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ARTICLE

# Can traditional methods of selecting food accurately assess fish health?

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**Abstract:** Indigenous peoples living in Canada's north have long-valued the livers of Burbot (*Lota lota*) as a traditional food source; however, there has been concern relating to liver quality and potential contaminants. In this study, livers of Burbot collected in lower Mackenzie River were ranked using a traditional appearance-based assessment. These rankings were compared to a variety of biological and contaminant metrics. Livers ranked "most palatable" had a significantly higher mass and lipid content and were from younger fish with greater hepatosomatic index and total mass and had lower parasite intensities. There were no differences in the concentrations of persistent organic pollutants or metals, except copper, which although still well below consumption guidelines, was significantly higher in fish with livers that appeared most palatable. The results of this study demonstrated that traditional methods effectively assessed the quality of livers by selecting for the most nutritious (high lipid levels) and safest (low parasite loading) food. This method could be incorporated into a community-based monitoring framework as a rough index of overall fish and ecosystem health; however, would not be effective in screening food for anthropogenic contaminants. This study highlights the importance and value of linking traditional knowledge into scientific studies.

*Key words: Lota lota*, contaminant, Mackenzie River, parasite, traditional knowledge.

**Résumé :** Les peuples autochtones vivant dans le nord du Canada valorisent les foies de la Lotte (*Lota lota*) comme source de nourriture traditionnelle. Récemment, il y a des préoccupations chez les autochtones concernant la concentration des contaminants affectant la qualité de leur nourriture traditionnelle, particulièrement pour les foies. Dans cette étude, les foies de la Lotte ont été recueillis en bas du fleuve Mackenzie et ont été classés en utilisant une évaluation basée sur l'apparence traditionnelle. Ces classements sur l'apparence traditionnelle ont été comparés à une variété de paramètres biologiques et de contaminants (i.e., concentration). Les foies classés « le plus savoureux » avait une masse et une teneur lipidique significativement plus élevées, provenaient de poissons plus jeunes avec un meilleur indice hépato-somatique, une masse totale plus élevée et des intensités de parasites plus faibles. Aucunes différences dans les concentrations de polluants organiques persistants ou de métaux ont été trouvées parmi les foies classifiés sur l'apparence traditionnelle, sauf pour le cuivre. Bien qu'en dessous des recommandations de consommation, les taux de concentrations de cuivre étaient significativement plus élevés pour les foies

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classifiés « savoureux ». Les résultats de cette étude ont démontré que la méthode de sélection par l'apparence traditionnelle a efficacement évalué la qualité des foies avec une préférence marquée chez les autochtones pour les foies plus nutritifs (niveau élevé de lipides) et les plus sûrs (faible charge parasitaire). Cette méthode de sélection par l'apparence traditionnelle pourrait être incorporée dans un cadre de surveillance communautaire comme un indicateur approximatif de l'état de santé de l'ensemble des poissons et des écosystèmes. Cependant, la méthode de sélection par l'apparence traditionnelle n'est pas efficace pour dépister les variations des concentrations des contaminants anthropiques. Cette étude met en évidence l'importance de l'intégration des connaissances traditionnelles dans les études scientifiques. [Traduit par la Rédaction]

*Mots-clés :* *Lota lota*, contaminant, fleuve Mackenzie, parasite, savoir traditionnel.



## Introduction

Northern environments have received contaminant loading via long-range atmospheric transport from industrial and agricultural activities in southern latitudes (Donaldson et al. 2010). These contaminants accumulate in a variety of taxa: fish (e.g., Kidd et al. 1995, 1998; Carrie et al. 2009; Stapanian et al. 2014), birds (e.g., Guzzo et al. 2013), and mammals (e.g., Muir et al. 2000; Riget et al. 2005) — including humans (e.g., Kuhnlein et al. 1995; Donaldson et al. 2010). Atmospheric contaminants tend to bioaccumulate and biomagnify with trophic position, with the highest concentrations in predatory animals (Donaldson et al. 2010). This is problematic for northern peoples who eat more wild fish and game than their southern counterparts, potentially exposing them to higher levels of contaminants (Donaldson et al. 2010). For example, >40% of the population in Canada's Northwest Territories (NWT) use wild foods to supplement their diet [Government of the Northwest Territories (GNWT) 2014]. Furthermore, many environmental pollutants are lipophilic and traditionally harvesters tend to target species that are naturally fat rich because of the caloric and nutritional advantage they provide (Donaldson et al. 2010). Consequently, "are the fish safe to eat?" is one of the fundamental questions relating to aquatic systems posed by members of northern communities (GNWT 2013).

The Burbot (*Lota lota*, Linnaeus 1758) is an important subsistence fish for Indigenous populations in northern United States and Canada (Stapanian et al. 2010). This top-level predator is found in cold-water lakes and rivers throughout the northern hemisphere (Cohen et al. 1990; McPhail and Paragamian 2000; Stapanian et al. 2010). Burbot, like other members of the cod family (Gadidae), have large lipid-rich livers that are high in *n*-3 fatty acids, and vitamins A, D, and K (Wong 2008), and are also high in protein and healthy lipids (Robidoux et al. 2009). The nutritional value of Burbot livers has long been recognized by the Indigenous people living along the lower Mackenzie River, NWT, Canada, and Burbot livers remain a culturally significant food source for the Gwich'in people [Gwich'in Renewable Resources Board (GRRB) 1997]. Burbot, locally known as "loche", are fished each year when the ice first forms by jigging a lure or baited hook in shallow water at the confluence of small creeks and larger channels (GRRB 1997). Concerns relating to the poor quality of Burbot livers in Canada's north are long-standing. Following community complaints of poor-quality fish in areas where there was oil and gas development, Lockhart et al. (1987) investigated the potential for hydrocarbon contamination of subsistence-harvested fish, including Burbot. Being a top predator and prone to the bioaccumulation of contaminants, Burbot have been used as biomonitors for metals, including mercury, and persistent organic contaminants in the Mackenzie River at Fort Good Hope and Great Slave Lake since the 1990s (Evans et al. 2005, Carrie et al. 2009; Muir et al. 2013) with past studies also conducted on the Slave River delta (McCarthy et al. 1997). Still, the concern over Burbot liver quality remains [H. Sayine-Crawford, GNWT Sahtu Region; A. Amos, GRRB; K. Hynes, Fisheries Joint Management Committee, Inuvialuit Settlement Region, pers. comm., January 2016].

Recognizing this persistant community concern over liver quality, the GRRB initiated a collaborative study with local harvesters and scientists to investigate the possible link between Burbot liver appearance (perceived palatability) and contaminant concentrations. The goals of this study were to investigate a problem identified by, and relevant to Gwich'in fishers, and conducted in collaboration with harvesters in conjunction with their traditional harvest activities. This study was designed to (1) evaluate associations between the condition of Burbot livers, as identified by traditional means, and contaminant concentrations, parasite loading, trophic position, and various biological metrics; and, (2) assess whether a traditional assessment of Burbot liver quality could be a useful community-based means to monitor the potential for increased contaminant levels in Burbot or detect broad-level fish health and environmental change.

We hypothesized that traditional local knowledge through visual assessment would be effective in selecting livers from fish that are safe to eat and screening out those that are not. Specifically, we predicted that Burbot livers that were deemed palatable would be from fish having (a) lower contaminant levels, (b) higher body condition, (c) higher gonadosomatic index (GSI), (d) higher hepatosomatic index (HSI), and (e) lower intensities of parasites relative to those that were deemed unpalatable, (f) and that there would be no correlation to perceived palatability and the other metrics investigated. This project is directed and informed by traditional and local knowledge and complemented by scientific methodology, bridging the qualitative and quantitative natures of each approach.

## Materials and methods

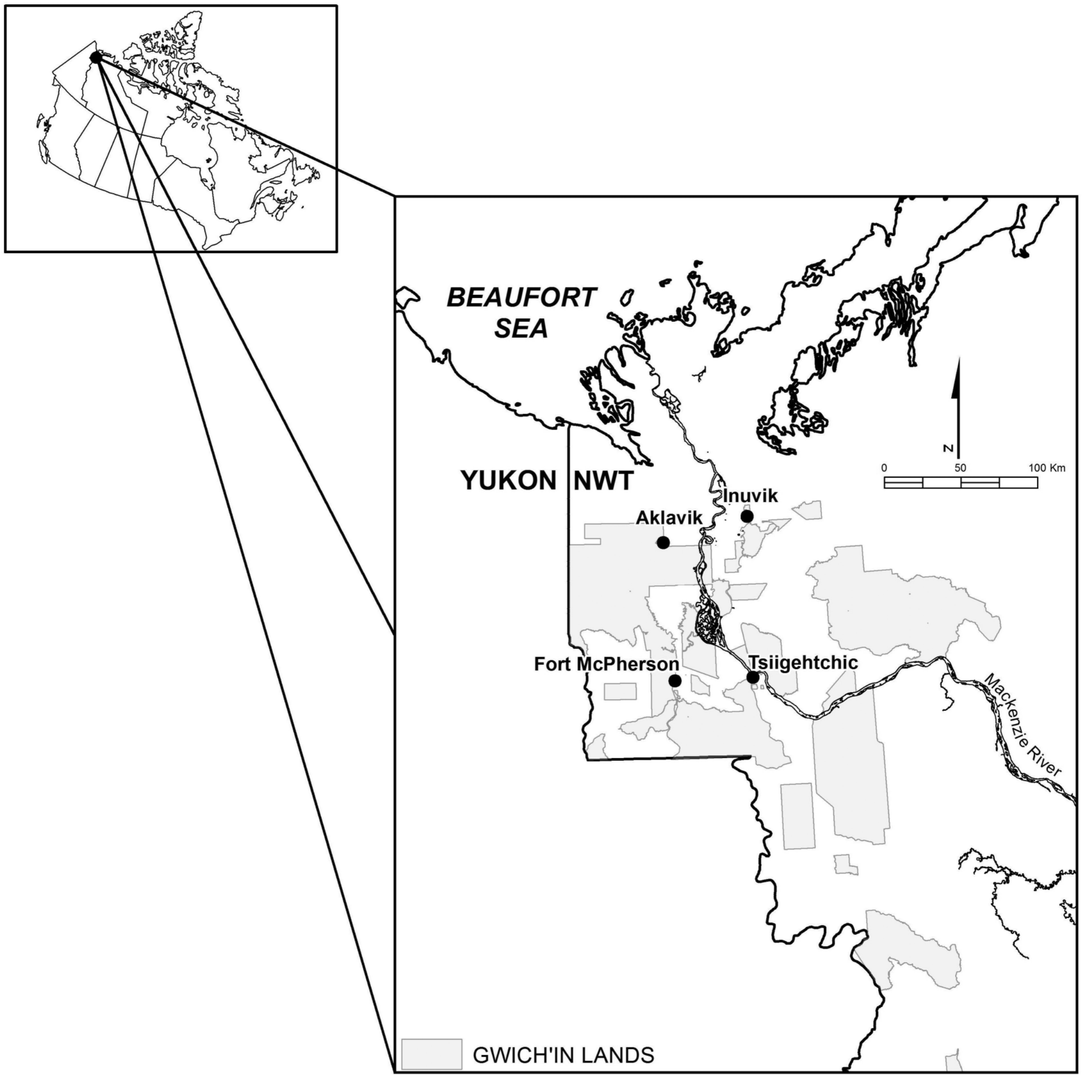
### Sample collection

Adult Burbot ($n$ = 136) were collected from traditional fishing areas in proximity to four communities; Inuvik, Aklavik, Fort McPherson, and Tsiigehtchic along the lower Mackenzie River system, in the Gwich'in Settlement Area (GSA), NWT, Canada (Fig. 1). In most cases, there were multiple sample sites near each community that provided a composite sample associated with each of the four communities. Sampling was conducted between October and December, in 2007 and 2008, using traditional hook and line methods (GRRB 1997). For each Burbot collected, the following information was taken: total length (± mm), total mass (± g), liver mass (± g), gonad mass (± g), sex, and liver appearance as described below.

### Traditional assessment of livers

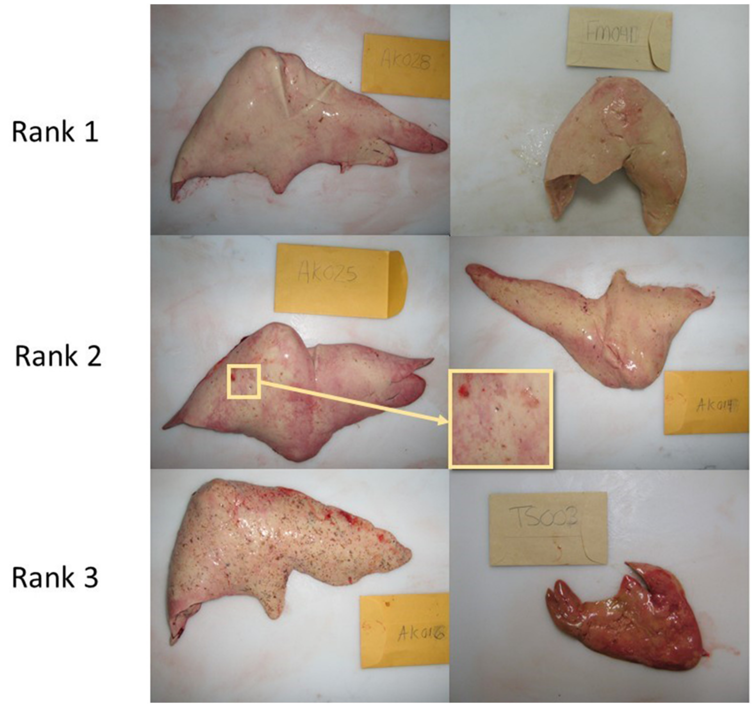
Livers were categorized by Gwich'in fishers based on liver appearance. The GRRB requested that the Renewable Resource Council (RRC) select appropriate volunteers from each Gwich'in community. A total of 18 harvesters were selected, four to five from each community. Each fisher had a minimum of 20 years experience of subsistence fishing and was able to visually characterize the variability in fish liver appearance. Ranking of livers was not standardized among individual fishers or among communities as we did not want to obscure or distort that decision-making process by having local fishers "see" livers differently than they currently do as that would be counter-productive in testing our hypothesis that traditional and local knowledge can be used to identify fish that are safe to eat. Therefore, variation in decision-making about liver ranking among individual fishers reflects real variation in fish use by people in the region. We used the traditional and local knowledge of these individuals to subjectively rank each liver by asking them for each; "would you eat it, feed it to your dogs, or throw it out?" (corresponding to ranks 1, 2, and 3, respectively) immediately after catching and filleting the fish. Fishers were

**Fig. 1.** Study area and communities within the Gwich'in Settlement Area (GSA), Northwest Territories, Canada. Shaded areas indicate Gwich'in owned lands within the GSA. Map data © 2013 CANVEC.




accompanied by the GRRB Fisheries Biologist during the actual fishing activity. The fisher dissected Burbot and ranked livers, and the biologist recorded the ranking and biological information and took photos of the livers. Visual assessments were of fresh, unfrozen Burbot livers sampled at time of harvest. If a ranker was unable to participate in the actual harvest, a photo of the fresh liver was used as a surrogate. Rank 1 livers were considered healthy and consumable, were white in colour, large and had no spots or marks visible (Fig. 2). Rank 2 livers were considered less healthy and harvesters would feed these fish to their dogs but would not eat the fish themselves. These livers were slightly discoloured, had a few spots or a few marks (Fig. 2, see inset). Rank 3 livers were very deformed livers, discoloured, small, and (or) had many spots/marks, and deemed unfit for consumption (Fig. 2).

**Fig. 2.** Photographs of Burbot livers ranked by appearance.




**Laboratory analyses**

After the ranking/photographing of liver was conducted, the fish carcass and liver were shipped frozen and whole from Inuvik to the Environment and Climate Change Canada laboratory in Saskatoon and samples were maintained at −40 °C until processing. Otoliths were taken to determine age of fish by the crack and burn technique (see Edwards et al. 2011). A subsample of liver was removed for persistent organic contaminant analysis and an assessment of parasite intensities (see below). Dorsal muscle tissue was taken for stable isotope analysis. Condition factor was calculated based on total length and total mass of the fish, GSI and HSI were calculated by dividing the total gonad mass and total liver mass, respectively, against the total body mass (Kristofferson and McGowan 1981).

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios were determined for all fish collected in 2007 to determine if the energy sources ($\delta^{13}C$) and trophic positions ($\delta^{15}N$) of Burbot related to the visual quality of their livers. A subsample of dorsal muscle was freeze-dried at −50 °C for percent water content determination. Approximately 1–2 mg of dried sample was then weighed into aluminum cups and analyzed using a Eurovector EuroEA elemental analyzer interfaced to a Nu Instruments Horizon isotope-ratio mass spectrometer using standard techniques. Stable carbon and nitrogen ratios are expressed in standard delta (δ) notation in “parts per mil” (‰) deviation from the international standards Vienna Pee Dee Belemnite ($\delta^{13}C$) and atmospheric air ($\delta^{15}N$). Internal references for calibration and QA/QC were run on every 24 samples. The estimated measurement precisions are ±0.1‰ for $\delta^{13}C$ and ±0.2‰ for $\delta^{15}N$. Prior to statistical analysis, we mathematically lipid normalized the $\delta^{13}C$ values using $\delta^{13}C_{normalized} = \delta^{13}C + [-3.32 + (0.99 \times C\text{:}N)]$ (Post et al. 2007). $\delta^{13}C$ values were normalized because lipid tissue is enriched in $^{12}C$ relative to bulk protein, and therefore differences in lipid content among fish may bias interpretation of energy sources of Burbot assigned to each liver ranking.

Subsamples ($n = 22$) of liver (0.5 g) were acid digested using an 8:1 ratio of nitric acid and hydrogen peroxide. A multielement suite including As, Se, Cu, and Zn was determined using inductively coupled plasma mass spectrometry (ICP-MS). The methodology is described in Riget et al. (2005). Total Hg analyses were conducted by automated thermal decomposition and atomic absorption detection using a Milestone Direct Hg Analyzer following US EPA method 7473. A subsample of 0.1–0.2 g of frozen liver was used; results were expressed on a wet weight basis. Reference materials were SRM 2976 from the National Institute of Standards and Technology (Standard Reference Materials Program, Gaithersburg, MD, USA) and DORM-3 and DOLT-4 from the National Research Council of Canada (Certified Reference Materials Program, Ottawa, ON, Canada). The method detection limit, determined as 3× the standard deviation of the blanks, was 0.3 ng Hg (approximately 2 ng/g wet weight).

The liver subsamples used for metals analysis were also analysed for polychlorinated biphenyl/organic chlorine (PCB/OC) pesticides at the National Laboratory for Environmental Testing, Environment and Climate Change Canada, using procedures outlined in Muir et al. (1988, 2000). Overall, samples were homogenized with sodium sulfate and Soxhlet extracted with dichloromethane–hexane (1:1). Legacy organochlorines were isolated by gel permeation chromatography followed by silica gel clean-up. Standard reference material (cod liver 1588a) was from the National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA) after every 20 samples. PCB congeners were generally within 25% of certified values.

All frozen livers were sent to the Parasitology Laboratory at the University of Lethbridge to evaluate the prevalence (proportion of hosts in a sample that are infected) and intensity (number of worms in an infected host) of larvae of the ascarid nematode *Raphidascaris acus* (Bloch, 1779). The results of previous host surveys show that larvae of this large-bodied worm are the only macroparasite present in livers of Burbot sampled from this region (Bernier 1986; Dick and Bernier 1987). Larvae observed in the livers of Burbot are typically associated within darkened, granulomatous nodules, each of which contains a dead worm. We estimated larval *R. acus* intensities by subsampling three randomly selected 5–6 mm sections of liver as per Goater and Doster (1997). The sections were weighed and the total number of nematodes in each section was counted under a dissecting microscope. Total larval intensities per host were estimated by scaling up to the total weight of the liver.

**Statistics**

All data analyses were completed using R (version 3.2.3, R Core Team 2016). We tested for differences in whole-body and liver characteristics of Burbot among collection sites using analysis of variance (one-way ANOVA). We tested for differences in whole-body characteristics and liver characteristics, as well as metal, OC, and parasite profiles among Burbot whose livers were ranked 1, 2, or 3 for palatability by traditional harvesters using a combination of linear and generalized mixed effects models. In each mixed model, we treated collection year and community as random intercepts so that the main effect of liver rank, treated as a factor (1, 2, or 3), could be analysed while accounting for potential variation across collection years and sites (Zuur et al. 2009). Chemical and stable isotope analyses were only run on samples collected in 2007, therefore, only community was included as a random intercept for those analyses. Where significant effects of liver rank were found, Tukey's tests with $p$-value adjustments for multiple comparisons were used to test for significant pairwise differences among ranks. Tukey's tests and estimation of least square means were performed using the R package "lsmeans" (Lenth 2016). We considered $P < 0.05$ to represent statistical significance.

Linear mixed models (LMM) were used for all response variables, except Burbot age, which was modelled with a generalized linear mixed model (GLMM) with Poisson distribution. For LMM, normality and heteroscedacity were tested graphically using QQ-plots and histograms of standardized residuals (Zuur et al. 2009). Where deviations from assumptions were found, data were transformed for LMM analysis. This included $\log_{10}$ transformation of fish body mass, HSI, liver mass, *R. acus* intensities, arsenic (As), total mercury (Hg), copper (Cu), zinc (Zn), carboxybenzyl (CBZ), dichlorodiphenyltrichloroethane (DDT), toxaphene (TOXA), chlordanes (CHL), and total PCB and square-root transformation of selenium (Se). GSI, condition factor, fish total length, liver lipids, hexachlorocyclohexane, $\delta^{13}$C, and $\delta^{15}$N did not require transformation. Mixed models were fit using the R package "lme4" (Bates et al. 2016) with *p*-values obtained using the Kenward–Roger modified *F* test for LMM from the R package "pbkrtest" (Halekoh and Højsgaard 2014) and likelihood ratio tests for GLMM from the R package "afex" (Singmann et al. 2016).

## Results

Overall, sampled Burbot averaged a total length of (mean ± SD) 727 ± 87 mm (range 535–990 mm), a mass of 3315 ± 1220 g (1000–8250 g), and were 13.7 ± 3.1 years old (8–27 years old). Individuals had an average condition factor of 0.7 ± 0.1 (−0.12 to 1.7), a HSI of 7.8% ± 2.3% (2.4%–18.3%), and a GSI of 6.8% ± 4.1% (0.001%–0.21%). Finally, muscle $\delta^{13}$C and $\delta^{15}$N values averaged −25.2‰ ± 1.1‰ (−27.7‰ to 23.1‰) and 12.1‰ ± 1.5‰ (7.9‰–15.4‰), respectively (Table 1). Burbot livers weighed on average 221 ± 114.6 g (42–624 g) and had lipid concentrations of 28.5% ± 7.9% (8.6%–41.9%). Biological and ecological characteristics of sampled Burbot demonstrated significant variation in total length, body mass, condition, HSI, GSI, $\delta^{13}$C, $\delta^{15}$N, and liver mass (ANOVA: all $P < 0.05$; Table 1) among the four northern communities, whereas age and liver lipids were comparable (ANOVA: all $P > 0.05$; Table 1). A total of 217 livers were ranked for palatability by harvesters, which were divided into three quality rankings (1–3; palatable to not palatable) as follow: 119 (54.8%) rank 1, 81 (37.3%) rank 2, and 17 (7.8%) as rank 3 (Fig. 3A). The frequency of ranked livers followed the same basic trend among communities with most of the livers sampled being of rank 1, followed closely with rank 2, and a smaller number of rank 3 livers. Fort McPherson had the highest percentage of rank 1 and lowest percentage of rank 3 livers; however, Aklavik, Inuvik, and Tsiigehtchic were similar in their relative frequency of livers by rankings (Fig. 3B).

Burbot body and liver characteristics ranked by harvesters for palatability differed in fish age ($F_{2,2} = 8.27$; $P = 0.02$), HSI ($F_{2,209.5} = 9.24$; $P < 0.01$), and liver mass (g) ($F_{2,210.3} = 8.10$; $P < 0.01$) (Table 2; Fig. 4). Specifically, livers ranked as unpalatable (rank 3) were from fish that were older and had lower HSI than livers ranked as palatable (ranks 1, 2). In addition, bigger livers were generally ranked as more palatable than smaller livers. Marginal evidence was found for selecting livers from fish with higher whole-body mass (g) ($P = 0.05$) and those with higher liver lipids ($P = 0.06$). The characteristics varied among ranked livers but, in general, livers from heavier Burbot and fatter livers were ranked as more palatable. Finally, no differences in the total length, condition factor, GSI, $\delta^{13}$C, or $\delta^{15}$N were found among fish whose livers were ranked for palatability (Table 2).

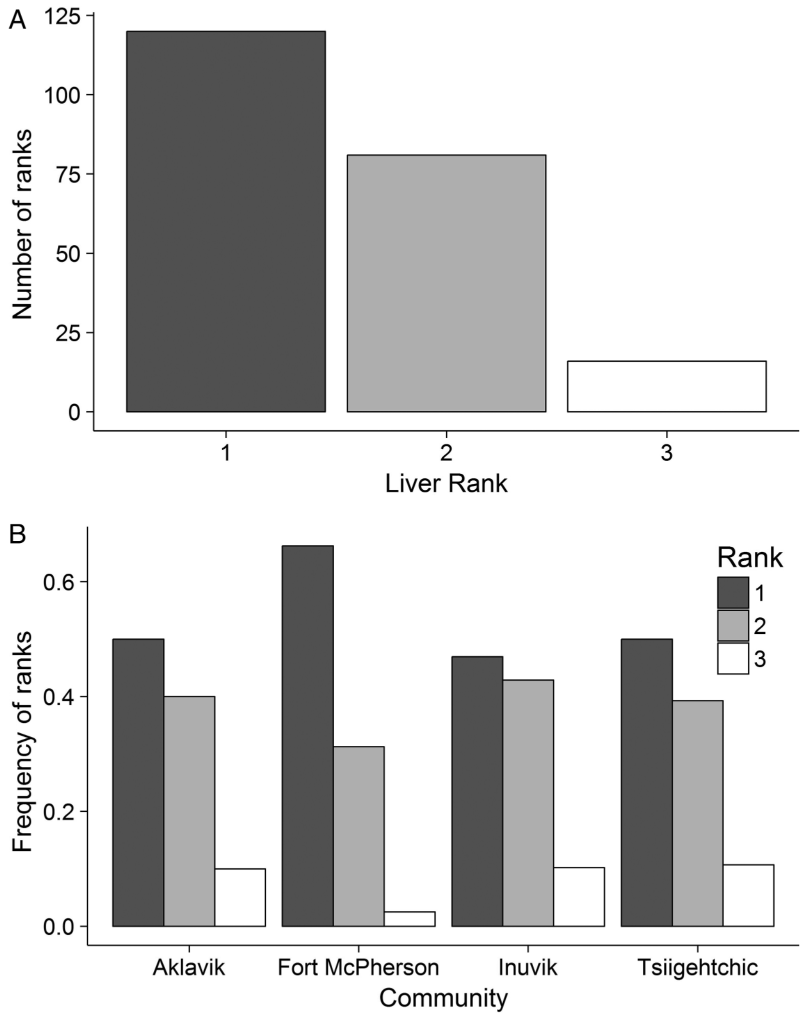
Livers ranked by harvesters for palatability differed in Cu ($F_{2,16.10} = 5.65$; $P = 0.01$) and in worm intensities ($F_{2,128.8} = 8.10$; $P < 0.01$), but did not differ for any other metals (Hg, As, Se, and Zn) or organochlorines (Table 3; Fig. 5). Specifically, higher concentration of Cu were found in livers ranked higher for palatability (rank 1) compared to livers described as unpalatable (rank 3). In contrast, *R. acus* intensities increased as the liver palatability decreased (rank 1–3).

Table 1. Among-community comparison of biological characteristics (mean ± SD) of Burbot (*Lota lota*) whose livers were ranked for palatability by aboriginal harvesters in each community and pooled.

| | | Community | | | | |
|---|---|---|---|---|---|---|
| Tissue | Measure | Aklavik | Fort McPherson | Inuvik | Tsiigehtchic | Sites Pooled |
| Whole body | Total length (mm) | 738 ± 67 ($n$ = 60) | 703 ± 97 ($n$ = 80) | 756 ± 85 ($n$ = 49) | 713.1 ± 74 ($n$ = 28) | 726 ± 86 ($n$ = 217) |
| | Body mass (g) | 3533 ± 931 ($n$ = 60) | 3141 ± 1212 ($n$ = 80) | 3776 ± 1455 ($n$ = 49) | 2526 ± 848 ($n$ = 28) | 3314 ± 1220 ($n$ = 217) |
| | Condition | 0.7 ± 0.1 ($n$ = 60) | 0.7 ± 0.1 ($n$ = 80) | 0.7 ± 0.2 ($n$ = 49) | 0.6 ± 0.1 ($n$ = 28) | 0.7 ± 0.1 ($n$ = 217) |
| | Age (years) | 13.5 ± 2.1 ($n$ = 60) | 13.1 ± 3.3 ($n$ = 80) | 13.9 ± 2.8 ($n$ = 49) | 14.9 ± 3.9 ($n$ = 28) | 13.7 ± 3.1 ($n$ = 217) |
| | HSI (%) | 8.6 ± 2.2 ($n$ = 60) | 7.9 ± 2.1 ($n$ = 80) | 7.6 ± 2.5 ($n$ = 49) | 5.9 ± 1.9 ($n$ = 28) | 7.8 ± 2.3 ($n$ = 217) |
| | GSI (%) | 7.4 ± 4.2 ($n$ = 60) | 6.7 ± 3.4 ($n$ = 80) | 7.6 ± 3.8 ($n$ = 49) | 4.6 ± 5.5 ($n$ = 28) | 6.8 ± 4.1 ($n$ = 217) |
| | $\delta^{15}$N (‰) | 12.6 ± 1.2 ($n$ = 33) | 11.3 ± 1.2 ($n$ = 50) | 13.4 ± 1.3 ($n$ = 19) | 12.2 ± 1.7 ($n$ = 28) | 12.1 ± 1.5 ($n$ = 130) |
| | $\delta^{13}$C (‰) | −25.6 ± 1.0 ($n$ = 33) | −25.5 ± 0.9 ($n$ = 50) | −24.1 ± 0.9 ($n$ = 19) | −24.8 ± 1.0 ($n$ = 28) | −25.2 ± 1.1 ($n$ = 130) |
| Liver | Mass (g) | 251.9 ± 104.8 ($n$ = 60) | 214.3 ± 120.2 ($n$ = 80) | 240.3 ± 114.1 ($n$ = 49) | 141.6 ± 78.7 ($n$ = 28) | 221.2 ± 114.6 ($n$ = 217) |
| | Lipid (%) | 30.0 ± 6.5 ($n$ = 7) | 29.5 ± 4.9 ($n$ = 6) | 21.5 ± 8.5 ($n$ = 8) | 33.4 ± 8.4 ($n$ = 5) | 28.5 ± 7.9 ($n$ = 26) |

**Note:** SD, standard deviation; HSI, hepatosomatic index; GSI, gonadosomatic index.

**Fig. 3.** Number of Burbot liver samples by palatability ranking (A), and frequency of Burbot samples by ranking per community (B), Gwich'in Settlement Area, Northwest Territories, Canada. Palatability rank of 1 being "good", 2 "fair", and 3 "bad".




## Discussion

The effectiveness of using traditional visual assessments to determine the quality of the liver as a general indicator of Burbot health was supported in our results. Traditional methods worked well for selecting lipid-rich Burbot livers with low intensities of fish parasites. However, these methods were not effective for detecting Burbot with elevated concentrations of heavy metals or organochlorine compounds.

There was no correlation observed between any of the metal or organochlorines parameters tested and the perceived palatability of livers, apart from Cu. Cu concentrations were significantly higher in the livers ranked "most palatable". It should be noted that Cu is an essential element for human health and the concentrations found in all livers assessed in this study (from most to least palatable) were well below consumption guidelines (WHO 2004). Further, Hg, As, and Se concentrations were comparable to other studies, but Cu concentrations were substantially lower in fish from our study area than from

**Table 2.** Among-rank differences in body and liver characteristics (mean ± SD) of Burbot (*Lota lota*) whose livers were ranked 1–3 for palatability by Indigenous harvesters (1 being "good", 2 "fair", and 3 "bad").

| | | Liver rank | | | Model results | | | |
|---|---|---|---|---|---|---|---|---|
| Specimen | Measure | 1 | 2 | 3 | *ndf, ddf* | *F* | *P* | Tukey[a] |
| Whole body | Total length (mm) | 730 ± 90 ($n$ = 119) | 721 ± 81 ($n$ = 81) | 721 ± 82 ($n$ = 17) | 2, 212.6 | 0.85 | 0.43 | N/A |
| | Body mass (g) | 3472 ± 1301 ($n$ = 119) | 3153 ± 1123 ($n$ = 81) | 2989 ± 937 ($n$ = 17) | 2, 210.0 | 2.77 | 0.07 | N/A |
| | Condition | 71.9 ± 16.0 ($n$ = 119) | 67.5 ± 9.7 ($n$ = 81) | 68.1 ± 15.4 ($n$ = 17) | 2, 210.9 | 1.28 | 0.28 | N/A |
| | Age (years) | 13.6 ± 2.9 ($n$ = 119) | 13.2 ± 2.9 ($n$ = 81) | 16.8 ± 3.7 ($n$ = 17) | 2, 2.0 | 8.27 | **0.02** | b, c |
| | HSI (%) | 8.1 ± 2.2 ($n$ = 119) | 7.6 ± 2.4 ($n$ = 81) | 6.2 ± 2.8 ($n$ = 17) | 2, 209.5 | 9.24 | <**0.01** | b, c |
| | GSI (%) | 6.9 ± 3.9 ($n$ = 119) | 6.5 ± 4.3 ($n$ = 81) | 7.6 ± 5.2 ($n$ = 17) | 2, 192.4 | 0.46 | 0.63 | N/A |
| | $\delta^{15}$N (‰) | 12.1 ± 1.6 ($n$ = 70) | 12.1 ± 1.4 ($n$ = 50) | 12.0 ± 1.1 ($n$ = 10) | 2, 124.5 | 0.38 | 0.69 | N/A |
| | $\delta^{13}$C (‰) | −25.0 ± 1.1 ($n$ = 70) | −25.3 ± 1.1 ($n$ = 50) | −25.5 ± 0.9 ($n$ = 10) | 2, 124.4 | 2.17 | 0.12 | N/A |
| Liver | Mass (g) | 243 ± 122 ($n$ = 119) | 199 ± 94 ($n$ = 81) | 170 ± 113 ($n$ = 17) | 2, 210.3 | 8.10 | <**0.01** | a, b, c |
| | Lipid (%) | 30.9 ± 7.0 ($n$ = 7) | 33.0 ± 4.9 ($n$ = 5) | 25.1 ± 8.4 ($n$ = 14) | 2, 18.3 | 3.94 | 0.06 | N/A |

**Note:** Model results indicating if body and liver characteristics differed among palatability rank were obtained using Kenward–Rogers *F* tests on linear mixed effects models and likelihood ratio tests on generalized linear mixed effect models with collection year and community treated as random intercepts. Tukey's tests were used to obtain pairwise multiple comparisons between liver ranks. SD, standard deviation.

[a]a, b, and c corresponds to significant differences at $P < 0.05$ determined by Tukey's tests between liver ranks 1–2, 1–3, and 2–3, respectively. An N/A value indicates a Tukey's test was not performed because the factor liver rank was not significant.

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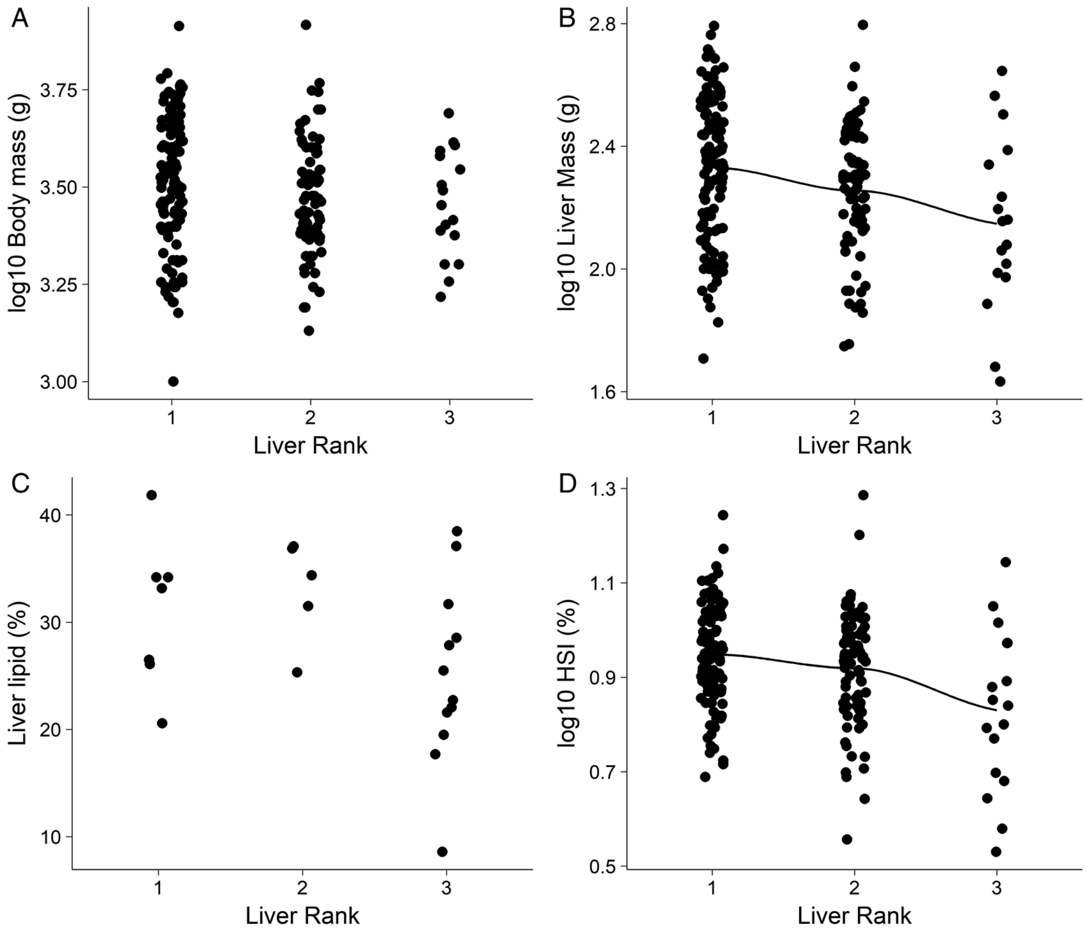
**Fig. 4.** (A) Body mass ($log_{10}$), (B) liver mass ($log_{10}$), (C) liver lipids, and (D) hepatosematic index (HSI; $log_{10}$) of individual Burbot sampled, organized by liver palatability ranking (1 being "good", 2 "fair", and 3 "bad"), Gwich'in Settlement Area, Northwest Territories, Canada. Black lines are loess smoothers to visualize trends where significant differences among liver ranks existed (Table 2).




Great Slave Lake. McCarthy et al. (1997) reported a median Cu concentration of 7.6–8.7 μg/g for Burbot collected annually in the Slave River at Fort Smith over 1991–1993 and 3.8–4.2 μg/g for two reference lakes. Although parasite intensities may affect the accumulation of metals by fish (Sures 2001), this was not apparent in our study.

Parasite intensity can physiologically compromise individual hosts, resulting in reduced overall fitness, and animals that are in otherwise poor health are often associated with reduced immune-competence (Goater et al. 2014). We found a clear inverse relationship between the perceived palatability of livers and parasite intensity. The larvae of *R. acus* are found in and on the livers of a range of fishes from Eurasia and North America (Goater et al. 2014). Unlike tapeworms, roundworm do not infect humans and dogs (Stewart and Bernier 1999). The larvae typically enter a resting stage that encysts on the stomach, caecae, and intestine of intermediate hosts such as coregoine fishes. Following the ingestion of an appropriate intermediate host, adult worms develop to reproductive maturity within the intestines of the definitive host, usually Northern Pike (*Esox lucius*, Linnaeus 1758). Infection characteristics of *R. acus* within Burbot are atypical because

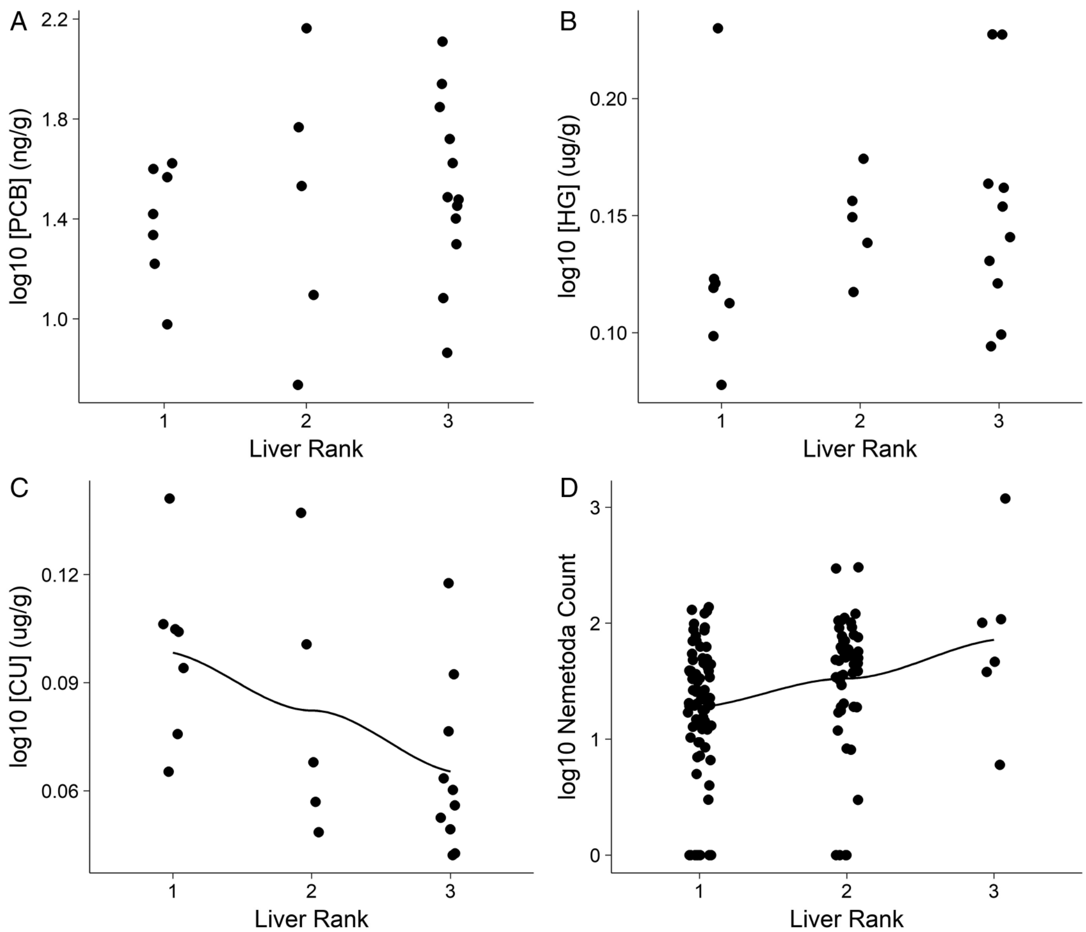
**Table 3.** Comparison of concentrations of organochlorines (ng/g) and metals (μg/g), and amount of the nematode (*Raphidascaris acus*) measured in Burbot (*Lota lota*) livers ranked 1–3 for palatability by Indigenous harvesters (1 being "good", 2 "fair", and 3 "bad").

| | | Concentrations/Counts | | | Model results | | | |
|---|---|---|---|---|---|---|---|---|
| Stressor | Measure | Liver rank 1 | Liver rank 2 | Liver rank 3 | *ndf, ddf* | *F* | *P* | Tukey[a] |
| Organochlorines | ΣPCB | 26.6 ± 12.4 (*n* = 7) | 50.2 ± 56.7 (*n* = 5) | 43.6 ± 35.4 (*n* = 14) | 2, 18.98 | 0.27 | 0.76 | N/A |
| | ΣDDT | 6.3 ± 4.4 (*n* = 7) | 15.0 ± 17.1 (*n* = 5) | 10.6 ± 10.3 (*n* = 14) | 2, 18.75 | 0.49 | 0.62 | N/A |
| | ΣCHL | 8.6 ± 5.1 (*n* = 7) | 17.1 ± 18.1 (*n* = 5) | 9.5 ± 9.3 (*n* = 14) | 2, 18.98 | 0.54 | 0.59 | N/A |
| | ΣHCH | 0.8 ± 0.4 (*n* = 7) | 0.9 ± 0.3 (*n* = 5) | 0.7 ± 0.3 (*n* = 14) | 2, 18.38 | 1.88 | 0.18 | N/A |
| | ΣCBZ | 3.0 ± 1.7 (*n* = 7) | 3.1 ± 0.9 (*n* = 5) | 2.8 ± 1.6 (*n* = 14) | 2, 18.98 | 0.15 | 0.86 | N/A |
| | ΣTOXA | 26.4 ± 20.2 (*n* = 7) | 37.7 ± 37.1 (*n* = 5) | 21.7 ± 25.8 (*n* = 14) | 2, 18.98 | 0.58 | 0.57 | N/A |
| Metals | HG | 0.3 ± 0.2 (*n* = 7) | 0.4 ± 0.1 (*n* = 5) | 0.4 ± 0.2 (*n* = 14) | 2, 16.28 | 1.96 | 0.17 | N/A |
| | AS | 2.7 ± 2.1 (*n* = 7) | 2.5 ± 1.8 (*n* = 5) | 2.4 ± 2.7 (*n* = 14) | 2, 16.20 | 0.49 | 0.62 | N/A |
| | SE | 0.5 ± 0.1 (*n* = 7) | 0.5 ± 0.1 (*n* = 5) | 0.5 ± 0.1 (*n* = 14) | 2, 16.56 | 0.03 | 0.97 | N/A |
| | CU | 0.3 ± 0.1 (*n* = 7) | 0.2 ± 0.1 (*n* = 5) | 0.2 ± 0.1 (*n* = 14) | 2, 16.10 | 5.65 | **0.01** | b |
| | ZN | 10.2 ± 7.8 (*n* = 7) | 7.5 ± 0.9 (*n* = 5) | 6.9 ± 1.0 (*n* = 14) | 2, 17.46 | 1.27 | 0.31 | N/A |
| Parasites | Nemetoda | 32.7 ± 32.6 (*n* = 77) | 56.6 ± 58.6 (*n* = 51) | 247.1 ± 462.4 (*n* = 6) | 2, 128.8 | 5.29 | <**0.01** | a, b |

**Note:** Model results indicate if body and liver characteristics differed among palatability rank using Kenward–Rogers *F* tests on linear mixed effects models with each community treated as a random intercept. Tukey's tests were used to obtain pairwise multiple comparisons between liver ranks.

[a]a, b, and c corresponds to significant differences at $P < 0.05$ determined by Tukey's tests between liver ranks 1–2, 1–3, and 2–3, respectively.

**Fig. 5.** Concentrations of (A) polychlorinated bi-phenyls (PCB; $\log_{10}$), (B) mercury (Hg; $\log_{10}$), (C) copper (Cu; $\log_{10}$), and number of Nemetoda parasites ($\log_{10}$) in the livers of individual Burbot sampled, organized by liver palatability ranking (1 being "good", 2 "fair", and 3 "bad"), Gwich'in Settlement Area, Northwest Territories, Canada. Black lines are loess smoothers to visualize trends where significant differences among liver ranks existed (Table 2).




individual hosts can harbour larvae within the viscera and also adults within the gut (Stewart and Bernier 1999). Therefore, a single individual can act as intermediate and definitive host. The development of larvae in the livers of Burbot is also unusual because worms rarely reach the encystment stage (Stewart and Bernier 1999). Instead, larvae migrate throughout the liver via the hepatic blood vessels, causing distortion, breakdown of blood vessel walls, and extensive tissue damage (Poole and Dick 1984; Stewart and Bernier 1999).

Burbot livers ranked as unpalatable were typically smaller, contained less lipid, and came from older fish that generally weighed less and had lower HSI. In the past, harvesters have blamed the watery-taste and texture of livers on hydrocarbon development (Lockhart et al. 1987). Lockhart et al. (1987) suggested that the watery livers were likely related to reproductive development. Although we found no relationship between GSI and liver selection in our study, this hypothesis is reasonable because Burbot draw on their liver lipid reserves to fuel reproductive demands and lipids in the liver are consequently replaced by water (Cott et al. 2013).

The fish used in this study were also used for a study on the ecology of Burbot where stable isotope analysis was conducted (see Recknagel et al. 2015). We used these data opportunistically to determine if any generalizations could be made on trophic ecology using this traditional monitoring approach that could be later incorporated into a community-based monitoring program. As with contaminants, we found no difference in $\delta^{13}C$ or $\delta^{15}N$ among Burbot with different liver-palatability rankings suggesting that energy sources or trophic position were not related to liver palatability. Burbot occupy a top trophic position in aquatic food webs (Cott et al. 2011), which is unsurprising as they become obligate piscivores upon reaching adulthood (Amundsen et al. 2003). Burbot in the lower Mackenzie River are no exception, with fish being their primary food source of the Burbot used is this study (see Recknagel et al. 2015), including a high degree of cannibalism (Gallagher and Dick 2015). Whether Burbot are in poor health with "bad" looking livers or not, they would still be eating fish, and therefore should occupy a trophic niche like those with "good" livers.

For millennia, Gwich'in hunters and fishers have used the appearance of the liver and intestines to determine the health of the animals they have harvested. The liver should be clear, dark (or creamy in the case of Burbot), and uniform in colour and be free of spots or blisters, otherwise the animal is deemed to be sick and is not eaten (GRRB 2001). The ability to identify and avoid eating physiologically compromised animals is an important skill and precautionary strategy for Gwich'in harvesters as the consequences of infection particularly without medical treatment, can be severe. This may simply be a form "of an adaptive disgust response" where possible pathways for disease are instinctively avoided (Curtis et al. 2011). The propensity for people to select for food that looks "good" may have evolved from a food safety standpoint but has developed into a habitual human trait in modern society as well. In a study by Yue et al. (2009), 75% of people were willing to pay a premium for organically grown apples over conventionally grown apples (i.e., where pesticides and chemical fertilizers are used), but this willingness was proportional to the appearance of the apple. If the organically grown apples appeared cosmetically imperfect they were rejected in favour of the nonorganic but aesthetically pleasing alternative. In other words, appearance of a food item is a fundamental driver of food selection even when presented with the knowledge that it may not be as healthy as less aesthetically pleasing alternatives, and our idea of what is palatable is subject to change over time. This hold true with the appearance of traditional foods as well. Robidoux et al. (2009) reported on an initiative to reintegrate traditional foods into the diets of people from a First Nation community on Northern Ontario. In their study, they documented the use of Burbot livers by community members and also quantified the nutritional value of Burbot livers. Like the Gwich'in, this First Nation historically used burbot livers and have long known that they are a healthy food. However, in contrast to the Gwich'in, these fishers no longer actively harvest Burbot. If caught Burbot are thrown away and fishers even avoid touching them (Robidoux et al. 2009).

The difference — and the problem — with environmental contaminants in subsistence foods is that in contrast to something like parasites, contaminants may not change a food's appearance, and harvesters likely do not have a priori knowledge of contaminant concentrations, or any way to visually detect and select foods that would be lower in contaminants. Being a product of the industrial era anthropogenic pollutants, including the increased concentrations of elemental metals, are recent occurrences relative to the amount of time Indigenous people have been relying on wild fish and game. Such pollutants are now ubiquitous and represent a potential health concern for traditional harvesters (Muir et al. 2005). It is conceivable that, due to the lipophilic nature of these compounds, selecting for the largest and fattiest livers also selects for livers with higher concentrations of contaminants as they cannot be seen directly. In a recent study, Burbot in a heavily industrialised area of Lake Erie and a point source for PCB pollution had 60 times the levels of PCBs per gram of tissue than Burbot from Great Slave Lake (Stapanian et al. 2014). Inability of traditional methods to avoid contaminated subsistence fish could be problematic where fish could be exposed to such contaminant "hot spots". Fortunately, contaminant concentrations in fish from the GSA are below consumption guidelines. In many cases, the nutritional benefits of eating traditional foods outweigh potential risk from potential contaminants that may be present in fish tissue (Donaldson et al. 2010; Reyes 2016). With the importance of harvesting and eating traditional foods to the Gwichi'in people, the monitoring of contaminants in subsistence food sources should be a priority.

Effective community/harvest-based environmental monitoring should satisfy several fundamental principles including being relatively simple to implement and complete, employing scientifically defensible methods, and being guided by community interests (Bell and Harwood 2012). The work presented here offers an example of a straightforward approach that can be easily implemented into a community-based monitoring template that could be conducted during regular harvesting practices and assist in the detection of environmental change. Furthermore, using traditional harvests — such as in this study — can be a cost-effective means of sample collection while combining the mutually beneficial aspects of traditional and local knowledge and scientific investigation (Moller et al. 2004; Bell and Harwood 2012). Future research could include conducting community-based monitoring to assess Burbot liver quality on an annual basis to enable the detection of interannual variation in different areas where Burbot are regularly harvested for their livers, such as in the Inuvialuit Settlement Region. Such an expansion in geographic scope would permit the investigation of regional variation. Burbot could also be sampled from an area that is known to be contaminated (e.g., areas of Lake Erie; see Stapanian et al. 2014), and their livers could be visually assessed by northern harvesters (through photos that were taken using a standardized approach). This would act as a surrogate to a traditional harvest scenario in a polluted area.

This research and proposed monitoring approach represents a successful and useful melding of traditional and local knowledge and science to address community concerns over a traditional food source. The wide pan-Arctic range of Burbot makes them as an excellent bioindicator species for environmental monitoring purposes (Stapainian et al. 2010). We demonstrate that the relative appearance of a Burbot liver can be an indication of overall condition of the fish. If the proportion of palatable to unpalatable livers is found to be beyond normal variability it could be an indication of environmental change. If so, a targeted scientific study could be aimed at investigating the metric further (e.g., are parasite intensities in Burbot livers increasing?). Our study was "user-inspired" and "user-useful" (Raymond et al. 2010) and demonstrated that the resource users — in this case subsistence Gwich'in fishers — can be integral in the development and implementation of scientific studies.

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