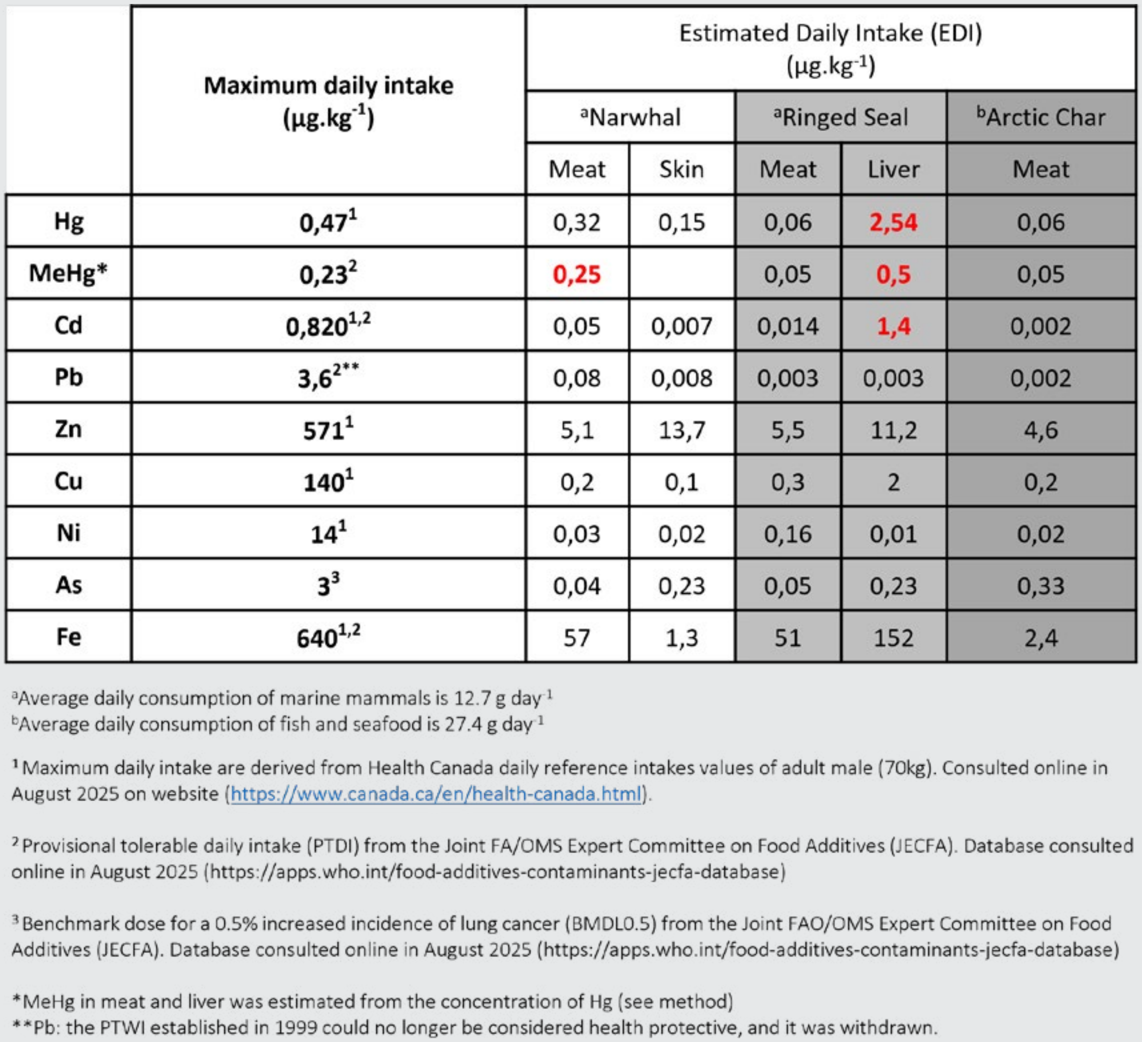
[Metals] in **Meat**		Significance	Kruskal-Wallis test
Hg	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 48$, $p = 4*10^{-11}$, $n = 86$
Cd	Narwhal > Ringed Seal ~ A.Char	****	$\chi_2(2) = 39$, $p = 3*10^{-9}$, $n = 86$
Cu	Ringed Seal > Narwhal > A.Char	****	$\chi_2(2) = 47$, $p = 7*10^{-11}$, $n = 86$
Fe	Narwhal ~ Ringed Seal > A.Char	****	$\chi_2(2) = 39$, $p = 4*10^{-9}$, $n = 86$
Ag	Narwhal > A.Char	****	$\chi_2(2) = 19$, $p = 9*10^{-5}$, $n = 86$
Mn		ns	
Se	Ringed Seal > A.Char	*	$\chi_2(2) = 9$, $p = 0.01$, $n = 86$
Zn	Narwhal ~ Ringed Seal > A.Char	****	$\chi_2(2) = 32$, $p = 1*10^{-7}$, $n = 86$
As		ns	
Cr		ns	
Pb	Narwhal > A.Char	***	$\chi_2(2) = 17$, $p = 0.0002$, $n = 86$
Ni		ns	
Al	Narwhal > A.Char	**	$\chi_2(2) = 10$, $p = 0.005$, $n = 86$

$p > 0.05$: ns
$0.01 < p \le 0.05$: *
$0.001 < p \le 0.01$: **
$0.0001 < p \le 0.001$: ***
$0.00001 < p \le 0.0001$: ****

3.5 Exposure risk for human health

Table 8 presents the estimated daily intake (EDI) of trace metals for an average-weight adult consuming narwhal, ringed seal, or Arctic Char from Eclipse Sound. In the calculation of the EDI, we used the mean concentration of trace metals for individual adults and the daily portion has been averaged based on annual consumption results obtained in Nunavik (Lemire et al. 2015, see methods). EDIs of total mercury (2.54µg/d), MeHg (0.5µg/d) and cadmium (1.4 µg/d) in ringed seal liver and EDI of MeHg in narwhal meat exceeded the maximum daily intake thresholds recommended by Health Canada (2009) and the World Health Organization (2017). Narwhal skin, seal meat, and fish meat did not exceed the maximum daily threshold.

Table 8 – Estimated daily intake (EDI) of trace metals (µg day^{-1} body weight) associated with the consumption of an averaged daily portion of narwhal, ringed seal, fish and sea food. EDI rates are calculated based on the trace metals mean concentrations presented in Table 1, 2, 3, 5 and 6 and are compared to the maximum and tolerable daily intake thresholds provided from Health Canada and the World Health Organization, respectively. Numbers in red highlight intake rates above the guidelines. Narwhal liver is not presented because not consumed.



	Maximum daily intake (µg.kg^{-1})	Estimated Daily Intake (EDI) (µg.kg^{-1})				
		[a]Narwhal		[a]Ringed Seal		[b]Arctic Char
		Meat	Skin	Meat	Liver	Meat
Hg	**0,47[1]**	0,32	0,15	0,06	**2,54**	0,06
MeHg*	**0,23[2]**	**0,25**		0,05	**0,5**	0,05
Cd	**0,820[1,2]**	0,05	0,007	0,014	**1,4**	0,002
Pb	**3,6[2]****	0,08	0,008	0,003	0,003	0,002
Zn	**571[1]**	5,1	13,7	5,5	11,2	4,6
Cu	**140[1]**	0,2	0,1	0,3	2	0,2
Ni	**14[1]**	0,03	0,02	0,16	0,01	0,02
As	**3[3]**	0,04	0,23	0,05	0,23	0,33
Fe	**640[1,2]**	57	1,3	51	152	2,4

[a]Average daily consumption of marine mammals is 12.7 g day^{-1}
[b]Average daily consumption of fish and seafood is 27.4 g day^{-1}

[1] Maximum daily intake are derived from Health Canada daily reference intakes values of adult male (70kg). Consulted online in August 2025 on website (https://www.canada.ca/en/health-canada.html).

[2] Provisional tolerable daily intake (PTDI) from the Joint FA/OMS Expert Committee on Food Additives (JECFA). Database consulted online in August 2025 (https://apps.who.int/food-additives-contaminants-jecfa-database)

[3] Benchmark dose for a 0.5% increased incidence of lung cancer (BMDL0.5) from the Joint FAO/OMS Expert Committee on Food Additives (JECFA). Database consulted online in August 2025 (https://apps.who.int/food-additives-contaminants-jecfa-database)

*MeHg in meat and liver was estimated from the concentration of Hg (see method)
**Pb: the PTWI established in 1999 could no longer be considered health protective, and it was withdrawn.

4. Discussion

4.1 Interpretation of Results

TRACE METALS

NARWHAL

Narwhal harvested in Eclipse Sound had higher concentrations of Hg and Se (liver, meat, skin) and Pb (meat) compared to narwhal from Admiralty Inlet (Table 1:3, Figure 2). Concentrations of Hg and Se found in the liver are often correlated, indicative of a detoxification mechanism where Se mitigates Hg (Endo et al. 2002). Bioaccumulation patterns of Hg and Pb in marine mammals involved the predation of prey sources from an elevated trophic level (Lavoie et al., 2013).

The more elevated concentration of Hg and Pb in narwhal from Eclipse Sound suggest that they might be feeding more extensively on Arctic char, a predator fish of higher trophic level, than narwhal from Admiralty Inlet known to feed on Arctic cod (Tester et al. 2025). Elevated Pb concentration in narwhal of Eclipse Sound might also be indicative of source contamination of Milne Inlet waters by the Baffinland's project area. The linkage between the elevated concentration of mercury found in the tissues of whales and activities of the mine is less evident. In fact, the EDI 2019 report and L'Hérault et al. 2025 showed that the concentration of Hg in ore source sample is very low and below the detection limits. However, this doesn't exclude the possibility that Baffinland activities plays a role in mercury bioaccumulation. Iron release can be significant around Milne Inlet and this metal can come in different oxidative states in sediments particles, with the potential to adsorb and concentrate some trace metals present in the environment (Cagnin et al 2017).

Concentration of Hg (73 mg kg^{-1}) in liver of one particular narwhal from Eclipse Sound exceeded the toxicity value of 61 mg kg^{-1} associated with liver abnormalities in Atlantic bottlenose dolphins (Rawson et al. 1993). However, this result remained below the range of 100 to 400 mg kg^{-1} associated with liver effects on marine mammals reported by other authors (Wagemann et al. 1983; Rawson et al. 1993). We also found one individual with Pb concentration peaking at 18 mg kg^{-1} in its meat: 50 times the sample average of the region.

Mean concentrations of aluminum, a major element of the red dust content released by Baffinland's project area EDI (2019), was found in elevated concentrations in several narwhal from Eclipse Sound, with one individual peaking at 272 mg kg^{-1} in its meat: 15 times the sample average. Several individuals were found with extreme concentrations of one or several other essential trace metals such as Cr, Cu, Ni, Co, Ag in the liver, meat or skin tissue (Figure 3;4). Al, as is true of any other essential metal, can become toxic at high concentrations (Botté et al. 2022).

In contrast, mean concentrations of Cd in the liver and skin were higher in narwhal from Admiralty Inlet than narwhal from Eclipse Sound. Bioaccumulation patterns of Cd in marine mammals differ from Hg; it is influenced by dietary selection (Dehn et al. 2005) of mollusks primarily, especially cephalopods, that concentrate Cd in their viscera (Das et al. 2003; Honda et al. 1983). Higher concentrations of Cd in narwhal from Admiralty Inlet suggest that they might be bottom feeders and consume more mollusks than narwhal from Eclipse Sound. The highest concentration of Cd in the liver of one particular narwhal from Admiralty Inlet was 163 mg kg^{-1} which remained under the threshold of 200 mg kg^{-1} for toxic effects in marine mammals (AMAP 2005).

Mean concentrations of Fe, Ag and Zn in liver were higher in narwhal from Admiralty Inlet than narwhal from Eclipse Sound (Figure 2). This suggest that regional natural sources of metals (metalliferous terrains, estuaries, coastal waters) or local anthropic sources related to the Nanisivik lead-zinc mine, decommissioned in 2002 near Ikpiarjuk, in Strathcona Sound, might be associated with the greater uptake of Fe, Ag and Zn in narwhal from Admiralty Inlet. On the other hand, we cannot exclude the possibility that some narwhal sampled in Admiralty Inlet were individuals that have relocated from Eclipse Sound to Admiralty in the last decade following the initiation of mining activity at Mary River (see limits of the study below).

COVARIABLES

Mean hepatic concentrations of Hg, Cd, Pb, and Se and maktaaq concentration of Hg and As were significantly higher in adult narwhal than subadults (Figure 5). These results were expected, as heavy metals are known to bioaccumulate with age (Muir et al. 1999; Wagemann, Innes, et Richard 1996), and Se is known to vary along with Total Hg (Endo et al., 2002). Mean hepatic concentrations of Hg, Cd, Cu, Ag, Mn, Se and Fe where significantly higher than in the meat or maktaaq (Table 4), which aligns with previous work done on narwhal (Sonne et al. 2018, Dietz et al. 2004) and ringed seal (Brown, 2005, Braune et al., 2015; Dehn et al., 2005; Wagemann et al., 1996). The year and season were not determinant in explaining the observed variation in trace metal concentration in narwhal. Differences observed among years and seasons were likely associated with individual variation rather than a multi-annual/ seasonal trend.

Hepatic concentrations of several trace metals (Cd, Ag, Pb and Cr) and meat concentration of Hg and Cd were significantly higher in narwhal than ringed seal and Arctic char as documented elsewhere (Dietz, et al., 1996; Riget et al. 2005; Brown et al. 2016; Braune et al. 2015). For Hg, the difference can be related to a long-living species and the limited ability of cetaceans, especially toothed whales, to metabolize and eliminate or excrete Hg (Wagemann et al., 1998; Das et al., 2003, Dietz et al., 2013; Monk et al., 2014, Sonne et al., 2018). Hepatic Cd and Ag can be associated to a greater consumption of benthic organisms especially mollusks (cephalopods, bivalves) (Das et al., 2003, Dehn et al., 2005).

RESIDENT SPECIES

Mean hepatic concentration of As and Zn and concentration of Cu in the meat of ringed seal were significantly higher than in narwhal or Arctic char. This can be explained either by differences in diet or source contamination in Milne Inlet. Cu and Zn are often intercorrelated and usually higher in animals feeding on benthic invertebrates (Dehn et al. 2005) and As concentrations tend to be higher in animals feeding on marine algae and crustaceans than piscivorous species (Kubota et al., 2001). However, a predominant benthic diet is unlikely for ringed seal in our study area. Ringed seal are known to prey on fish and on amphipods and copepods in the water column. As discussed above, Cd levels is a marker of benthic feeding and was quite low in the ringed seal of Milne Inlet.

A shift in the diet of ringed seal, from arctic to more subarctic prey source, is another hypothesis to explore because subarctic species can convey contaminants to the more northern latitudes (McKinney et al., 2015). Alternatively, it is possible that diet is not the primary explanation for the elevated concentrations of Cu, Zn and As observed. Source contamination of Cu, Zn and As originating from the Baffinland's project area is another possibility. Concentrations of Cu and Zn can also vary with age (Wagemann 1989; Wagemann et al. 1988; Watanabe et al. 2002).

As observed in narwhal, inter-individual variation in certain trace metals (Al, Pb, Hg, Ni, Cu, Zn) was observable in resident species of ringed seal and Arctic char up to 10 to 100 times the average in some instance (Figure 12 and 13). Individual-level contamination in Fe, Mn or Al suggest potential intake from dust contamination in Milne Inlet near the project area.

AGE AND YEAR

Age of fish was positively correlated to the hepatic concentrations of Hg and Se, a result of bioaccumulation (AMAP 2005; Hudelson et al. 2019) (Figure 15). Mean concentration of Cd and Zn was negatively correlated to the age of fish and suggests a benthic component to the diet of young fish (Figure 15). We observed, for the same age group, a significant decrease in Hg concentration between fish sampled in 2023 in Qurluqtuuq lake and fish sampled in 2016 at the same location, revealing that Hg bioaccumulation is lesser either from the diminution of Hg concentrations in the prey sources from the area, or from the relocation of the summer feeding ground of the fish. Using data from previous years (Simonee et al. unpublished), results show no multi-year differences in Hg and Cd concentrations between the Milne Inlet ringed seal sampled in 2023 and seal from Eclipse Sound sampled in 2018. Our sample size was nonetheless quite small.

POPS

Mean concentrations of POPs were higher in narwhal from Eclipse Sound than narwhal from Admiralty Inlet although the difference was not significant, possibly explained by our small sample size. Multi-year comparison of POPs concentrations in narwhal from Eclipse Sound (2022 vs 2019- Figure 7) revealed some consistency in the area supporting the argument that regional differences, Eclipse Sound vs Admiralty, is observable. As discussed above, large-scale circulation of POPS in troposphere or ocean currents is also determinant in POPs intake by Arctic marine mammals (Macdonald et al. 2000; Macdonald, Harner, et Fyfe 2005).

STRESS AND BODY CONDITION

Mean level of cortisol appeared significantly higher in narwhal from Eclipse Sound than narwhal from Admiralty Inlet in the fall of 2022 (Figure 8). Two adults harvested in the summer of 2023 in Eclipse Sound exhibited worrisome levels of cortisol, as high as 16.5 ng g^{-1} and 11.3 ng g^{-1}. These values exceed levels reported in narwhal experiencing ice entrapment (10.52 ± 0.59 ng g^{-1}, Watt et al. 2021) and were two to three times the most elevated level measured in an individual from Ikpiarjuk.

Cortisol is an indicator of stress response in mammals and of the severity of the stressor (Hennessy et al. 1979; Bechshoft et al. 2020). Underwater noise generated by shipping vessels is a significant stressor for narwhal as documented in the literature (Rolland et al. 2012; Gomez et al. 2016; Erbe et al. 2019) and reported by local hunters and Elders (Tester, unpublished). Local hunters reported that narwhal are restless in Milne Inlet, their behavior is one of avoidance of the ships. Several studies reported that shipping traffic can alter movements, behavior and acoustic responses of marine mammals (Rolland et al. 2012; Gomez et al. 2016; Erbe et al. 2019).

Chronic exposure of narwhal to shipping activities and shipping noise in Milne Inlet and Eclipse Sound is a serious hypothesis that may explain the elevated cortisol levels observed in some individuals. Another result, potentially correlated to the high cortisol levels, revealed that fat thickness in narwhal from Eclipse Sound was significantly less than narwhal from Admiralty Inlet at springtime (Figure 11). Visual inspections made by hunters also revealed that individuals below average condition where more often seen in Eclipse Sound than in Admiralty Inlet, particularly at fall time. Local hunters have also reported several unhealthy young narwhal in the fall in Eclipse Sound, a phenomenon not observed in Admiralty Inlet. This suggests that Eclipse Sound narwhal may struggle to build up their fat reserves before fall because they have to cope with disturbances. Ivanova et al. (2020) has demonstrated that shipping traffic can also alter the movement and behavior of prey species. Lowered body condition of the Eclipse Sound narwhal could also be explained by a potential depletion of food sources in Milne inlet, that has always been a major feeding ground.

TOXICITY FOR HUMAN HEALTH

Estimated daily intake values calculated in this study suggest potential risk to the consumption of narwhal meat and ringed seal liver because of the elevated concentration of mercury and cadmium (seal liver) (Table 8). Similar results have been reported in other studies (Chan et al. 1995; AMAP 2005). However, it is important to note that EDIs were calculated using averaged daily portions from northern Nunavik where a terrestrial diet is predominant (Lemire et al. 2015). Factoring in the actual averaged daily portion based on food habits of Mittimatalirmiut, which is predominantly marine-based, is a necessary next step to address the exposure risk with more confidence. Patterns of consumption, for example of narwhal maktaaq, need to be evaluated because one narwhal can last several months in a given family. Thus, on an annual basis, the consumption of one contaminated individual might be of a great importance to the contaminant intake of a family.

4.2 Limits of the study

Determining the origin of the contaminant intake in both Eclipse Sound and Admiralty Inlet remains challenging given the migratory nature of narwhal. Determining the contribution of natural sources (land geology, metalliferous terrain, erosion processes, etc.) versus anthropogenic activities, either source (mining) or global (air and ocean transport of contaminants from worldwide industries), is another hurdle. Narwhal migrate long distances back and forth between their summer and winter grounds and contaminants can be absorbed in both areas through food sources. However, because narwhal from both Eclipse Sound and Admiralty spend winter in Baffin Bay (Marcoux et al. 2021) and feed on a common prey source (turbot), one can argue that regional differences observed in concentrations of trace metals and POPs are attributable to food intake from their summer ground.

To complicate the picture, aerial surveys have reported a massive relocation of the narwhal from Eclipse Sound in the summer of 2020 when the population declined by one half of the numbers reported in 2019 (Golder (2021)). In parallel, hunters from Ikpiarjuk have reported a surge of the narwhal population in Admiralty Inlet in the summer of 2021 as a result of the relocation (Tester, 1925 & al. 2025). As a consequence, some individuals harvested in Admiralty Inlet in 2022/2023 could well be narwhal that formerly inhabited Eclipse Sound who have a different history of contaminant intake. Another determinant factor to consider is the time of the narwhal harvest. At fall, narwhal from Admiralty Inlet can migrate through Eclipse sound (Tester et al. 2025) and catches reported by hunters from Mittimatalik can well be a mix of some narwhal summering in Eclipse Sound and Admiralty Inlet. The issue is less probable with narwhal caught in spring and summer who are several hundred kilometers apart, from Eclipse Sound to Admiralty Inlet.

For the resident species of Milne Inlet/Eclipse Sound, ringed seal and Arctic char, determining the origin of contaminant intake remains challenging as contaminants may originate from both source contamination (mining activities) and global circulation.

4.3 Recommendations

The study of contaminant concentration and their impacts on marine species and humans can be hindered by the multiple origins of contaminants in the Eclipse Sound area. Future studies can overcome current limitations by implementing the following recommendations:

1. **REGIONAL MONITORING OF NARWHAL**
   Pursue the monitoring of contaminants, stress levels and body condition of narwhal from Eclipse Sound on a multiyear perspective during the spring and summer. Stress levels indicators such as cortisol hormone and other indicators such as oxidative stress should be used to further explore the systemic impact of shipping traffic on narwhal. We recommend the monitoring of the same parameters with narwhal from other regions of the Qikiqtani to enable comparisons between impacted (Eclipse Sound) and non-impacted populations. Such comparisons are critical, given the capacity of the species for movement.

2. **DIET AND TROPHIC LEVEL**
   Determining the diet of narwhal is essential to interpreting the contaminant concentrations observed and to identify the potential source of contaminants. For example, the nature and the trophic level of the prey source is determinant for mercury and cadmium intake. Analyzing stomach content in combination with molecular methods, such as stable isotopes or highly branched isoprenoids (HBIs), will help to identify the contribution of different prey sources to the diet. The methods can also track the origin of the food source and the season in which they were consumed.

3. **FOOD-WEB MONITORING IN IMPACTED AREAS**
   Extending the diet analyses, monitoring contaminant levels in food sources throughout the marine ecosystem is essential to identify the origin of contaminant intake. Priorities should be put on benthic organisms, zooplankton and demersal fish in the Milne Inlet port area. The monitoring of non-impacted areas is also essential for comparison purpose.

4. **SEDIMENTS MONITORING IN IMPACTED AREAS**
   Study the composition of the sediments on the sea floor of the Milne Inlet port area and how it relates to the source production of fugitive dust by the mining activities. Core sampling can help to determine deposition rate of sediments and address the natural concentrations of contaminants in sediments before the mining project.

5. **MONITORING OF RESIDENT SPECIES**
   Pursue the monitoring of contaminants, stress level and body condition of ringed seal and Arctic char residing in the Milnet Inlet area because of their proximity with what might be the pollution source. We recommend the monitoring of the same parameters with seal and fish from other areas of the Eclipse Sound and other regions of the Qikiqtani to enable comparisons.

6. **FOOD HABITS AND INTAKE**
   Document the actual consumption habits of different country foods and tissues by Mittimatalirmiut. It will help to further our understanding of the exposure risk using indicators such as the Estimated Daily Intake.

7. **INUIT QAUJIMAJATUQANGIT**
   Several components of the above recommendations can, to a certain extent, be further explored by documenting the knowledge and observations of Elders and local hunters from Mittimatalik. For example, IQ can address questions pertaining to the diet of species or the range of the fugitive dust deposition in impacted areas.

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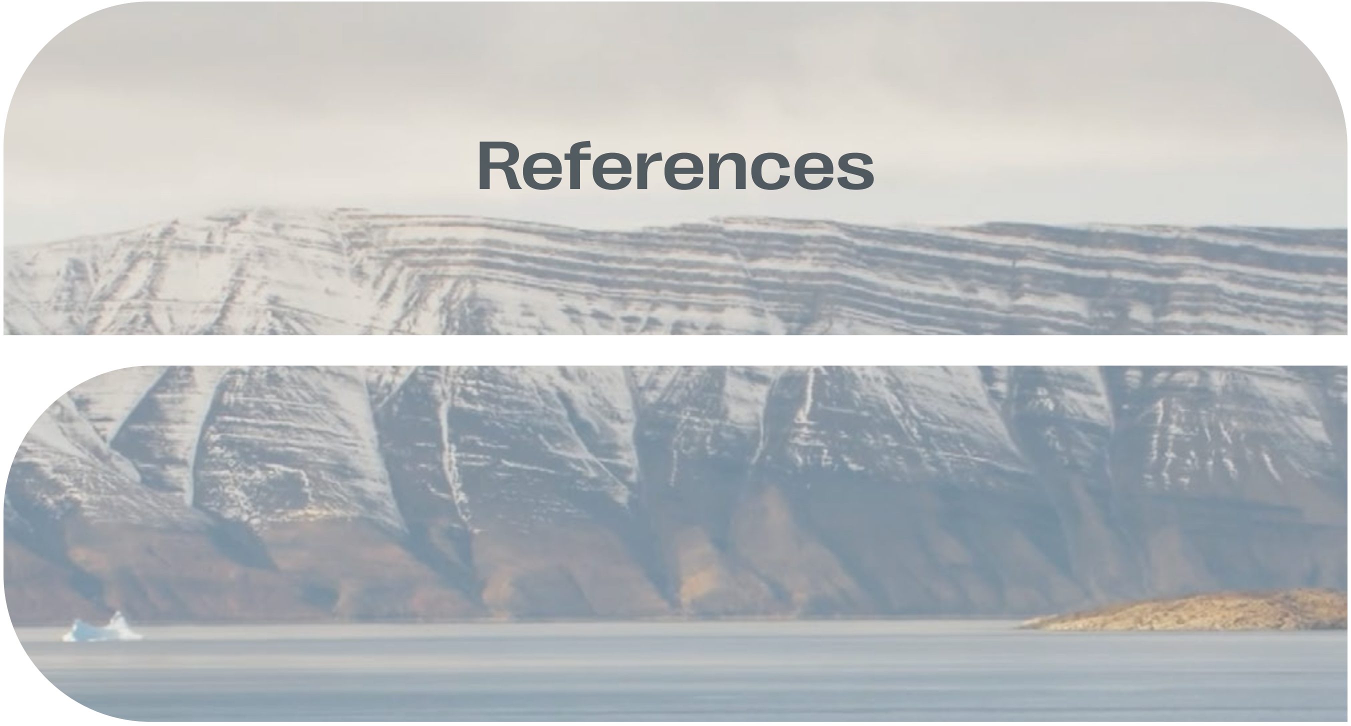

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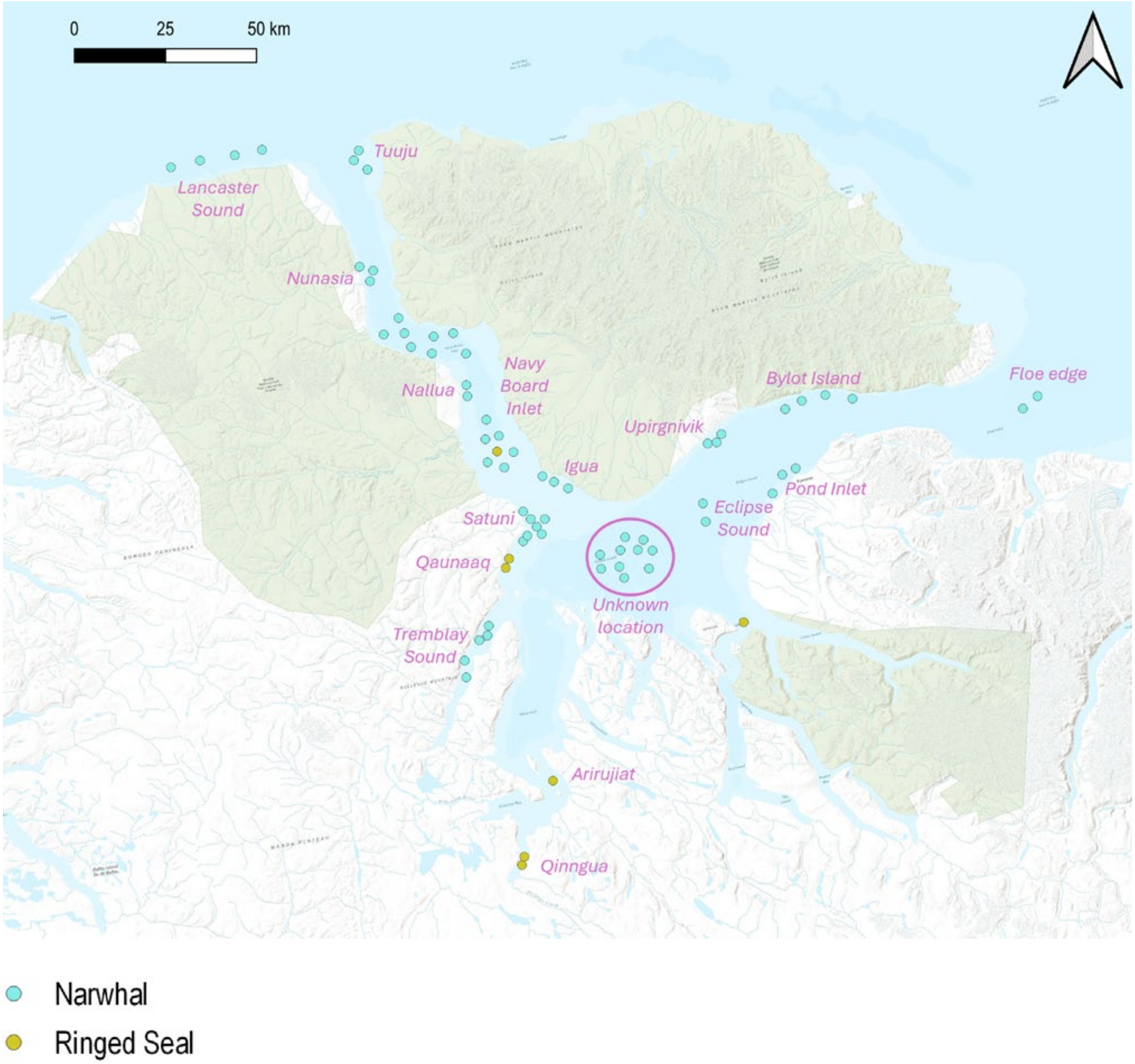
Appendix 1

Map showing the harvest location of the narwhal and ringed seal in Eclipse Sound and Milne Inlet at summer 2022 and 2023.



Appendix 2

FISH NECROPSY FORM

OBSERVATIONS

HUNTER'S NAME:_________________ DATE:________________ LOCATION:____________

FISH ID (# showing on bag): ______ MALE/FEMALE:______ ADULT/YOUNG:_____

CONDITION OF THE FISH (check one option):

☐ HEALTHY / FAT ☐ BELOW AVERAGE ☐ UNHEALTHY / SKINNY

ANY SIGNS of DISEASE OUTSIDE or INSIDE THE FISH?: ☐ Yes ☐ No

If yes, WHAT DO YOU SEE AND WHERE: ____

MEASUREMENTS (measuring tape)

BODY Weight:__ __ __(kg) LENGTH :__ __ __ (cm) HEAD GIRTH :__ __ __(cm)

Checklist of Samples to Collect in bags (store on ice in cooler)

FIN – HEAD – MEAT – LIVER - REPRO ORGAN - WHOLE STOMACH

You can enjoy and eat the fish once samples are done !!!

NARWHAL NECROPSY FORM

OBSERVATIONS

HUNTER'S NAME:_________________ DATE:________________ LOCATION:____________

NARWHAL ID (# showing on bag): ______ MALE/FEMALE:______ ADULT/YOUNG:_____

CONDITION OF THE WHALE (check one option):

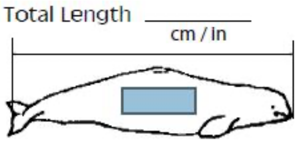
☐ HEALTHY / FAT ☐ BELOW AVERAGE ☐ UNHEALTHY / SKINNY

ANY SIGNS of DISEASE OUTSIDE or INSIDE THE WHALE?: ☐ Yes ☐ No

If yes, WHAT DO YOU SEE AND WHERE: ____

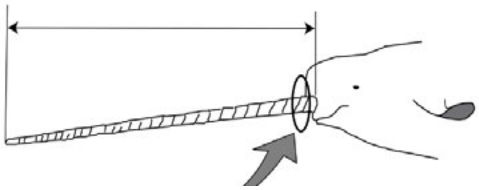
MEASUREMENTS

TOTAL LENGTH (measuring tape): __ __ __



TUSK LENGTH (measuring tape): __ __ ____

TUSK CIRCUM (measuring tape): __ __ __



TAIL WIDTH (measuring tape): __ __ __

BLUBBER THICKNESS (plastic ruler): ______ __ __

Checklist of Samples to collect in bags (store on ice in cooler)

Meat – Liver – Maktaaq – Blubber - Eye ball – Embedded tusk- Ovaries

SEAL NECROPSY FORM

OBSERVATIONS:

HUNTER'S NAME:________________ DATE:_______________ LOCATION:______________

SEAL ID (# showing on bag): _______ MALE/FEMALE:______ ADULT/YOUNG:_____

CONDITION OF THE SEAL (check one option):

☐ HEALTHY / FAT ☐ BELOW AVERAGE ☐ UNHEALTHY / SKINNY

ANY SIGNS of DISEASE OUTSIDE or INSIDE THE SEAL?: ☐ YES ☐ NO

If yes: WHAT DO YOU SEE AND WHERE?____

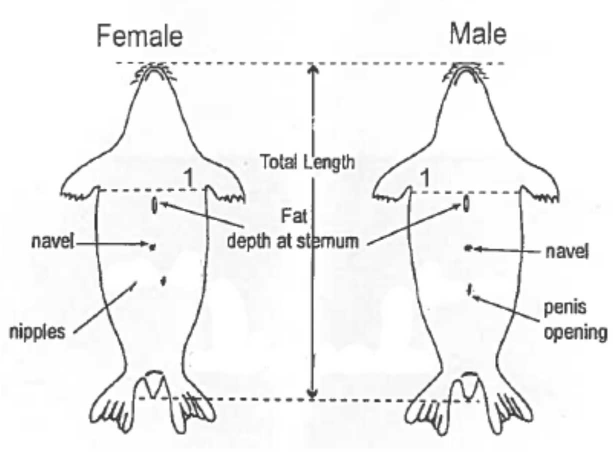
MEASUREMENTS

TOTAL LENGTH (measuring tape): __ __ __

FAT DEPTH (ruler): __ __ __

REPRODUCTION

NB of FETUSES in the womb: __ __ __



Checklist of Samples to collect in bags (store on ice in cooler)

Lower jaw -- Whiskers (2-3) -- Blubber -- Meat -- Whole stomach (please don't open it) -- Liver -- Kidney – Skin with Fur –

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