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Towards a better understanding of the benefits and risks of country food consumption using the case of walruses in Nunavik (Northern Quebec, Canada)

Laura M. Martinez-Levasseur [a,b,*], M. Simard [c], C.M. Furgal [b], G. Burness [a], P. Bertrand [d,e], S. Suppa [c], E. Avard [c], M. Lemire [f,g]

[a] Department of Biology, Trent University, Peterborough, Ontario K9L 0G2, Canada
[b] Indigenous Environmental Studies & Sciences Program, Trent University, Peterborough, Ontario K9L 0G2, Canada
[c] Nunavik Research Centre, Makivik Corporation, Kuujjuaq, Québec J0M 1C0, Canada
[d] Department of Biology and Center for Northern Studies, Université du Québec, Rimouski, QC G5L 3A1, Canada
[e] Norwegian Polar Institute, Fram Centre, Tromsø 9296, Norway
[f] Département de médecine sociale et préventive, Université Laval, Québec City, Québec, Canada
[g] Axe Santé des populations et pratiques optimales en santé, Centre de recherche du CHU de Québec, Université Laval, 1050 Chemin Ste-Foy, Québec City, Québec G1S 4L8, Canada

HIGHLIGHTS

- Sharing Inuit knowledge is key for safe consumption of Atlantic walrus in Nunavik.
- Walruses are low in mercury but high in nutrients (omega-3 fatty acids; selenium).
- Only 3% of 755 walruses (1994–2013) were infected with *Trichinella nativa*.
- With the Nunavik Trichinellosis Program, walrus hunt could support food security.
- Sharing walrus meals with the youth will increase their taste for it.

GRAPHICAL ABSTRACT

HEALTH BENEFITS

High levels of omega-3 fatty acids

High levels of selenium

Low levels of mercury

RISKS

Clostrodium botulinum

Trichinella nativa
(3% out of 755 walruses)

LIMITING RISKS

Transmission of scientific and Inuit knowledge (hunting, butchering, preparing, storing and sharing aged walrus meat) is key for safe consumption of Atlantic walrus in Nunavik.

With the Nunavik Trichinellosis Prevention Program, walrus harvest can help support food security in Nunavik.

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ABSTRACT

Food insecurity affects Inuit communities. One solution is to consume locally harvested foods, named country foods. However, some country foods are not eaten as often as before, and pressures including contaminants and environmental changes threaten the health of Arctic fauna, thus its suitability for local consumption. By combining Inuit Knowledge with laboratory data, our study assessed the benefits and risks of walrus consumption by Inuit in Nunavik, Québec, Canada. It aimed to increase understanding of: 1) the hunt of healthy Atlantic walruses (*Odobenus rosmarus rosmarus*); 2) the safe preparation of walruses; 3) the nutritional benefits and risks of consuming walruses. To do so, we interviewed 34 hunters and Elders from Nunavik. Levels of mercury, omega-3 polyunsaturated fatty acids and selenium were evaluated from locally harvested walruses. Through the Nunavik Trichinellosis Prevention Program, a total of 755 Atlantic walrus samples, collected between 1994 and 2013, were tested for *Trichinella nativa*. Information on botulism was reviewed. While interviews informed on how to select healthy walruses and prepare them for consumption, laboratory analyses revealed that walruses had elevated levels of omega-3 fatty acids and selenium but low levels of mercury compared to some other wildlife. Only 3% of the 755 walruses were infected with *T. nativa*. Most walruses' infections were found within individuals from

* Corresponding author at: Environment and Climate Change Canada, Montréal, Québec H2Y 2E7, Canada.
E-mail address: lmmartinezlevasseur@gmail.com (L.M. Martinez-Levasseur).

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Country food

the South East Hudson Bay stock, where Inuit have thus decided to stop hunting since mid-2000s. Finally, although the number of outbreaks of trichinellosis related to the consumption of walruses has significantly reduced in Nunavik, botulism could continue to be an issue when igunaq (i.e. aged walrus) is not properly prepared. With the support of the Nunavik Trichinellosis Prevention Program and transmission of Inuit knowledge on igunaq preparation, the consumption of Atlantic walruses has the potential to help address issues related to food insecurity in Nunavik in the future.

1. Introduction

Food insecurity affects Inuit communities throughout the Canadian Arctic (Council of Canadian Academies, 2014; Huet et al., 2012). Solutions to this issue are not simple because Inuit food systems are impacted by several ecological changes, including environmental contamination, natural resource depletion and climate change, as well as several social changes, such as Inuit population increase, challenges in Inuit Knowledge transmission, and local food transition towards a larger proportion of market foods (Council of Canadian Academies, 2014). From human and ecosystem health perspectives, promising practices to improve food security rely on promoting Inuit Knowledge about local foods from the land - commonly referred to as country, traditional or wild foods by Inuit - and diversifying these foods harvested and eaten locally (Council of Canadian Academies, 2014). Country foods (the term to be used in this paper) such as caribou (*Rangifer tarandus granti*), beluga (*Delphinapterus leucas*), Arctic char (*Salvelinus alpinus*) or berries continues to play a key part in Inuit diet and culture in Nunavik, northern Quebec (Blanchet and Rochette, 2008; Lemire et al., 2015). Conversely, some other country foods, such as walruses, are not eaten as often as before. A survey performed in 2004 in Nunavik (northern Quebec, Canada) revealed that 83% of the population had not consumed walrus during the previous year (Blanchet and Rochette, 2008) although it used to be an important country food historically (Krupnik and Ray, 2007; Larrat et al., 2012).

Since the end of commercial walrus hunting, which was mostly abandoned in the 1880s and then banned in the 1930s, walrus populations have successfully recovered in most areas across the Arctic (Fay, 1985; Weslawski et al., 2000). Pacific walruses (*Odobenus rosmarus divergens*) abundance was estimated above 200,000 whereas those of Atlantic walruses (*Odobenus rosmarus rosmarus*), the species found on Nunavik coasts, has been estimated above 25,000 when all the stock numbers are combined (Kovacs, 2016; Lowry, 2016), and among which approximately 21,500 are found in Canada (COSEWIC, 2017). The global worldwide status of walruses is considered by the IUCN (International Union for Conservation of Nature) as "Near Threatened", because of uncertainties surrounding future decline in their habitat quality, and because of the lack of data on general walrus abundances and trends, although in the last decade research effort has documented some positive trends in populations sub-species (Kovacs, 2016). Although the IUCN SSP (Species Survival Commission) Pinniped Specialist Group has recommended Atlantic walruses to be listed as "Near Threatened" for the same reasons (Lowry, 2016), Inuit consider Atlantic walruses not at risk (DFO, 2013).

For thousands of years, walruses have been hunted by Northern Indigenous communities including Inuit, which have relied on walruses and other marine mammal species for survival in the Arctic (Huntington et al., 2013; Krupnik and Ray, 2007). Indeed, walrus meat has been playing an important role in the traditional Inuit diet, and hides were used to make traditional clothes, such as footwear (DFO, 2013). Today, walruses continue to be hunted by Inuit, a right protected by agreements between federal and state governments and Indigenous peoples (Wiig et al., 2013). In Canada and Greenland, subsistence harvest is regulated by quotas (Lowry, 2016; Wiig et al., 2013). For example, according to the Part III, article 26 of the *Marine Mammal Regulations*, in Nunavut, the communities of Coral Harbour, Sanikiluaq, Arctic Bay and Clyde River have a quota that varies from 10 to 60 animals per year. There is no quota for Nunavik, however, and in general the reported harvests have decreased within the last decade (COSEWIC, 2017). While in the 1980s, the mean number of harvested Atlantic walruses for the entire region of Nunavik was around 100 individuals, in the 2000s it had decreased in half (DFO, 2002; Larrat et al., 2012). Such decline results from a variety of factors including the decrease in the number of sled dogs to feed and the high costs of fuel (DFO, 2013; Dorais, 1997).

Inuit traditionally used to age marine mammals, and particularly walrus skin, fat, meat and other parts of the animal to make *igunaq*, a fermented Inuit delicacy. The local knowledge on how to prepare and age marine mammals used to be transmitted from one generation to the next. However, unsafe preparation of *igunaq* has led to recurrent cases of botulism among Inuit particularly between the 1970s and the 1990s (Austin and Leclair, 2011; Blanchet and Rochette, 2008; Leclair et al., 2013b). Human botulism results from the ingestion of foods contaminated with neurotoxin types A, B, E, or F, produced by the bacteria *Clostridium botulinum* groups I and II (Leclair et al., 2013b). In Northern Canada, the most common serotype of the bacteria is the type E, which is the least lethal type. In the Canadian Arctic, type E outbreaks were mostly linked to the consumption of marine mammals *igunaq* (Leclair et al., 2013b). Although different sources may be involved in the contamination of country foods by the bacteria *Clostridium botulinum*, higher risks seem to occur during the butchering of marine mammals when the carcass is exposed to *C. botulinum* spores commonly found in the environment along the shoreline (Leclair et al., 2013a, 2017). Those spores are heat-resistant, and in the absence of oxygen, will germinate, grow and then excrete botulin neurotoxins (Leclair et al., 2013b). Interestingly, although walrus is most often used by Inuit to make *igunaq*, 78% of the botulism outbreaks in Nunavik (32 out of 41) between 1985 and 2005, were linked to the consumption of fermented seal meat and flippers (Leclair et al., 2013b). For the same period for the entire Canada, only three botulism outbreaks were linked to walrus *igunaq*, which infected nine persons but caused no death (Leclair et al., 2013b). The case-fatality rate linked to botulism in Canada were divided by three (from 17% to 5.4%) between 1985 and 2005, likely due the increased awareness of the related symptoms that leads to quick treatment with antitoxin (Leclair et al., 2013b). Every year, a few cases of botulism continue to be declared in Nunavik (Blanchet and Rochette, 2008; Leclair et al., 2017) and the two cases recorded in 2017 were linked to the consumption of beluga aged fat known as *misiraq* (Paquin, pers comm).

Another zoonotic disease called trichinellosis is associated with the consumption of raw or aged walrus infected with the parasitic nematode *Trichinella nativa*. While the aging process does not destroy the parasite, heating the meat thoroughly does (Larrat et al., 2012). *Trichinella* spp. is a parasitic round worm that can infect humans and cause trichinellosis. The transmission of *Trichinella* spp. generally occurs via ingestion of an infective encysted *Trichinella* spp. larvae, which often occurs through predation or scavenging (Jenkins et al., 2013; Vlasman and Campbell, 2003). After ingestion, the cysts release the larvae, which then develop in the intestine of the host into adults where they reproduce. Then females *Trichinella* spp. release new larvae that circulate in the host's circulatory system and then settle and encyst in muscle tissue, where they can remain dormant for years (Jenkins et al., 2013;

Vlasman and Campbell, 2003). This zoonotic disease shows its clinical signs only a few weeks after ingestion, and depending on the quantity of infected meat ingested, its level of infection and stage can lead to a wide array of symptoms such as fever, facial oedema, muscle pain, diarrhea, vomiting, and in rare occasion, death (Larrat et al., 2012). While the pathological significance of *Trichinella* spp. infection is well described in humans, in wildlife, it is poorly known (Jenkins et al., 2013).

Trichinella spp. is found in most terrestrial ecosystems and several marine ecosystems (Pozio, 2007). Due to the tolerance of their larvae to freezing conditions, *Trichinella nativa* (genotype T2; hereafter called *T. nativa*) and *Trichinella T6* (genotype T6) are the only *Trichinella* species present in the Arctic (Forbes, 2000; Jenkins et al., 2013). In marine mammals, *Trichinella* spp. has a circumpolar Arctic distribution and is commonly found in polar bears (*Ursus maritimus*). It has also been reported in walruses, hooded seals (*Cystophora cristata*), ringed seals (*Pusa hispida*), bearded seals (*Erignathus barbatus*), grey seals (*Halichoerus grypus*) and belugas (Forbes, 2000; Isomursu and Kunnasranta, 2011; Møller, 2007). The highest prevalence of *Trichinella* spp. in the Arctic is found in carnivores such as polar bears, but also non-marine species such as Arctic foxes (*Alopex lagopus*) and domestic dogs (*Canis familiaris*). Those carnivores likely get infected by depredating or scavenging infected animals (Forbes, 2000). Similarly, researchers have suggested that walruses could get infected by eating infected seals or infected carcasses of polar bears (Forbes, 2000). Some records of carnivorous walruses eating ringed and bearded seals exist for the Pacific walruses (*Odobenus rosmarus divergens*) (Lowry and Fay, 1984). However, those observations are rare and thus might not explain the high prevalence of infected walruses, which mostly feed on bivalve molluscs such as clams (*Mya truncata*, *Serripes groenlandicus*) and cockles (*Hiatella arctica*) (Born et al., 2003).

Since the mid-1980s, outbreaks of trichinellosis have had significant public health implications in Nunavik communities (Larrat et al., 2012; Proulx et al., 2002). Consequently, in 1992, the Nunavik Trichinellosis Prevention Program was created to prevent trichinellosis outbreaks and foster safe walrus raw meat or *igunaq* consumption in the region. Since then, each year the Nunavik Research Centre of the Makivik Corporation tests for the presence of *Trichinella* spp. in Atlantic walruses hunted from participating communities. Within 24 h of receipt, residents are informed of the status of parasitic infection in the raw meat of the walrus hunted and therefore its safety for consumption (Larrat et al., 2012; Proulx et al., 2002). This program has significantly reduced the number of outbreaks of trichinellosis related to the consumption of walruses in Nunavik, a public health success based on a fruitful Inuit-scientific partnership (Larrat et al., 2012; Proulx et al., 2002).

The Arctic pole acts as a sink for pollutants produced in areas as far as Europe or Asia. Thanks to the Stockholm Convention, many Persistent Organic Pollutants (POPs) such as PCBs or DDT have decreased markedly in the Arctic and its fauna (AMAP, 2016). However, mercury remain a priority for Arctic communities, such as Nunavik, particularly as prenatal mercury exposure has been associated with visual, cognitive and behavioral deficit later in childhood (Lemire et al., 2015; Pirkle et al., 2016). But contrary to other Arctic marine mammals, less information is available on chemical contaminants such as mercury in Atlantic walruses (Braune et al., 2005). Similarly, limited information on nutrient concentrations in Atlantic walruses from Nunavik is available, although the Government of Nunavut produced Nutrition Fact Sheet Series recommend walrus meat for its source of proteins, iron, zinc, omega-3 fatty acids and selenium, and walrus fat for its richness in omega-3 fatty acids, vitamins A and E (Caughey et al., 2013).

Lastly, we have traditionally separated the investigation, analysis and reporting of research on these topics, which has resulted in a disconnected understanding of these complex phenomena. By combining Inuit Knowledge (IK) with laboratory data, our study aimed to shed light on the current risks and nutritional benefits of Atlantic walrus as country food, and its consumption across Inuit generations in Nunavik in a more integrated manner. Specifically, this study aimed to increase understanding of 1) the selection and hunt of healthy-looking Atlantic walruses; 2) the safe preparation of walruses as country food; and 3) the nutritional benefits and risks of consuming walruses, including mercury levels and *Trichinella* spp. prevalence. Based on the case of Atlantic walruses, this study proposes an interdisciplinary framework to provide a comprehensive portrait of current benefits and risks of contemporary country food consumption in Nunavik.

2. Materials and methods

This study is part of a larger project, "Walruses and population health in Nunavik, drawing upon both scientific methods and local ecological knowledge", which was approved by the four participating Inuit communities and their local Hunting Fishing and Trapping Associations, Northern Villages and Landholding Corporations (March–September 2013), the Nunavik Marine Region Wildlife Board (December 2012) and by Trent University Research Ethics Board (December 2012) and the Trent Aboriginal Education Council (February 2013). The corresponding methods used, including the selection of participants, the development of the questionnaire and interview support guides, as well as the interviews and internal validation workshops, followed the standards of the social research methods used to document local and traditional knowledge (Creswell, 2009; Furgal and Laing, 2012; Huntington, 2000; Seidman, 2006). Some results of the larger project were published in 2016 and 2017 and provide detailed methodology (Martinez-Levasseur et al., 2016, 2017), including the importance to document the geographic and temporal limits of participants 'common areas of observations. In the planning and conduct of the gathering of Inuit observations and knowledge, as well as biological sampling and laboratory analyses, we paid particular attention to the issues of compatibility of spatial, temporal and biological scales across the knowledge sources so that findings had the greatest chance of supporting the creation of a more comprehensive understanding on the same topic (Furgal and Laing, 2012; Martinez-Levasseur et al., 2017). The Nunavik Nutrition and Health Committee (NNHC) reviewed and accepted the draft version of the proposed article. All the authors identify themselves as southern non-indigenous, except one author (SS), and acknowledge that the interpretations of the results of this study reflect their own perspectives and worldviews.

2.1. Documentation of Inuit Knowledge (IK)

Between June and September 2013, we interviewed 34 walrus hunters and Elders recognized for their knowledge and activity in hunting Atlantic walruses (*Odobenus rosmarus rosmarus*) (Table 1) by their communities and the local Hunters Fishers and Trappers Association of Inukjuak, Ivujivik, Quaqtaq and Kangiqsualujjuaq in Nunavik (Northern Quebec, Canada) (Fig. 1). Interviews followed the protocol previously reported (Martinez-Levasseur et al., 2016, 2017). In each community, we interviewed between 7 and 10 participants, ranging from 35 to 85 years of age, who provided observations of walruses extending back to the 1930s. Since women are involved in preparation of walrus for food, four women were included. An additional participant, an elderly woman from Ivujivik, was invited to share her knowledge specifically on walrus health and walrus food preparation. Among the 34 interviewees, one non-Inuk hunter, who had been living in Quaqtaq since 1983 and recognized as a walrus expert by the local Hunters Fishers and Trappers Association, was included in our study. Because his knowledge was transmitted to him via his Inuit parents-in-law, we considered the knowledge he shared with us, particularly information related to hunting methods and walrus food preparation, as Inuit Knowledge. Note that, the total number of participants speaking to any topic in the interview and reported in the results below differed from one topic to the other as participants were encouraged to share their experience and knowledge on those topics they were most comfortable and confident with. For example, only 19 participants had

Table 1
Details on the characteristics of walrus hunting activities since the 2000s for Quaqtaq, Ivujivik, Inukjuak and Kangiqsualujjuaq in Nunavik (Northern Quebec, Canada).

Community	Number of participants	Main hunting area	Average length of hunt	Type of boat	Hunting timing[a]	Type of hunt[b]
Quaqtaq	10	Quaqtaq area	One day	personal motor canoe	Summer (end June–July)	Specialist
Ivujivik	8	Nottingham & Salisbury	One week	Peterhead community boat	Fall (mid-September)	Specialist
Inukjuak	7	Nottingham & Salisbury	One week	Peterhead community boat	Fall (mid-September)	Specialist
Kangiqsualujjuaq	8	Killiniq area	One week	Peterhead community boat	Summer (July or August)	Opportunist

[a] The seasons were defined and confirmed by participants as: fall (September–mid-December), winter (end December–April), spring (May–mid-June) and summer (end June–August).
[b] Specialist hunters refer to hunters that go hunting specifically to harvest Atlantic walruses. Opportunist hunters refer to Inuit that harvest Atlantic walruses while hunting other species.

knowledge on how to age walrus to make *igunaq*. Only participants who agreed have their names mentioned in this article.

Semi-directive interviews, conducted with the help of English-Inuktitut interpreter/translators, were used to document Inuit Knowledge on walrus hunting, health and food preparation practices in Nunavik. As part of the information documented on walrus hunting, we were interested to learn about the criteria used by hunters to select which walruses to hunt, as it might reflect hunters' knowledge on how to choose healthy looking animals. Furthermore, we wanted to learn about the conditions of the butchering of the walruses, particularly as those conditions could increase the risk of contamination by the bacteria *Clostridium botulinum*. Additionally, we documented Inuit observations on the general health of Atlantic walruses in Nunavik including the presence of external or internal abnormalities (e.g. skin lice, stomach worms). In order to increase precision in knowledge exchange between participants and interviewers, we used an illustrative guide to common disease and parasites in wildlife from the Eastern Canadian Arctic including walruses (Canadian-Cooperative-Wildlife-Health-Center, 2011). We also asked questions about the general body condition of the walruses observed (i.e. whether abnormally thin walruses had been observed), as well as the approximate thickness of the blubber layer of the walruses killed, which corresponds to one of the parameter measured when studying wildlife health (Trites and Jonker, 2000). To obtain an approximation of the thickness of the blubber layer observed, we used the number of fingers of the interviewer (LML) as an approximate scale (one finger measuring approximately 2 cm; Fig. 4b). Finally, we also questioned participants about the preferred organs of walruses for human consumption and the different methods used to prepare and cook them. We were particularly interested in the diverse ways of preparing *igunaq* (aged walrus).

The audio-recorded interviews were then entered into the qualitative analytical software program NVivo (Version 10, 2012; QSR International) and analysed using thematic content analysis (Creswell, 2009). To ensure the information provided by participants had been interpreted accurately, data were verified during subsequent workshops held in July 2014 with 69% of the participants previously interviewed.

Final results and interpretation were then presented to each community during a final trip in March 2015. For that a presentation entitled "Using Inuit and scientific knowledge to study walruses in Nunavik", which included a selection of results from our larger project, was presented to different local Inuit organisations including the *Parnasimautik*

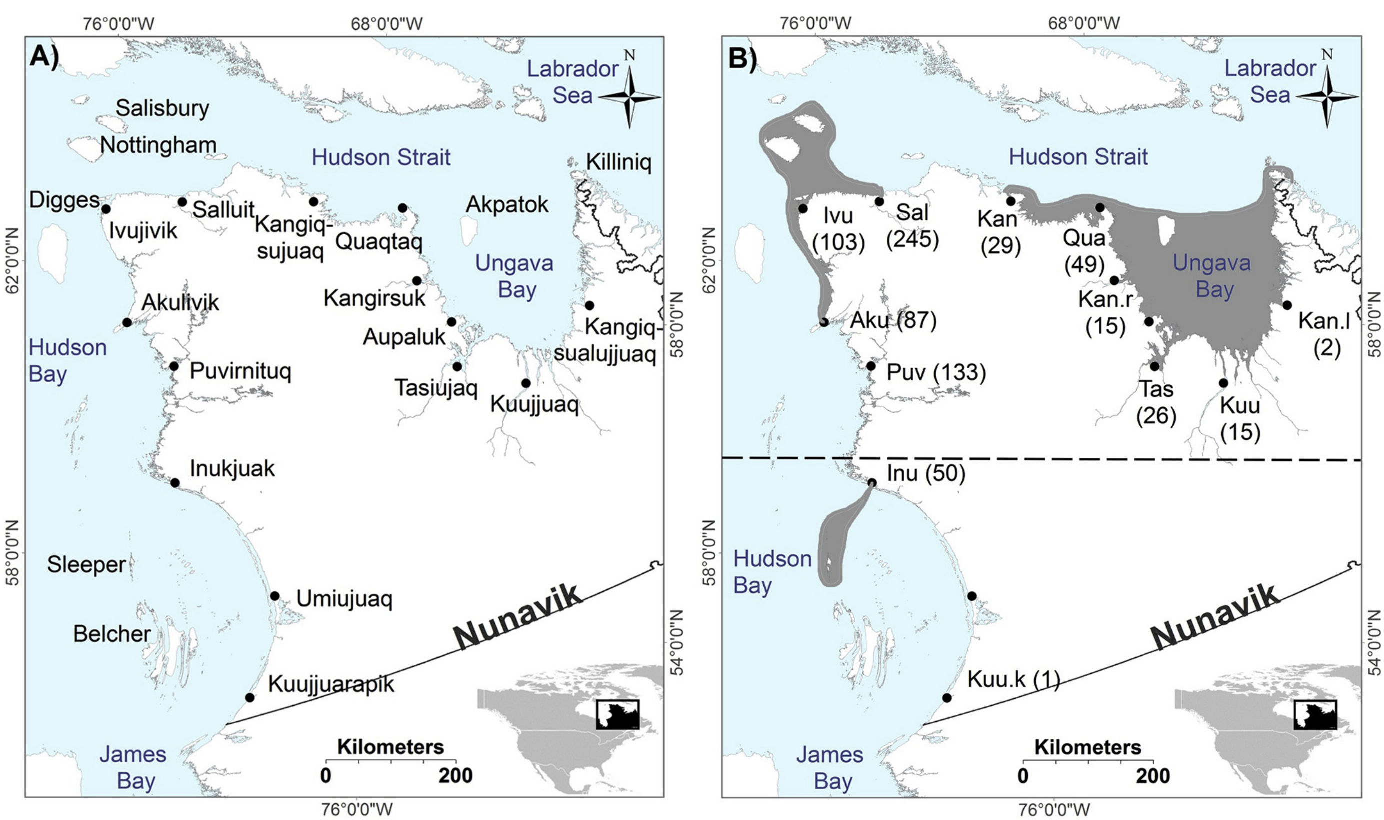

Fig. 1. Map of Nunavik (Northern Quebec, Canada). A) Map showing the study area including the full names of the different communities of Nunavik. B) Inuit communities that provided samples between 1996 and 2013 to be tested for *Trichinella nativa* (number of samples tested within parentheses; 755 in total). Approximate sampling locations of Atlantic walruses (grey area). The dotted line divides the communities according to which stock of Atlantic walruses hunters mainly go: the SE Hudson Bay stock and the Hudson Strait stock (Stewart, 2008). Map created using the geographic information system software ArcMap 10.4.1 (Digital vector datasets: RNCan-National Topographic Database) and GIMP 2.8.

Kangiqsualujjuaq annual meeting, which was broadcasted on the local radio, the monthly local LNUK (hunting, fishing and trapping associations) meeting of Quaqtaq, Ivujivik and Inukjuak, as well as the annual meeting of the Nunavik Marine Region Wildlife Board (NMRWB) held in Inukjuak on March 12th 2015. A final short report was distributed to the Inuit community members interested in the project results. Finally, an adapted and interactive version of the oral presentation was provided to the students of Kangiqsualujjuaq, Quaqtaq and Inukjuak schools. Note that Quaqtaq and Ivujivik schools were visited during our first visits in March and October 2013.

2.2. Sampling and detection of *Trichinella nativa*

A total of 755 Atlantic walrus muscles samples (i.e. tongue) were collected between 1994 and 2013 as part of the Nunavik Trichinellosis Prevention Program, which tests for the presence of *Trichinella* spp. in Atlantic walruses hunted for subsistence from northern participating communities (Larrat et al., 2012). For most animals, the following data were collected: community, date of harvest, location of kill, sex ($n = 391$; 208 females, 183 males) and age-class ($n = 398$). Atlantic walrus age-classes were categorized in two groups: juvenile (young of the year to 2 years old; $n = 171$) and adult (3 years and older; $n = 227$), following estimations given by hunters. Based on harvest location, animals were assigned to one of their two stocks in Nunavik, the southern and eastern Hudson Bay stock ($n = 33$), hereafter called the SE Hudson Bay stock, and the Hudson Bay-Davis Strait stock ($n = 722$), hereafter called the Hudson Strait stock (Stewart, 2008) (see Fig. 1). Muscle samples (10-25 g) were tested for *T. nativa* using the artificial digestion and double separatory funnel technique as previously described (Leclair et al., 2004). Briefly, pieces of meat including the capsule surrounding the larvae were digested in a 3 l solution (30 ml of 1% HCL, 30 g of pepsin, 2.7 l water), which was heated in an incubator at 470 °C for 1.5 h. The mixture was poured in a 180 μ sieve over a 4 l funnel for 30 min. The solution (125 ml) was then released into a 500 ml separatory funnel, in which 375 ml of lukewarm water was added to clarify the solution that was left to settle for 10 min. Finally, 22–27 ml of the solution was used to count the number of *T. nativa* larvae in a gridded Petri dish.

2.3. Sampling and concentrations of mercury, selenium and omegas-3

Thirteen samples of walrus tongue muscle and liver collected in 2013 during northern subsistence hunt were selected for chemical analysis. Samples - pre-digested in nitric acid -were analysed for total mercury concentration by cold vapour atomic absorption spectrometry (CVAAS) using a model PinAAcle 900Z atomic absorption spectrometer (Perkin Elmer Inc.) equipped with an electrodeless discharge (EDL) mercury lamp and a Model FIAS-100 flow injection analysis system (Perkin Elmer Inc.) at the Nunavik Research Centre in Kuujjuaq. These digested samples were also analysed for total selenium concentration by graphite furnace atomic absorption spectrometry (GFAAS, model PinAAcle 900Z atomic absorption spectrometer, equipped with a transversely-heated graphite atomiser (THGA)). For both analyses, automation was achieved using a Model AS90 autosampler (Perkin Elmer Inc.) and interfacing the system with a personal computer running the AAWinLab software (version 2.3, Perkin Elmer). All analyses were subjected to an established quality assurance/quality control (QA/QC) protocol using Certified Reference Materials (DORM2, DOLT2, Mussel 2976) from the National Research Council of Canada, which consistently reached a percentage of recovery between 90% and 103% (full protocol available upon request to the corresponding author). The trace metal analytical lab at the Nunavik Research Centre has been a participant of the Inter-laboratory QA/QC program of the Northern Contaminants Program since 1998. Part of these data was published in the supplementary materials provided with Lemire et al. (2015). In addition, five samples of walrus fat collected during subsistence harvest by Quaqtaq hunters participating in the present project in 2013 were analysed at the Lipid Research Centre at the CHU de Québec – Université Laval for fatty acids composition, including long-chain n−3 polyunsaturated fatty acids (PUFAs) (eicosapentaenoic acid (22:6; DHA) (eicosapentaenoic acid (20:5; EPA), docosapentaenoic acid (22:5; DPA) and docosahexaenoic acid (22:6; DHA)) after chloroform/methanol lipid extraction and methylation of fatty acids. Fatty acids profiles were obtained by capillary gas chromatography using a DB-23 column (39.0 × 0.25 mm ID × 0.25 μm thickness) in a Hewlett–Packard gas chromatograph. The results are expressed over the total of lipids and the complete analytical method is described in Lucas et al. (2010).

2.4. Statistical methods

All statistical analyses were performed using the R programming language R 3.1.3 (Ihaka and Gentleman, 1996; R-Development-Core-Team, 2017). Binomial regressions using the logit link function were applied to identify which variables among sex, age class and stock explained best the variability in the prevalence of *T. nativa* in walruses. The effect of the sampling years was also investigated. To satisfy model convergence and avoiding separation, years were categorized in two bins corresponding to the period up to 2005 and after 2005. This categorization optimized balanced dataset between the two categories (i.e., year ≤2005 $n = 384$; >2005 $n = 371$). Due to the low prevalence of the infection, we used the Firth's penalized likelihood logistic regressions using the *logistf* package (Heinze and Ploner, 2004). The Firth's procedure, using the invariant Jeffreys prior, has been developed to reduce bias in maximum likelihood estimates associated with the analysis of rare events (Firth, 1993; Heinze and Schemper, 2002). Confidence intervals were calculated also through a penalized likelihood profile (Heinze and Ploner, 2004). A top down strategy (i.e., deletion test) was used to define the minimal adequate model. Contribution significance of each factor was further evaluated by penalized likelihood ratio tests for nested models (nominal threshold of $p \leq 0.05$).

3. Results

3.1. Selection and hunt of healthy-looking Atlantic walruses in Nunavik (IK)

3.1.1. Selecting which walrus to hunt

In total, 89% of participants (24 of 27) reported that while hunting walruses, middle sized females or young individuals were preferred. Old walruses, recognized by their large size, their long or broken tusks and their rough skin, were reported by 65% of participants (13 of 20) to potentially have diseases. Shaomik Inukpuk, from Inukjuak explained that "*when the walrus is too old it is most likely to have disease or Trichinella, male or female. But in the past we never identified the parasite or disease. It is only recent that we have received the word Trichinella. But even before, we never hunted the old walruses*." In total 53% of participants (8 out of 15) clarified that old males and old females could be infected with *Trichinella*.

Participants from Quaqtaq reported that, in general, walruses are first shot in the head – in order for them to die instantly -, and then harpooned (Fig. 2). The harpoons thrown at the animal are connected with lines to buoys, which help to keep the animal floats. The animal is then hooked to the boat and dragged to a place where it can be butchered (Fig. 2).

"*The tradition* [of hunting walruses] *is passed on to each generation. That's how I know how to do it. That's how my son will know how to do it.* […] *Now, we are doing a trip each year with the youth to teach those who don't have the opportunity to go with their parents. Most people don't have boats. Some of the students never went out before.* […] *It is not a concern of losing tradition but more efforts need to be done*", explained Sammy Unatweenuk from Kangiqsualujjuaq, who each year try to lead a group of students for few days on a boat trip to the area of Killiniq (Fig. 1).

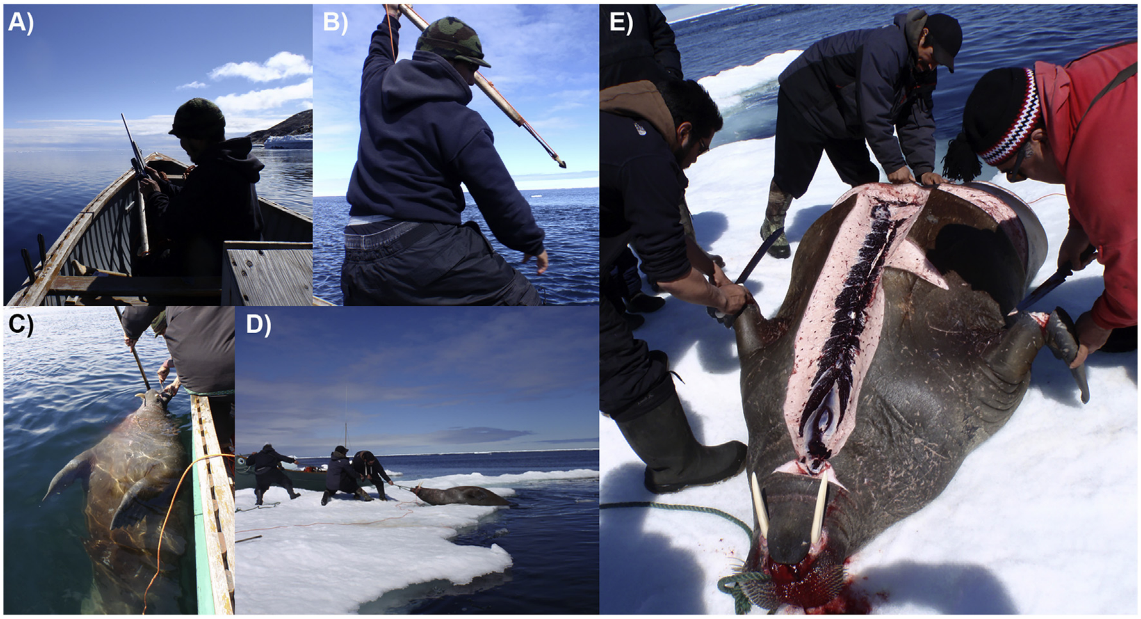

Fig. 2. A typical walrus hunt near Quaqtaq with captain Johnny Oovaut and his two sons (July 2013). Johnny kindly invited the main author of this paper (LML) to participate in one of their subsistence hunts. In order, A) walrus are shot, B) harpooned, C) hooked to the boat, D) dragged to a butchering site and E) butchered. Photos: Laura M. Martinez-Levasseur.

Participants reported that walrus carcasses, including the bones and part of the internal organs, were generally left on the butchering site (i.e. flat rock, floating ice). Natural scavengers such as polar bears, sea gulls and foxes consume the carcasses and clean the site, as explained by 69% of participants (18 out of 26). Finally, when left in or close to the water, marine scavengers such as shrimp consume the remains, as explained by 19% of participants (5 out of 26). Participants, who reported having harvested an infected walrus in the past (19%, 6 out of 31), as confirmed by the diagnostic of the Nunavik Trichinellosis Prevention Program, explained that they brought the infected pieces of meat to the community dump (83%, 5 out of 6), corresponding to a vast open space for northern residents waste disposal. These northern landfills are generally accessible to carnivores such as dogs, foxes and polar bears. The contaminated meat could also be simply left behind or sunk in water, as reported by 33% of participants (2 out of 6). One participant suggested to give the infected meat to dogs.

3.1.2. General health of the harvested walruses

The thickness of the blubber layer of walruses killed by hunters was reported to vary from 4 cm to >8 cm. Eighty percent of hunters (25 of 31) explained that such fluctuations were due to difference in the activity, sex, age, harvesting seasons or health of the walrus harvested. As a whole, abnormally thin walruses were rarely observed by participants. No participant (0 of 31) reported a temporal change in the body condition of the walruses they have observed (i.e. increase in occurrence of lean walruses).

While 25% of participants (7 of 28) had observed, at least once in their lifetime, worms in the stomach or intestines of the killed walruses, 75% of participants (21 of 28) reported no internal abnormalities. Among the participants who reported stomach worms, 57% (4 of 7) explained that when worms were found in the digestive system, they were removed, and the meat was kept. One Elder from Quaqtaq explained that after removing the worms, they would let the meat stand for few days to see if more worms appear. Finally, two participants explained that it is more frequent to see stomach worms in abnormally thin walruses.

Lice were infrequently observed on walrus skin, as reported by 29% of participants (8 of 28) (Fig. 3). Those explained that lice were mainly located around the neck, under the armpits and in the folded skin of the killed Atlantic walruses. No participant (0 of 28) reported a temporal change in the number of lice observed, and no participant (0 of 28) reported severe infection of Atlantic walruses with lice. An Elder explained that walruses have more lice when they spend time in large herds compared to when they are in small groups.

3.2. Safe preparation of walruses as country food (IK)

3.2.1. Walrus butchering

The butchering occurs generally close to the kill site, on a flat rock or an ice platform, as reported by all participants (28 of 28). If the walrus is killed close to the community, or near a campsite (e.g. around Quaqtaq), the hunters bring back the killed walrus there, where community members can help with the butchering. If hunters used the community boat to go walrus hunting (i.e. hunters from Ivujivik and Inukjuak), and if it is equipped with a hoist, then the butchering occurs on the boat, although this is rare.

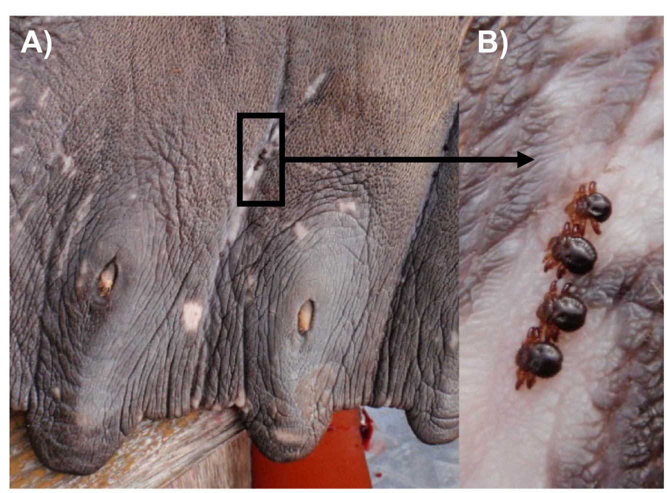

Fig. 3. Lice (*Antarctophthirus trichechi*) photographed on the flipper (A) of a walrus hunted for subsistence near Quaqtaq in July 2013 (captain, Johnny Oovaut) by LML. Even though lice were not observed at first by either the researcher (LML) who was invited to follow the hunt and neither the hunters, when looking carefully, lice were present in the folding skins and between the hairs of the killed walrus. Photos: Laura M. Martinez-Levasseur.

Charlie Okpik, an Elder from Quaqtaq, explained that during the butchering the meat can get infected: "*It's not* [toxicity or disease] *on the animal right away*. […] *It happens when hunters are cutting the meat, if they're not careful being clean, and if they let it stand there with the sun coming on*."

3.2.2. Parts of walrus collected and prepared as igunaq

"*We take everything. Our ancestors have never wasted a piece of meat. We are trying to do the same today*", explained Paul Jararuse from Kangiqsualujjuaq. Although, 77% of participants (24 of 31) reported taking everything from the killed walrus (Fig. 4A), when participants were asked which organs they usually take for human consumption, 61% of participants reported taking the skin, fat and meat (19 of 31) in one piece of walrus (Fig. 4B). In addition to these parts, 42% reported taking the liver (13 of 31), 32% the head (10 of 31) (Fig. 4C), 23% the flippers (7 of 31) (Fig. 4D), 19% the intestines (6 of 31) (Fig. 4E) and 13% reported taking the heart (4 of 31). More participants in Ivujivik reported collecting the head, flippers, intestines and heart than participants from other communities (Table 2). Participants explained that the different pieces of walrus can be either aged as *igunaq* (e.g. skin, fat, meat, flippers), boiled (e.g. meat, fat, intestine, cheek) (Fig. 4F), or eaten fresh (e.g. heart or liver), as reported respectively by 88%, 83% and 63% of 24 participants.

3.2.3. Preparing Igunaq

All participants (19 of 19) explained that at least the skin, fat and meat of the walrus are used to prepare *igunaq*. Conversely, 42% of participants (8 of 19), all from Ivujivik and Kangiqsualujjuaq, explained that the flippers can be aged as well. Similarly, the head and the liver of the walrus can be aged, as reported by two participants from Ivujivik. None of the participants reported mixing walrus parts with other animal parts.

Traditional *igunaq* preparation, as described by 83% of participants (19 of 23), mostly from Quaqtaq and Kangiqsualujjuaq (Table 3), consists of three steps (Fig. 5):

1. Bagging (*ungirlaq* in Inuktitut) large pieces of walrus skin, meat and fat (Fig. 4B), by sewing it with a nylon rope, traditionally made of walrus skin (Fig. 5ABC).
2. Burying (*pirugaq* in Inuktitut) the bags. Traditionally, bags were placed under rocks or pebbles in a particular place, called a cache. Nowadays, they are mainly placed in an open plastic or wooden box under the house (Fig. 5D).

Table 2
Walrus parts eaten as reported by participants in Quaqtaq (Quaq), Kangiqsualujjuaq (Kang), Ivujivik (Ivuj) and Inukjuak (Inuk). For each community, the number of participants is provided as a percentage. Different responses can be provided by the same participant, so column totals can exceed 100. Sample sizes, representing number of individuals interviewed and with knowledge on this topic, are bracketed.

Parts eaten	Quaqtaq (n = 8)	Kangiqsualujjuaq (n = 8)	Ivujivik (n = 8)	Inukjuak (n = 7)
Everything	50 (4/8)	88 (7/8)	88 (7/8)	86 (6/7)
Skin, fat & meat	50 (4/8)	63 (5/8)	75 (6/8)	57 (4/7)
Liver	38 (3/8)	13 (1/8)	88 (7/8)	29 (2/7)
Head	13 (1/8)	13 (1/8)	75 (6/8)	29 (2/7)
Flippers	13 (1/8)	25 (2/8)	38 (3/8)	14 (1/7)
Intestines	13 (1/8)	13 (1/8)	38 (3/8)	14 (1/7)
Heart	0 (0/8)	13 (1/8)	38 (3/8)	0 (0/7)

3. Letting the bags age for at least four weeks (Table 3). The result of the aging process is called *puurtaq* by Ivujivik participants.

"*To do igunaq, we wrap the skin, tie it, sew it, bury it underground and let it age. The sewing of the walrus we call it ungirlaq and when we bury it under the ground, we will call it pirugaq […] It would become igunaq after it has been aged*", explained Shaomik Inukpuk from Inukjuak.

The Inuktitut names for each step are not specific to walrus meat as clarified by Ivujivik participants during the validation workshop.

The main rule reported for the safe process of aging is that the bags of walrus skin, fat and meat need to be protected from the sun. "*Here, we hunt only in spring* [end June-July] *because we prepare a special ferment* [igunaq] *and we have to do it with the season, with the warmth of the sun, and at the same time be careful the sun is not getting dangerous. We don't really hunt walruses in the fall because the meat doesn't ferment due to the cold*", explained Charlie Okpik from Quaqtaq.

Participants from Ivujivik and Inukjuak (7 of 23) reported another contemporaneous way to age walrus. Indeed, they explained that they also age walrus by placing walrus' parts, generally the flippers, in a container, for example a pot lined with plastic. Those are then covered with walrus fat or fat from other marine mammals, like beluga, to keep them from drying, as reported by an Elder from Ivujivik. Importantly, the pot, generally placed in a cool place such as a shack, needs to stay open to allow enough ventilation to avoid the meat to turn toxic, informed the same participant.

The length of the fermentation process depends on the season of the year, according to participants. Hunters from Inukjuak and Ivujivik, who

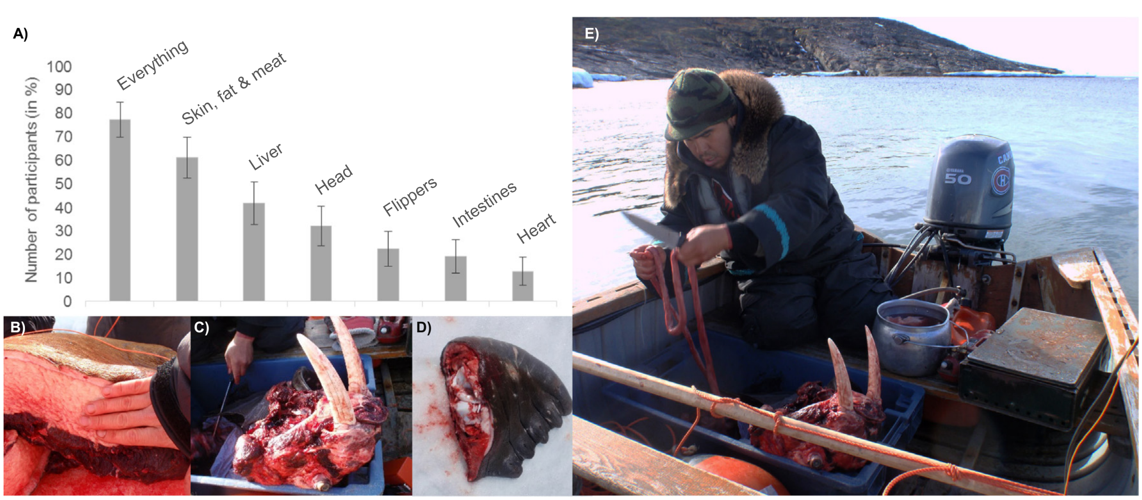

Fig. 4. Walrus organs collected for Inuit consumption. A) Walrus organs collected as reported by the 31 participants. Bars ± SE. Different responses can be provided by the same participant, so bar totals can exceed 100%. B) Walrus skin, fat and meat. The fingers were used to calculate the approximate size of the blubber layer thickness of the walrus killed. C) Walrus head. D) Walrus flipper. E) Walrus intestines. F) Meal made of walrus meat, fat, intestine and cheek, boiled in sea water, at the end of a typical walrus subsistence hunt near Quaqtaq with Captain Johnny Oovaut and his two sons (July 2013). Photos: Laura M. Martinez-Levasseur.

Table 3
Details on *igunaq* preparation as reported by participants in Quaqtaq (Quaq), Kangiqsualujjuaq (Kang), Ivujivik (Ivuj) and Inukjuak (Inuk). For each community, the number of participants in percentage is provided. Different responses can be provided by the same participant, so column totals can exceed 100. Sample sizes, representing number of individuals interviewed and with knowledge on this topic, are bracketed.

		Quaq (n = 5)	Kang (n = 6)	Ivuj (n = 7)	Inuk (n = 5)	All (n = 23)
Container	Sewed skin bag	100 (5/5)	100 (6/6)	57 (4/7)	80 (4/5)	83 (19/23)
	Pot lined with plastic	0	0	71 (5/7)	40 (2/5)	30 (7/23)
Location	Buried under rock	20 (1/5)	83 (5/6)	57 (4/7)	80 (4/5)	61 (14/23)
	In a cool place (e.g. shack)	60 (3/5)	17 (1/6)	29 (2/7)	20 (1/5)	30 (7/23)
Time	2–3 weeks	20 (1/5)	0	14 (1/7)	0	9 (2/23)
	4 weeks or more	40 (2/5)	33 (2/6)	57 (4/7)	80 (4/5)	52 (12/23)
	When skin peels off	20 (1/5)	0	43 (3/7)	20 (1/5)	22 (5/23)

hunt Atlantic walruses in September–October, reported that burying the meat in the fall doesn't give enough time to age walrus properly, because the temperatures are too cold. They reported that they try to age walrus as long as possible, even though they know that the fermentation might be too short and the taste not strong enough. They can leave the walrus preparation to ferment until December. Participants from Quaqtaq and Kangiqsualujjuaq, who respectively hunt Atlantic walruses in July and August, explained that when the *igunaq* is ready, it needs to be kept in the freezer otherwise the fermentation will not stop.

Few participants (5 of 23) explained that the *igunaq* is ready when you can peel the skin off (Table 3). At this point the meat will be covered with maggots, explained Johnny Oovaut from Quaqtaq. Few participants said that they use the smell as an indication. One participant from Inukjuak explained that he was taught that when the fat starts turning blue it is ready, although he had never personally observed such colour when doing *igunaq* in the fall.

3.3. Temporal changes in walrus eating habits (IK)

Two participants explained that nowadays, not all Inuit like the taste of *igunaq*. "*In the past more people used to eat aged walrus compared to today. Young people don't eat aged walrus. But we still eat it*", explained Mattiusi Iyaituk, an Elder from Ivujivik. Johnny Oovaut, a renowned *igunaq* cook from Quaqtaq, is trying to retain the taste for *igunaq* within his family. "*We are passing it down to the younger generation and we train*

Fig. 5. *Igunaq* preparation. ABC) Throughout the day of a typical walrus subsistence hunt near Quaqtaq (July 2013), captain Johnny Oovaut and his two sons are sewing large pieces of walrus made of skin, fat and meat on clean floating ice packs. D) The bagged skin, fat and meat are then generally aged in wooden box placed under the house. Photos: Laura M. Martinez-Levasseur.

Table 4
Deletion tests (penalized likelihood ratio tests; left half of the table) used to obtain the estimated values of the minimal adequate model explaining part of the variation in *T. nativa* prevalence in 348 Atlantic walruses harvested around Nunavik.

Exp. var[a]	df	χ^2	*p*	Exp. var	Estimate (CI 95%)	Odds ratio (CI 95%)	χ^2	*p*
Year	1	0.212	0.645	Intercept	−0.647 (−1.759; 0.352)	0.524 (0.172; 1.421)	1.589	0.207
Sex	1	0.734	0.391	Stock HS	−3.127 (−4.398; −1.833)	0.044 (0.012; 0.160)	18.763	<**0.001**
Age	1	2.430	0.119					
Stock	1	18.763	<**0.001**					

[a] The explanatory variables (Exp. var) included in the full models were the year (defined as 0, 1 for respectively before 2005 and 2005 and later), sex (defined as factor), the age class (age = 0, 1 for respectively juveniles and adults) and the stock of Atlantic walruses (defined as factor) corresponding to the Hudson Strait stock (HS) and SE Hudson Bay (HB) stock. For each explanatory variable, the degree of freedom (*df*), the Chi-squared (χ^2) and *p*-value (*p*) were reported (left half of the table). The right part of the table presents the summary of the model including the value of the estimated coefficients (log odds), odds ratio, the confidence intervals (CI 95%), the Chi-squared (χ^2) and the *p*-values obtained using penalized profile likelihood. Bold text indicates $p \leq 0.05$.

our children to eat fermented walrus. So they get used to it. My two oldest sons eat fermented foods but my youngest one doesn't. […] *My grandsons are eating it too*", he explained.

Although some participants raised some concern about the loss of knowledge on walrus hunting and food preparation of the younger generation, according to Ivujivik participants, Inuit continue to hunt walruses and prepare *igunaq*. "*Even though the population of the town is growing and the number of people who makes igunaq is decreasing, the custom of preparing igunaq is not dying*", clarified Adamie Kalingo, an Elder from Ivujivik.

3.4. Prevalence of *Trichinella nativa*

In total, 2.9% of Atlantic walruses (22 out of 755 sampled between 1994 and 2013) were infected with *T. nativa*. Sampling year had no effect on *T. nativa* prevalence (i.e., proportion of infected individuals) (Table 4). Neither the sex nor age explained the variation in *T. nativa* prevalence in Atlantic walruses around Nunavik (Table 1). On the contrary, the stock of Atlantic walruses played a significant role in explaining the variation in *T. nativa* prevalence in individuals harvested in Nunavik marine areas where higher prevalence occurred in SE Hudson Bay stock (Table 1). While only 1.5% of Atlantic walruses (11 out of 722) from the Hudson Strait stock were infected, prevalence in the SE Hudson Bay stock were 22 times higher (33.3%, 11 out of 33).

3.5. Levels of mercury, selenium and omega-3 fatty acids in Atlantic walruses

The geometric means of mercury concentrations in raw walrus muscle and raw liver samples were 0.07 μg/g and 0.10 μg/g, respectively (Table 5). For selenium levels, the geometric means were 1.53 μg/g and 2.18 μg/g for raw walrus muscle and raw liver, respectively (Table 5). Walrus fat had an average 113 mg/g of long-chain omega-3 fatty acids in total (Table 5).

4. Discussion

This study highlights the value of better connecting and drawing upon both IK and scientific knowledge related to animal ecology, zoonotic and infectious disease biology, toxicology, nutrition and public health to more comprehensively understand and address issues that span these fields. The current study shows the particular relevance of this approach for challenges being faced in the Arctic in relation to environmental, wildlife, Inuit health, well-being and cultural change. Further, it underlines the importance of prospective, purposefully planned approaches to gathering and linking knowledges from different sources, paying particular attention to issues of scale (spatial, temporal and biological). Finally, as shown in Table 6, this interdisciplinary approach informed the formulation of critical steps to foster the continuity of walrus hunting and related Inuit Knowledge as well as safe butchering, preparation and consumption of this important country food species in Nunavik.

4.1. General health of the harvested Atlantic walrus

While hunters from Quaqtaq can go walrus hunting around their community by motor canoes within a day, hunters from Ivujivik and Inukjuak need to use the community boat to reach far-off walrus hunting areas, where they spend generally a week (unpublished results). It is possible that the reduced number of spaces on the community boats, as well as the timing of the hunt, which generally happens during school time (i.e. mid-September), partially explains why only few Inuit youth from communities such as Inukjuak and Ivujivik join the annual walrus hunt. On the contrary, in Quaqtaq, it is more common to see Inuit going walrus hunting with their children. For example, during the two hunts on which we were invited, in July 2013 and 2014, Johnny Oovaut went walrus hunting with at least one of his sons. As walrus hunting is an unusual activity for Kangiqsualujjuaq, it is rare that youth participate in walrus hunting. However, transferring hunting skills to the

Table 5
Levels of total mercury, total selenium and long-chain omega-3 fatty acids (Eicosapentaenoic Acid (EPA), Docosapentaenoic Acid (DPA), Docosahexaenoic Acid (DHA) in muscle (meat), liver or fat of Atlantic walruses harvested by Nunavik hunters in 2013, northern Quebec, Canada.

	Walrus meat (raw) (n = 8) Geometric mean (min–max)	Walrus liver (raw) (n = 5) Geometric mean (min–max)	Walrus fat (raw) (n = 5) Geometric mean (min–max)
Total mercury (μg/g, wet weight)[a]	0.07 (0.04–0.11)	0.10 (0.05–0.21)	
Total selenium (μg/g, wet weight)	1.53 (0.72–3.38)	2.18 (1.39–3.46)	
EPA (mg/g)			36.72 (31.36–51.49)
DPA (mg/g)			39.28 (30.97–51.42)
DHA (mg/g)			35.25 (29.01–45.11)
EPA + DHA (mg/g)			72.66 (62.00–80.50)
EPA + DPA + DHA (mg/g)			112.51 (97.37–121.10)

[a] The chemical forms of mercury found in marine foods greatly influence its intestinal absorption and toxic effects (Clarkson, 2002). Contrary to fish and marine mammal flesh, in which most of mercury is the form of methylmercury - the most absorbed and neurotoxic form of mercury (Bloom, 1992; Lemire et al., 2015) - a very large proportion of mercury found in the organs of marine mammals and seabirds has been shown to be inorganic mercury or inorganic mercury-selenium complexes, which are much less absorbed by the human intestine (Clarkson, 2002; Ikemoto et al., 2004). For walrus, unpublished data from Nunavik Research Center show that the average proportion (GM) of methylmercury is 71% in meat and 5% in liver. Therefore, in the Table above, total mercury concentration is reported for walrus meat, but only the effective methylmercury concentration is presented for walrus liver samples.

Table 6
Key points to consider when hunting, butchering, aging and consuming Atlantic walruses in Nunavik, based on Inuit and scientific knowledge, including laboratory findings and literature.

WALRUS HUNTING
Do not hunt unhealthy looking individuals (i.e. abnormally thin).[a]
Avoid old individuals (i.e. large ones with long and/or broken tusks and rough/thick skin with scars).[a]
When possible, bring Inuit youth for them to learn walrus hunting practices.
WALRUS BUTCHERING
As soon as possible, the harvested meat must be chilled (on ice, in the refrigerator or in the freezer).[b]
To avoid poisoning from botulism
Butcher the walrus on flat rock surfaces or ice platforms, ideally on top of a clean tarp.
Place parts in clean plastic containers immediately after cutting, and keep on ice until preparation.
Clean and disinfect butchering tools after each use.
To avoid: rinsing parts or tools with shoreline water.
To avoid: butchering an animal at the same site as previously butchered animals (if not possible, use a clean tarp).
To avoid getting sick from Trichinella
Do not eat fresh parts of the walrus (e.g. raw meat including heart) during the hunt.
Using the kit provided by the NRC: tag all pieces of meat & place the tongue in the plastic bag – send it to the NRC for *Trichinella*.[c]
If the harvested walrus is infected with *Trichinella*, all pieces of meat from the infected walrus should be retrieved and destroyed (by burning or sinking).
Do not provide infected parts of the walrus to dogs.
AGING WALRUS
To avoid poisoning from botulism
Do not age walrus in air tight containers (ex. plastic container tightly closed). The preparation should be well ventilated.
Age walrus in a cool place, protected from the sun, that lets air in (e.g. under the house).
Once igunaq is ready, keep it frozen.
If hunted in the summer, the Nunavik Regional Board of Health and Social Services (NRBHSS) and the Department of Public Health recommend storing the raw meat in the freezer (home or community) and begin the fermentation process in the fall, when temperatures are cooler.[b]
To avoid getting sick from Trichinella
Always test the walrus tongue meat for *Trichinella*. Indeed, the process of aging does not kill the parasite.[c]
CONSERVATION AND STORAGE
When the igunaq is ready, keep it in the freezer to stop the fermentation.
Igunaq preparations should be stored in areas below 3°C to avoid any contamination.
CONSUMING WALRUS
When properly butchered and prepared, walrus meat and igunaq contribute greatly to a healthy diet - walrus is rich in nutrients important for strong healthy bodies.
Share your meals with younger Inuit so that they can learn to appreciate the taste of igunaq.

[a] Martinez-Levasseur et al., 2016.
[b] NRBHSS Press Release on July 3rd, 2018 entitled "Botulism poisoning: marine mammal meat precaution" [https://nrbhss.ca/sites/default/files/press_release_botulism_en.pdf].
[c] Larrat et al., 2012.

younger generation is particularly important as it has been shown that the presence of an active hunter in the household increases predisposition to food security (Huet et al., 2012).

Hunters do not select Atlantic walruses randomly but choose healthy looking individuals, as they always have, and as is recommended by veterinarians (Nunavut-Food-Security-Coalition and Government-Health-Department, 2017). In general, medium sized females or young individuals were preferred by the walrus hunters interviewed, who reported that old walruses were avoided as they may have diseases. Consequently, the reported general health parameters, including blubber thickness and external/internal abnormalities, correspond to those of the healthy-looking individuals that have been harvested. Participants reported that abnormally thin Atlantic walruses or walruses with abnormalities were rare. Atlantic walruses from Nunavik were generally reported to be in good body condition. In the rare cases, walruses were found with stomach worms, although those were simply removed and the meat was kept, as reported by participants. Unfortunately, the safety manual for harvesters of fish and wildlife in Nunavut does not give any recommendations related to the presence of stomach worms in pinnipeds (Canadian-Cooperative-Wildife-Health-Center, 2011). This is partly due to lack of information and uncertainty on the identification of this worm. Those worms are likely from the Polychaete's family that would not be infective to humans (Fisher and Stewart, 1997) but a specimen would be required for identification and evaluation of its health risk.

Lice on the skin of the Atlantic walrus harvested were infrequently observed by hunters. It is possible that due to the highly cornified and wrinkled skin of walruses, as well as the elevated number of injuries resulting from fights (Fay, 1982; Martinez-Levasseur et al., 2016), lice occurrence was under-estimated. However, lice are recognized to be safe for human consumption (Canadian-Cooperative-Wildife-Health-Center, 2011). Lice do not appear to cause pathological symptoms in pinnipeds, although severe infection with lice has been associated with poor nutritional status in seals (Leonardi and Palma, 2013). Finally the louse observed and reported by participants is likely the species *Antarctophthirus trichechi*, which is the only louse species reported in Atlantic and Pacific walruses (Fay, 1982; Leonardi and Palma, 2013). An Elder explained that walruses have more lice when they spend time in large herds compared to when they are in small groups, suggesting that lice in Atlantic walruses are transmitted horizontally during haul outs where close contact is increased, as it is also the case for seals (Leonardi and Palma, 2013).

4.2. Preparing walrus as country food (IK)

4.2.1. Safe walrus butchering

Inuit hunters are well aware that during the butchering, the meat can get infected. It is possible that the toxicity that one participant refers to is related to the botulin toxin released by the bacteria *Clostridium botulinum* under anaerobic and specific temperature conditions (Cherington, 1998). Although different sources, including environmental and animal, may be involved in the contamination of the meat by the bacteria, higher risks seem to occur during the butchering of the animals when the meat is exposed to *C. botulinum* spores commonly found in the environment along the shoreline (Leclair et al., 2013a). Consequently, animal tissues placed during butchering in contact with contaminated shoreline soil, rocks or seawater (e.g. if seawater is used to rinse the meat) can get contaminated (Leclair et al., 2013a).

In this study, participants reported that the butchering occurs generally close to the kill site, on a flat rock or an ice platform. Clean snow and ice is indeed one of the butchering platform recommended by the Nunavut Food Security Coalition (Nunavut-Food-Security-Coalition and Government-Health-Department, 2017). Butchering platforms should then be washed if those will be used again in the future for butchering (Nunavut-Food-Security-Coalition and Government-Health-Department, 2017). Participants in this study reported that if the walrus is killed close to the community or a campsite, the hunters bring back the killed walrus there, where other community members can help with the butchering. In such cases, the possibility to butcher an animal at the same site of previous butchered animals is increased, as well as the risk of contamination depending on the community location.

Leclair et al. (2013a) have studied the presence of *C. botulinum* type E along the coast of Nunavik, and reported that the incidence rate of the bacteria in shoreline soil samples from seal butchering sites differs among regions. Indeed, while the bacteria was absent from the 19 shoreline soil samples tested in the Hudson Strait, the incidence rates of the bacteria were 50% and 87.5% for the regions of the Hudson Bay (14 samples tested) and the Ungava Bay (16 samples tested), respectively (Leclair et al., 2013a). Spores were also detected in seawater or coastal rock surfaces, mostly from seal butchering sites located in southern Ungava Bay (Leclair et al., 2013a). It is also possible that a warmer climate will increase the germination of *C. botulinum* spores and toxin production on the shoreline (Parkinson and Evengård, 2009).

4.2.2. Testing the harvested walruses for Trichinella nativa

The low prevalence of *T. nativa* reported in our study for Atlantic walruses (3%) is similar to the 4% prevalence of infection reported in a study conducted in the eastern Canadian Arctic that examined 394 Atlantic walruses sampled before 1950s (Forbes, 2000; Kuitunen, 1954). Our results are also comparable to those reported for Atlantic walruses from Greenland (2%; 2 out of 126) (Born et al., 1982) but are lower than those reported in Atlantic walruses from the Barents and Greenland seas, for which prevalence was around 10% (7 individuals infected out of 74 examined) (Forbes, 2000; Thorshaug and Rosted, 1956).

In this study, participants reported that they prefer hunting middle size females or young individuals, males or females, and they are suggesting that no difference exists in the prevalence of *T. nativa* among sexes in Atlantic walruses, which was confirmed by the laboratory analyses. Participants also reported that old walruses may have more diseases, which is why they avoid hunting them. It is also recommended by veterinarians to avoid hunting older individuals as they are more likely to eat carrions and thus be infected (Jenkins et al., 2013). The fact that no samples from old Atlantic walruses were collected, as old individuals are avoided by hunters (Martinez-Levasseur et al., 2016), may explain the absence of difference in the prevalence of *T. nativa* observed among age groups.

The higher prevalence of *T. nativa* reported in SE Hudson Bay walruses compared to those from Hudson Strait may come from differences in their movement patterns and habitat use, which might cascade into their feeding ecology thus potentially modifying the parasite's transmission pattern and infection level. Indeed, Atlantic walruses from the SE Hudson Bay stock remain in eastern Hudson Bay throughout the year, whereas Atlantic walruses from the Hudson Strait stock distribute over 1500 km from east to west in Hudson Strait and adjacent waters (Stewart, 2008) and do not range as far south as the SE Hudson Bay stock. Instead they use haul-outs from Nottingham and Salisbury Islands during the summer. Differences in latitudes might lead to differences in environmental conditions such as temperatures and ice cover, which could affect the presence of the parasite. In Alaska, the lack of access to benthic mollusks due to ice retrieval have modified the diet of Pacific walruses, which now consume more ringed and bearded seals (Rausch et al., 2007). Similar changes in feeding behaviour might be occurring in SE Hudson Bay. Inukjuak hunters, who used to hunt in the fall (i.e., September–October) near Sleepers Islands in the Hudson Bay, stopped hunting there due to the high levels of *T. nativa* infections in the Atlantic walruses they were harvesting. Therefore, since 2005, Inukjuak hunters travel >500 km to Nottingham and Salisbury Islands to go walrus hunting (unpublished results).

Carcasses of Atlantic walruses, including the bones and part of the internal organs, are generally left by Inuit hunters on the butchering site (i.e. along the coast, on floating ice). Participants reported that natural scavengers such as polar bears, sea gulls and foxes eat the carcasses left behind and then marine scavengers (i.e. amphipods) consume the remains in the water. Infected carcasses left on the butchering site or brought to community landfills likely infect mammal scavengers (Jenkins et al., 2013), as well as invertebrates feeding on infected carcasses. Indeed, experimentally, marine invertebrates can ingest *T. spiralis* larvae and hold them undigested for as long as 28 h (Hulebak, 1980). Furthermore, insects may be part of the transmission cycle when feeding on infected terrestrial or beached carcasses (Forbes, 2000). Furthermore, experimental ingestion of bird droppings infected with *Trichinella* spp. by invertebrates, fish, birds and mammals contaminated them, revealing that birds may play a role in the transmission of *Trichinella* spp. to terrestrial mammals (Britov, 1962; Odoevskaya et al., 2013).

4.2.3. Safely preparing walrus

Participants reported that they eat the skin, blubber and meat of the harvested walruses, but also the head, liver, flippers, intestines and heart. Those parts can be either aged (e.g. skin, fat, meat, flippers), boiled (e.g. meat, fat, intestine, cheek) or eaten fresh (e.g. heart or liver). The traditional method for preparing *igunaq*, generally made from walrus skin, fat and meat, consist in three steps: bagging (*ungirlaq*), burying (*pirugaq*) and aging (*puurtaq* as named by Ivujivik participants) in a wooden or an open plastic box, placed under the house. The aging step can last between two to more than four weeks depending on the season. Similar methods were reported previously by an Elder from Nunavik (Weetaluktuk, 1997). Interestingly, preparing seal *igunaq* follows similar steps, as reported by 20 producers of seal *igunaq* from five communities of the East coast of Nunavik. However, while half of them occasionally used a skin pouch as a natural container for aging seal meat and blubber, the majority used plastic containers, plastic bags or wooden boxes (Leclair et al., 2017). Similar changes in type of containers were previously reported (Austin and Leclair, 2011).

In this study, participants reported that the main rule for the safe process of aging is that the bags of walrus skin, fat and meat need to be protected from the sun and from the heat during the aging process. Actually, the Nunavik Regional Board of Health and Social Services (NRBHSS) and the Department of Public Health recommend storing the meat in the freezer and beginning the fermentation process in the fall, when temperatures are cooler, as the risk of botulism poisoning is greater during the summer (Press Communication, July 2018). Conversely, participants from this study mentioned that the temperatures in the fall are often too cold to age walrus properly.

Participants from Ivujivik and Inukjuak reported another way to age walrus is to place the walrus' parts (generally the flippers) in a container and covering them with fat from marine mammals. For this method, the safety rule mentioned by participants is to place the open container (absence of lid) in a cool place that is well ventilated. More generally, any animal fermentation should occur in an un-sealed container, placed in an area well ventilated and protected from the sun, explained Johnny Oovaut when discussing via emails about the results. Johnny added that the government shacks behind the dwellings can sometimes get too hot and thus increase the risk of botulism contamination. Similar methods were reported by the Nunavut Food Security Coalition, which remind Inuit to not age meat or fat in a plastic container with a tight lid at room temperature (Nunavut-Food-Security-Coalition and Government-Health-Department, 2017). Furthermore, once ready for consumption, it is recommended to store igunaq preparations in areas below 3 °C to stop the aging process, which could reduce the risk of contamination by *C. botulinum* (Austin and Leclair, 2011).

4.3. Consuming Atlantic walrus in Nunavik

In this study, participants explained that not all Inuit like the taste of *igunaq*. Additionally, some participants were concerned about the loss of knowledge on walrus hunting and food preparing of the younger generation. Johnny Oovaut also mentioned the importance of sharing his knowledge to keep among his family the taste for *igunaq*. Nowadays, only few of the marine mammals reported to be consumed by Inuit corresponded to Atlantic walruses (Council of Canadian Academies, 2014), highlighting the importance of culinary tradition transmission to younger generations as a mean to foster country food consumption in the Arctic.

Based on our results on IK and laboratory analyses, when butchered and prepared properly, Atlantic walrus from Nunavik is a healthy country food. The samples tested were found to be low in chemical contaminants and rich in several key nutrients. Indeed, contrary to lake trout and beluga meat, which can contain higher levels of mercury (in average 1 μg/g, but up to 6 μg/g for air-dried beluga meat) (Lemire et al., 2015), walrus muscle and liver were found to have very low mercury levels (0.07 and 0.10 μg/g respectively). The Health Canada's recommended provisional tolerable daily intake (pTDI) for women of child-bearing age and children is of 0.2 μg/kg body weight per day to protect the foetus and children from harmful neurodevelopment effects of elevated mercury exposure (Legrand et al., 2010). Thus, a 60-kg pregnant woman could eat a portion 150 g of walrus meat (with 0.07 μg/g of mercury) once per day without exceeding the pTDI, whereas lake trout or beluga meat (1 μg/g) could be safely consumed only about once every two weeks or even less if higher in mercury (Pirkle et al., 2016). The Atlantic walruses feed essentially on clams and other benthic organisms (Born et al., 2003). Consequently, mercury levels in Atlantic walruses are considerably lower than in the meat of species feeding at higher trophic levels like lake trout and beluga in Nunavik (Lemire et al., 2015). For this same reason, and although only few monitoring data are available for persistent organic pollutants (POPs) in Atlantic walruses in the Canadian Arctic, there is no reason to believe that POPs or other new lipophilic contaminants could be elevated in fat or other parts of Atlantic walruses (AMAP, 2017).

The Nutrition Fact Sheet Series produced by the Government of Nunavut (Caughey et al., 2013) recommend walrus meat as an excellent source of proteins, iron, zinc, omega-3 fatty acids and selenium, and walrus fat, as rich in omega-3 fatty acids, vitamin A and E. Indeed, we found that walrus meat and liver were exceptionally high in selenium (above 1 μg/g) as are beluga skin, other marine mammal organs, and fish eggs in Nunavik (Lemire et al., 2015). A new form of selenium named selenoneine was recently identified in high concentrations in beluga skin (Achouba et al., 2019), and increasing evidence suggests that selenium/selenoneine may help mitigate mercury-related neurodevelopmental and cardiovascular toxicity among Inuit populations in the Arctic (Ayotte et al., 2011; Boucher et al., 2010, 2012; Hu et al., 2017; Valera et al., 2009). It is likely that selenoneine also exists in Atlantic walruses, although further studies are needed to confirm this.

Moreover, walrus fat presented on average 113 mg/g of omega-3 fatty acids in total, which is ten times higher than in market foods (above 10 mg/g). Such uniquely high concentration of omega-3 are found in beluga and seal aged fats (known as *misiraq*) (above 75 mg/g), followed by Arctic char flesh, salmon flesh and eggs in Nunavik (between 15 and 25 mg/g) (Gebauer et al., 2006; Lemire et al., 2015). Omega-3 fatty acids in marine foods are well-known for their multiple health benefits with respect to child neurodevelopment and cardiovascular health in Nunavik and elsewhere (Boucher et al., 2011, 2012; Jacobson et al., 2015; Valera et al., 2009).

4.4. Ensuring sustainable walrus harvest

Although the reported walrus harvests have decreased in Nunavik within the last decade (COSEWIC, 2017), due to a variety of factors including the reduction in the number of sled dogs to feed, but also the high costs of fuel (DFO, 2013; Dorais, 1997), it is important to ensure that the harvesting of walrus is sustainable. According to the Committee on the Status of Endangered Wildlife in Canada, there are three designable units (DUs) of Atlantic walrus populations, based on genetics. The High Arctic population (DU1), the Central-Low Arctic population (DU2) and the extinct population of Nova Scotia-Newfoundland-Gulf of St-Lawrence (DU3) (COSEWIC, 2017). Nunavik harvested walruses are considered in the DU2 category, which is considered of special concern according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Under article 65 of the Species at Risk Act, the government of Canada has the obligation to “prepare a management plan for the species and its habitats” to insure population health and stability, through co-management entities from Nunavik (Nunavik Marine Wildlife Management Board), Nunavut (Nunavut Wildlife Management Board) and Fisheries and Oceans Canada (Article 66 (2), Species at Risk Act). Furthermore, the Nunavik and Nunavut wildlife management boards have the responsibility to protect wildlife in their respective land claims (Nunavik Inuit Land Claims Agreement (NILCA) and Nunavut Land Claims Agreement (NLCA)). They also have the responsibility to protect the Inuit harvesting rights and long term cultural, social and economic interests (Article 5.1.2, 5.1.3 in NILCA and NLCA). Inuit Knowledge is one of the tools used by wildlife managers to evaluate the status of walrus population and sustaining harvesting needs in Nunavut through and Integrated Fisheries Management Plan (DFO, 2018). The Nunavik wildlife management board is presently working on a similar walrus management plan since they share with Nunavut some hunting grounds. These plans will provide key information to keep the walrus harvest and practices sustainable.

4.5. Conclusion

In conclusion, with the support of the Nunavik Trichinellosis Prevention Program and the research conducted on walrus health, including botulism, the present study highlights the value that the consumption of Atlantic walruses has as a potential resource to help address issues related to food insecurity in Nunavik in the future (see summary shared with participating communities in supplementary data). Based on previous studies as well as Inuit Knowledge and laboratory findings outlined in this study, there remains some important points to be considered when hunting, butchering, aging, conserving and consuming walruses in Nunavik (Table 6). Taking into account the active transmission of IK among experienced and new hunters regarding the proper preparation of *igunaq* and taste for it, walrus consumption could continue to be promoted among a variety of locally harvested foods as long as the harvest keeps the walrus population at a sustainable level. Finally, the approach adopted in this study enforces the value of learning from multiple perspectives and knowledge systems and is a reminder of the importance of paying particular attention to issues of scale (spatial, temporal and biological) when wanting to adopt such an approach.

CRediT authorship contribution statement

Laura M. Martinez-Levasseur: Conceptualization, Methodology, Validation, Formal analysis, Resources, Data curation, Funding acquisition, Investigation, Writing - original draft, Visualization.**M. Simard:**Investigation, Resources, Writing - review & editing.**C.M. Furgal:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing - review & editing.**G. Burness:**Conceptualization, Funding acquisition, Project administration, Supervision, Writing - review & editing.**P. Bertrand:**Formal analysis, Writing - review & editing.**S. Suppa:**Investigation, Resources, Writing - review & editing.**E. Avard:**Resources, Writing - review & editing.**M. Lemire:**Conceptualization, Funding acquisition, Project administration, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.137307.

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