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Surveillance for zoonotic pathogens and Inuit Qaujimajatuqangit of ringed seals (nattiit) (*Pusa hispida*) in Frobisher Bay and Eclipse Sound, Nunavut, Canada

Enooyaq Sudlovenick,[1,8] James Simonee,[2] Megan E. B. Jones,[1] Vincent L'Hérault,[3] Adrián Hernández-Ortiz,[4] Emily Jenkins,[4] Sarah Parker,[5] Fabien Mavrot,[6] Angie Schneider,[6] Susan Kutz,[6] Jeremiah T. Saliki[7,9] and Pierre-Yves Daoust[1,10]

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ABSTRACT. Ringed seals (*Pusa hispida*) (nattiq (s.), nattiit (pl.) [Inuktut]) provide an important food staple for Nunavummiut (Indigenous residents of Nunavut). We studied the health of nattiit harvested by hunters from Baffin Island, Nunavut, via Inuit Qaujimajatuqangit and veterinary science. We conducted serological surveys and polymerase chain reaction (PCR) for select zoonotic pathogens, including *Brucella* spp., *Erysipelothrix rhusiopathiae, Leptospira interrogans* and *Toxoplasma gondii*, in 55 nattiit from Frobisher Bay (FB) and 58 nattiit from Eclipse Sound (ES). We used a digestion assay to determine the presence of *Trichinella* spp. larvae in muscle samples from these seals. We conducted interviews with nine Local Knowledge Holders (LKHs) from Iqaluit (FB) and nine from Pond Inlet (ES) to gather their observations about nattiq health. The hunters evaluate nattiq health through a combination of behavior, nutritional condition, and appearance of skin and organs. They rarely observed severely ill nattiit. Hunters from ES but not from FB observed declining nattiit population numbers. In both regions, they observed increased numbers of harp seals (*Phoca groenlandica*). Frequencies of natural exposure among nattiit from FB and ES, based on seroprevalence, were 20.5% and 37% for *Brucella* spp., 25% and 11% for *E. rhusiopathiae*, 93% and 100% for *L. interrogans*, and 10% and 27% for *T. gondii*, respectively; PCR was negative for these pathogens in organs and tissues of seropositive animals. We did not detect larvae of *Trichinella* spp. Knowledge and experience from the LKHs in assessing nattiq health, complemented by negative findings from direct detection methods, provide reassurance about the safety of nattiit as country food, despite their exposure to some zoonotic pathogens in their natural environment.

Keywords: *Brucella*; *Erysipelothrix*; Inuit Qaujimajatuqangit; *Leptospira*; nattiit; *Pusa hispida*; ringed seal; *Toxoplasma*; *Trichinella*

RÉSUMÉ. Les phoques annelés (*Pusa hispida*) (nattiq (s.), nattiit (pl.) [en inuktut]) constituent une source de nourriture importante pour les Nunavummiut (habitants autochtones du Nunavut). Nous avons étudié l'état de santé des nattiit collectés par les chasseurs de l'île de Baffin, au Nunavut à l'aide de l'Inuit Qaujimajatuqangit et de la science vétérinaire. La sérologie et l'amplification en chaîne par polymérase (PCR) ont été employées pour étudier certains pathogènes susceptibles de causer une zoonose, dont *Brucella* spp., *Erysipelothrix rhusiopathiae, Leptospira interrogans* et *Toxoplasma gondii*, chez 55 nattiit de la baie Frobisher (BF) et 58 nattiit du détroit d'Éclipse (ES). Un test de digestion a été utilisé pour déterminer la présence de larves de *Trichinella* spp. dans des échantillons de muscle de ces phoques. Nous avons interviewé neuf détenteurs de savoirs locaux (DSL) d'Iqaluit (BF) et neuf DSL de Pond Inlet (ES) afin de recueillir leurs observations sur l'état de santé des nattiit. Les chasseurs évaluent l'état de santé des nattiit à partir de leur comportement, de leur état nutritionnel ainsi que de l'apparence de leur peau et de leurs organes. Ils ont rarement vu des nattiit sévèrement malades. Les chasseurs d'ES ont

[1] Canadian Wildlife Health Cooperative, Department of Pathology and Microbiology, Atlantic Veterinary College, University of Prince Edward Island, 550 University Avenue, Charlottetown, Prince Edward Island C1A 4P3, Canada
[2] P.O. Box 23, Pond Inlet, Nunavut X0A 0S0, Canada
[3] ArctiConnexion, 422 3e Avenue, Québec, Québec G1L 2W1, Canada
[4] Department of Veterinary Microbiology, Western College of Veterinary Medicine, 52 Campus Drive, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5B4, Canada
[5] Large Animal Clinical Sciences, Western College of Veterinary Medicine, 52 Campus Drive, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5B4, Canada
[6] Department of Ecosystem and Public Health, Faculty of Veterinary Medicine, University of Calgary, 3280 Hospital Dr NW, Calgary, Alberta T2N 4Z6, Canada
[7] `Athens Veterinary Diagnostic Laboratory, University of Georgia, Athens, GA 30602, USA
[8] Present address: Centre for Earth Observation Science, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada
[9] Present address: Oklahoma Animal Disease Diagnostic Laboratory, College of Veterinary Medicine, Oklahoma State University, Stillwater, OK 74078, USA
[10] Corresponding author: daoust@upei.ca

observé un déclin de la population de nattiit, ce qui n'a pas été le cas des chasseurs de la BF. Dans les deux régions, ils ont observé une augmentation du nombre de phoques du Groenland (*Phoca groenlandica*). Les fréquences d'exposition naturelle parmi les nattiit de la BF et d'ES, basées sur la séroprévalence, étaient de 20,5 % et de 37 % pour *Brucella* spp., de 25 % et de 11 % pour *E. rhusiopathiae*, de 93 % et de 100 % pour *L. interrogans* et de 10 % et de 27 % pour *T. gondii*, respectivement. La présence de ces pathogènes dans les tissus et organes d'animaux séropositifs n'a pas *été* détectée par PCR. Des larves de *Trichinella* spp. n'ont pas été détectées. Le savoir et l'expérience des DSL pour déterminer l'état de santé des nattiit ainsi que les résultats négatifs obtenus des méthodes de détection directes fournissent une preuve de la salubrité des nattiit comme source de nourriture traditionnelle, malgré le fait qu'ils soient exposés à certains agents pathogènes zoonotiques dans leur milieu naturel.

Mots-clés : *Brucella*; *Erysipelothrix*; Inuit Qaujimajatuqangit; *Leptospira*; nattiit; *Pusa hispida*; phoque annelé; *Toxoplasma*; *Trichinella*

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INTRODUCTION

Marine mammals have been essential for coastal Inuit across the Arctic, from the Bering Strait to Baffin Island, Labrador, and Greenland, peoples collectively known as Inuit Nunaat (Borré, 1994). The ringed seal (*Pusa hispida*) (nattiq (s.), nattiit (pl.) [Inuktut]) has maintained the Baffin Island Inuit through diet and physical, spiritual, and cultural health for time immemorial. To understand the importance of marine mammals to any Indigenous group, it is important to understand Indigenous perspectives on food. Traditional food, more accurately referred to as country food, is central to the personal, cultural, nutritional, and social well-being of Indigenous peoples (Furgal et al., 2005). Nattiq meat is believed to have healing properties and to nourish not only the body but the soul (Borré, 1994). For example, it is known by Inuit that eating raw nattiq meat provides warmth to the body that store-bought foods cannot provide (Borré, 1994; Van Oostdam et al., 2005). When hunters are out in fall or winter, they will eat raw nattiq meat, liver, and blood to warm up.

Notwithstanding the many benefits of eating country foods, there are also potential negative health effects, such as exposure to zoonotic pathogens (Chan et al., 2006; Lambden et al., 2007; Jenkins et al., 2013; Keatts et al., 2021; Stimmelmayr and Sheffield, 2022). For example, Inuit have a higher seroprevalence of antibodies to the protozoan *Toxoplasma gondii* than other Indigenous communities, such as the Cree, or among Caucasian people living in the same communities (Messier et al., 2009). This higher seroprevalence may be attributable to the Inuit customs of food preparation and consumption, frequency of eating wild game, or variation in the prevalence of pathogens in different Arctic animal species. Other important pathogens, from the perspective of food safety, for Arctic Indigenous communities include the nematode *Trichinella* spp. (Oksanen et al., 2022) and various bacteria of terrestrial and marine origin, such as *Brucella* spp. (Orsini et al., 2022; Whatmore et al., 2017), *Leptospira* spp. (Cameron et al., 2008), and *Erysipelothrix rhusiopathiae* (Kutz et al., 2015).

A multiple evidence-based approach, whereby different but potentially parallel knowledge systems can be combined to create new and complementary insights, has proven useful to untangle food safety questions (Tengö et al., 2014; Abu et al., 2020). For example, this approach can use Indigenous perspectives of the people who consume nattiit together with laboratory-based investigation of pathogen prevalence. In Nunavut, Inuit Qaujimajatuqangit (IQ) is Indigenous Knowledge specific to Inuit peoples. It is the way of knowing that encompasses the past, present, and future of Inuit experiences and values, principles, skills, and beliefs that have evolved over time (SEDSSC, 2003; Tester and Irniq, 2008; Tagalik, 2010). Understanding the importance of the nattiq through IQ provides context for the issue of assessing food safety and food security. Inuit Qaujimajatuqangit can provide insight into cultural perceptions of risk, inform risk communications and approaches, and influence decisions (Friendship and Furgal, 2012).

Food safety and food security in northern communities encompass several elements, including Inuit knowledge, access to country food, traditional food preparation, and exposure to old and new pathogens. We focused on only some of these elements by using IQ, serology, and direct pathogen detection methods in order to explore the health of nattiit from the Qikiqtaaluk (Baffin Island) region of Nunavut. Specifically, we examined the association of nattiit subpopulations (northern Baffin and southeastern Baffin) and demographics (age and gender) with their exposure to five pathogens of potential public health significance: *Brucella* spp., *L. interrogans, E. rhusiopathiae*, *T. gondii*, and *Trichinella* spp.

METHODS

Study Area

The nattiq is a circumpolar species, with five recognized subspecies worldwide, one of which occurs in Canada, and a latitudinal range extending from 63˚ to 73˚ north (COSEWIC, 2019). This study involved two communities on Baffin Island: Iqaluit (63.746693˚N, 68.516968˚ W) and Pond Inlet (72.7001˚ N, 77.9585˚ W) (**Fig. 1**). These two

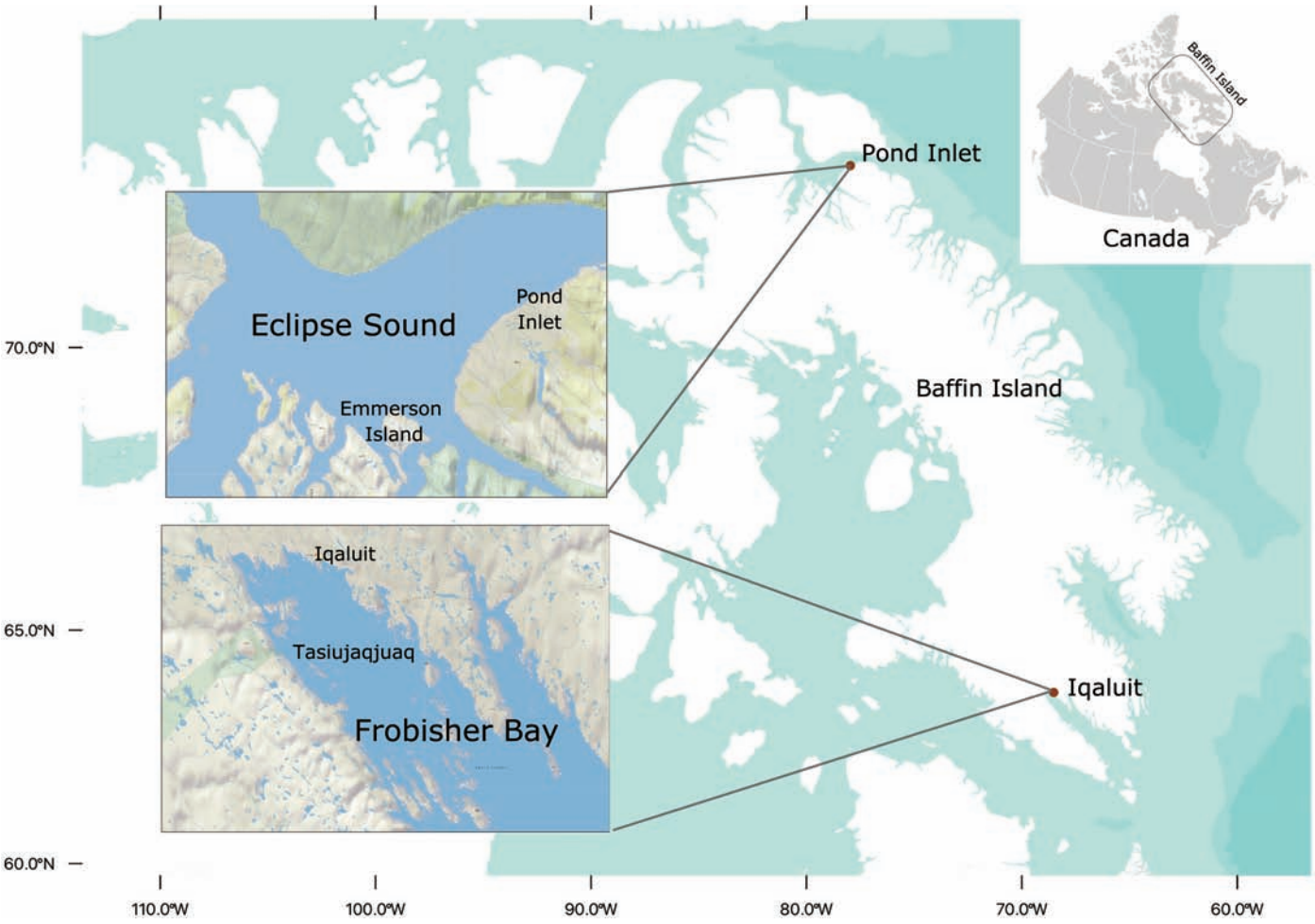

FIG. 1. Map showing the communities of Pond Inlet and Iqaluit, Baffin Island, Nunavut. In northern Baffin Island, ringed seals were harvested in Eclipse Sound, between Emmerson Island and Pond Inlet, a distance of approximately 50 km. In southern Baffin Island, ringed seals were harvested in the upper region of Frobisher Bay, or Tasiujaqjuaq, an area of approximately 50 km in diameter.

communities have a regular harvest of nattiit throughout the year, representing a central part of the daily diet. In southeastern Baffin Island, we collected nattiq samples in the upper region of Frobisher Bay (FB), or Tasiujaqjuaq, an area of approximately 50 km in diameter between Iqaluit and a chain of islands to the south. In northern Baffin Island, we collected samples Eclipse Sound (ES) between Pond Inlet and Emmerson Island, approximately 45 km to the west (Fig 1).

Inuit Qaujimajatuqangit

We conducted semi-structured interviews, either individually or in groups, with nine Local Knowledge Holders (LKHs) in Iqaluit (nine men and one women, 40–80 years old) and nine LKHs in Pond Inlet (six men and 3 women, 70–80 years old). Interview questions were open-ended, and we included several probes to clarify and guide the conversation (Huntington, 1998). These LKHs are all Inuit or lifelong residents of Nunavut who are actively hunting and have specific knowledge with regards to nattiit within FB or ES, including hunting, food selection, food preparation, and nattiq skin preparation. In Iqaluit and Pond Inlet, we used a community knowledge referral system (snowball sampling) to select LKHs (Biernacki and Waldorf, 1981), whereby participants identified other individuals based on their local expertise and involvement in local hunting and land programs. In order to draw on a range of experience levels, we selected participants who differed across age groups and genders. However, most participants were local elders (60+ years).

In Iqaluit, an Inuk hunter and researcher fluent in both languages conducted all interviews in September 2018 in either English or Inuktut. After receiving consent, this researcher audio recorded the interviews (via a digital audio recorder) and took notes, which they later used to supplement interview transcripts. Following preliminary transcript readings, we used qualitative content analysis to develop a coding scheme based on the topic (i.e., nattiq abundance, methods of inspection of nattiq health, etc.). In contrast to latent qualitative analysis, which searches for implied meanings, we chose manifest content analysis in order to focus on factual knowledge. In our case, the manifest content was literal and surface level information

provided by the LKHs (Kondracki et al., 2002; Braun and Clarke, 2006). To address questions of food preparation methods and observations of nattiq health, we undertook several rounds of reading and categorizing the data. We then sub-categorized themes to identify recurrent patterns. We attached direct quotes from the transcriptions to themes in order to clearly demonstrate the importance of each of these themes (Toerien and Wilkinson, 2004). We coded and analyzed transcriptions using NVivo 12 software (NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012). We obtained ethics approval for the interviews from the University of Prince Edward Island (file number #6007591).

In Pond Inlet, an Inuk hunter and researcher conducted all interviews in Inuktut in April 2018. This researcher informed all participants of the project objectives, the nature of their involvement, and their rights, and, with their consent, recorded the interviews (via a digital audio recorder and a camera). Before analysis, members of the team who are fluent in Inuktut and English and highly proficient in butchering and processing wild animals, including nattiit, translated the interviews from Inuktut to English. We used a coding scheme to classify information based on topics. Interviews with LKHs in Pond Inlet were exempt from university ethics approval because they were conducted within the context of a distinct, non-academic, community-driven project that centered around marine mammal observations, harvesting, and health, the greater part of which pertained to nattiit around Pond Inlet.

Seal Samples

Two local Inuit researchers collected all nattiit. Based on relationships of trust and communication, they shared this effort with their friends and families. Collection took place during subsistence harvests within FB in spring 2017 and spring and fall 2018 and within ES in spring 2016, spring and fall 2017, and spring 2018. Since an important goal of this project was to assess the health of animals that would normally be consumed in the community, hunters decided which nattiit to collect. Whether on the ice in spring or in the water in fall, all animals were shot with high-caliber rifles with lead-based ammunition, the hunters always aiming for the seal's head for an instant kill. Inasmuch as possible, hunters recorded the following information: sex, approximate age, standard length (from nose to tip of tail), axillary girth, and sternal blubber thickness. Typically, hunters aged the nattiit themselves, based on standard length and pattern of the pelt. Classification used was: young of the year (YOY), juvenile (approximately 1 – 5 years old), and adult. Some nattiit were not aged in the field, and we submitted their lower jaws for age determination based on counts of growth layer groups in the cementum of a mandibular canine tooth (Matson's Laboratory, Milltown, MT, USA).

We provided hunters with 10 mL tubes for blood sampling (BD Vacutainer® SST, Becton Dickinson, and Company, Mississauga, ON, Canada) prior to leaving for their hunt, and instructions to collect free-flowing blood from the bullet wounds. The researchers kept blood samples cool until they centrifuged them at 4000 rpm for 15 minutes within 24 hours of collection. They harvested serum from these samples and stored them in individual cryo-vials. With the help and guidance of a southern university partner, the two Inuit local researchers collected the following tissue samples in leak-proof polyethylene bags (Whirl-Pak): tonsils, pulmonary lymph node, intestinal lymph node, liver, kidney, diaphragm, tongue, and skeletal muscle. Serum and tissue samples from FB nattiit were stored at −20˚C shortly after collection, whereas several of the samples from ES nattiit were buried in snow (at a temperature around 0˚C) for up to one week before being moved to a −20˚C freezer. After a maximum of 50 days, we transferred all samples to the Atlantic Veterinary College, University of Prince Edward Island, where we stored tissue samples at −20˚C and serum samples stored at −80˚C.

Pathogen Surveillance

Full details of the serological methods used to determine whether nattiit had been exposed to the five pathogens of interest are provided in a similar study on grey seals (*Halichoerus grypus*) in the Gulf of St. Lawrence, Canada (Sauvé et al., 2020). We briefly summarize these methods below.

We detected antibodies against *Brucella* spp. using the brucellosis card test, with *B. abortus* (strain 1119-3) and *B. canis* as test antigens (OIE, 2018). We assessed exposure to *E. rhusiopathiae* d by an enzyme-linked immunosorbent assay (ELISA; Giménez-Lirola et al., 2012; Mavrot et al., 2020). We express results as percent positivity (PP) of a positive control. No species-specific cut-off currently exists for nattiit. Therefore, on the basis of 107 nattiit serum samples tested, we calculated a cut-off using a mixture distribution modeling approach and bootstrapping (Mavrot et al., 2020). The small sample size resulted in a wide 95% confidence interval (95% CI) around the estimated cut-off (36 PP, 95% CI = 15 – 43). We considered samples above the upper CI limit (43 PP) as positive, and those above the cut-off but smaller than the upper CI limit as suspect.

We detected antibodies against *L. interrogans* by a microagglutination test (MAT) (OIE 2021) using mixtures of serially diluted serum (starting at an initial dilution of 1:100) and live antigen suspensions of the following six leptospiral serovars: Bratislava, Canicola, Grippotyphosa, Hardjo, Icterohaemorrhagiae, and Pomona. We defined serological titers as the highest dilution in which 50% agglutination occurred compared to a control suspension. We considered titers ≥ 1:100 positive for exposure to the corresponding serovar (Calle et al., 2002; Colagross-Schouten et al., 2002; Delaney et al., 2014), although in human literature titers ≥ 1:800 are viewed as more conservative and confirmatory of infection (Ahmad et al., 2005; Kassim et al., 2018).

We determined the presence of serum antibodies against *T. gondii* using a commercial indirect ELISA kit according to the manufacturer's instructions (ID Screen Toxoplasmosis Indirect Multi-species, IDvet Innovative Diagnostics, Grabels, France; Sharma et al., 2019). We used sera collected from grey seals prior to and post experimental exposure to *T. gondii* as internal negative and positive controls, respectively (Gajadhar et al. 2004). We expressed results as sample/positive percentage (S/P %), where values ≥50 were considered positive and values between 40 and 50 were considered suspect.

We assessed the presence of DNA of *Brucella* spp., *E. rhusiopathiae*, *Leptospira* spp., and *T. gondii* in tissue samples of a subset of seropositive animals. We performed a multiplex quantitative polymerase chain reaction (qPCR) targeting *Brucella* spp. on samples of pulmonary lymph nodes from eight seropositive nattiit from FB, and 19 seropositive nattiit from ES (Probert et al. 2004). We performed a qPCR targeting *Leptospira* spp. on kidney samples from 12 nattiit from FB and seven nattiit from ES that had a serological titer of ≥1:800 to any of the six serovars tested (Smythe et al. 2002). For both *Brucella* spp. and *Leptospira* spp. we considered cycle thresholds (Ct) <35 to be positive, Ct between 35 and 40 to be suspect, and Ct > 40 negative.

We performed a qPCR using *E. rhusiopathiae*-specific primers and probe (Forde et al. 2016) on pooled samples of tonsils and intestinal lymph nodes from 10 seropositive nattiit from FB, and six seropositive nattiit from ES. We considered Ct <50 positive, and Ct >50 negative. For *T. gondii*, we extracted DNA from 20 mg each of muscle and liver from five seropositive nattiit from FB, and 15 seropositive nattiit from ES using the QIAGEN DNeasy® Blood & Tissue Kit according to the manufacturer's protocol, and we determined the presence of DNA of *T. gondii* by a conventional PCR targeting the 200–300-fold repeating 529 bp segment (Homan et al. 2000).

We examined samples of tongue and diaphragm from 54 nattiit from FB (11 adults, 11 juveniles, 32 YOY), and 53 nattiit from ES (20 adults, three juveniles, 30 YOY) for the presence of *Trichinella* spp. larvae by the double separatory funnel digestion method, which is currently the best test available (Forbes and Gajadhar, 1999; Barlow et al., 2021). We pooled five grams of each tissue type from each of five nattiit for a total of 25 g per digest. We resolved that, if any pools were positive, we would individually analyze remaining samples.

Histology

We thawed samples of kidney from 12 nattiit with serologic titers ranging between 1:800 and 1:1600 to at least one serovar of *L. interrogans*, all from FB, then fixed them in 10% neutral buffered formalin, and processed them routinely for microscopic examination. We strained five µm–thick histological sections with hematoxylin and eosin.

Statistical Analysis

For analysis, we considered two age groups: YOY and Older (juvenile and adult). We used Fisher's Exact test of independence to assess univariable association with location, age, and sex for nattiit seropositive for *Brucella* spp., *E. rhusiopathiae, L. interrogans*, and *T. gondii*. For each pathogen, we determined final relationships with the same model building procedure. We conducted multivariable logistic regression with a forward stepwise procedure based on the number of nattiit for which there was information on age, location, and seroprevalence. We considered all variables (age, sex, location) for model building. We retained variables in the model if they were independently associated with the occurrence of the pathogen at a relaxed level of significance ($p < 0.1$) or if they were important confounders (changed coefficients of other variables by >20%). In the final model, we tested the effects of all 2-way interactions for all variables. Where we identified important interaction effects, we constructed composite variables (i.e., we used a new, four-level variable for the analysis when two, two-level variables interacted). We reported outcomes for logistic models as model-predicted seroprevalence with 95% confidence intervals. We made pairwise comparisons between subgroups for variables and between highest and lowest predicted values for seroprevalence; we corrected the significance level for pairwise comparison of predicted seroprevalence values for multiple comparison with a Bonferroni correction (p = 0.05/number of comparisons). We performed all analyses using a commercial software package (Stata statistical software: Release 17. College station, TX: StataCorp LLC).

RESULTS

Inuit Qaujimajatuqangit

After completion of the final interview in both Iqaluit and Pond Inlet, we determined that the responses to the questions were consistent across all LKHs and that additional interviews were not needed, as we had reached thematic saturation. Combining the results from both Iqaluit and Pond Inlet interviews, we identified four principal themes in the thematic analysis of the interviews.

1. Preferences in Food Harvest, Preparation, and Consumption: LKHs in both communities consistently reported a preference for young nattiaviniq (i.e., YOY) and smaller nattiit over older, larger nattiit in both communities, although we did not explore specific reasons for this.

> The young ones. I think all Inuit are like this (*Natchiavinimiq pigasuratakkai. Inulimaaqai taimattu*)
> (L. Kootoo, Iqaluit)

Three Iqaluit hunters did not mind eating older rutting male seals, or "tiggak," which are the least desirable nattiit

to harvest because they have a strong odor that permeates the meat. The hunters who did not mind consuming these large male seals were all Elders and male and had spent parts of their lives living in outpost camps.

Most participants liked to consume raw seal products, particularly the liver, immediately after butchering the seal. Seal meat, brain, and blood are also consumed raw, the blood particularly by the older LKHs:

> Right, take like three or four bites of raw seal and it sends a rush of blood all over your body.
>
> (S. Lonsdale, Iqaluit)

> When I go out hunting during winter, once I catch one, cut up the seal, then eat some liver, some meat with blubber, that's what I do at first place.
>
> (J. Kiliktee, Pond Inlet)

All LKHs liked to boil the seal meat for consumption. Fermentation of some seal parts also appeared to be popular, but only with the oldest of the participants in both communities. Although our interviewers not specifically ask about which nattiq parts are fermented, some LKHs reported the use of fermented seal flippers and meat. All participants consumed the small intestine, either raw-frozen, dried, or boiled. Small intestine is always cleaned out and rinsed with ocean water before it is prepared and consumed. All LKHs indicated that they consumed liver and seal meat raw, frozen, or boiled:

> …liver is really good frozen; it's like dark chocolate. In the winter.
>
> (G. Williams, Iqaluit)

> We eat it raw if we want to, liver with its blubber, heart, and boiled meat.
>
> (R. Ootook, Pond Inlet)

Lungs are also consumed, either frozen-raw or boiled, especially from YOY seals. Some LKHs also consume the kidneys boiled. All participants said they freeze their seal meat in plastic bags if they are not going to eat it fresh (within 2 to 3 days). All participants also preferred to eat seal when it is fresh and has never been frozen.

2. Nattiit Health and Food Quality: Nattiq health is judged throughout the whole hunting process. The LKHs will observe the behavior of the nattiq first before deciding to shoot it:

> You know, you don't necessarily know why they're sick, but you recognize that this is out of the norm, and so it may not be limited to just the color of meat or bad patches on the seal, it could have been the seal behavior.
>
> (S. Lonsdale, Iqaluit)

Once the nattiq is harvested, its health is judged through multiple criteria, such as fur condition, fat content, condition of internal organs, and presence of abnormalities (unusual growths, size of lymph nodes). Most of the LKHs mentioned the condition of the liver, which is the most prized organ for consumption, and those with spots or discolorations are not consumed. All LKHs were selective about what nattiit they would butcher and bring home. Many hunters, when they harvest a visibly ill or abnormal looking nattiq, will not butcher it for fear of contaminating their equipment or contracting an illness. LKHs mentioned shooting a nattiq that, upon closer inspection, was not fit for consumption because of visible lesions or unhealthy appearance. The hunters did not want to sample these nattiit because they were repulsed and discarded it by opening it up and leaving it to the birds or putting it back into the ocean.

Two LKHs in the women's group in Pond Inlet have seen lice on nattiq pelts regularly enough that these were considered a normal occurrence. One LKH from Iqaluit had similar observations:

> Some seals have more bugs than others.
>
> (M. Paniapik, Iqaluit)

Severe illness in nattiit was not commonly seen. However, we discovered through the interview process that, in seeking knowledge from LKHs about what, to them, made a seal ill, terminology was key. For example, one hunter said that they had never seen a sick nattiq, but later stated that they had seen nattiit with no fur. Another LKH had never seen a sick nattiq, but when asked specific question about internal health, the same LKH indicated that they had seen nattiit with bad livers. This highlighted the importance of asking specific questions using the right terms, where "sick" may not include a nattiq with single or minor physical abnormalities that have no obvious clinical significance to the animal, such as spotted livers or missing fur patches. The LKHs also indicated that if the nattiq was otherwise in perfect health (good fat stores, no swollen lymph nodes or visible signs of illness), they would cut the affected area away and eat the rest of the nattiq. This showed that the term "sick" is reserved for severely ill nattiit and does not include milder abnormalities. This separation between "sick nattiq" and minor abnormalities was evident in both English and Inuktut interviews.

3. Ringed Seal Abundance: All LKHs stated that nattiq abundance was decreasing within the Tasiujaqjuaq, or in areas that are closer to the city of Iqaluit. They offered three main explanations for this observed decline: 1) natural fluctuations, and we are in a time of low abundance; 2) an increased number of hunters over the years, who harvest the nattiit closest to the town; and 3) movement of seals away from the city. Most LKHs in Iqaluit explicitly stated that the nattiit population as a whole is not in decline:

> But I think the population itself is not really reducing in number. I think they sort of move away to some other places where there's less human activity.
>
> (G. Williams, Iqaluit)

TABLE 1. Seroprevalence1 by age and sex against four infectious agents in ringed seals (nattiit) (*Pusa hispida*) from Frobisher Bay (FB) and Eclipse Sound (ES), Nunavut, collected between 2017 and 2018. Number of seropositive seals/total number of seals tested for each infectious agent. Sexes combined for the age groups, and ages combined for the sex groups. YOY, young of the year; Unk, unknown age; na, not applicable.

Species	*Brucella abortus*		*Leptospira interrogans*[2]		*Erysipelothrix rhusiopathiae*		*Toxoplasma gondii*	
	FB	ES	FB	ES	FB	ES	FB	ES
Adults	1/7	10/22	7/7	23/23	3/11	5/23	1/11	8/23
Juveniles	2/7	3/4	6/7	4/4	0/9	0/4	2/9	2/4
YOY	5/29	6/25	27/29	25/25	10/31	1/28	2/30	5/28
Unk	1/1	na	1/1	na	0/1	na	0/1	na
Females	3/21	7/17	20/21	17/17	5/26	1/20	1/26	4/20
Males	5/20	12/33	18/20	34/34	8/22	5/34	4/21	11/34
Unk	1/3	0/1	3/3	1/1	0/4	0/1	0/4	0/1
Total	9/44	19/51	41/44	52/52	13/52	6/55	5/51	15/55
(%)	(20.5)	(37)	(93)	(100)	(25)	(11)	(10)	(27)

[1] Tests used were: brucellosis card test, microagglutination test (*L. interrogans*), and enzyme-linked immunosorbent assay (*E. rhusiopathiae, T. gondii*).

[2] Titers ≥ 1:100 to any of the six serovars tested (Bratislava, Canicola, Grippotyphosa, Hardjo, Icterohaemorrhagiae, Pomona) were considered positive for exposure to this bacterium.

Two LKHs in Iqaluit did not explicitly say that there was no decline, but rather, that nattiit would not go extinct and that the nattiit simply moved around.

In Pond Inlet, the consensus among all the LKHs was that there are less nattiit than there have been in the past. All of the LKHs from Pond Inlet reminisced about the great abundance of nattiit in the 1950s and said they have noticed there are fewer nattiit around ES in the present day.

> Many years ago, in the spring the ice used to be full of seals that surfaced on the ice, we could even choose the seal to get when we wanted fresh seal meat. That has changed today. But today one [caught] seal for food is not enough due to decreasing [number of] seals.
>
> (S. Omik, Pond Inlet)

LKHs offered two main reasons for the observed decline in nattiq abundance in the ES area: an increased number of polar bears preying on seal pups, and the increase in shipping within ES, which causes the nattiit to flee:

> The seal pups are being eaten more than ever by polar bears anywhere, even around near Pond Inlet here. It's hard to hunt for seal pups for us today, because polar bears are taking over that hunting.
>
> (J. Killiktee, Pond Inlet)

> It seems that since the ship loaders [are] going back and forth, the seals seem decreasing around here.
>
> (A. Kunnuk, Pond Inlet)

4. Interactions with Harp Seals: Most LKHs from Iqaluit mentioned harp seals, although they were not part of the questionnaire. LKHs expressed concern over their increasing numbers and state of health*:*

> Number, big numbers. Thousand, hundred thousand coming up. They kind of over taking the nattiit.
>
> (S. Awa**,** Iqaluit)

Most of the LKHs from Iqaluit also consume harp seals, but only the young ones, primarily because the adult harp seals are too large to butcher and because of taste preferences. One LKH from Pond Inlet also observed the increase in harp seals: "Harp seals are getting more abundant. They just keep coming" (J. Killiktee, Pond Inlet).

Pathogen Testing: Serological and Direct Detection

Seal Samples: We sampled a total of 55 nattiit from FB and 58 nattiit from ES. With the exception of four nattiit from FB (three with skin lesions, two of which were rejected by the hunters; one with lung lesions), they all appeared healthy and in good nutritional condition based on their blubber thickness, axillary girth, and overall appearance. Nattiit sampled from FB included 11 adults, 11 juveniles, 32 YOY and one of unknown age, and 27 females, 24 males and four of unknown sex. Nattiit sampled from ES included 23 adults, of which four were juveniles and 31 YOY, and 20 females, 35 were males, and three were of unknown sex. Samples for the different analyses (serology, detection of larvae of *Trichinella* spp. in muscle) were not available from all seals.

***Brucella* spp.**: All 44 nattiit from FB and 51 nattiit from ES that we tested for antibodies against *B. canis* were negative. We detected antibodies against *B. abortus* in nine (20.5%) of the 44 nattiit from FB and 19 (37%) of the 51 nattiit from ES (**Table 1**). On logistic regression, antibodies against *B. abortus* were significantly associated with location (OR = 2.3, p = 0.1) and age (OR = 2.3, p =

0.08), but not sex. We detected no significant interactions. The predicted seroprevalence was highest in Older seals in ES (47%; 95% CI 29% to 64%), although this was only significantly different ($p = 0.006$) from YOY in FB (14%; 95% CI 3% to 25%). We did not detect DNA of *Brucella* spp. in pulmonary lymph nodes from eight seropositive nattiit from FB or 19 seropositive nattiit from ES.

Erysipelothrix rhusiopathiae: Thirteen (25%) of 52 nattiit from FB and six (11%) of 55 nattiit from ES that we tested for antibodies against *E. rhusiopathiae* were positive (Table 1). There was no overall effect of age, sex, or location. However, there was a significant interaction between location and age, and therefore we created a composite variable for location and age (4 levels: FB Older seals, FB YOY, ES Older seals, ES YOY), which was significantly associated with seroprevalence ($p = 0.09$). The highest predicted seroprevalence was in FB YOY (32%; 95% CI 16% to 49%) which was significantly different ($p = 0.002$) from that in ES YOY (4%; 95% CI 0 to 10%). We did not detect DNA of *E. rhusiopathiae* in pooled samples of tonsils and intestinal lymph nodes from 10 seropositive nattiit from FB, and six seropositive nattiit from ES.

Leptospira interrogans: Based on a seropositive titer of ≥1:100, 41 (93%) of 44 nattiit from FB and all 52 (100%) nattiit from ES that we tested for antibodies against six serovars of *L. interrogans* were positive to at least one of these serovars (Table 1). Combining all serovars, we found no significant difference in seroprevalence against *L. interrogans* between the two regions in terms of total number of seropositive nattiit ($p = 0.09$, Fisher's Exact test). There was also no significant effect of age or sex. Twenty-seven of the 41 seropositive nattiit from FB, and 51 of the 52 nattiit from ES were seropositive to more than one serovar. No nattiit from either FB or ES had titers against serovars Canicola and Hardjo. The highest seroprevalence (>90%) was reached against serovar Icterohaemorrhagiae in both regions and against serovar Bratislava in ES (Table 2). We found a higher seroprevalence to serovars Bratislava ($p < 0.001$, Fisher's Exact test) and Pomona ($p < 0.001$, Fisher's Exact test) in nattiit from ES than in those from FB (Table 2). Using a more conservative positive titer of ≥1:800 against *L. interrogans* (Ahmad et al. 2005), we found that 12 nattiit from FB and seven nattiit from ES were seropositive to serovar Icterohaemorrhagiae. This included three nattiit from FB with a titer of 1:1600, one of which, a YOY harvested in September, also had titers of 1:800 to serovars Bratislava and Pomona (Table 2).

We did not detect DNA of *Leptospira* spp. in samples of kidney from all 12 nattiit from FB and seven nattiit from ES with a titer of ≥1:800. In addition, we identified no lesions microscopically in samples of kidney from 12 nattiit from FB with a titer of ≥1:800.

Toxoplasma gondii: We detected antibodies against *T. gondii* in five (10%) of 51 nattiit from FB, and 15 (27%) of 55 nattiit from ES (Table 1). Overall, males (OR = 3.2; $p = 0.04$) and Older seals (OR = 2.8; $p = 0.05$) had significantly higher odds of seroprevalence of antibodies against *T. gondii*. Location was not associated with seroprevalence. We detected no significant interaction. The highest predicted seroprevalence was in older male seals (38%; 95% CI 20% to 56%), which was significantly different ($p = 0.003$) from that in female YOY (6%; 95% CI 0 to 13%). We did not detect DNA of *T. gondii* in muscle and liver from five seropositive nattiit from FB and 15 seropositive nattiit from ES.

***Trichinella* spp.**: We detected no larvae of *Trichinella* spp. in muscle samples (tongue or diaphragm) from 54 nattiit from FB and 53 nattiit from ES.

DISCUSSION

The present study used a multiple evidence-based approach (**Fig. 2**), with two knowledge sources: IQ and veterinary science. These sources complemented each other to create a broader understanding of nattiq health and provided context to the importance of wholistically monitoring wildlife health. We used interviews to focus on food preparation methods and seal abundance and health over the long term, serology to establish a history of past exposure to pathogens, and direct detection methods to determine current infection status. Together, these results have outlined a more complete view of nattiq health, where historical nattiq samples may not exist, but where the oral attestation from LKHs fills this gap.

Inuit Qaujimajatuqangit

Similar information was obtained through interviews of LKHs in the two communities of Iqaluit and Pond Inlet, which are separated by 1000 km, indicating close social and cultural interconnectivity among Inuit of Baffin Island. Knowledge and experience from the LKHs in assessing nattiq health, together with negative findings from the direct detection methods, provide reassurance about the safety of nattiit as country food, while serology demonstrates that, as expected, nattiit are exposed to pathogens in their natural environment over their lifetime. The preference of hunters and their families for young nattiaviniq adds another layer of safety, since young animals with a healthy appearance are less likely than older animals to carry pathogens.

Conducting interviews in two languages also provided a unique opportunity to explore scientific and Inuktut terminologies for defining seal health. During the interviews, it became apparent that terminology is extremely important when defining unusual findings in seals in both languages. Several LKHs indicated that they reject obviously ill nattiit, which highlights two points: hunters are actively selecting against potentially infectious animals, and this study focused on harvested seals that appeared healthy, rather than the whole nattiq population. Because these nattiit present a subset of the population with a bias towards healthy animals, testing seropositive nattiit for the potential presence of pathogens could have missed

TABLE 2. Prevalence of positive agglutination by dilution titers and ages for four serovars1 of Leptospira interrogans in nattiit from Frobisher Bay and Eclipse Sound, NU collected between 2017 and 2018, using the microagglutination test. Number of seropositive seals/ total number of seals tested. Sexes combined. Ad, adult; Juv, juvenile; YOY, young of the year; Unk, unknown age. For the total number of seals for each of the four serovars (numbers in bold characters), different superscripts indicate a significant difference ($p < 0.05$, Fisher's Exact test).

Serovar	Dilution titer	Frobisher Bay					Eclipse Sound			
		Ad	Juv	YOY	Unk	Total	Ad	Juv	YOY	Total
Bratislava	1:100	3	2	13	1	19	5	2	10	17
	1:200	3	2	2	–	7	10	1	6	17
	1:400	–[2]	–	–	–	–	7	1	9	17
	1:800	–	–	1	–	1	–	–	–	–
	Total	6/7	4/7	16/29	1/1	27/44	22/23	4/4	25/25	51/52
	(%)					(61)[a]				(98)[b]
Grippotyphosa	1: 100	1	–	1	–	2	4	–	2	6
	Total	1/7	0/7	1/29	0/1	2/44	4/23	0/4	2/25	6/52
	(%)					(4.5)[a]				(12)[a]
Ictero-haemorrhagiae	1:100	1	–	3	–	4		1	–	– 1
	1:200	1	5	1	7		6	1	9	16
	1:400		4	4	9	–	17	13	2	11 26
	1:800		1	8	–	9		3	1	3 7
	1:1600		1		2	–	3	–	–	–
	Total	6/7	6/7	27/29	1/1	40/44	23/23	4/4	23/25	50/52
	(%)					(91)[a]				(96)[a]
Pomona	1: 100	2	1	3	–	6	13	2	14	29
	1: 200	–	1	1	–	2	6	1	7	14
	1: 400	1	–	–	–	1	1	–	–	1
	1:800	–	–	1	–	1	1	–	–	1
	Total	3/7	2/7	5/29	0/1	10/44	21/23	3/4	21/25	45/52
	(%)					(23)[a]				(87)[b]

[1] Serum samples from all seals were negative for serovars Canicola and Hardjo.

[2] –, no seal seropositive at this dilution titer for this serovar.

acutely infected animals, as seropositive animals may have cleared acute infections. Further and more detailed conversations with LKHs and also with Hunters and Trappers Organizations and territorial wildlife officers in the communities are needed. These conversations should focus on how best to monitor nattiq health and nurture closer links with veterinary scientists. Taken together, these approaches would act as an early warning system regarding the health of the nattiq population and provide ecological insights that may be missing in the local baseline information (Eckert et al., 2018; Reid et al., 2021). While all five pathogens examined in this study have zoonotic potential, their mode of transmission from nattiit to people, their pathogenicity in nattiit and people, and their potential impacts on the nattiq populations are not yet fully understood.

Interviews focused on nattiq health and not on human health in relation to nattiit, such as whether hunters ever experienced illness after getting seal blood into an open wound or became sick after consuming seal. Asking questions related to infection or illness in the LKHs' own experience could have aided in understanding the prevalence of illness caused by nattiit. For example, seal finger, caused by *Mycoplasma* spp. has been associated with bites from seals, whereas a comparable disease caused by *E. rhusiopathiae* is more commonly associated with landing fish. Both are treatable with antibiotics, but of different types (White and Jewer, 2009). It would be pertinent to educate hunters and health care providers working in the north about the risks of contracting illnesses from nattiit, such as seal finger or brucellosis, and ways to mitigate these risks, such as fully cooking country food and thus killing many pathogens. Further work is needed to explore the risks of contracting illnesses from handling or consuming nattiit.

We found a remarkable similarity between the Indigenous approach and western science–based criteria for harvesting healthy animals for human consumption. As with federally mandated procedures used in commercially operated slaughterhouses (Government of Canada, 2019), Inuit hunters use a systematic process to assess the health of the seals they wish to harvest. Before shooting a seal, they determine that its behavior is normal. After shooting, they observe its external appearance (nutritional condition, skin integrity), and carefully examine all internal organs, including lymph nodes, and either reject the carcass as a whole or trim abnormal areas away if few and relatively small. Great care to avoid any contamination of the nattiit carcasses by their fecal contents is also identical to procedures in commercial slaughterhouse operations. Notably, Stimmelmayr and Sheffield (2022) made very similar observations among Alaskan Iñupiat. Consumption

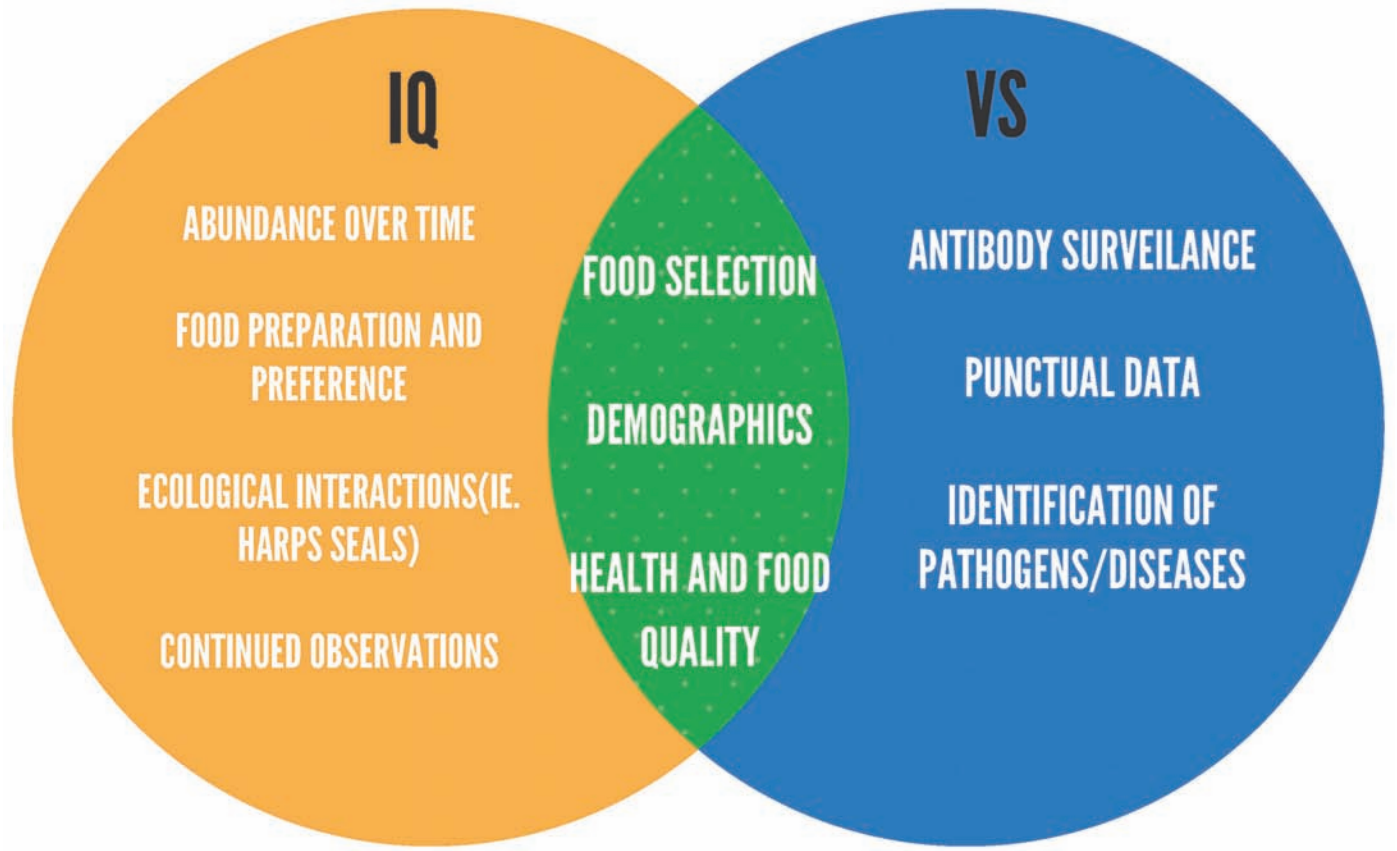

FIG. 2. Evidence contributed by Inuit Qaujimajatuqangit (IQ) and veterinary science (VS) in investigation of nattiq health. Whereas IQ provided information on long-term health, VS provided specific data on a limited time scale. Both knowledge sources examine nattiq health closely by considering animal health, food quality, and demographics.

of the brain of some of the nattiit, as mentioned by the LKHs, raises the potential issue of lead poisoning, since most nattiit are shot in the head with lead-based ammunition. This particular point was not explored during the interviews. However, one of the Inuit researchers commented that, in general, hunters will go to great lengths to keep the nattiq's head intact if the family has made a specific request for nattiq brain, either by using nets or hunting at the nattiq's breathing hole in the ice.

The difference in observations of ringed seal abundance between LKHs in Pond Inlet and Iqaluit is worth noting. This difference is based on limited observations on a spatial scale, and it would not be possible to extrapolate its significance to larger regions without similar observations by LKHs in other communities. However, the concerns expressed by hunters in Pond Inlet about the potential impact of shipping traffic associated with a nearby mining operation in ES is also worth noting (Teichroeb, 2022).

The unsolicited observation by several LKHs of increased sightings of harp seals in their region is pertinent in view of the recent expansion of this population in the western North Atlantic (Hammill et al., 2014). Being larger animals, harp seals might compete successfully with ringed seals for habitat and food, although Desforges et al. (2022) found little overlap in diet between these two species when they co-occurred in the open-water season. Even without direct competition between them, however, an increased number of harp seals could potentially introduce important pathogens to the ringed seal population. In particular, this species is suspected of being a reservoir for the highly contagious phocine morbillivirus, which in previous decades caused severe mortality in the population of harbour seals (*Phoca vitulina*) in western Europe (Jensen et al., 2002; Daoust et al., 2020).

Veterinary Science

We found serological evidence that at least some nattiit in both FB and ES had been exposed to four of the five pathogens studied. Because a large proportion of the nattiit sampled were YOY, antibodies detected in these animals may have been of maternal origin, but they nonetheless reflect population exposure to these pathogens. While the source of these pathogens is unclear, this seroprevalence provides baseline information that will help to monitor some future changes in the environment. However, caution must be used in interpreting some of these results, since the serological tests have been validated for use in domestic animals and humans and may not always be directly applicable to marine mammals (Duncan et al., 2014). There was no evidence of the actual presence of these pathogens in the animals through detection of their DNA

by PCR analysis of tissues, and no nattiq showed clinical signs of disease or pathological changes that would have suggested an active infection. Nonetheless, it is important to recognize that DNA is extracted from very small samples (i.e., 20 mg of tissue), and therefore it is possible that active infections were simply missed. In addition, PCR was performed only on seropositive animals, which may bias against detection of acute infections, since antibodies generally take two weeks to develop. Likewise, only 5 g of tissue were examined from each seal for *Trichinella*, little is known about the predilection sites (if any) for this parasite in ringed seals, and low larval counts can be missed even in established hosts (Barlow et al., 2021).

Seroprevalence against *Brucella* spp. (specifically, *B. abortus*) was high in nattiit in both FB and ES (20.5% and 37%, respectively) when compared to that in previous studies of ringed seals in Alaska, across Nunavut, in waters around and east of Svalbard, and in the Baltic Sea (14%, 4%, 10%, and 16%, respectively) (Nielsen et al., 1996; Tryland et al., 1999; Nymo et al., 2018; Sonne et al., 2018). However, the brucellosis card test may yield false positives because of cross-reactivity between antigens of *Brucella* spp. and those of other bacteria, such as *Yersinia enterocolitica* (Bonfini et al., 2018). Serum lipids, often present in marine mammals, may also interfere with the accuracy of this test unless at least partly removed (Godfroid et al., 2016; Nymo et al., 2018). A competitive ELISA developed with the use of a *Brucella* sp. of marine origin was shown to be more sensitive than traditional tests validated for *B. abortus*, including the brucellosis card test (Meegan et al., 2010). Based on these observations, the results of our study may demonstrate an increased seroprevalence against *Brucella* spp. among ringed seals over time or, alternatively, differences in methodology. The higher seroprevalence in Older seals may have reflected an increased likelihood of exposure to this pathogen with time. However, the reason for the apparently higher seroprevalence in nattiit from ES as compared to those from FB is unknown. Forbes et al. (2000) succeeded in isolating *Brucella* spp. from pooled lymph nodes of four out of six seropositive ringed seals harvested by Inuit hunters in Cumberland Sound, eastern Baffin Island.

Our finding of a relatively high seroprevalence of antibodies against *E. rhusiopathiae* in nattiit in both FB and ES (25% and 11%, respectively) is substantially greater than the seroprevalence of 3% reported by Sauvé et al. (2020) in grey seals in the Gulf of St. Lawrence. In both nattiq and grey seal studies, the same serological test was used, and both used the same approach to define a species-specific cut-off. However, the number of grey seals available to calibrate this test (59 serum samples) was much smaller than in the present study (107 ringed seal samples). This resulted in an even wider 95% CI around the estimated cut-off in the former study, and the conservative approach by Sauvé et al. (2020) to consider only samples above the upper CI limit as positive may have ruled out more potentially seropositive animals in that study. *Erysipelothrix rhusiopathiae* is ubiquitous in nature and an opportunistic pathogen (Wang et al., 2010; Forde et al., 2016), and widespread mortality events caused by this bacterium have been described among muskoxen (*Ovibos moschatus*) on Victoria Island and Banks Island, western Nunavut (Kutz et al., 2015; Forde et al., 2016). Although we did not notice, or look for, lice on pelts of harvested nattiit, the unsolicited comment by some LKHs that they see them regularly is interesting in view of the potential role of ectoparasites, including seal lice, as vectors of some pathogens (Chirico et al., 2003; Hirzmann et al., 2021). Conversely, fish can harbor this bacterium on their epidermal mucus and may represent another source of exposure for seals (Wang et al., 2010). A difference in diet between the northern and southeastern regions of Baffin Island (e.g., fish vs. invertebrates) could thus possibly explain the significantly higher seroprevalence in YOY in FB as compared to those in ES.

A high proportion of nattiit in both FB (93%) and ES (100%) were seropositive for at least one of the six *Leptospira* serovars tested using the MAT, a standard serological method with high specificity commonly used in marine mammals on the west coast of North America (Colagross-Schouten et al., 2002; Ahmad et al., 2005; Prager et al., 2013; OIE, 2021). Similarly, all grey seals (100%) examined in the southern Gulf of St. Lawrence were found to be seropositive to at least one serovar (Sauvé et al., 2020). California sea lions (*Zalophus californianus*) at some locations of coastal California, US, also had a very high seroprevalence to *L. interrogans* (Colagross-Schouten et al., 2002). Infection by *Leptospira* spp. has rarely been reported in seals from the western North Atlantic (Bogomolni et al., 2008), and we are not aware of serological surveys for this bacterium in ringed seals or other seal species in these waters. We did not identify carriers of this bacterium using PCR analysis among nattiit in FB and ES. However, the high seroprevalence in these populations suggests that ringed seals can act as maintenance hosts for this bacterium. This high seroprevalence is nonetheless intriguing considering that, in contrast to species like grey seals and California sea lions, nattiit are largely solitary animals and consequently have limited close contact with each other and that leptospires are not salt-tolerant and do not survive well in cold water (Khairani-Bejo et al., 2004; Andre-Fontaine et al. 2015).

Although there is a high degree of serological cross-reactivity among the different serovars of *L. interrogans*, the highest titers (≥1:800) reached in most nattiit in both FB and ES were against serovar Icterohaemorrhagiae, suggesting that this is the predominant serovar infecting nattiit in waters of Baffin Island, as it also appears to be among grey seals in the Gulf of St. Lawrence (Sauvé et al., 2020; OIE, 2021). By comparison, California sea lions along the eastern North Pacific almost always have the highest MAT titer against serovar Pomona, which is also the only serovar isolated in that species (Prager et al., 2013).

Renal damage is typically associated with both acute and chronic leptospirosis (Colagross-Schouten et al.,

2002; Kik et al., 2006). Microscopic examination of the kidneys from 12 seals with titers ≥1:800, including three with a titer of 1:1600, did not reveal any lesions suggesting infection by *Leptospira* sp. One of the seals, a YOY from FB harvested in September, had titers of 1:1600 for serovar Icterohaemorrhagiae and 1:800 for serovar Pomona and Bratislava. Such high titer (1:1600) would suggest active disease in domestic animals, but this seal had no gross or microscopic evidence of renal damage and no gross evidence of lesions in other organs. This seal may have just been exposed to Leptospira for the first time and been experiencing the early stages of infection, including high antibody levels.

The seroprevalence of antibodies against *T. gondii* in FB and ES (10% and 27%, respectively) was considerably lower than that recently reported in grey seals in the southern Gulf of St. Lawrence (53%), but comparable to those in ringed seals in Nunavik (30%) and Alaska (16%), and in seals (mainly ringed) in the Canadian Arctic (10%) (Dubey et al., 2003; Simon et al., 2011; Bachand et al., 2019; Sauvé et al., 2020). No *T. gondii* DNA was detected in any of the samples tested in the present study, but a poor correlation between serological results and tissue infection status has been observed by others for this protozoan (Simon et al., 2011; Bachand et al., 2019). However, Reiling et al. (2019) identified *T. gondii* DNA by PCR in tissue samples of 26% of nattiit collected in northern Nunavik in 1993 and 1994. In our study, older seals were significantly more likely to have been exposed to *T. gondii*. Similarly, Sharma et al. (2019) observed an increased seroprevalence against *T. gondii* with age in wolverines (*Gulo gulo*) from the Northwest Territories, western Canada, possibly reflecting an increased likelihood of exposure to this pathogen with time. However, seroprevalence against *T. gondii* did not differ between age groups in wolverines from western Nunavut (Reichard et al. 2008). We also observed a male bias, in contrast to other studies on free-living seals (Cabezón et al. 2011; Sauvé et al. 2020). Factors such as geographic location, behavior, and diet of the seals could have influenced the level of exposure to this protozoan in these different studies.

Toxoplasma gondii is a highly ubiquitous protozoan, and there is increasing evidence to support marine cycles of transmission of this pathogen in the Canadian Arctic (Ducrocq et al. 2021). Besides vertical transmission from mother to fetus, exposure can occur via ingestion of either oocysts or tissue cysts. Domestic cats and wild felids are the only recognized definitive hosts of *T. gondii*, shedding the highly resistant oocysts in their feces. Conversely, tissue cysts can occur in a wide variety of birds and mammals, including marine mammals and humans (Dubey et al., 2003; Uzal et al., 2016). There are no felids native to Nunavut, and domestic cats, which are present in low numbers, rarely roam outside. However, wild birds can carry tissue cysts, and various species of migratory geese have been proposed as potential vectors of *T. gondii* from temperate to Arctic regions (Sandström et al., 2013; Elmore et al., 2014; Bachand et al., 2019). Interestingly, Bylot Island, along the north shore of ES, has the largest known colony of Greater Snow Geese (*Anser caerulescens atlantica*) in Canada, with a summer population estimated at approximately 100,000 birds (Bellrose, 1976; ECCC, 2019). Nonetheless, the specific dietary sources of infection by *T. gondii* in ringed seals remain unknown (Tryland et al., 2014). Depending on age groups, sex, and regions, these seals' diet may include different proportions of fish and pelagic zooplankton, which may filter environmentally resistant oocysts transported in marine currents from subarctic regions (Thiemann et al., 2007; Yurkowski et al., 2016).

Lack of evidence of *Trichinella* spp. in any of the muscle samples tested from ringed seals was reassuring. The method used could have detected as few as 1 to 2 larvae per gram of tissue, which is the threshold associated with the development of clinical disease in humans who consume insufficiently cooked contaminated meat (Forbes et al., 2008; Barlow et al. 2021). In the Arctic, consumption of raw or undercooked meat from polar bears (*Ursus maritimus*) and walrus (*Odobenus rosmarus*) is the most common source of human infection (MacLean et al., 1992; Tryland et al., 2014). Phocids are rarely infected, with a reported prevalence between 0% and 2.3%; none of 244 ringed seals from the eastern Canadian Arctic were infected (Forbes, 2000; Møller, 2007; Tryland et al., 2014).

CONCLUSIONS

Inuit communities are well aware of the importance of health parameters in the wild animals on which they rely for their country food, and recently their concerns have been amplified by accelerating environmental changes affecting the Arctic. The present study sought to provide information on some of the health parameters for nattiit, a species central to the diet and culture of many Inuit. This information combined with the knowledge we obtained from LKHs can, in turn, guide communication to community members and health care providers about potential risks, as well as benefits, associated with consumption of country food. Although serological surveillance confirms natural exposure of nattiit to some zoonotic pathogens, their lack of direct detection indicates a likely low infection risk from handling and consuming ringed seal products. Inuit Qaujimajatuqangit provides timely wildlife health information within a long-term regional context. Moreover, IQ practitioners are well versed in assessing the health of country food and making informed decisions about food safety as it relates to the animals they harvest. Nonetheless, much remains unknown about the wide variety of pathogens in the natural environment. Ongoing studies involving collaboration with LKHs and inclusion of IQ are therefore essential, especially in relation to the emergence or re-emergence of zoonotic pathogens in a rapidly changing environment (Keatts et al., 2021; Stimmelmayr and Sheffield, 2022).

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