Towards a transdisciplinary characterisation of the Indigenous food systems of Inuit Nunangat and Eeyou Istchee

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Abstract

Indigenous foodways are unique and contemporary economies that people rely on to feed themselves that have existed since time immemorial. These food systems are social-ecological phenomena situated at the intersection of economy and environment, food and wildlife, biodiversity and well-being, and Indigenous culture and identity. Harvesting wildlife for food is a constitutionally protected right of Indigenous Peoples within Canada. Indigenous food systems are a key contributor to the food security, nutrient intake, and the social economy in Inuit Nunangat and Eeyou Istchee. Chapter 2 combines harvest data reported in support of the James Bay and Northern Quebec Agreement (JBNQA) and food recall information from independent health surveys in the Cree region of Eeyou Istchee and the Inuit region of Nunavik to characterize the social-ecological and biocultural foundations of local Indigenous food systems across two regions and two time periods. Multivariate redundancy analysis of local food use in relation to region and survey reveals distinct regional use patterns that have remained consistent over two surveys spanning a 30-year period of accelerating socio-ecological change. Limited access and availability of healthy country and store-bought food have led to high rates of food insecurity across northern Canada, especially in Nunavut, where food insecurity affects 50 to 80% of households, which is ten times higher than the Canadian average. Because food is a fundamental need that must be replaced and cannot be exchanged, in Chapter 3, I adopt a replacement value approach, estimating what it would cost to purchase enough store-bought food to replace the protein and energy offered by reported country food harvest in Nunavut. This methodology of valuing the nutritional content of local country food harvests relative to the local cost of store-bought nutrients arrives at a $140-200 million replacement value estimate, eclipsing both the $3.5 million reported for "hunting, fishing, and trapping" activities by the Nunavut Bureau of Statistics and the Government of Nunavut's estimated replacement value of $35 million for the country food economy. Chapter 4 applies approaches developed in the previous two chapters to harvest and food recall data from Eeyou Istchee and Nunavik to assess the numeric, value, and nutritional gaps between guaranteed levels of harvest established in the 1970's and reported food use in the 2000's. Estimated total use declined by nearly 50% in both regions between the 1970's and the 2000's. Given substantial population growth in both regions during the

same period, this reduction in total use translates to a 85% decrease in reported per capita use in Nunavik and a 74% decrease in reported per capita use in Eeyou Istchee. I estimate a $20 million annual value gap between guaranteed levels of harvest established in the 1970's and food use reported in the 2000's. I also estimate that reported use was sufficient to satisfy 100% of the population's protein requirements in the 1970's but in the 2000's provided for only 51% of recommended dietary allowances in Nunavik and 40% in Eeyou Istchee. By combining publicly available data on harvest, community population/demographics, food consumption, food prices, income, and nutritional content, this thesis offers improved methodologies for describing community and regional differences in use, based on ecological niche metrics, and for estimating the value of local foods, based on a local cost of nutrient replacement. Thesis results also emphasize that the Indigenous food systems of Inuit Nunangat and Eeyou Istchee remain a high value economy and that regional use niches remain distinct over time, despite rapid socio-ecological change.

Résumé

Les modes d'alimentation autochtones sont des formes d’économies uniques et contemporaines sur lesquelles les gens comptent pour se nourrir et qui existent depuis des temps immémoriaux. Ces systèmes alimentaires sont des phénomènes socio-écologiques situés à l'intersection de l'économie et de l'environnement, de l'alimentation et de la faune, de la biodiversité et du bien-être, ainsi que de la culture et de l'identité autochtones. La récolte d'animaux sauvages à des fins alimentaires est un droit constitutionnellement protégé des Peuples Autochtones du Canada. Les systèmes alimentaires autochtones contribuent de manière essentielle à la sécurité alimentaire, à l'apport en nutriments et à l'économie sociale de l'Inuit Nunangat et de l'Eeyou Istchee. Le chapitre 2 combine les données sur les récoltes déclarées dans le cadre de la Convention de la Baie James et du Nord québécois (CBJNQ) et les informations sur les rappels alimentaires provenant d'enquêtes indépendantes sur la santé dans la région crie d'Eeyou Istchee et la région inuite du Nunavik, afin de caractériser les fondements socio-écologiques et bioculturels des systèmes alimentaires autochtones locaux dans deux régions et à deux époques. L'analyse multivariée de la redondance de l'utilisation des aliments locaux en fonction de la région et de l'enquête révèle des schémas d'utilisation régionaux distincts qui sont restés cohérents sur deux enquêtes couvrant une période de 30 ans d'accélération des changements socio-écologiques. L'accès, la disponibilité et l'utilisation limités d'aliments locaux sains ou d'aliments sains achetés en magasin ont entraîné des taux élevés d'insécurité alimentaire dans le nord du Canada, en particulier au Nunavut, où l'insécurité alimentaire touche de 50 à 80 % des ménages, ce qui est dix fois plus élevé que la moyenne canadienne. Étant donné que la nourriture est un besoin fondamental qui doit être remplacé et qui ne peut être échangé, j'adopte au chapitre 3 une approche fondée sur la valeur de remplacement, en estimant ce qu'il en coûterait pour acheter suffisamment d'aliments en magasin pour remplacer les protéines et l'énergie offertes par la récolte d'aliments traditionnels déclarée au Nunavut. Cette méthode, qui consiste à évaluer le contenu nutritionnel des récoltes locales d'aliments traditionnels par rapport au coût local des nutriments achetés en magasin, aboutit à une estimation de la valeur de remplacement de 140 à 200 millions de dollars, dépassant à la fois les 3,5 millions de dollars déclarés pour les activités de " chasse, de pêche et de piégeage " par le Bureau des statistiques du Nunavut

et la valeur de remplacement estimée à 35 millions de dollars par le gouvernement du Nunavut pour l'économie de l'alimentation traditionnelle. Le chapitre 4 applique les approches développées dans les deux chapitres précédents aux données de récolte et de rappel alimentaire de l'Eeyou Istchee et du Nunavik afin d'évaluer les écarts numériques, nutritionnels et de valeur entre les niveaux garantis de récolte établis dans les années 1970 et l'utilisation alimentaire déclarée dans les années 2000. L'utilisation totale estimée a diminué de près de 50 % dans les deux régions entre les années 1970 et 2000. Compte tenu de la forte croissance de la population dans les deux régions au cours de la même période, cette réduction de l'utilisation totale se traduit par une diminution de 85 % de l'utilisation déclarée par habitant au Nunavik et de 74 % dans l'Eeyou Istchee. J'estime à 20 millions de dollars la différence de valeur annuelle entre les niveaux garantis de récolte établis dans les années 1970 et l'utilisation alimentaire déclarée dans les années 2000. J'estime également que l'utilisation déclarée était suffisante pour satisfaire 100 % des besoins en protéines de la population dans les années 1970, mais que dans les années 2000, elle ne représentait que 51 % des apports nutritionnels recommandés au Nunavik et 40 % dans l'Eeyou Istchee. En combinant des données publiques sur les récoltes, la population et la démographie des communautés, la consommation alimentaire, le prix des aliments, le revenu et le contenu nutritionnel, cette thèse propose des méthodologies améliorées pour décrire les différences d'utilisation entre les communautés et les régions, sur la base de métriques de niche écologique, et pour estimer la valeur des aliments locaux, sur la base d'un coût local de remplacement des nutriments. Les résultats de la thèse soulignent également que les systèmes alimentaires autochtones de l'Inuit Nunangat et de l'Eeyou Istchee demeurent une économie de grande valeur et que les niches d'utilisation régionales restent distinctes au fil du temps, malgré des changements socio-écologiques rapides.

Dedication:

For my grandparents,

who instilled in me the value of an education,

and provided for my own.

Land Acknowledgements and Statement of Positionality

This research uses data collected from multiple regions of Indigenous Canada and the work itself has been completed in the treatied and un-treatied territories of Calgary and Montreal respectively.

McGill exists on the traditional and unceded territory of the Anishinaabe and Haudenosaunee nations who long used Montreal as a meeting place on portage around the Lachine rapids.

Calgary or Mohkinstsis, is within the territory of Treaty 7 covering the traditional territories of the Blackfoot confederacy, including Stoney, Blood, Tsuut'ina (Sarcee), Siksika and Peigan.

The importance of Indigenous food systems is best expressed by Indigenous authors and researchers; the best this white researcher can hope to do is align with community interests and contribute research approaches that help to communicate the value of local systems to a broader audience. To quote Wilson et al. (2020), "Ultimately, sustainable northern food systems must be defined by and for Northerners at community, local, and regional levels, with particular attention paid to treaty rights and the right to self-determination of First Nations and other Indigenous communities."

As a non-Indigenous researcher with training in multi-disciplinary environmental sciences, I seek to align my work with points of focusrecommended by Indigenous communities, and to ensure previous research and pre-existing datasets are combined and made accessible in a way that produces new insights, without placing more demands on communities for data collection. Whether these analysis and insights have validity, significance, and value is best evaluated by the people who create and rely on these food systems and the local, regional, and territorial organizations tasked with promoting and protecting local subsistence economies and food security. My hope is that the data synthesis offered here can inform northern food policy and at the same time identify knowledge gaps and adaptation measures that might be pursued and prioritized by communities and regional organizations. This alternative approach could be called "data jamming", taking pre-existing datasets, and combining them to produce new insights.

Acknowledgements

A thesis is like a ship. This ship has had to navigate tumultuous times and sailing under a quarantine flag. As a ship is only as good as her crew, I feel fortunate to have sailed with some of the best.

Murray, captain of the Humphries' privateers under marque from King James, our face to the world and compass bearer. Without his guidance this thesis would never have found its way. Someone who never stops fighting for his people and is blessed with the patience for leadership, I hope I can build on what he has taught me.

Manu, our quartermaster, keeping us shipshape so our sails will always catch the wind. There are not enough words, even in a dissertation, to describe how essential Manu has been to this venture. Always willing to lend a hand or an ear, she never shies away from a challenge. I can't imagine trying to do this without her constant support.

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My parents, master shipwrights, who laid down a keel three decades ago and built something capable. Always on hand to lend advice, none of this could have happened without them.

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And lastly Tank, the ship's cat, the protector of our grains and my furriest companion. I'm slightly biased, but I think he's the best kitty, even if he can be a bed hog. Thank you for the unconditional love, much of this thesis has been written with you on my lap or sitting on your bed next to my computer. You're the best.

Contributions to Original Knowledge

The three research chapters presented here contribute original knowledge addressing knowledge gaps in the social-ecological characterization of Indigenous food systems, food system valuation, and post-agreement assessment of guaranteed levels of harvest. These contributions to knowledge:

1) **Respond to and follow-up on research gaps identified by the 2014 Council of Canadian Academies state of knowledge report, "Aboriginal Food Security in Northern Canada".** This thesis directly addresses knowledge gaps raised by the CCA report, specifically food system assessment methodologies included mixed data sources. The report identifies the existence of numerous data sets, but a lack of standardisation for data collection methods. This thesis work addresses this issue by using mixed datasets, collected using various methodologies, making them interoperable, and generating new knowledge from pre-existing data (Chapter 2, 3 & 4). This work also incorporates the report's suggestions to include the cost of store-bought food in assessments of northern food systems and to estimate the value of harvested foods using a nutrient-based approach (Chapters 3 & 4). This thesis also responds to the reports call for closing knowledge gaps using pre-existing data while developing new multidisciplinary or transdisciplinary approaches to Indigenous food security.

2) **Introduce new methodologies for combining local harvest and food surveys and the application of multivariate approaches to assess regional social-ecological differences and change over time in Indigenous food systems.** In chapter 2, this approach is applied to harvest and food recall data across two adjacent regions of Northern Quebec. Using constrained ordination, a form of multivariate linear regression, I determine the ecological dissimilarity between reported use among Inuit communities in Nunavik and Cree communities in Eeyou Istchee in the 1970's relative to the 2000's. The analysis illustrates variation in use of different wildlife species across regions and time points, with the general conclusion being strong regional variation that has remained distinct over time.

3) **Introduce new methodologies for estimating the cost to replace energy and protein harvested in Northern communities, which yields a harvest value estimate that exceeds many prior estimates by an order of magnitude.** Chapter 3 analysis suggests a chronic undervaluation of local Indigenous food systems in northern regions of Canada. I develop a local food system valuation approach based on in-community cost of store-bought energy and protein as a basis for valuation, arriving at a replacement value. Many previous studies had only considered exchange value or used a non-hunted analogue food stuff to construct a value for harvested foods without consideration for nutritional content. I apply this valuation approach to reported harvests in Nunavut (chapter 3) and reported harvest and food use in Nunavik and Eeyou Istchee (chapter 4). The Nunavut valuation has already been incorporated in the Inuit Tapiriit Kanatami (ITK) food security strategy.

4) **Estimate the nutritional adequacy of country food and the affordability of store-bought food in Nunavut.** Annual food costs were estimated to be 52 times the cost of a Weekly Revised Northern Food Basket (RNFB) and compared with annual incomes by community in Nunavut (Chapter 3). The ratio of RNFB prices to annual income allows for an estimation of the financial burden to feed a household. This estimate is based off an assumed ratio of one income earner per three dependants, or a single income earner purchasing food for a household of four. The literature indicates food costs that exceed 80% of income are indicative of severe food poverty; averaged across Nunavut communities, the purchase of store-bought food for a family of four for one year (52 RNFB = $22,489) requires 81% of a single median income (Nunavut community average = $27,890). The Nutrition North federal subsidy program already reduces the cost of store-bought food in Nunavut by about 28%. In the absence of this subsidy program, the financial burden to feed a household averaged across all Nunavut communities would be 122% of household income.

5) **Show how methodological integration of harvest and food survey results allow for the estimation of value and nutritional adequacy lost or gained over time and in relation to guaranteed harvest levels.** Chapter 4 estimates numeric, value, and nutritional gaps between guaranteed levels of harvest established in the 1970's by the James Bay and Northern Quebec Agreement and local food use reported 30 years after the signing of the agreement. 1970's and 2000's data from Nunavik and Eeyou Istchee are compared, combining harvest and food recall data to show that use has reduced below legally guaranteed levels set 30 years prior. The value of this gap is estimated at $20 million a year, a potential loss of approximately $500 million since the 2000's surveys were completed. Nutritional adequacy was estimated by comparing total harvested nutrients to estimated requirements of energy and protein per community member. The general conclusion is that contemporary use is providing for much less of the population's protein and energy requirements than harvests did historically.

6) **Reinforce that effective monitoring of food systems and community nutrition is an under-recognized requisite to upholding modern treaty and compensation agreements.** This monitoring is essential to identify when and where agreements are not being upheld and to better understand why. The strength of these agreements depends on how Indigenous food systems are assessed and monitored and the respect for Indigenous nations as unique cultures. Monitoring results must be considered valid to all parties to the agreements and capture their diversified understanding of the agreements themselves and the systems they are intended to protect. At its core, validity is about social agreement. Achieving collective social agreement about the status, the importance, and the collective measures required to achieve and maintain local food security will never be easy but is impossible in the absence of shared information about these food systems. This work highlights that land claims are only as strong as the corresponding monitoring programs, and

for strong monitoring programs the correct metrics must be used (face validity). These metrics must be grounded in local realities (construct validity).

Author Contributions

This thesis follows a manuscript-based format comprised of three manuscripts of which I am the primary author. Primary academic supervision and writing support was provided by Prof. Murray M. Humphries (McGill University). Substantial academic support and intellectual input was provided by Manu Landry-Cuerrier (McGill University). For each of the following manuscript-based chapters, the CReDiT author contribution statements are outlined below.

For Chapter 2:

Duncan W. Warltier: Conceptualization; Validation; Methodology; Software; Data Curation; Formal analysis; Investigation; Writing – Original Draft.

[Pierre Legendre: Methodology; Formal analysis; Software; Writing – Review and Editing.]

Manuelle Landry-Cuerrier: Conceptualization; Writing – Review and Editing; Project Administration.

Murray M. Humphries: Supervision; Writing – Review and Editing; Funding Acquisition.

For Chapter 3, published in *Arctic* (2021):

Duncan W. Warltier: Conceptualization; Validation; Methodology; Software; Formal analysis; Investigation; Writing – Original Draft; Visualization.

Manuelle Landry-Cuerrier: Data Curation; Resources; Project administration; Writing – Review and Editing; Visualization (Maps).

Murray M. Humphries: Conceptualization; Supervision; Writing – Original Draft; Writing – Review and Editing; Funding Acquisition.

For Chapter 4:

Duncan W. Warltier: Conceptualization; Validation; Methodology; Software; Data Curation; Formal analysis; Investigation; Writing – Original Draft.

Manuelle Landry-Cuerrier: Writing – Review and Editing; Project Administration; Visualization (Maps).

Murray M. Humphries: Conceptualization; Methodology; Supervision; Writing – Review and Editing; Funding Acquisition.

Introduction

Food security is a state in which all people, at all times, have sufficient and acceptable food to eat that allows them to enjoy an active lifestyle (FAO 1996). Indigenous food systems allow people to meet their dietary needs with a variety of hunted, trapped, and harvested foods (Kuhnlein & Receveur 1996; Jackley et al. 2016; Kenny et al. 2018a). The traditional food systems of Indigenous peoples, or Indigenous food systems, in northern Canada connect people to the land and their identity while playing a major role in regional food security (King & Furgal 2014; Bunce et al. 2016; Maurice, Philip & Bersamin 2017). These food systems can be threatened by land use change, climate change, pollution, and biodiversity loss (AMAP 2015; Ford, Clark & Naylor 2019; Naylor et al. 2020). Protecting regional food security can be assisted by an improved understanding and articulation of Indigenous food systems threatened by change (Ford et al. 2018; Wilson et al. 2020). In Canada, Indigenous food systems are often the subject of legal agreements protecting harvest rights and habitat, and in many cases compensating for damage or guaranteeing continued use (Caine & Krogman 2010; Constantino, Benchimol & Antunes 2018). The strength of these agreements depends on how Indigenous food systems are assessed and monitored and the respect for Indigenous nations as unique cultures.

In this chapter I consider the transdisciplinarity and Indigeneity of food systems, briefly review Indigenous harvest rights in Canada, the wildlife management implications of these rights and their interaction with wildlife management policy, the understanding of Indigenous food security, and lastly an economic perspective on Indigenous food systems. This thesis aims to provide novel descriptions of Indigenous food systems and their importance to their communities for food security. The specific objectives for each of my three research chapters are:

- **Chapter 2:** Develop a new methodology for combining harvest and food surveys to describe the differences between Cree and Inuit wildlife utilisation in Northern Quebec and describe how both systems have changed or remained constant through time

- **Chapter 3:** Develop a new methodology for valuing Indigenous food systems and apply this approach to estimate the value and nutritional adequacy of annual harvests and the affordability of store-bought food in Nunavut.
- **Chapter 4:** Combining use and valuation approaches developed in previous chapters to assess numeric, value, and nutritional gaps between guaranteed levels of harvest, established for Inuit communities in Nunavik and Cree communities in Eeyou Istchee by the 1975 James Bay Northern Quebec Agreement , relative to use reported 30 years after signing of the agreement.
- Another general objective of this thesis is to promote more recent, consistent, and community-based monitoring of Indigenous food systems by illustrating the state-of-the-system assessments made possible from past harvest and food use surveys, by indicating that available assessments are consistent with dramatic change in these food systems over time, and by emphasizing the non-existence of comparable recent and contemporary data.

These chapters will attempt to answer the following research questions:

- How can harvest and food surveys be combined to assess change over time and differences between regions? (Chapter 2)
- Are Indigenous food systems becoming homogenised or remaining distinct through time as the land and society changes? (Chapter 2)
- How have Indigenous food systems been financially valued previously and how do previous valuations compare to a nutrient-based replacement cost? (Chapter 3)
- How much energy and protein are harvested from the land and is this enough to meet peoples' dietary requirements? (Chapters 3 & 4)
- How affordable is storebought food relative to reported incomes? (Chapter 3)
- How does reported use compare to guaranteed harvest levels established through comprehensive agreements? (Chapter 2 & 4)

Chapter 1: Literature review

Indigenous food system are complex systems that connect ecosystems to community food security, health, and household economics. This thesis presents a transdisciplinary approach and a series of analyses that help to explore, understand, and communicate the complexity and value of Indigenous food systems. Transdisciplinarity seeks to integrate knowledge from social, natural, and health sciences in a manner that transcends the boundaries of the disciplines themselves (Choi and Pak 2006). A transdisciplinary approach is useful when addressing complex entities that span multiple disciplines and multiple jurisdictions (Farley et al 2010). The study of food systems in inherently transdisciplinary as it links health and well-being, livelihoods and culture, and the local ecologies of food producing areas and habitats. The study of food security tends to become compartmentalised and siloed within academic disciplines viewing food systems and food security from health, social, or ecological perspectives but rarely from all three perspectives at once. This compartmentalization is partially bridged by interdisciplinary approaches, including but not limited to a focus on social determinants of health (Richmond & Ross 2009) or social-ecological systems (Berkes & Jolly 2002; Jackley et al. 2016; Thompson et al. 2019; Tremblay, Landry-Currier & Humphries 2020). Nevertheless, a more general multidisciplinary or transdisciplinary food systems literature or theoretical foundation is largely lacking. This thesis attempts to advance Indigenous food systems research towards this transdisciplinarity through purposeful inclusion of concepts and methods from multiple disciplines, including recommended dietary allowances from the nutritional sciences, valuation approaches from economics, and niche metrics from the ecological sciences. Gaining the greatest amount of valuable knowledge out of a dataset helps reduce research fatigue and build credibility with both communities and funding agencies (Burnette et al. 2014). However, an additional goal of transdisciplinary Indigenous food systems research is the direct involvement of community members and their knowledge at all stages of the research process and the use of mixed-methods research approaches spanning qualitative and quantitative methodologies. Research outcomes should also be highly accessible and applicable to communities and policy, broadening the audience and end users of the research beyond the research community. This inclusion not only enhances the quality of the research, but also increases its usefulness to communities by being sensitive to their problems and experiences (Burnette et al. 2014). This thesis develops a description of Indigenous food systems drawing on pre-existing knowledge and surveys from wildlife ecology, community food use, household provisioning, and human nutrition. In this way, the current thesis demonstrably achieves inter-disciplinarity, while also aspiring to support and inform new and emerging transdisciplinary frameworks, research, and policy focused on northern food systems and food security.

In simplistic terms, any food system is a strategy for meeting basic human needs that requires specific food knowledge and techniques, resilient ecosystems that consistently produce food, and decision making for the most efficient and culturally consistent solution to meet nutritional needs (Kuhnlein & Receveur 1996; Godfray et al. 2010; Tendall et al. 2015). A food system consists of the natural, social, physical, and financial systems that allow individuals and communities to meet their nutritional needs, from small landholders cultivating their own foods to large international trade systems transporting foods across the globe (Kuhnlein, Erasmus, & Spigelski 2009). Most food systems are highly pluralistic and malleable, allowing for great diversity in how needs are met. In contexts such as northern Canada, where both wild and store-bought food are accessible to members of a community, food systems can be highly varied at a household, family and individual level and consist of a mixed utilisation of available foods, based on individual accessibility to and preference for each food system. Food systems define food security and other components of community health, including as these systems change over time through internal or external influences. Food systems connect people to the environment (Hutchings and Post 2013), because all foods are created by ecosystem processes, whether agricultural and non-agricultural and whether natural or processed. Food systems are also culturally specific (Delormier et al. 2009); food offers positive outcomes that stretch beyond nutritional fulfilment into cultural reaffirmation (Newell et al 2020).

Food system approaches focused on meeting basic nutritional needs (e.g., energy, protein, vitamins, and minerals) emerge from an explicitly materialist political economic lens focused on work that must be undergone to fulfil the needs of the household, through planning, decision making, and action (Marx & Engels 1845). Through this materialist lens I define food security as a functional prerequisite (Parsons &

Turner 1951) of greater well-being; basic physiological needs (e.g., food, water, shelter) must be met to attain psychological well-being. This is similar to a quality of life (QOL) approach (Costanza et al. 2007) without subdividing basic human needs and psychological well-being. However, metrics for expressing well-being can be flawed and obscure the underlying conditions experienced by peoples in a place (Maridal et al. 2018). Wesche et al. (2016) present a hierarchical discussion of well-being, health, and food security. Basic needs and overall well-being are achieved through a livelihood, a set of capacities, assets, activities, as a means for survival (Chamber & Conway 1992). This framework is commonly presented as a human actor that exploits, links and transforms various capitals (human, natural, financial, social, & physical) into the materials required to meet basic human needs (De Haan 2012). Indigenised conceptions of well-being (e.g., Dennis and Robin 2020) provide strong potential application and future directions for the research presented here.

Indigenous food systems include the harvest of locally available, non-domesticated wildlife by Indigenous Peoples for their own consumption and for food sharing with family and community. Also referred to as traditional food, country food, or wild food, the rights of Indigenous Peoples to hunt for food was enshrined in Canada's first historical treaties and is a key consideration in modern comprehensive land claims. Local food represents an important source of energy, protein, and micronutrients to Indigenous communities across northern North America and consumption of local food has been associated with lower rates of obesity, diabetes, cardiovascular disease, and food insecurity (Ford & Berrang-Ford 2009; Egeland et al 2011; Kenny et al 2018a). Indigenous food systems also embody the knowledge, relationships, and reciprocities that connect people to nature and create the possibility of "being alive well" (Adelson 2000). Accordingly, Indigenous food systems are inextricably linked with identity and the cultural and spiritual well-being of Indigenous peoples, representing both a cultural strength and a source of identity (Maurice, Philip & Bersamin 2017). Language and food are closely related components of Indigenous cultures and the richness of Indigenous languages, particular with respect to words describing land and water, seasons and weather, plants and animals, as well as harvest and food, across a multitude of Indigenous dialects, languages, and language families speaks to the collective richness and diversity of local food and culture (McIvor, Napoleon & Dickie 2009). Indigenous Peoples continue to depend on the harvest and consumption of wild plants and animals as critical sources of nutrition, tradition, identity, culture, and relationship to land, which individually and collectively relate to Indigenous conceptions of health.

Indigenous food systems forge a direct coupling between ecosystem productivity and community health, transforming wildlife into available nutrition (Kuhnlein & Soueida, 1992; Kuhnlein & Receveur 1996; Wenzel, Dolan, & Brown 2016; Kenny et al., 2018a; Kenny et al., 2018b). Because of this linkage, Indigenous foods can be threatened by land use change and loss of land sovereignty (Lemke & Delormier 2017), which has given rise to numerous historic and contemporary agreements and many past and contemporary conflicts organized around the integrity of Indigenous food systems.

In an introduction to a thesis focused on Indigenous food systems, I explicitly acknowledge that the challenges faced by Indigenous communities, including but not limited to food insecurity, are not coincidental. Rather they stem from deliberate genocidal processes foundational to the British Empire, and its successor, the Canadian state (Brunet, Hay & Chambers 2016). Within his definition of genocide, Lemkin (1944) lists "racial discrimination in feeding" as one of the physical techniques of genocide. Conley and de Waal (2019) describe the purposes of starvation thusly (emphasis mine): *(i) extermination or **genocide**; (ii) control through weakening a population; (iii) **gaining territorial control**; (iv) flushing out a population; (v) punishment; (vi) **material extraction** or theft; (vii) extreme exploitation; (viii) war provisioning; and (ix) **comprehensive societal transformation**.* Mosby & Galloway (2017) have used testimony from the Canada Truth and Reconciliation Commission to estimate diets fed to children at the Mohawk Institute (in operation from 1831 to 1970) in Brantford, Ontario constituted only 1,260 kilocalories per day, a starvation diet (see Mosby 2013 for a comprehensive overview of human nutritional experimentation in residential schools during the 1940s and 1950s). Even if the amount of food provided had been adequate, the type of food provided was purposefully culturally inadequate. Destruction of traditional food systems and monopolised control of food markets (Hudson's Bay trading posts particularly) have made food a tool of control for the state within state coercion of Indigenous communities (Brunet, Hay & Chambers 2016). State led or approved alteration of Indigenous territories (land use change) are also a powerful mechanism by which the state can negatively impact food systems and food security, gaining an unequal position of power in negotiation (Grey & Newman 2018). Forced settlement through violence of unsettled or semi-nomadic peoples by the state can be fundamentally incompatible with sustainable harvests of local wildlife, further eroding identity and food security (Stephenson &Wenzel 2017; Snook et al. 2020). The roots of the food security crisis are a colonial genocide (Woolford & Benvenuto 2015; Greer 2019) perpetrated in part by the Canadian government (Truth and Reconciliation Commission of Canada, 2015). While the institutions have changed, many of these patterns continue into the modern relationship between the Canadian State and Indigenous peoples (Caine & Krogman 2010; Preston 2017). This thesis seeks to fill knowledge gaps in a manner that elevates understanding of Indigenous food systems, hopefully towards reduced marginalisation of Indigenous livelihoods and food systems. However, a broad overview of the legal rights of Indigenous peoples and their treaties with the Canadian crown can help to contextualise this research as not only a human rights issue, but a legal one as well.

Recognition of the Rights of Indigenous Peoples

Prior to the 1970s, Indigenous livelihoods in Canada did not garner the same consideration that they do today. The text that follows provides examples of how legal considerations around Indigenous livelihoods have progressed in recent history and build towards a “rights-based framework” of food security.

In 1973, Calder and the Nisga’a Nation argued that title exists prior to state recognition, challenging British Columbia’s *Terra Nullius* assertions (Asch 2002) against pre-contact Indigenous title (Calder v British Columbia (AG) [1973] SCR 313). The court ruled in favour of the Nisga’a Nation and brought Indigenous title into Canadian case law with the recognition that Indigenous Peoples held title to land on which they could practice their livelihoods, including harvesting wildlife for food.

In 1973, the Quebec Association of Indians sued the Government of Quebec seeking to block hydroelectric development envisioned for northern Quebec, beginning a series of legal battles that led to the creation of the *James Bay and Northern Quebec Agreement* (JBNQA, 1975), signed by the Cree of Eeyou Istchee and the Inuit of Nunavik and which has been interpreted to be Canada's first modern land claims agreement (Scott 2020). In 1978, the agreement was amended with the *Northeastern Quebec Agreement*, covering Naskapi territory. The primary concerns of the JBNQA are fourfold: defining the extent of Indigenous territory, the forms of control communities may exert over their territory, ensuring local communities benefit from development in their territory, and the dispute resolution mechanism that may be employed arising from further conflicted development. Section 24 of the JBNQA covers wildlife management and hunting in the Cree and Inuit territory in Northern Quebec, particularly the establishment of guaranteed levels of harvest, intended to ensure access to traditional foods is maintained over time, which is a major point of focus in chapter 4. The inclusion of guaranteed levels of harvest and financial support to harvesters within the JBNQA marked a progression in state recognition of harvest rights and guarantees.

In 1977, the Mackenzie Valley Pipeline Inquiry (also referred to as the Berger Inquiry after Justice Thomas Berger, British Columbia supreme court justice and commissioner of the inquiry) was tasked with estimating the potential impacts (social, economic and environmental) of the proposed natural gas pipeline to run from the Arctic Ocean into Northern Alberta, across the territories of multiple Indigenous groups. The inquiry culminated in a recommendation that the pipeline should not be built or, if it was to be built, that construction should not begin before Indigenous land claims had been settled in the project area. In his letter to the Minister of Indian Affairs and Northern Development, Thomas Berger introduced the Mackenzie Valley Pipeline Inquiry saying, "We are now at our last frontier." The finality of this statement obscures the efforts involved in traversing this "frontier".

The events and outcomes associated with the Calder and the Nisga'a Nation decision, the JBNQA, and the Berger Inquiry, combined with many other rulings and cases involving Indigenous Peoples across Canada, contributed to development of a Comprehensive Land Claims Policy by the Government of

Canada, which aimed "*to provide certainty and clarity of rights to ownership and use of land and resources in those areas of Canada where aboriginal title has not been dealt with by treaty or superseded by law (Indian and Northern Affairs Canada, 1987).*" These events and this period represented a new paradigm of natural resource exploitation in Canada regarding consultation with Indigenous communities. It is arguable that the conclusions reached by the Mackenzie Valley Pipeline Inquiry were influenced by the 1973 Calder case, a claim reinforced by the fact that Thomas Berger, commissioner of the Mackenzie Valley Pipeline Inquiry, served as a lawyer for Calder and the Nisga'a Nation before the supreme court. Together with the JBNQA, these events shaped much of what was to come in relation to modern land claims in Canada. However, there have been other important events, including the Nunavut Land Claims Agreement signed in 1993. In addition to creating a new territory, the Nunavut agreement granted Inuit title to large portions of the new territory and mineral rights to smaller portions, while also guaranteeing harvesting rights and benefit sharing from natural resource development. Nunavut harvesting rights included co-management of wildlife and a guaranteed level of harvest into the future. This guaranteed level of harvest was estimated using the results of the Nunavut Wildlife Harvest Study (Priest & Usher, 2004), which will be a major focus of Chapter 3.

These case studies from across Canada help to illustrate the ongoing process of Indigenous communities gaining back agency from the Canadian state. This does not mean that the relationship between Indigenous communities and Canada is ideal in anyway, just that the last 50 years have marked a shift towards more respectful nation-to-nation relationships, and this is an ongoing process that requires significant effort from all actors. The Canadian Truth and Reconciliation Commission final report (2015) represents another important step in advancing these nation-to-nation relationships.

Wildlife management

While Eurocentric practices of wildlife management in North America have advanced beyond game keeping for a local lord (Haraway, 1984), many conservation practices continue to dispossess Indigenous people of their territory under the guise of "conservation" (Mulrennan and Scott, 2002; Murray and King, 2012), under a presumption that white men know best (Krech 1999; Feit 2007; Snook et al. 2020). Instead of privatisation or state level management, contemporary literature about managing common pool resources suggests that in circumstances where robust social structures exist surrounding natural resources, and these social structures can partially mediate access to these resources, then it is possible for these resources to be collectively managed (Ostrom 1987; Roach et al, 2006; Ostrom 2009, also see Ostrom's eight principles). Such systems are common in Indigenous communities across Canada. Historical models of wildlife management may vary somewhat between themselves, with varying degrees of emphasis on preservationism, conservationism, or a land ethic (sometimes called the "North American Model" or NAM), but are often flawed in their dealing with Indigenous worldviews and land rights. An Indigenised model of wildlife management, or I-NAM, seeks to adapt the historical North American model to better address these shortcomings. I-NAM emphasises plurality and multiple stakeholders, reciprocal relationships between people and nature, and Indigenous representation in wildlife management (Hessami et al. 2021). In Eeyou Istchee (Eastern James Bay) a complex system of traplines and *uchimaau* (hunting bosses) form their traditional land tenure system, through which access to territory and total harvesting efforts can be managed (Scott 2008). Other regions of Canada show archaeological evidence of landscape modification to increase productivity of key food species (Jackley et al, 2016). These and other examples show clear evidence of wildlife management regimes employed by Indigenous communities prior to contact and local development.

Modern land claims agreements have helped to promote co-management arrangements for wildlife populations, to serve community food security needs while also allowing for sport hunting. The co-management of wildlife creates a "double administration", sharing the responsibility and authority of management between Indigenous communities and state (provincial/ territorial/ federal) governments (Spak 2005). The three regions included in the chapters of this thesis - Nunavut, Nunavik and Eeyou Istchee - are all covered one or more co-management agreements, including the creation and commissioning wildlife management boards intended to execute a co-managerial regime. Section 24 of the James Bay and Northern

Quebec Agreement (JBNQA), Article 5.6 of the Nunavut Land Claims Agreement, and Articles 5 and 14 of the Nunavik Land Claim Agreement all establish guaranteed harvest levels, a management regime designed to allow for the possibility of wildlife harvest by Indigenous as well as non-Indigenous harvesters while ensuring priority to Indigenous subsistence harvest (Feit 1980). Wildlife management regimes prioritising Indigenous subsistence harvest need to simultaneously support wildlife conservation and the food security and food sovereignty of Indigenous Peoples. Achieving these goals could be achieved through collaborative monitoring and adaptive management of wildlife populations, recreational and subsistence harvest, and local food use. But this potential for collaborative monitoring and management must be reconciled with colonial legacies and presumptions, Indigenous harvest rights, the self-determination of Indigenous peoples, and often conflicting priorities for lands, waters, and wildlife.

Food Security and Food Sovereignty

Since 1996, the Food and Agriculture Organisation of the United Nations (FAO) has defined food security under a hierarchical, four-pillar framework, stating that food security exists in a situation "*where all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life*", or when food is available, accessible, useable (or adequate), and stable (FAO 2022**)**. Available food, or food availability, is the first step towards food security and refers to the physical presence of food in an area. In an ideal scenario, is there food available for someone to utilise? Accessible food, or food accessibility, is the second step towards food security and generally refers to the absence of barriers between a person and food that is otherwise available. Examples of barriers could be the lack of financial resources to purchase food in a market or the imposition of a protected area or harvest moratorium that impinges on subsistence harvest of wildlife that is otherwise present and available. Useable food, or food utilisation (sometimes referred to as "adequacy") is the third step towards food security and refers to the quality of food being accessed. Food utilisation and adequacy includes considerations and combinations of food taste, nutrition, safety, and cultural appropriateness. Food safety and sanitation plays a major role in utilisation. Stable food, or food stability is the fourth and final step towards food security in the FAO framework and considers change over time, including the future of people's food situation, and whether food is available at all times. Food security questionnaires have begun to incorporate this final stability pillar, which relates to precarity in food systems, with questions such as "*how confident are you that you [and your family] will have sufficient food to eat tomorrow?"* (Clapp et al. 2022**)**.

Across the globe and for a plethora of reasons, Indigenous communities are experiencing a "nutritional transition" where traditional dietary foods (often hunted and gathered) are being replaced by store-bought foods, including increased use of processed foods with a long shelf life (Kuhnlein and Receveur 1996; Popkin 1998; Kuhnlein et al. 2004; Dammon, Eide & Kuhnlein 2008). This change has been attributed to factors including colonial processes, poverty and socio-economic factors, changing food preferences and knowledge, and climate change (Little et al. 2020). The "nutritional transition" also features an age cohort structure, with Elders consuming the most traditional food and youth the least (Delormier and Kuhnlein 1999).

Indigenous food security can be described using the FAO framework, but nuances must be understood (Harder & Wenzel 2012; CCA, 2014; Ready 2016; Wesche et al 2016; Lysenko & Schott 2019**)**. The extent to which economy, environment, and culture co-determine food security is reflected in how the Nunavut Food Security Coalition (2014:2) describes the four components of food security in Nunavut: "*availability (enough wildlife on the land or groceries in the store), accessibility (adequate money for hunting equipment or store-bought food, and the ability to obtain it), quality (healthy food that is culturally valued), and use (knowledge about how to obtain, store, prepare, and consume food)."* Food availability and accessibility for Indigenous Peoples includes their ability to travel from a settlement to harvest locations and/ or, which requires vehicles, fuel, logistics, and know-how. In a local food system context, the distinctions between availability, accessibility, and utilization are complicated. For example, consider a flock of geese flying over the heads of a hunting party. When does a goose go from available to accessible? Do all geese in range of a shotgun become accessible? What about birds flying out of the sun? What about birds that were downed but could not, despite best efforts, be retrieved? What if the hunting party does not have effective firearms and ammunition? What if they do, but lack the experience to know how and when to use this equipment effectively? What if the hunting party was not present where the geese were flying, but were instead back in town participating in the wage economy? Whether those geese were unavailable, inaccessible, or unused, the point is the geese are still flying and the goose pot is empty. Barriers to harvest are of major concern for communities. Changing patterns of land, water, and ice safety may be considered as contributors to local food inaccessibility. Utilisation in Indigenous community may also incorporate traditions around food sharing, particularly sharing with Elders. Concerns about contaminant exposure and changing taste and condition of harvested species also affect food utilisation (AMAP 2014; Golzadeh et al 2020**)**. Concerns about the safety of harvested foods can led to a decline in consumption of these foods and negative health consequences because of this declining consumption (Kuhnlein and Chan 2000). The high cost of kitchen sanitation products in Northern Canada, like soap and bleach, can also affect food safety and utilisation in communities.

Indigenous food systems are unique, but not static. Indigenous food systems adapt to shifting environments, both physical and cultural. Understanding the state and change of the food systems of the more than 600 Indigenous communities in Canada could be improved by more effective and ethical monitoring of these systems, including routine observations, analysis, communication, and decision making that respects the self-determination of Indigenous Peoples (Thompson et al. 2019). Effective and ethical monitoring requires respectful dialogue between traditional ecological knowledge (TEK) and western science, which often relies on the ability to catalogue more than just simple quantities and variables, including complex contexts and interrelations (Nadasdy 1999; Nadasdy 2005; Pulsifer et al. 2012). Indigenous food systems do not represent a random and unbiased sample of the local ecology; they represent how underlying social relations and structures configure food choices, for individuals and for households, from within a local ecological context (Delormier, Frohlich, & Potvin 2009). Prior study has quantified the cultural contribution to use of wildlife species, finding significantly more similarity between Indigenous communities sharing linguistic similarity (a proxy for cultural relatedness) than ecoregion similarity or spatial proximity (Tremblay, Landry-Cuerrier, and Humphries 2020). Distinct food system survey approaches, including harvest surveys and food use surveys, have been shown to converge to similar values, suggesting a potential compatibility of multiple datasets from multiple collection methodologies (Kenny and Chan 2017). Challenges remain overcoming power imbalances between Indigenous communities and state wildlife management, specifically management regimes that disempower Indigenous knowledge, monitoring, and priorities (Thompson, Lantz, and Ban 2020). Indigenous monitoring comes in many forms but is often embedded within land-based harvesting and stewardship, such that understandings, observations, interpretations, and actions are combined as ways of knowing and being. (Thompson et al. 2020). When land-based and harvest-based observations are shared beyond family and community members, questions of knowledge ownership, control, access, and possession (OCAP) become critical considerations (Schnarch 2004).

Household studies have correlated the consumption of traditional foods to improved food security (Ford and Berrang-Ford 2009), while regional studies have documented the contributions of traditional foods to satisfying nutritional requirements, including proteins (Feit 1980) and essential micronutrients (Kenny et al. 2018a; Kenny et al 2018b). One analysis from Eeyou Istchee focused on Canada Geese and found they contributed up to a quarter of all harvested protein consumed by community members (Scott 1988). Because of these contributions to community health and well-being, wildlife conservation and management decisions, especially decisions that could see harvests decrease, must be sensitive to community food insecurity (Kenny et al 2018c).

In 2021, the FAO estimated 29% of the global population experienced some form of moderate to severe food insecurity, with the North American average at 8.3% of the population (FAO et al. 2022). However, Indigenous Canadians experience much higher rates of food insecurity , measured at 31% in 2021 (Tarasuk et al. 2022), than North American averages. Within certain regions and Indigenous cultures, the rate of food insecurity can be even higher. Data from Inuit Nunangat measured rates of moderate and severe food insecurity to be 63% of households between 2007 and 2008 (Council of Canadian Academies 2014), with rates of marginal, moderate and severe food insecurity reported at 76% from 2017 data (ITK 2021). The 2017 data also reports that over 30% of Inuit living outside of Inuit Nunangat experience food insecurity (ITK 2021).

Food sovereignty generally refers to a situation where a population has the agency to address their food security needs in an internally acceptable manner (Demarais & Wittman 2014). Food sovereignty is both a concept and an international movement focused on the reconceptualization of food and food system away from commodified, globalised, and neoliberalised food systems, towards more locally focused and derived solutions that value the livelihoods of local food producers, including hunters, fishers, and trappers (Rudolph & McLachlan 2013). Indigenous food sovereignty can be described as a decolonial movement focused around self-determination, traditional knowledges, Indigenous foodways, land rights, and harvest rights (Coté 2016; Stavenhagen 2006). Indigenous food sovereignty and self-determination has been interpreted as a threat to national unity, prosperity, and sovereignty, and at odds with federal government policy (Grey & Patel 2015). The synthesis of these visions and the histories of government food planning in northern Canada place federal policy and local food security in direct opposition (Stephenson 2020). Grassroots movements, such as food sovereignty, have the capacity to shape global policy and local decision-making through best practices and common goals (Johnston and Spring 2021). Under Sections 5 and 7 of the James Bay and Northern Quebec Agreement (JBNQA) three land categories were created to ensure continued access to traditional territory and harvest for Cree and Inuit (JBNQA, 1975). Category 1 and 2 lands contain explicit provisions for excusive Indigenous rights to harvest in these territories, although the tenure of category 1 and 2 lands differs. Territory and harvest are legally stipulated in a different manner in the Nunavut Land Claims Agreement. Article 5.7.16 of the land claim lays out the rights of all Inuit to harvest from all lands within the territory, with a narrow set of exclusions, primary disallowing hunting on Canadian Forces bases and within townsites (Nunavut Land Claims Agreement 1993). Article 5.6.40 further outlines how surplus allowable harvest may be allocated to recreational hunters through a standard licencing system. This management paradigm gives Inuit first right to harvested species across the territory, with non-Indigenous harvests allowed to take identified surpluses (Nunavut Land Claims Agreement 1993). As such, comprehensive agreements across these three territories seek to support food sovereignty through control over wildlife harvest and lands (Grey & Patel 2015). Locally initiated programming is more likely to capture the nuances of the challenges facing Indigenous food systems and local circumstance. Identity and demographics can be important parts of a community member's experience with food and environment (Bunce et al. 2016). These capacities will be crucial as communities encounter the growing impacts of climate change of their food systems and their territories.

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Northern food policy and food security programs have historically prioritized settler food systems over Indigenous livelihoods, subsistence economies, and local food sources (Brunet, Hay & Chambers 2016; Stephenson 2020). These programs are the direct result of colonial policies and continue to exist as a lever of power over Indigenous communities (Brunet, Hay & Chambers 2016; Grey & Newman 2018). These food policies intermingle with the legacies of past colonial policies, including the 1953 High Arctic relocation that moved families from their homes and communities in Nunavik and forcibly relocated further north, to Resolute Bay and Grise Fiord in Nunavut. The 1970's "Nutrition Canada Survey" explicitly relegates Indigenous food systems to second class status, "*Indigenous foods were treated as limited and supplementary, rather than as normative, legitimate dietary choices with adequate nutritional composition*." (Walters 2012). While some literature within the international development field warns that wild or traditional food systems may form a poverty trap and not a safety net for food security (Paumgarten, Locatelli & Witkowski 2018), these findings ignore systemic issues involving race and colonial histories. Interpreting a reliance on wild or traditional food systems as a form of vulnerability is often rooted in ignorance of local culture, economies, and capabilities (Haalboom & Natcher 2012). This vulnerability framework can actively imperil communities through misguided policy (Haalboom & Natcher 2012), simplifying complex relationships and interactions (Naylor et al. 2020) and dismissing contributions to local food security made by a biodiverse local environment (Powell et al. 2015). Adaptations, like wild food markets, may also be inappropriate in northern Canada (Ford et al. 2016). These normative prescriptions for trajectories of development can be described as a form of "coloniality" (Escobar 2011). In Escobar's (2011) own words, "massive poverty in the modern sense appeared only when the spread of the market economy broke down community ties and deprived millions of people from access to land, water and other resources". Wild food systems bare no guilt for "systemic pauperization" under capitalist regimes. From the 1960's to 2012 the Northern Air Stage Program, or Food Mail, was a federal policy designed to subsidise the transport of goods into the North, first administered by Canada Post and then Indian and Northern Affairs Canada (INAC). However, the goods subsidised were not based on the local food harvested by Indigenous communities, but rather the purchasing habits of low-income settler Canadians; INAC's own conclusions were that the basket of food subsidised did not constitute an ideal diet, merely sufficient (Brunet, Hay & Chambers 2016). In 2011, federal cost saving interests led to the implementation of Nutrition North Canada (NNC), the successor program to Food Mail. As opposed to a transportation subsidy, NNC operates as a subsidy to retailers which is expected to be passed onto consumers. However, many communities are subject to a near monopoly by the Northern Store (the North West Company), failing to achieve the "competitive market" and cost savings to consumers envisioned when NNC was first proposed. Critics have highlighted the framework and structure of NNC as systemically flawed, leading to the failure to provide quality, nutritious food to the north in an affordable manner (Galloway 2017); statistics show that food security has fallen in the area serviced by NNC since the program's inception, outline its ineffectiveness (St-Germain, Galloway & Tarasuk 2019). NNC has recently introduced a new program that directly supports community harvesters with financial support intended to lower economic barriers to local wildlife harvest by communities (GC 2022).

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The words "food security" or "food sovereignty" do not appear in any of the 94 calls to action recommended by the Truth and Reconciliation Commission (TRC) of Canada; the word "food" itself is absent, as is "harvest" and "wildlife". This is but one illustration of the challenges faced by food security proponents and researchers, who focus on an entity positioned at the nexus of wildlife, community health, and local livelihoods. Law and legal scholarship may be an added requisite for those entangling treaty rights and minimum or guaranteed harvest levels into their study of Indigenous food security and harvesting traditions. In transcending these boundaries, food security connects people and the environment in support of household and community well-being. How does variability in a wildlife population affect the nutrition of local communities? How do international decisions regulating the trade and sale of wildlife affect the ability of household to purchase harvesting equipment? How does a change in sea ice affect the species that communities can safely harvest? These are all interdisciplinary and transdisciplinary questions required to advance understanding of Indigenous food security. How Indigenous food systems and food security are conceptualised and valued by wildlife biologists, natural resource policy makers, and public health professionals is also of vital importance, as policy decisions often place an estimated value on Indigenous food systems, either implicitly or explicitly, without a robust methodology for this valuation.

Climate Change

Climate change has contributed to the disruption of Indigenous food systems with important health and cultural ramifications (Furgal & Seguin 2006; Turner & Reid 2022; Charlie et al. 2022). Indigenous food systems and food security in northern Canada will face additional pressures in the coming decades, primarily from global climate change and its effects on seasonality, phenology and access. Climate justice is an emerging field focused around the injustices of communities that have made very minor contributions to global greenhouse admissions feeling some of the most damaging effects of climate change, such as northern Indigenous communities in Canada, where the concept of “the right to be cold” is being popularised and used in legal argumentation (Jodoin, Snow & Corobow 2020). Other anthropogenic impacts, including natural resource development projects and pollution, will also have ramifications (AMAP 2015). Climate change requires Indigenous food system adaptation (Ford et al. 2014). As noted by Wenzel (2009) and others, Indigenous food systems are not purely nutritional. These systems have a significant social component, focused around food sharing. Embedded within the Inuit food system are ideas and normative practices whose goal is collective social and material well-being (Sahlins 1972; Wenzel 2016). This traditional system of food sharing may be forced to adapt as the underlying food system itself changes, including as a result of altered harvest opportunities prompted by environmental change. Adaptation measures are beginning to emerge, including community freezer program to facilitate the sharing of traditional foods (Organ et al. 2014). These solutions lend themselves to a further discussion of emerging economic organisations in Indigenous communities to address food security issues. These are not to replace traditional food sharing arrangements, but an addition to them. Social media has become one such non-traditional market forum, with Facebook being used by Northern communities to buy and sell whole caribou (The Canadian Press 2016, O'Donnell et al. 2016). Nutrition North already facilitates the sale of traditional foods from both Cambridge Bay, NU and Rankin Inlet, NU base distributors. Alternatively, this grey market for caribou could imply that the Nutrition North administrated caribou sales are too expensive to be affordable, causing the alternative market to organise. The opening of three Nunavut based retailers in the summer of 2017 (Iqaluit Eats, IqaluEAT, and Arctic Fresh) suggests further dissatisfaction with the current retailers (Frizzell 2017). These case studies, as well as the existing literature (Wenzel 2009; Harder & Wenzel 2012; Ford et al. 2016; Searles 2016) on Indigenous mixed-economies present a picture of a highly dynamic system responding to changes and challenges.

As higher latitudes experience climate change at faster rates than other places on the globe, northern Indigenous communities, particularly Inuit communities, will experience some of the most severe consequences of climate change. Ice cover is an important component for safe travel and harvesting and changing ice patterns and confidence in ice conditions is already affecting northern harvesters and food systems (Ford et al. 2019). While modelling climate effects on the abundance and distribution of key wildlife species is valuable, documenting or predicting the collective and cumulative impacts of environmental change on the entirety of the Indigenous food system is more challenging, and requires strong metrics and baselines to document change (Donatuto, Campbell & Trousdale 2020). Strong frameworks exist for understanding these potential impacts, including livelihood-focused approaches that consider how climate change will affect certain capitals available to communities (Spring, Carter & Blay-Palmer 2018). Effective understanding of food system impacts and adaptations need to avoid marginalizing

Indigenous perspectives, voices, and priorities (Nadasdy 1999, 2005; Ford et al. 2016). Northern Indigenous communities are active agents, building capacity and adapting to climate change through the combination of traditional knowledge, scientific practice, and community monitoring (Pearce et al. 2015; Galappaththi et al. 2019; Naylor et al. 2020).

The Value of Food

The creation and perception of value is in itself a transdisciplinary study, linking economic, political, and anthropological, and sociological thinking. Graeber (2001) defines three broad definitions of value: sociological value (morals or virtues), economic value (the desirability of objects, defined in an exchange for labour), and semiotic value (how meaning is ascribed though linguistic context); this thesis will focus primarily on economic value, though will not be limited entirely to financial value. Similarly, Escobar (1999) elaborates upon a pluralistic trinity of political ecology, describing capitalist nature (that which creates natural resources), organic nature (that which helps to create a sense of “place”), and technonature (that which generates knowledge that transcends a social-nature divide, e.g., biotechnology), and their ability to hybridize into multifaceted value-framework for nature(s). The plurality of views of value and nature give rise to a complex system for value natural resources, one where nature not only has value as a commodity but also has value as a system helps humans define themselves.

Because of power asymmetries, which reproduce existing inequalities in the access to natural resources, the commodification of ecosystem services gives rise to serious technical difficulties and ethical implications as it can deny the plurality of values attributed to these resources by narrowing down the complexity of ecosystems to a single service and assigning a single exchange value (Kosoy and Corbera 2010). However, where these power asymmetries have already commodified certain ecosystem services, as state policy does when it ascribes a financial value to a food system or harvest (or an alternative activity that impinges on these), it becomes important to validate the valuation framework used.

Feit (1980), in preparation for the harvest estimates from the JBNQA, estimated Cree harvesting in Northern Quebec to be valued at \$4.5-\$5 million a year (~\$14.6 million in 2016 dollars) from ~ 1,000,000 kg harvested, or ~\$16.09/ kg. The earliest record of traditional foods being given a substitution value in dollars in the Canadian north comes from a government report by Peter Usher (1971, two volumes), valuing traditional foods on Banks Island (Inuvialuktun: Ikahuak) at \$0.50 per pound, or approximately \$3.12 per kilogram in 2016 dollars. This value itself is taken from a report on the Mackenzie Reindeer Project (\$0.40 per pound wholesale in Hill 1967, page 30). This value was used as the basis for Gemini North's reports to the Mackenzie Valley Pipeline Inquiry and is discussed at length in final report (Cultural Impact – The Native Economy, Berger 1977). The report concludes that the use of an in-community exchange value is inappropriate to measure the value of Indigenous harvesting, especially in a context where that harvest is threatened (it does not comment on this value being derived from farmed reindeer). If ecosystem productivity is lost and harvest declines, community members still have to eat. Because of this reality, it is best to use a framework based on "replacement value". This expands on ideas first proposed by DeLury et al.'s (1975:238) recognition that food is a fundamental need that must be replaced and cannot be exchanged: *"[Exchange] values may have some relevance to a commercial fishery but not to a subsistence fishery. If fish keep an individual from starvation or even hunger then the fish assume a unit of value not found in any monetary system. To obtain a meaningful value for the fish, the costs of substitutes might be applied*." This is also a way to explicitly acknowledge that many contemporary Indigenous food systems are21uncandised, they rely on both harvested and store-bought foods to meet their nutritional needs (ITK 2021). While this hybridised food system can provide resiliency to communities, it also forces community members to divide their resources between harvesting and affording food in a store.

The burden on household decision makers in Northern Canada to provide enough food for the household is increased by several factors: financial poverty, a high cost of living (especially store-bought food), and barriers to accessing traditional foods. Nunavut has the third lowest median regional income in Canada, at less than \$25,000 per year, and the cost of living is 30% above the Canadian average (ITK 2017).

The high cost of living is not a new problem either, nearly 30 years ago researchers commented that at contemporary food prices and levels of government assistance, a family of four could not afford to buy all the food they need (Hill, Lawn & Robbins 1994). Despite the transition of food subsidy programming from Food Mail to Nutrition North Canada (NNC), food costs in stores remain high (Duhaime & Édouard, 2015; Galloway, 2017; Kenny et al. 2018c; St-Germain et al., 2019). Globally, food affordability is a recognized barrier to food security, with severe food poverty defined as food costs that exceed 80% of income (Lee et al., 2013). Given financial barriers to accessing store-bought foods in the North, a logical question arises, "what does it cost to access the traditional food system?". Although few studies have directly examined the capital costs associated with a successful harvest (see Pal, Haman & Ribidoux, 2013 for an example from further south) multiple studies and community voices repeat that country food consumption is being negatively impacted by the high costs of harvesting equipment and fuel (Wenzel, 2000; Lambden et al., 2007; Naylor et al. 2021). Although hunter assistance programs, where some of these costs can be covered for an individual hunter, are prioritized in many northern regions, historic food security investment has focused on subsidy programs intended to reduce the cost of store-bought food (Galloway, 2017; St-Germain et al., 2019), as opposed to reducing financial barriers to accessing the traditional food system.

Indigenous food systems have value to communities beyond food security, they represent a fundamental component of cultural identity. Traditional hunting and culinary practices serve to reinforce cultural identity (King & Furgal 2014**)**. Therefore, a loss of local food means not only hunger, but the loss of cultural knowledge; not just any cultural knowledge, but the knowledge vital to feeding that society (Pollan 2016). Protecting these systems can require a compromise of ideas, best described by Scott (2001), "*Political survival demands a dual, seemingly contradictory, strategy. On the one hand, First Nations are impelled to enlighten and persuade outsiders about the character and meaning, in Aboriginal cultural terms, of their relationship to homelands and waters. On the other hand, in order to create legal and constitutional space for the defence and autonomous development of their territories, they are forced to negotiate Aboriginal cultural and political landscapes in relation to Euro-Canadian concepts of property* *and jurisdiction*.". Although the value of Indigenous food systems is much greater than just its nutritional use value (nutrients gained by consuming the food), there are circumstances where Indigenous communities are compelled to frame these food systems in ways that are more directly understood by the Canadian state or resource development proponents. Again, market-based studies of harvested wildlife evaluate only part of the amount extracted and often ignore the larger subsistence value (Golden et al 2013).

Through the integration of wildlife management, community food security, and economic valuation, this thesis hopes to illuminate a tiny sliver of the transdisciplinary entity that is Indigenous food security. Chapter 2 combines harvest data reported in support of the James Bay and Northern Quebec Agreement (JBNQA) and food recall information from independent health surveys in the Cree region of Eeyou Istchee and the Inuit region of Nunavik to characterize the social-ecological and biocultural foundations of Indigenous food systems across two regions and two time periods. Because food is a fundamental need that must be replaced and cannot be exchanged, in Chapter 3, I adopt a replacement value approach, estimating what it would cost to purchase enough store-bought food to replace the protein and energy offered by reported country food harvest in Nunavut. Chapter 4 applies approaches developed in the previous two chapters to harvest and food recall data from Eeyou Istchee and Nunavik to assess the numeric, value, and nutritional gaps between guaranteed levels of harvest established in the 1970's and reported food use in the 2000's. Together these chapters suggest that Indigenous food systems are vital cultural and food security touchstones that are chronically underappreciated and changing faster than guarantees and interventions can be realized. As these systems are further threatened by climate and land use change, developing effective monitoring, adaptation, and intervention strategies will be essential to northern Indigenous food security.

Chapter 2 linkage

As outlined above in the literature review, describing the nature and change over time of Indigenous food systems is challenged by incomplete and differing survey methods combined with the diversity of wildlife species used as local food. Chapter 2 combines Indigenous food systems survey data from two contiguous regions in northern Quebec, the Cree region of Eeyou Istchee and the Inuit region of Nunavik, and two data collection methods, harvest surveys from the 1970's and dietary recall surveys from the early 2000's. This chapter contributes an analytical approach that is able to accommodate the diversity of species and survey approaches common to Indigenous food systems, while highlighting the continued importance of a wide diversity of locally available wild fish, birds, and mammals in the food systems of Eeyou Istchee and Nunavik and emphasizing the persistence of social-ecological differences in local Indigenous food systems over time.

Chapter 2: Using constrained ordination to characterize place-based differences and change over time in local food harvested and consumed by Cree and Inuit communities in Northern Quebec, Canada

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Abstract

Indigenous food systems are socio-ecological systems that arise from cultures relying on local wildlife to meet their dietary needs. Indigenous food systems are likely to differ from place to place and to change over time as a result of cultural differences and environmental change. But describing and tracking this social-ecological variation requires tools able to accommodate the diversity of species and uses included in our understanding of Indigenous food systems. Here we combine Indigenous food systems survey data from two contiguous regions of northern Quebec, the Cree region of Eeyou Istchee and the Inuit region of Nunavik, and two data collection methods, harvest surveys from the 1970's and dietary recall surveys from the early 2000's. Multivariate redundancy analysis of local food use in relation to region and survey reveals distinct regional use patterns that have persisted over two surveys spanning a 30 year period of accelerating socio-ecological change. Our analysis highlights the continued importance of a wide diversity of locally available wild fish, birds, and mammals in the food systems of Eeyou Istchee and Nunavik and emphasizes the persistence of social-ecological differences in local Indigenous food systems over time.

Introduction

Local Indigenous food systems, also referred to as traditional or country food systems, are socio-ecological systems situated at the intersection of community and cultural practice (Lemire et al. 2015), the abundance and distribution of wild plants and animals (Kenny et al. 2018), and subsistence economies and livelihoods (Wenzel 2000; Hickey at al. 2016). Describing the nature, status, and importance of local food systems is challenged by their diversity and intersectionality. Natural scientists tend to focus on ecological research and harvest estimates of species used as food. Public health professionals and researchers tend to focus on community nutrition and food use documented through dietary and health surveys. Social scientists most often focus on local practice, knowledge, traditions, and economies explored through qualitative methods. The importance of culture and ecology in shaping local food systems has been described through case studies (Liu et al. 2007; Kuhnlein et al. 2009; Burlingame & Dernini 2012). Food and eating are recognized explicitly as cultural practice (Delormier et al. 2009) and global and regional analyses have quantified the economic contribution of wild food harvests to rural livelihoods (Hickey et al. 2016; Warltier et al. 2021). Substantial change over time in the use of local foods have been documented in many regions (Kuhnlein & Receveur 1996, Delormier & Kuhnlein 1999, Damman et al. 2008, Johnson-Down & Egeland 2012, Chee et al. 2019, Fernandez 2020), often in the form of a nutritional transition from reliance primarily on locally harvested food towards greater reliance on store-bought food (Receveur, Boulay & Kuhnlein 1997, Kuhnlein et al. 2004, Little et al. 2020).

Wildlife harvest and dietary recall surveys represent two important sources of information that can be used to describe local food systems, including how they change over time and differ from place to place. Wildlife harvest surveys generate counts, or estimates, of the number of animals by category taken by a specific group of harvesters during a specific time period (Usher & Wenzel 1987). In a subsistence harvest context, harvest surveys are often used to establish baseline harvest levels that inform comprehensive land claims or compensation benefit agreements (Feit 1980; Usher & Wenzel, 1987; Wenzel, Dolan & Brown, 2016). Thus, harvest survey results reflect reporting accuracy, bias and methods of extrapolation, the socio-economic circumstances of harvesters, and the abundance and accessibility of wildlife populations (Usher & Wenzel 1987, Cidro et al. 2015). Food frequency questionnaires are a method used to collect dietary data, usually intended to establish relationships between consumption patterns and health indicators. Most food frequency questionnaires focus on a context-specific food item list and asks respondents how frequently each item is eaten (e.g., times per day or days per week or month; Cade et al. 2002, Cade et al. 2004). In some cases, food frequency questionnaires include questions about typical servings or portion size, allowing estimates of food consumption frequency to be converted into estimates of food intake (e.g., Sheehy et al. 2013). Dietary surveys, like harvest reporting, are recognized to be influenced by recall and reporting inaccuracies and biases (Usher & Wenzel 1987, Molag et al. 2007). Although harvest surveys and dietary recall surveys provide potentially comparable information, albeit focused at different points along the harvest-to-consumption sequence, surprisingly few studies have included both sources of information in the same analysis. An important exception is Kenny & Chan (2017), who used responses to a food frequency questionnaire and edible yield conversions to estimate harvest numbers of key wildlife species in five regions of Inuit Nunangat, then compared these estimates to harvest survey estimates from the same regions. A key finding of this comparison was a remarkable agreement between the two estimates, despite important differences in methodology.

Characterizing change over time and place-to-place differences in local food systems that involve the use of many different species, introduces multidimensionality that is best accommodated by multivariate statistics and visualisation (Tremblay, Landry-Currier & Humphries 2020). Fortunately, directly applicable multidimensional concepts and analytical tools have been developed within the ecological sciences, especially related to the conception and analysis of ecological niches. According to the ecological niche concept, first proposed by Hutchinson's (1957), every individual or population occupies a certain ecological space based on its interactions with other biotic and abiotic components of its environment. This set of relations that an individual or population maintains with its environment is referred to its ecological niche (Hutchinson 1957) and is recognized to be multi-dimensional. An important niche dimension is an individual's or a population's diet, reflecting its trophic or food-based relationships with other species. An individual's or a population's trophic niche position reflects its dietary position in multidimensional species space – positioned closest to the food source it consumes the most – and its trophic niche width indicates its degree of dietary specialization. The narrowest, most specialized trophic niche is comprised of a single food source (i.e., a niche width of zero), while the widest, most generalized trophic niche includes all available food sources in proportion to their availability (i.e., a niche width of one; Colwell & Futuyma 1971, Feinsinger et al. 1981). Given different households, communities, or regions consume different local food resources in different proportions, available datasets on local food harvest and consumption resemble those used in trophic ecology. Specifically, harvest surveys and food frequency questionnaires yield a species (column) by community (row) matrix with cell values representing mass harvested or consumed. Canonical analysis can then be used to correlate this matrix to a set of possible explanatory variables (Legendre & Legendre 2012), preferably using redundancy analysis (RDA), which is a form of constrained ordination that performs multivariate linear regression of a set of response variables onto a set of explanatory variables (Legendre & Gallagher 2001). RDA is a two-step process, with dependent variables being regressed onto multiple independent variables, creating a set of fitted dependent variables, which are then analysed by principal components analysis (PCA; Legendre & Legendre 2012). Linear combinations of independent variables form axes along which dependent variables are regressed, from which several summary statistics, similar to those in multiple linear regression, can be produced.

Here we characterize the wildlife harvest and food use by the Nunavimmiut Inuit of Nunavik and the Eeyou Cree of Eeyou Istchee in a single multidimensional analysis inclusive of Inuit and Cree cultures, forest to tundra environments, and thirty-years of local food system change, from around the 1975 signing of the James Bay and Northern Quebec Agreement (hereafter JBNQA) to the early 2000's, coinciding with the signing of the New Relationship Agreement by the Grand Council of the Crees and a few years prior to the signing of the Nunavik Inuit Land Claims Agreement (NILCA 2008). Our analysis focuses on four individual datasets, including two 1970's harvest surveys and two 2000's dietary recall surveys from Eeyou Istchee and Nunavik. Using constrained ordination, we characterize regional differences and change over time in harvest and food use. Our study builds on the basic analytical approach described by Tremblay, Landry-Currier & Humphries (2020) and their examination of continental scale variation in local food use as documented by dietary recall surveys but expands the approach and the analytical framework to accommodate combining results from harvest surveys and dietary recall surveys to assess change over time in reported patterns of use. Analysing edible yield estimated from harvest surveys in relation to reported food use from food frequency surveys extends an approach and comparability first described by Kenny & Chan (2017). Here we show how RDA can be applied to harvest and food recall data to document food system similarity and differences among different places, and at different points in time, including the interactive possibility of regional differences changing over time.

Methods:

Our analyses are based on harvest surveys conducted by the James Bay and Northern Quebec Native Harvesting Research Committee, hereafter JBNQNHRC, in the 1970's in Eeyou Istchee (JBNQNHRC 1982) and Nunavik (JBNQNHRC 1988) and food frequency questionnaires conducted in the 2000's in Eeyou Istchee (Bonnier-Viger et al. 2007, Nieboer et al. 2011, Nieboer et al. 2013) and Nunavik (Rochette & Blanchet 2007, data from Lemire et al. 2015).

1970's harvest surveys

The harvest data presented here for Eeyou Istchee and Nunavik arose from an agreement, reached during negotiations leading up to the signing of the JBNQA, to jointly fund and conduct studies intended to quantify present levels of harvesting of wildlife by the Cree and Inuit in northern Quebec. We focus on annual reported harvest of the 32 species for each of the eight Cree communities included in JBNQNHRC (1982) and the 40 species groups for each of the 13 Inuit communities included in JBNQNHRC (1988). The body size and consumed edible fraction of Cree harvested species, as well as Cree community population size were reported by JBNQNHRC (1982), permitting estimation of annual reported harvest in animals per year, edible kg per year, and edible kg per person per year (Supp. Table 1). Because JBNQNHRC (1988) did not include body size and edible fraction information for species harvested in Nunavik, edible yield mass for those species was obtained from Ashley (2002); for species with multiple masses reported in Ashley (2002), masses from the James Bay region were used, which permitted estimation of annual reported harvest estimates in animals per year, edible kg per year, and edible kg per person per year (Supp. Table 2), using Nunavik community population size reported for 1976 in JBNQNHRC (1988).

2000's dietary recall surveys

The food frequency data presented here for Nunavik and Eeyou Istchee arose from two independently conducted health surveys, both of which intended to assess the overall health of Indigenous populations, including contaminant exposures through consumption of local food species (Bonnier-Viger et al. 2007; Nieboer et al. 2011; Nieboer et al. 2013;)

The *Nituuchischaayihtitaau Aschii* Environment-and-Health Longitudinal Study in Eeyou Istchee (Nieboer et al. 2013) was conducted during two- to four-week periods during the spring and/or summer in Mistissini in 2005 (Bonnier-Viger et al. 2007), Eastmain and Wemindji in 2007 (Nieboer et al. 2011), Chisasibi and Waskaganish in 2008 (Nieboer et al. 2013), and Waswanipi and Whapmagoostui in 2009 (Nieboer et al. 2013). This study documented consumption frequency across 49 local food categories representing different species (e.g., sturgeon) or species groups (e.g., suckers, which would have included red and white suckers) as well as different parts and cooking methods of a single species (e.g., moose meat dried; moose meat cooked; moose liver or kidney). Results from this study are presented as a series of community-by-community tables (Bonnier-Viger et al. 2007; Nieboer et al. 2011; Tables A7.2A-D in Nieboer et al. 2013), with the percentage of respondents reporting consumption of the local food category and, if consumed, the number of days per month that it was consumed. To facilitate species comparisons, we summed categories representing different parts or cooking methods of the same species, which reduced the number of local food species categories to 24. Then, to calculate the number of consumers of each local food species category in each community, we multiplied the percent of respondents who reported consumption for a given local food species category in a given community by that community population size. The number of consumers was multiplied by the days per month consumed to estimate a community-wide total number of days consumed per month, which was multiplied by 12 for an annual number of days consumed per year. Although portion sizes for the local food categories appear to have been estimated as part of the 2005 Mistissini survey (Bonnier-Viger et al. 2007), these results were not included in Bonnier-Viger et al. 2007 or Nieboer et al. (2013). Accordingly, we calculated the average daily portion size across all local foods reported in Sheehy et al. (2013) and multiplied this 174 g average portion size by the days per year community total to estimate consumed kg per person per year (kg/p/y; Supp. Table 3).

The *Qanuippitaa? How are we?* Nunavik Inuit Health Survey was a cross-sectional study conducted in the fall of 2004 (August 27 to October 1) on a representative sample of the Inuit population (889 adults aged between 18 and 74 years old) present in the 14 communities of Nunavik (Blanchet & Rochette 2008). The questionnaire estimated consumption frequency of the different local food species categories (days per year) as well as item-specific daily portion size (grams per day), allowing an estimate of annual consumption in kg per person per year (kg/p/y). Here, we use summary data from this food frequency questionnaire published in Lemire et al. (2015), with survey results presented for adult females in three Nunavik regions (Hudson Bay, Hudson Strait, and Ungava Bay) and in Nunavik as a whole. The local food portion of the questionnaire documented consumption across 23 local food categories representing different species (e.g., lake whitefish), species groups (e.g., trout and salmon), different parts and cooking methods within a single species (e.g., beluga mattaaq, beluga blubber, beluga meat), and preparation methods inclusive of multiple species (e.g., Pitsik made from Arctic char, brook trout or lake whitefish). Multiple tissues from a single species (e.g., caribou meat, caribou liver, caribou heart) were all merged into a single species category (e.g., caribou). Given data presented by Lemire et al. (2015) focus only on adult female respondents and expressed consumption as gram consumed per kilogram of adult female body mass per year, we used reported adult female body masses from the three regions (Lemire et al. 2015; Table 1) to re-express consumption values as kg per person per year (Supp. Table 4).

Homogenizing species and taxonomic categories

Species and taxonomic categories were homogenised across the four surveys in order to analyse similar local food species categories and to minimise possible errors introduced into canonical analyses by excluding reported species or other taxa (Lavoie, Dillion & Campeau 2009; Carnerio, Bini & Rodrigues 2010; Poos & Jackson 2012). These merges and reclassifications were typically necessitated by one survey documenting harvest or consumption of aggregated species categories (e.g., seals, geese, etc.) and another survey documenting less aggregated categories (e.g., ringed seal, bearded seal, Canada Goose, Snow Goose, etc.). Snow and Canada geese were merged into a single “Goose” category, while brants were maintained as their own category. Loons were merged with “Loon and merganser”; ptarmigan were merged with “Ptarmigan, grouse and other birds”. Arctic hares and snowshoe hares were merged into a “Hare” category. All seals, both speciated and generic were merged into a “Seals” category. Lake and brook (or speckled) trout, and salmon were merged into a “Salmonids” category. Sculpin was merged with “Sculpin and other fish”. Murre and guillemot were merged into an “Auks” category. Species harvested primarily for fur, including wolves and foxes were removed due to a lack of evidence of their consumption in all four datasets. Consumption was for wolves and foxes was implied in the Nunavik dietary recall surveys, but not in the other three datasets. Details and results of this homogenisation are in the supplementary materials (Supp. Table 6 and Supp. Table 7).

The combined harvest and dietary recall data is referred to as “species use” data and the final species use matrix includes four survey datasets (harvest and food frequency surveys from Eeyou Istchee and Nunavik), with each row identified by a unique “*community_survey*” key, each column identified by a species category, and cell values indicating the average use (kg/person/year) of a given species category (columns) reported for a given community in a given survey (rows). We present summary bubble plots for all four datasets and all communities. Species icon plots are also presented for reported 1970’s per capita harvest from the Cree community of Whapmagoostui and the adjacent Nunavik community of Kuujjuarapik with icons scaled to reflect variation in reported harvest amounts. Changes in rank importance of wildlife used is also reported. This analysis was generated by comparing the common categories of harvest and dietary recall within a region and subtracting the harvest rank from the recall rank. Species that increased in usage are therefore assigned a positive value and species that declined in usage are assigned a negative value.

Multi-variate analysis

Our analysis of regional differences is informed by multiple Cree communities in the region of Eeyou Istchee and multiple Inuit communities in the region of Nunavik, while our analysis of change over time is informed by harvest surveys conducted in the 1970’s and dietary recall surveys conducted in the

2000’s. The constraining dataset mirrors the species use dataset as a matrix having rows identified by a unique “*community_survey*” key. But in the case of the constraining dataset, columns indicate region and survey, with cell values indicative of binary categories of Eeyou Istchee or Nunavik for region, and 1970’s harvest or 2000’s food for survey method. These two binary variables are used as explanatory variables for the multilinear regression of species use performed in redundancy analysis.

A permutational Bray-Curtis based MANOVA was used to determine significant correlation between the region and survey binary categorical variables (and their interaction) and species use values. This was done using `adonis2()` in the R vegan package (Oksanen et al. 2020); a Hellinger transformation was used to compensate for frequent species use values of zero. The Hellinger transformation is defined as,

$$X_t = \sqrt{(X_0 + 1)}$$

where X_0 is the original value and X_t is the new value.

Redundancy analysis (RDA, ter Braak 1994) was used to visualise significant correlation between constraining factors (and their interaction) and the species use data, constructed from the four surveys previously described. Where **Y** is a matrix of response data (species by community data), and **X** is a matrix of constraining variables, $\hat{\mathbf{Y}}$ can be calculated as a multivariate linear regression of **Y** on **X** thusly:

$$\hat{Y} = \mathbf{X}[\mathbf{X}'\mathbf{X}]^{-1}\mathbf{X}'\mathbf{Y}$$

Where $\mathbf{A}'$ is the transpose of **A**, and $[\mathbf{B}]^{-1}$ is the inverse of **B**, such that $\mathbf{B}\mathbf{B}^{-1} = \mathbf{B}^{-1}\mathbf{B} = \mathbf{I}$, where **I** is the identity matrix. A principal components analysis (PCA) of $\hat{\mathbf{Y}}$ is performed and the resulting RDA biplot and summary statistics are analysed for magnitude of relationships between constraining and explanatory variables. In our case, this allows for the comparison of use from two regions and two surveys. The communities of Nemaska, Mailasi, and Killiniq that were not included in the 2000’s survey data. For Nunavik species use, because the 2000’s food recall data was only for each of the three Nunavik regions (Hudson Bay, Hudson Strait, and Ungava Bay), all communities from a given region surveyed in the 1970’s were given the regional value for the 2000’s data. A secondary permutational Bray-Curtis based MANOVA was performed to ensure the significance of the constraining dataset (Anderson 2008). Binning of distinct species into broader categories, required because the harvest and food survey questions occasionally differed in degree of taxonomic resolution (e.g., harvest surveys separated seal harvests into four species-specific categories, while food surveys combined all four species in a single 'seals' category) can introduce error into canonical analyses. In addition, our analysis may be prone to overfitting because our explanatory dataset contains no gradients, only polar, binary labels (Austin 1985).

Results:

The 1970's harvest and 2000's dietary recall surveys from Eeyou Istchee and Nunavik in northern Quebec, Canada indicate first, and most generally, the importance of a wide diversity of fish, birds, and mammals in both regions and both survey periods (Figure 1). Between the two survey periods, there is a consistent importance of the use of moose, geese, caribou, and whitefish in Eeyou Istchee and of caribou, char, beluga, geese, and seals in Nunavik. However, some species use, like ptarmigan in Eeyou Istchee and whitefish in Nunavik, increased in importance, while other species, like in beaver in Eeyou Istchee and trout and salmon in Nunavik, decreased in importance between the two survey periods (Figure 1).

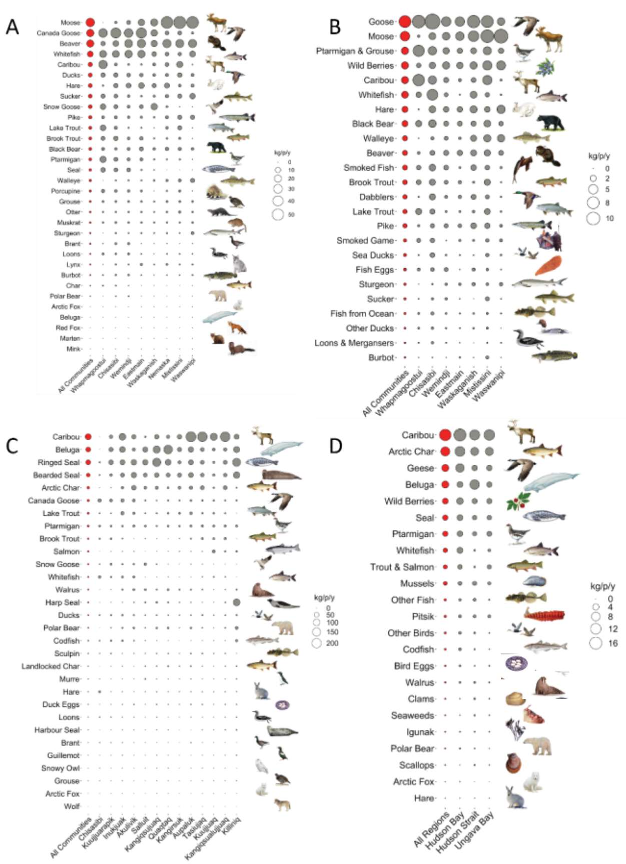

Figure 1. Bubble plots summarizing species use by community, expressed as kg per person per year (kg/p/y) for Eeyou Istchee according to (A) 1970's harvest survey and (B) 2000's food recall survey and for Nunavik according to (C) 1970's harvest survey and (D) 2000's food recall survey.

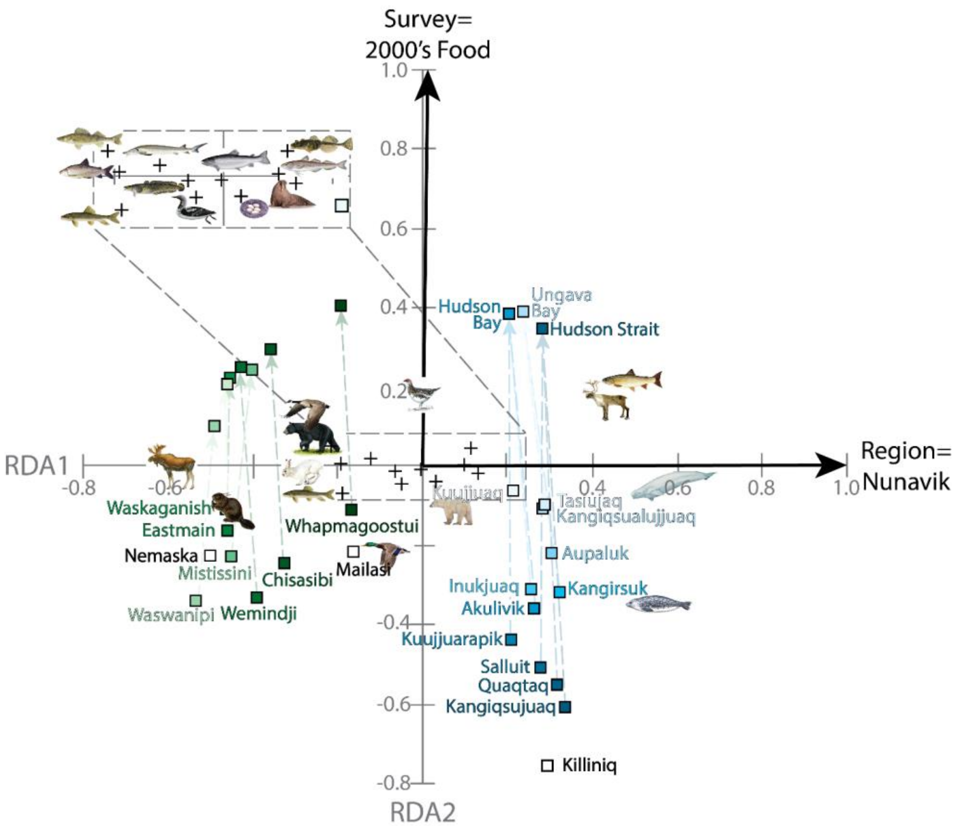

Figure 2. Transformation based redundancy analysis (tb-RDA) biplot of Hellinger transformed species use from 1970's harvest surveys and 2000's food recall surveys in communities of Nunavik (in shades of blue) and Eeyou Istchee (in shades of green), constrained by region and survey method. The surveyed communities are connected by arrows pointing from the 1970's harvest surveys to the 2000's food recall surveys, except for the communities of Nemaska, Mailasi, and Killiniq that were not included in the 2000's surveys (presented as white symbols). For Nunavik species use, because the 2000's food recall data was not presented for each community and only for each of the three Nunavik regions (Hudson Bay, Hudson Strait, and Ungava Bay), all communities from a given region surveyed in the 1970's are connected to a single regional value in the 2000's. The large black arrows show the regional constraining vector along RDA axis 1 (RDA1) (100% biplot score), and the survey constraining vector along RDA axis 2 (RDA2) (99.98% biplot score). These constraining vectors explain 64.7% of the variance in species use, 54.42% along RDA1 and 10.42% along RDA2.

Redundancy analysis (RDA) shows strong sorting of species use by region and survey; each dataset clustering among itself in the RDA visualisation (Figure 2). All surveyed communities from Eeyou Istchee appear on the left-hand side of the plot, while those from Nunavik appear on the right-hand side, and all communities surveyed in1970's appear in the lower half, while those surveyed in 2000's appear in the upper half. Visual analysis of the RDA implies that although the Eeyou Istchee and Nunavik niches have changed though time, they have remained distinct from each other. The interaction between region and survey method was also found to be significant, accounting for 12.5% of variance in the socio-biological data. Our model, consisting of two binary explanatory variable and their interaction explains 71% of the total variation in reported use. Focusing on RDA1 and region, moose, black bear, geese, and hare are sorted into the Eeyou Istchee side of the plot, while char, caribou, beluga, and seals are sorted into the Nunavik side of the plot. Focusing on RDA2 and survey, beaver and ducks (on the Eeyou Istchee side) and polar bears, beluga, and seals (on the Nunavik side) are sorted into the 1970's harvest survey at the bottom of the plot, 38uncae bears and geese (on the Eeyou istchee side), caribou and char (on the Nunavik side), and ptarmigan and other grouse (in the middle) are sorted into the 2000's food consumption survey at the top of the plot. Fish species (other than Arctic char and northern pike) are clustered around the middle of the plot, implying weaker differentiation according to region or survey. The regional constraining vector aligns perfectly with RDA axis 1 (100% biplot score and the survey constraining vector aligns very strongly with RDA axis 2 (99.98% biplot score). Together, the two constraining vectors explain 64.7% of the variance in species use, 54.42% along RDA axis 1 and 10.42% along RDA axis 2. Equal amounts of the variation in use are explained by region and survey (~30%), implying that regional use niches are distinct from one-another, but have changed though time.

Table 1: Results of permutational Bray-Curtis based MANOVA of species use constrained by region (Eeyou Istchee and Nunavik), survey (1970's harvest and 2000's food consumption), and their interaction.

	Df	Sum of Squares	R^2	F	P
Region	1	3.1434	0.29891	36.731	<0.001
Survey	1	2.9728	0.28268	34.737	<0.001
(interaction)	1	1.3193	0.12545	15.416	<0.001
Residual	36	3.0809	0.29296		
Total	39	10.5165	1.0		

According to a permutational MANOVA, both constraining factors and their interaction were significantly correlated with species use (Table 1). Region and survey explain respectively 30% and 28% of variation in species use, and their interaction explains a further 13%, leaving a residual 29% of unexplained variation (Table 1).

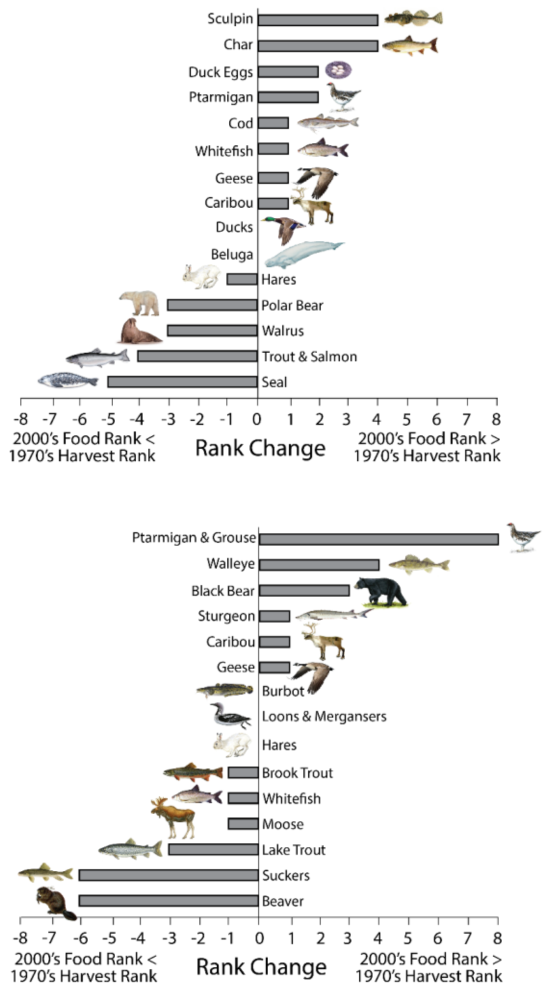

Figure 3: Change in rank importance of common species in both areas.

The use of species common to both the 1970's and 2000's surveys shows changes in both regions between the survey periods (Figure 3; which parallels sorting along RDA2 in Figure 2). In both Nunavik and Eeyou Istchee, the use of ptarmigan increased between the 1970's harvest surveys and the 2000's food consumption surveys, while trout and salmon use decreased in both regions. In Nunavik, sculpin, char, and duck eggs increased in use from the 1970's to the 2000's, while seal, walrus, and polar bear declined in use. In Eeyou Istchee, walleye and black bear have increased in use, while beaver and sucker have decreased in use (Figure 3). Figure 4 highlights the pronounced differences in reported wildlife harvest between the Cree community of Whapmagoostui, Eeyou Istchee (A) and the adjoining Inuit community of Kuujjuarapik, Nunavik (B).

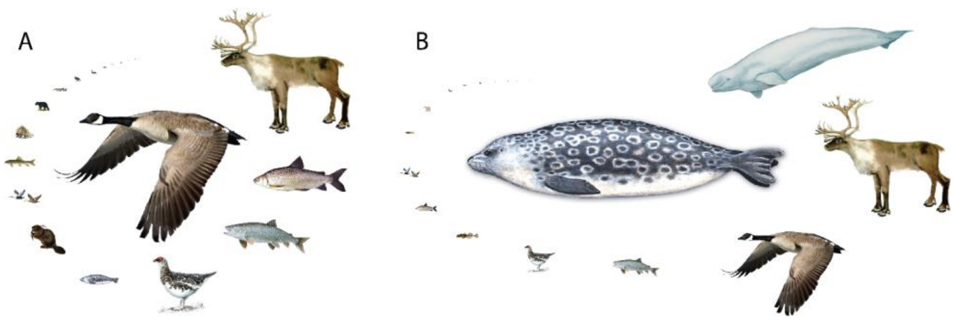

Figure 4. Same place, same time, but different people and different harvested wildlife. Species icon plots for A. the Cree community of Whapmagoostui, Eeyou Istchee, which is directly adjacent to B. the Inuit community of Kuujjuarapik, Nunavik.

Discussion:

Here we describe a multivariate analytical framework for quantifying variation in local Indigenous food systems, using community species utilisation niches as a basis to track socio-ecological variation in local food use over space and time. The framework described here advances Tremblay et al's (2020) application of a basic multivariate analysis to local food frequency surveys into an explicit multivariate framework, including redundancy analysis (RDA) and assessment of statistical significance using permutational Bray-Curtis based MANOVA. We also show how harvest surveys and dietary recall surveys can be included in the same analysis, a possibility first considered by Kenny & Chan (2017), but here extended to assess change in wildlife use over time.

Better understanding of the nature and the importance of local Indigenous food systems is a widely identified research priority. Community-based participatory research approaches are critical contributors to advancing understanding of local food systems because they include local knowledge, values, and guidance in the research process and its outcomes (Cargo et al. 2007; Castleden, Morgan and Lamb 2012; Brunet, Hickey and Humphries 2014a; Durkalec at al. 2015; Naylor et al. 2021). However, northern knowledge holders and organizations have also been clear that many studies have already been done, that many of the same questions are repeatedly asked of knowledge holders, and that current research and researchers should make better use of previous studies prior to initiating new research (Darling et al. 2022). Furthermore, because past research results have not always been shared well and effectively with the communities involved in the research, past research results are not always well known or easily accessed by regional organizations and decision-makers (Darling et al. 2022). In this context, secondary analysis of pre-existing data offers not only new research insight, but also an opportunity to inform contemporary research, monitoring, and decision-making. Although research on local Indigenous food systems is gaining recent momentum (Coté 2016), components of these food systems have been well-studied in the past, especially via harvest and food frequency surveys that have been completed in many places and regions for a variety of purposes (Usher & Wenzel 1987). By offering an analytical framework able to quantify comparable socio-ecological indicators from past harvest and food use surveys, we hope to contribute to the understanding variation in local food use, over time and from place to place, in a manner that can inform current and future research and policy priorities. Importantly, the indicators described here are inclusive of all species reported used and are thus representative of the full breadth of biodiversity contributing to local food systems, rather than focused on only one or a few key species used.

Application of this multivariate niche approach to two 1970's wildlife harvest surveys and two 2000's food consumption surveys conducted across Cree communities in Eeyou Istchee and Inuit communities in Nunavik indicate pronounced differences in local food use between and within regions that have been maintained over time, despite substantial social and ecological change and declining reported use of several key species. Survey results confirm the continued importance of a wide diversity of locally available wild fish, birds, mammals, and plants in the food systems of Eeyou Istchee and Nunavik. Our analysis indicate that region, survey, and their interaction account for 71% of the variation in reported wildlife use reported by Eeyou Istchee and Nunavik communities. A key result of our analysis is that community and regional differences in use patterns have remained consistent over time during a period of accelerated social and environmental change. The significant interaction between region and survey, accounting for 12.5% of variance, indicates some change in regional differences between the two surveys, but may result in part from differences in the taxonomic and regional resolution of the harvest and food frequency surveys

Our analyses indicate a decline in the reported use of furbearers, especially seals in Nunavik and beaver in Eeyou Istchee, between the 1970's harvest surveys and the 2000's food surveys. Because seals and beaver are harvested for fur as well as food, consumption surveys could be expected to indicate lower importance than harvest surveys if not all animals harvested for fur are consumed by people or if the edible yield fraction consumed of these furbearers is not always maximized, especially when amounts harvested are very high (Usher 1971). On the other hand, there is good reason to expect that the overall per capita harvest and consumption of both species has declined over the 30-year period due to the collapse of the fur economy. Reduced demand and price of fur over the latter part of the 20th century has had a major impact on land-based livelihoods, greatly diminishing a subsistence economy and an opportunity to make money or trade fur for goods that has existed in the region for nearly 300 hundred years (Francis & Morantz 1983, Morantz 2010). Increased price of fuel over the same period acerbates the decline in the price of fur (Brinkman et al. 2014, Dorendorf et al. 2016). Wenzel (1987, 2019) has written extensively on how the collapse of the seal fur economy has impacted Inuit harvesters and the mixed economy in Nunavut. Fast & Berkes (1994) make mention of related impacts among Cree communities in northern Quebec and Ontario. But, in general, how the collapse of the fur economy has impacted and altered the local food systems of Eeyou Istchee and Nunavik remains under-considered. Harvest practices and food systems have changed in many other ways between the 1970's and 2000's, including more reliance on motorized vehicles and less reliance on dog teams, paddle boats (e.g., canoes, kayaks), and snowshoes to access harvest locations and more time spent living in larger communities farther away from seasonal camps and harvest sites. Studies from the period before snow machines state that approximately 75% of country food, by mass, was fed to dogs (Usher 1971). Because dogs were primarily fed fur-bearer carcases (Usher 1976) and non-salmonid fishes (DeLury 1975) changes in the reported use of these species may be driven by reduced demand from dogs rather than or in addition to changes in fur prices, food used by people or their ecological availability. However, the use of motorized vehicles in place of dog teams and the emergence of centralized and relocated communities changed more in the three decades preceding the JBNQA than in the three decades after (Levesque 2018), whereas the collapse of fur prices and the fur economy, combined with rising fuel prices, were especially pronounced after the 1970's

The consistent regional differences in reported use between Eeyou Istchee and Nunavik and by different communities within each region is likely to reflect a combination of ecological and cultural differences. Ecologically, Nunavik is comprised mostly of herbaceous, shrub, or forest tundra, whereas Eeyou Istchee is comprised mostly of lichen or moss black spruce forest (Saucier et al. 2009). Thus, the spatial and ecological extent of these four surveys encompasses areas of the Canadian shield and boreal forest all the way to areas of continuous permafrost north of the treeline (Fortier, LeBlanc & Yu 2011). Despite these ecological differences, many harvested and consumed wildlife species are present in both Nunavik and Eeyou Istchee, though their relative abundance differs between and within the regions and many are restricted to either coastal or inland areas. Culturally, Eeyouch living in Eeyou Istchee speak an eastern Cree dialect of the Cree language spoken from Labrador to the Rocky Mountains, with the Cree language itself classified within the Algonquin language family. Nunavimmiut of Nunavik speak a dialect of Inuktitut, one of several Inuit-language dialects, and can trace their cultural lineage to the Thule culture that radiated out of Alaska to reach Northern Quebec, Greenland, and Labrador approximately 1350 CE (Moody & Hodgetts 2013; Lynnerup 2015). The unique harvest and food practices of Nunavik Inuit and Eeyou Istchee Cree communities are described elsewhere (Usher 1976; Wenzel 1991; Scott 2003). Tremblay et al.'s (2020) analysis of food frequency surveys conducted in 32 First Nation and Inuit communities considers geographical, ecological, and cultural contributions to differential food use and emphasizes culture as a particularly important and general influence. Within northern Quebec and our current analysis, cultural differences in wildlife use are best exemplified by the harvest reported for the Cree community of Whapmagoostui and the adjacent Inuit community of Kuujjuarapik. Despite sharing the same surroundings and ecological setting, the communities report harvesting distinct sets of wildlife (Fig. 4). While caribou and Canada goose are harvested by both communities, Cree in Whapmagoostui harvest more whitefish and trout, whereas Inuit in Kuujjuarapik harvested more seals and beluga. Regionalized reporting of results from the 2000's Inuit food survey (Blanchet & Rochette 2008) prevents replicating this direct comparison with food frequency results, but our overall analysis suggests these types of community-level and regional-level distinctions are being strongly maintained across 30 years of accelerated social and ecological change.

Most of the limitations of this research are inherent in the novel combination of datasets. Our data spans four datasets, 30 years, and two regions that comprise the majority of northern Quebec, and all territory north of the 55th parallel. The different methodologies and points of survey focus – the 1970's harvest surveys focusing on year-round harvest diaries, over a 5-year period, while the 2000's food consumption surveys focused on data collected through a single interview conducted on one day, based on the recall of food consumption prior to that interview, present a challenge. Food frequency questionnaires are recognized to be influenced by recall and reporting inaccuracies and biases (Coughlin 1990); whereas harvest surveys can be confounded by a lack of consistent methods for surveying and tallying data (Usher & Wenzel 1987). The comparability of harvest and food use surveys depends on the extent to which all edible yield from harvest is consumed by people. As discussed above, a possible explanation for the apparent decline in use of furbearers between the 1970's and 2000's surveys involves the switch between a harvest focused survey in the 1970's and a food focused survey in the 2000's. However, there are good reasons to expect that furbearer harvest underwent a real decline between the two periods.

The most important data limitation in this study, which extends to local food systems across northern Canada, is a lack of recent, consistently documented, and continuously monitored information about local food systems. Allaire et al. (2021) present recent data from the 2017 Nunavik Inuit Health Survey, including direct comparison to the 2004 survey (Rochette & Blanchet 2007), which provides an opportunity to extend our analysis to a third temporal snapshot for Nunavik but not for Eeyou Istchee. The 2014 Council of Canadian Academics state of knowledge report, "Aboriginal Food Security in Northern Canada" identifies the existence of numerous past surveys, but a lack of cross-cultural and over-time consistency in information about local food systems. Comprehending changes in Indigenous food systems across Canada requires effective monitoring of these systems (Thompson et al. 2019), with challenges remaining concerning power imbalances between Indigenous communities and state wildlife management, and management regimes that disempower Indigenous knowledge and monitoring (Thompson, Lantz, and Ban 2020). Indigenous monitoring includes ongoing land-based practice, such as harvesting, and emerging research advocates for using harvesting data as monitoring data (Thompson et al. 2019) allowing for ongoing monitoring (Thompson et al. 2020, Thompson, Lantz, and Ban 2020). Monitoring should be undergone in such a way as it supports plural view, values, and knowledges (Rahman et al. 2019) and data remains accessible, or controlled, for stakeholders to analyse, interpret, and apply (Schnarch 2004; Darling et al. 2022). We hope that our development of new methodological tools and our application of these approaches to single time point surveys completed in the past prompts further consideration of how information gaps about local food systems can be best addressed, while respecting and advancing the self-determination of the Indigenous people and nations who create these systems.

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Chapter 3 linkage

Chapter 2 describes Indigenous food systems using multi-species use data from a combination of harvest and dietary surveys conducted in two regions. Chapter 3 that follows, focuses in on a single use survey – a comprehensive harvest survey from Nunavut - but goes beyond reported use to estimate the nutritional content of reported use. By combining information on the amount of wildlife harvested (from the Nunavut Wildlife Harvest Study), the nutritional composition of country food (from Health Canada's Canadian Nutrient Files), and the nutritional content and local price of store-bought food (from Nutrition North Canada), Chapter 3 achieves an estimate of country food value in Nunavut based on the amount of energy and protein contained in harvested wildlife multiplied by the in-community cost of store-bought energy and protein. This chapter was presented at the 2017 CANSEE conference, the 2018 Hudson's Bay summit, the 2019 ArcticNET GSM, and published in the September 2021 issue of *Arctic* and the results of this research have been included in the Inuit Nunangat Food Security Strategy.

Chapter 3: Valuation of Country Food in Nunavut Based on Energy and Protein Replacement

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Keywords: subsistence; traditional food; mixed economies; wildlife; hunting; nutrition; Arctic; food policy; Inuit, Nunavut

Abstract

Communicating value across the pluralities of Indigenous Peoples' food systems requires attention to economy and environment, food and wildlife, and the health of the people and that of the land. Valuation of distinct entities is always difficult but often essential to describe collective wealth and well-being, to quantify trade-offs, and to consider compensation when one is compromised for another. Here we estimate the replacement value of Nunavut country food by combining information on the amount and nutritional composition of harvested country food with the nutritional content and local price of store-bought food. Comparing the five-year average of energy and protein available in reported harvest to recommended dietary allowances indicates that 17 of 21 Nunavut communities harvest enough country food to satisfy the protein requirements of all community members. Nunavut's country food system annually harvests five million kg of protein-rich food from across the territory, which would cost $198 million to purchase as store-bought protein, with a replacement value between $13.19 and $39.67 per kg depending on energy versus protein replacement and the inclusion versus exclusion of store-bought food subsidies. These valuations are higher than most previous estimates of local food value because they are more reflective of the energy and nutrient richness of country food and the high price of store-bought food in northern communities. The country food system is priceless in many, profound ways; better awareness of its energy and protein cost of replacement, together with the breadth of its nutritional and cultural value, may help to ensure local food systems are prioritized in northern food security and economic development initiatives.

Introduction

The lifeways of Indigenous Peoples and northern regions connect economy and environment (Kuokkanen, 2011), food and wildlife (Kuhnlein and Humphries, 2017), and the health of the people to the health of the land (Dudley et al., 2015). Communicating value and status across these pluralities is always difficult because they are segregated in contemporary governance, policy, and assessment (Lysenko and Schott, 2019) but is often essential to describe collective wealth and well-being, to quantify trade-offs, and to consider compensation when one system is compromised for another. Nevertheless, cross-system valuations are contested and controversial. For example, ecosystem services approaches (especially payments for ecosystem services) are frequently criticized as a commodification of nature through which dominant political and economic views are allowed to define how we conceive of, communicate, and compensate for the value of biodiversity and nature (Gómez-Baggethun and Ruiz-Pérez, 2011).

Kosoy and Corbera (2010) refer to this problem as commodity fetishism, arguing that monetary valuation of any biocultural system obliterates the social, cultural, and ecological qualities embedded in these systems, thereby failing to account for value in a broader sense. But despite their anthropocentric framing, an ecosystem services approach and natural capital accounting are also promoted as an argument for protection of nature, as means to support conservation and sustainable use, and as boundary concepts capable of connecting and distinguishing diverse perspectives and values (Abson et al., 2014; Schröter et al., 2014).

The food systems and food security of northern and Indigenous Peoples are social-ecological phenomena situated at the intersection of economy and environment, food and wildlife, and biocultural well-being (Kuhnlein et al., 2009). Country food (subsistence focused on the hunting, fishing, and gathering of local wild animals and plants; Searles, 2016) is a key contributor to the food security (Ford and Berrang-Ford, 2009), nutrient intake (Johnson-Down and Egeland, 2010; Kenny et al., 2018a), and the social economy in Inuit Nunangat (Natcher, 2009; Harder and Wenzel, 2012). However, country food consumption is being negatively impacted by the high costs of harvesting equipment (Wenzel, 2000; Lambden et al., 2007), changing food preferences (Kuhnlein and Receveur, 1996; Sheehy et al., 2013), and climate and land-use changes that are impacting wildlife and restricting access to harvesting areas (Chan et al., 2006; Wenzel, 2009).

Store-bought food is also a key contributor to nutrition and food security in northern and Arctic communities, and the high cost of store-bought food, combined with low incomes and limited access to wage economies, is a widely identified barrier to food security in Nunavut (Nunavut Food Security Coalition, 2014) and across northern regions (CCA, 2014). High rates of food insecurity across northern Canada have been attributed to a variety of factors including limited access, availability, and use of healthy country food or healthy store-bought food (CCA, 2014), especially in Nunavut, where food insecurity affects 50% to 80% of households, which is 10 times higher than the Canadian average (Wakegijig et al., 2013; Nunavut Food Security Coalition, 2014). The extent to which economy, environment, and culture co-determine food security is reflected in how the Nunavut Food Security Coalition (2014:2) describes the four components of food security in Nunavut: "*availability (enough wildlife on the land or groceries in the store), accessibility (adequate money for hunting equipment or store-bought food, and the ability to obtain it), quality (healthy food that is culturally valued), and use (knowledge about how to obtain, store, prepare, and consume food).*"

Economic development, food security, and climate change adaptation have emerged as key pillars of northern policy and investment. However, economic investment often focuses on job creation through natural resource exploration and extraction (e.g., Caine and Krogman, 2010; Rodon and Lévesque, 2015), food security investment in subsidy programs intended to reduce the cost of store-bought food (Galloway, 2017; St-Germain et al., 2019), and climate adaptation in relation to transportation, infrastructure preparedness, and technology-assisted agri-food production (Prowse et al., 2009; Hjort et al., 2018; Sustainable Development Working Group, 2019). While these are important initiatives and investments that are helping to transform northern economies and communities, they can be argued to be peripheral and transient to the primary economy that has long defined and continues to define northern regions (Wenzel, 2017). The country food system is the food that feeds *Nunavummiut* (the people of Nunavut), the labour that employs *Nunavummiut*, the economy that supports *Nunavummiut*, and the culture that defines *Nunavummiut* (Nunavut Food Security Coalition, 2014; Quintal-Marineau, 2017; Ready, 2017; Wenzel, 2017).

Not surprisingly, local opposition to or approval for transportation and resource development initiatives most often depends on their impacts on wildlife populations, the environment, and the integrity of the country food system (Caine and Krogman, 2010; Rodon and Lévesque, 2015; Carter et al., 2019). As articulated by the Nunavut Food Security Coalition (2014:7), "*preserving the ecological integrity of*

Nunavut food resources is a key component of a sustainable food system in Nunavut, and is therefore of concern to food security." Community-suggested improvements for the subsidy program emphasized the need to expand the program to address economic barriers to country food access (GC, 2017). Community-led research on climate change adaptation has shifted adaptation focus towards helping hunters to safely access harvest sites, community freezers for the safe storage of country food, and Elder-to-youth knowledge transmission related to the land and country food harvest and its preparation (Furgal and Seguin, 2006; Ford et al., 2014; Champalle et al., 2015).

Although country food has long been recognized and communicated by *Nunavummiut* as a made-in-Nunavut sustainability and food security solution, it has been marginalized and, in some cases, compromised by economic, food policy, and adaptation initiatives often envisioned and sometimes implemented from outside the region. Marginalization of local food systems may reflect broader and more complex dynamics rooted in legacies of colonialism, dispossession, a Eurocentric worldview, and modern power asymmetries (Caine and Krogman, 2010; Burow et al., 2018; Bernauer, 2019). In this context, the failure to quantify and communicate the value of local food systems may both arise from and contribute to their marginalization; a positive feedback loop that causes the system to be undervalued and underappreciated except by those directly involved in the system. Any one study or analysis can only scratch the surface of communicating the nature, value, and complexities invoked by the governance of food systems and traditional lifeways (CCA, 2014).

Cognizant of these limitations and our own positionality as Euro-Canadian, university-based researchers, we proceed by proposing a hypothesis. If the lack of reproducible quantification and economic valuation of the Nunavut country food system has contributed to its discounting and marginalization in northern economic development and food security policy, and we can provide a reasonable valuation that communicates the magnitude and scope of its contributions, then future discussions and decisions related to Nunavut and northern economic development and food security will be better able to situate the value of country food in descriptions of collective wealth and well-being, quantify trade-offs, and contemplate compensation when one economy is compromised for another. Unfortunately, this hypothesis cannot be tested by the results presented here, but rather by how these results are interpreted and applied by others. For Nunavummiut, the results presented here may offer nothing new; all the evidence they need may already be provided by the stories they know to be true, by the experience of their family's harvests, and by the food in their freezers that they share with others and eat themselves. However, other readers and policy makers, who rely more on numbers and currencies to define value, will offer a more direct test of this hypothesis. We hope that the valuation methodologies described here might prove useful to community and regional organizations in communicating at least some of the value offered by their local food systems and in emphasizing the importance of considering this value in policy decisions related to Arctic lands, wildlife, and food systems.

Given local food systems are fundamentally priceless, communicating their monetary value requires equating them to a monetized commodity, while recognizing this equivalency is inevitably imperfect and incomplete. Because of the partial nature of this estimate and the irreplaceability of many culturally appropriate foods, it logically follows that it will form a highly conservative estimate—what could be considered a lower boundary for future elaborations. Past attempts at local food valuation have been based either on exchange value (the monetized value of a commodity for which local food is traded for or exchanged; e.g., Usher, 1971) or replacement value (money that must be spent to replace what local food provides; e.g., DeLury et al., 1975; Berkes et al., 1994; Pal et al., 2013). We adopt a replacement value approach, which reflects DeLury et al.'s (1975:238) recognition that food is a fundamental need that must be replaced and cannot be exchanged: "*[Exchange] values may have some relevance to a commercial fishery but not to a subsistence fishery. If fish keep an individual from starvation or even hunger then the fish assume a unit of value not found in any monetary system. To obtain a meaningful value for the fish, the costs of substitutes might be applied."* We also improve upon previous replacement valuations focused only on food weight (e.g., Berkes et al., 1994; Pal et al., 2013) by assessing the local, store-bought food cost of nutrient replacement, which also serves to situate country food value in a broader economic and nutritional context.

Methods

Our country food valuation methodology combines harvest data from the Nunavut Wildlife Harvest Study (NWHS; Priest and Usher, 2004), nutrient composition of country food from the Canadian Nutrient Files (CNF; Health Canada, 2018), and the price and nutrient content of store-bought food included in Revised Northern Food Baskets (RNFB; Nutrition North Canada, 2018). Our analysis includes wildlife harvest data from 27 Nunavut communities (including 13 Qikiqtaaluk communities, seven Kitikmeot communities, and seven Kivalliq communities) and RNFB price data from 21 communities (Fig. 1). We situate the estimated value of country food within a broader socioeconomic context through comparisons to recommended dietary allowances (RDA; Health Canada, 2010), reported incomes, and estimated economic productivity by sector (GN, 2019). To standardize financial valuations made several decades apart, all dollar values have been converted into 2016 Canadian dollars, using the Bank of Canada Inflation calculator (Bank of Canada, 2019).

Country Food Harvest and Nutrient Composition

We base our analysis on the five-year NWHS (June 1996 – May 2001, treated as the 1996 – 2000 harvesting seasons for this analysis), which was mandated by the Nunavut Lands Claim Agreement to determine current harvesting levels and patterns of Inuit use of wildlife resources and aid in the calculation of basic needs levels (Priest and Usher, 2004). Harvest data were collected monthly from Inuit hunters for a total of five years (except Cape Dorset and Iqaluit, which were limited to 1997 – 2000). For our present analyses, we obtained NWHS data from the Arctic Observation Network (AON) subsistence database (Kruse, 2011), maintained by the Institute of Social and Economic Research at the University of Alaska, Anchorage (Kruse, 2011). This database uses edible weights published by the Subsistence Division of the Alaska Department of Fish and Game (Conger and Magdanz, 1990; Titus et al., 2009; Magdanz et al., 2010) to convert whole animals harvested as reported in NWHS to kilograms of country food available to each community member (kg person^{-1}). Although the AON database includes harvest studies from other regions, our current analysis is restricted to results from the NWHS. We further limit our analysis to the 10 most harvested species in each community in each year, which encompass at least 97% of the total biomass harvested in each community in each year.

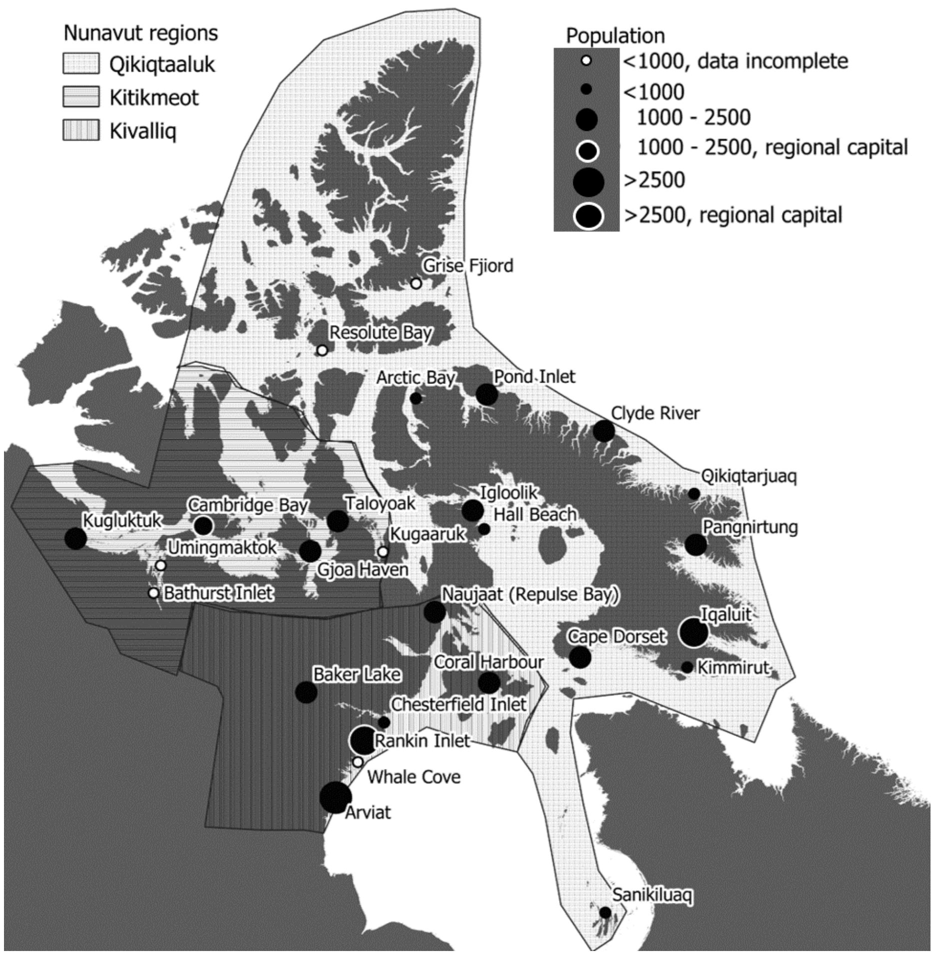

FIG. 1. Nunavut communities reporting country food harvest in the Nunavut Wildlife Harvest Study, with community symbols scaled to indicate population size (from the 2016 Canadian census). Patterned areas indicate Nunavut regions, and communities with white outlines are regional capitals (Rankin Inlet in Kivalliq and Cambridge Bay in Kitikmeot)

and the territorial capital of Iqaluit. Six communities reporting harvest data but lacking store-bought food price data or censused inhabitants are indicated with white circles.

Harvest data were converted to available energy (kcal) and protein (g) (Tables S1, S2), using energy (kcal kg^{-1}) and protein (g kg^{-1}) contents reported in the CNF (Health Canada, 2018). Eider (*Somateria mollissima*) and Arctic hare (*Lepus arcticus*) nutritional data were obtained from Kuhnlein and Humphries (2017). The portion consumed was assumed to consist primarily of muscle for most wildlife species (Table S1), except for pinnipeds and cetaceans, which were constructed assuming preferential consumption of multiple tissues, including dried meat, maktaak/muktuq (skin), or misiraq (rendered oil; Table S2). Note that these assumptions are not equivalent to assuming all other parts were discarded. All parts routinely consumed are included in the edible yield (kg) calculation from AON. The assumptions stated here and in Tables S1 and S2 relate only to estimating the average nutrient composition of the fraction consumed (kcal kg^{-1} or g kg^{-1}). Data for unspecified species or species without nutritional data were constructed using the average of their taxonomic group (Tables S1, S2).

Country Food Available Energy and Protein in Relation to RDA

The energy and protein available from reported country food harvests were estimated by multiplying the edible yield of harvested species by their species-specific nutrient composition, then summing across the top 10 harvested species to yield per capita estimates of country food available energy (kcal $pers^{-1}$ d^{-1}) and country food available protein (g $pers^{-1}$ d^{-1}). To assess the adequacy of country food harvest to meet nutritional requirements of the population, available energy and protein were compared to energy (2300 kcal $pers^{-1}$ d^{-1}) and protein (47 g $pers^{-1}$ d^{-1}) RDA, averaged across an adult male, adult female, teenage male, and pre-teen female (Health Canada, 2010), the same family-unit composition assumed by the RNFB. Relating country food available energy and protein estimated at a community level to an individual RDA implicitly assumes all foods harvested are consumed and harvested food is shared among community members proportional to their nutritional needs. These assumptions represent a simplification of the food system for analysis, which is a food system often characterized by highly unequal harvesting efforts (ranging from non-hunters to “super hunters”, Chabot, 2003:19; Lysenko and Schott, 2019: Fig. 6) and within which country food accessibility that are partially but not fully equalized by food-sharing traditions (Ready and Power, 2018; Lysenko and Schott, 2019).

RNFB Prices and Nutrient Content

The cost of store-bought energy and protein in Nunavut was estimated from the price and nutrient content of a RNFB, designed to provide a week of food to a family unit of four, from reporting retailers in Nutrition North eligible communities in March 2016 (Nutrition North Canada, 2018). Given household crowding in Inuit Nunangat (Ruiz-Castell et al., 2015), the assumption of four individuals per household will be in many cases incorrect. Because this assumption forms the basis of the RNFB estimation, we retain it but ensure it is made explicit by hereafter referring to a four-person household. The total energy content and total protein content of a RNFB were calculated based on the itemized content of a food basket, including serving mass or volume, adjusted by item density when necessary, and multiplied by CNF-reported energy and protein content (Revised Northern Food Basket, 2007; Health Canada, 2018). Energy and protein content were then divided by the community-specific price of the RNFB to arrive at a community-specific unit price for energy (store-bought food energy cost; $\$ kcal^{-1}$) and protein (store-bought food basket protein cost; $\$ g^{-1}$).

Because store-bought food prices are subsidized in Nunavut by the Nutrition North program (in addition to other agricultural and food subsidies), we also estimated store-bought food basket energy and protein cost in the absence of the Nutrition North subsidy provided to eligible retailers in eligible communities. Nutrition North subsidies, calculated according to food item mass and category (higher, lower, no subsidy) and a community-assigned subsidy rate, were obtained via a data access request fulfilled by Nutrition North in February 2020. The unsubsidized RNFB cost was calculated as retail price plus the total subsidies applied to a RNFB in each community. The unsubsidized RNFB price was then divided by energy and protein content to estimate the unsubsidized store-bought food energy cost ($\$ kcal^{-1}$) and unsubsidized store-bought food protein cost ($\$ g^{-1}$).

Store-bought Food Affordability

The affordability of store-bought food was estimated for four-person households located in different Nunavut communities by comparing a community-specific estimate of annual four-person household income to a community-specific store-bought food price of 52 weekly RNFBs. Four-person households were assumed to be supported by a single total income, which was assumed to equal the median total income reported by all tax filers in that community in 2016 (GN, 2019). Total income was chosen over employment income for this analysis, as it comprises labour income plus other sources including pensions, childcare benefits, and other government assistance and is therefore more reflective of the total financial resources available to a four-person household. Because the fraction of total income required to purchase basic food requirements is used as a measure of food poverty (Lee et al., 2013), we express annual RNFB food costs as a proportion of total annual income and refer to this community-specific measure as a store-bought food poverty index.

Country Food Nutrient Replacement Value

The nutrient replacement value of country food was estimated by multiplying the total energy (kcal yr^{-1}) and protein harvested (g yr^{-1}) by the local store-bought cost of energy (\$ $kcal^{-1}$) and protein (\$ g^{-1}), including Nutrition North subsidized and unsubsidized costs. The average value of country food per unit mass (\$ kg^{-1}) was calculated by dividing total harvest value (\$ yr^{-1}) by total harvest mass (kg yr^{-1}).

Comparison to Previous Country Food Valuations

Several previous values presented in the literature were adjusted from the form in which they were originally published, including inflation adjustments and conversion of pounds to kilograms. Wenzel (2009) published a value of \$35 million for the annual country food harvest in Nunavut but did not reference a harvest level, so we assumed the NWHS edible yield harvest level of 3.4 million kg, as estimated in our current analysis, and converted \$35 million yr^{-1} to \$39.3 million yr^{-1} to reflect 2016 dollars. Dividing \$39.3 million yr^{-1} by 3.4 million kg yr^{-1} yields a value estimate of \$11.56 kg^{-1} from Wenzel (2009). O'Garra (2017) used a value of \$6 USD lb^{-1} (from Fall, 2014), which we converted to \$7.46 CAD (assuming \$1 CAD = \$0.74 USD) and re-expressed per kg, yielding a CAD value estimate of \$17.81 kg^{-1}. For Berkes et al. (1994), total replacement value ($7,846,155) was divided by total harvest (686,713 kg) to yield $11.43 kg^{-1} or 18.86 kg^{-1} in 2016 dollars. We also compare our valuations to a previous Government of Nunavut territory-wide estimate of country food value on its website (GN, 2021) without an explanation of methodology.

Country Food System as an Economic Sector

Country food values were compared to territorial economic sector gross domestic product (GDP) data (GN, 2019), organized by North American Industry Classification System (NAICS) codes (NAICS, 2017). The value of the oil and gas sector was estimated as the difference between the code 21 sector (Mining, quarrying, and oil and gas extraction) and its subsectors (2122: Metal ore mining and 2131: Support activities for mining and oil and gas extraction). The hunting, fishing, and trapping sector was defined by code 114 and intended to represent "establishments primarily engaged in catching fish and other wild animals from their natural habitats" (NAICS, 2017:99).

Country Food Wealth Indices

We are not aware of preexisting food affordability or food poverty indices that incorporate access to country foods, so we developed two measures. The first considers country food as a non-monetized commodity by relating country food harvest amounts to community nutritional requirements as outlined above (see Country Food Available Energy and Protein in Relation to RDA). We refer to this measure as a country food wealth nutrition index (CFWNI) and base it on nutrient amounts harvested per capita relative to recommended dietary allowances. Thus, for protein, this nutrition index is calculated as:

$$\mathrm{CFWNI_{protein}} = \frac{\text{harvested protein (g person}^{-1}\text{ d}^{-1})}{\text{protein RDA (g person}^{-1}\text{d}^{-1})} = \frac{\text{harvested protein (g person}^{-1}\text{ d}^{-1})}{47\text{ g person}^{-1}\text{d}^{-1}}$$

and for energy as:

$$\mathrm{CFWNI_{energy}} = \frac{\text{harvested energy (kcal person}^{-1}\text{ d}^{-1})}{\text{energy RDA (kcal person}^{-1}\text{d}^{-1})} = \frac{\text{harvested energy (kcal person}^{-1}\text{ d}^{-1})}{2300\text{ kcal person}^{-1}\text{d}^{-1}}$$

The second index we developed acknowledges the reality and the importance of the mixed economy in Nunavut communities by comparing the value of harvested country food to reported incomes. This country food wealth income index (CFWII) is calculated for protein value as:

$$\mathrm{CFWII}_{\mathrm{protein}} = \frac{\text{harvested protein value (\$ person}^{-1}\text{ year}^{-1}\text{)}}{\text{reported income (\$ year}^{-1}\text{)}}$$

and for energy value as:

$$\mathrm{CFWII}_{\mathrm{energy}} = \frac{\text{harvested energy value (\$ person}^{-1}\text{ year}^{-1}\text{)}}{\text{reported income (\$ year}^{-1}\text{)}}$$

Results

The NWHS included 39 harvested species, species groups, or items (e.g., eggs), with estimated edible yield protein content ranging from 88 to 348 g kg^{-1} and energy content ranging from 820 to 5934 kcal kg^{-1} (Fig. 2a, b). Most Nunavut communities harvested edible yields exceeding 5 kg person^{-1} year^{-1} across four or more species categories (Fig. 2c), with caribou (median 68.5 kg person^{-1} year^{-1}, range 0.369 – 757 kg person^{-1} year^{-1}), ringed seal (28.6, 0.192 – 270 kg person^{-1} year^{-1}), and char (12.0, 0.159 – 101 kg person^{-1} year^{-1}) as the three most harvested categories. In general, fish have lower protein content than birds and mammals. Within mammals, beluga and narwhal have the highest estimated protein per consumed fraction, contributed primarily by the dried meat component of assumed intake (bowhead has lower protein content because meat is assumed to be not consumed; Table S2). Whales are, collectively, also among the most energy rich country food items, along with seals and goose eggs (Fig. 2a), presumably because of their high lipid content. Char and caribou are both relatively low in energy content, but high in protein (though this partly reflects our assumption that the consumed portion of char and caribou is predominately muscle).

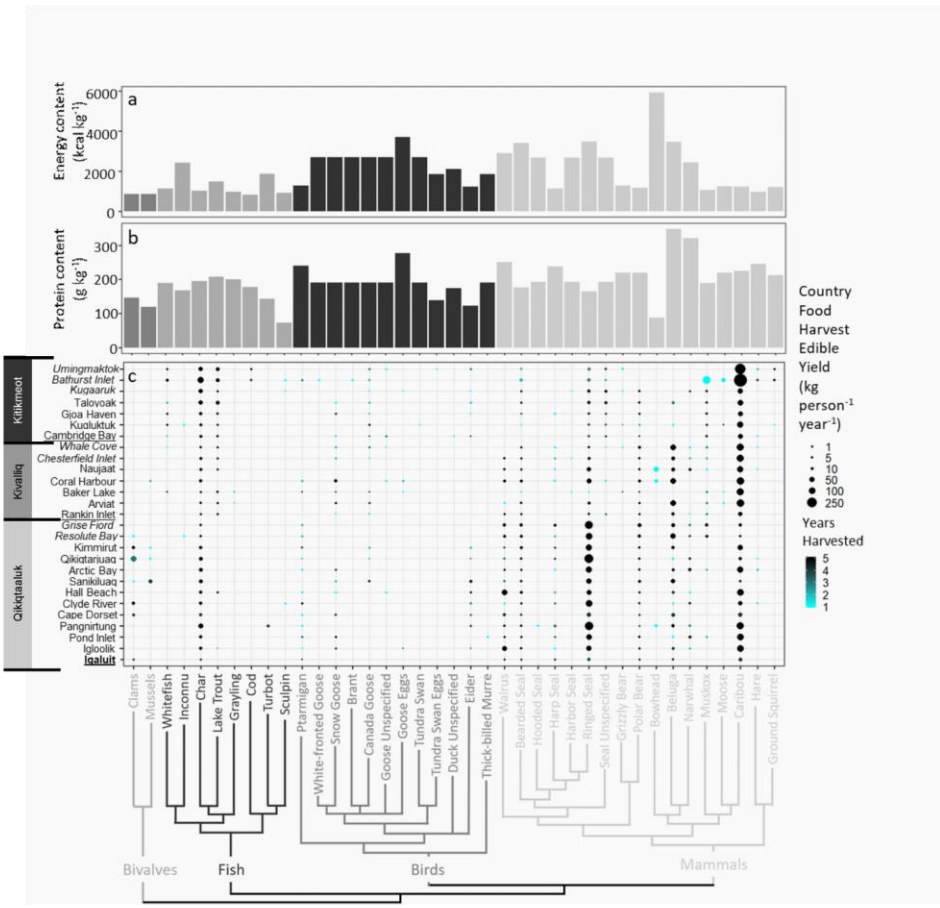

FIG. 2. Energy content (a), protein content (b), and reported edible harvest yields (c) of the 10 most harvested wildlife species for each Nunavut community. Nutritional content (a and b) is estimated per kg serving of consumed tissues (Tables S1, S2). Species-specific harvest (c) is reported in units kg person^{-1} year^{-1}. In (c), communities are grouped by region and ordered by population size (smallest communities at the top) with regional capitals at the bottom and underlined; italicized communities have reported harvest but are not included in subsequent analyses because store-bought food or income data are lacking. Wildlife species (or species categories) are ordered and dendrogram-connected according to hypothesized phylogenetic relatedness. For harvest level symbols, the blue (1 yr) to black (5 yr) colour ramp indicates the number of years (out of the five years surveyed) that a species was among the 10 most harvested species within a given community. Phylogenetic sources used to construct the wildlife species dendogram (c) include Dunn et al. (2014) for animals, Cotton and Page (2002) for vertebrates, Hughes et al. (2018) for ray-finned fishes (Lecaudey et al., 2018 for salmonid genera), Prum et al. (2015) for birds, Eo et al. (2009) for fowl genera, and Bininda-Emonds et al. (2007) for mammals (Nyakatura and Bininda-Emonds, 2012 for carnivore genera).

Comparing the energy and protein available in reported harvest to the RDA indicates that 17 of 21 Nunavut communities harvest enough country food to satisfy the protein requirements of all community members, whereas only one of 21 communities harvest enough country food to satisfy everyone's energy requirements (Fig. 3; Table S3).

Across Nunavut, store-bought food prices are high relative to reported incomes (Fig. 4). The cost of a RNFB with the Nutrition North subsidy included ranges from $382.38 per week ($19,883.76 annually) in Arviat to $478.19 per week ($24,865.88 annually) in Pangnirtung (Fig. 4a). The cost of a RNFB excluding the Nutrition North subsidy was, on average, 139% of the discounted price, ranging from 115% in Sanikiluaq to 178% in Arctic Bay. Median reported total income averaged $27,890 across 24 Nunavut communities, ranging from $19,220 in Sanikiluaq to $67 260 in Iqaluit (Fig. 4b).

Comparing annual store-bought food costs to reported incomes indicates that estimated store-bought food costs account for more than 50% of median total income in 19 of 21 Nunavut communities and more than 80% in 15 of 21 communities (Fig. 4c). This store-bought food poverty index varied widely among communities, reaching a maximum value in Sanikiluaq where food cost is 122% of median total income and much lower (relatively more affordable) values of 32% in Iqaluit (the territorial capital) and 45% in Rankin Inlet (Kivalliq's regional capital). This poverty index was more affected by variation in income than variation in food costs, because the former varied more (from $19,220 to $67,260) than the latter (from $19,884 to $24,866).

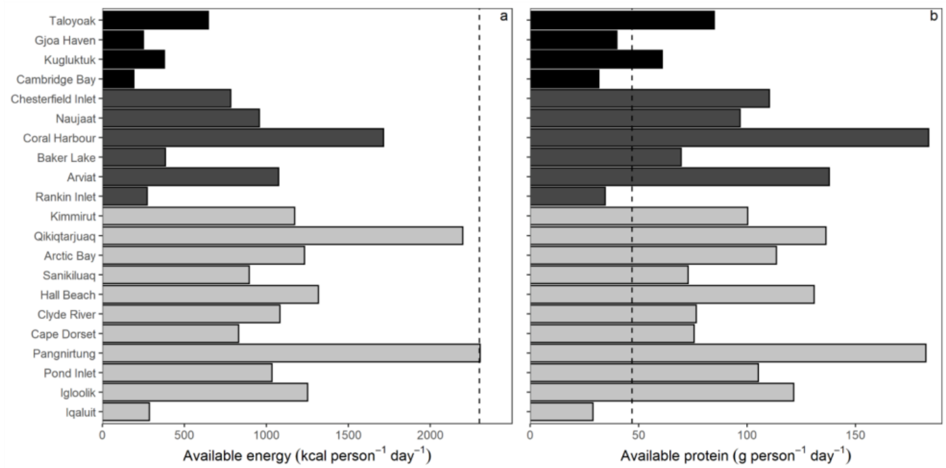

FIG. 3. Available energy (a; kcal person^{-1} d^{-1}) and protein (b; g person^{-1} d^{-1}) from reported country food harvest across Nunavut regions and communities, assuming homogenous distribution and consumption of harvest. Dotted lines represent average recommended daily allowances (RDA) for energy and protein.

The total country food energy harvested averaged 422.7 million kcal yr^{-1} per Nunavut community, ranging from 121.8 million kcal yr^{-1} in Resolute Bay to 1,372.5 million kcal yr^{-1} in Pangnirtung (Fig. 5a; Table S3). The country food protein harvest averaged 43,696 kg yr^{-1} per Nunavut community, ranging from (among data-complete communities), 16,472 kg yr^{-1} in Kimmirut to 139,676 kg yr^{-1} in Arviat (Fig. 5e; Table S3). Given a RNFB that was estimated to contain 69,419.6 kcal of energy and 3,097.1 g of protein, the energy cost of store-bought food across Nunavut communities averages \$0.0062 kcal^{-1}, ranging from \$0.0055 kcal^{-1} in Arviat to \$0.0069 in Pangnirtung (or excluding the Nutrition North subsidy, averages \$0.0087 kcal^{-1} and ranges from \$0.0066 in Arviat to \$0.0118 in Arctic Bay; Fig. 5b) and the protein cost of store-bought food in Nunavut averages \$0.140 g^{-1}, ranging from \$0.123 g^{-1} in Arviat to \$0.154 g^{-1} in Pangnirtung (or excluding the Nutrition North subsidy, averages \$0.195 g^{-1} and ranges from \$0.148 in Arviat to \$0.265 in Arctic Bay; Fig. 5f; Table S3).

Multiplying country food total energy harvested (kcal yr^{-1}) by the store-bought food energy cost (\$ kcal^{-1})indicates a country food energy replacement value ranging from \$736,127 yr^{-1} in Cambridge Bay to \$9.454 million yr^{-1} in Pangnirtung, totalling \$63.215 million yr^{-1} across all of Nunavut (or excluding the

Nutrition North subsidy, \$857.724 in Cambridge Bay, \$12.757 million yr^{-1} in Pangnirtung, and totalling \$87.889 million yr^{-1} across all of Nunavut; Fig. 5c, d). Multiplying country food total protein harvested (kg yr^{-1}) by the store-bought food protein cost (\$ kg^{-1}) indicates a country food protein replacement value ranging from \$2.301 million yr^{-1} in Kimmirut to \$17.242 million yr^{-1} in Arviat, totalling \$142.937 million yr^{-1} across all of Nunavut (or excluding the Nutrition North subsidy, \$3.168 million yr^{-1} in Cambridge Bay, \$22.665 million yr^{-1} in Pangnirtung, totalling \$198.845 million yr^{-1} across all of Nunavut; Fig. 5g, h; Table S4).

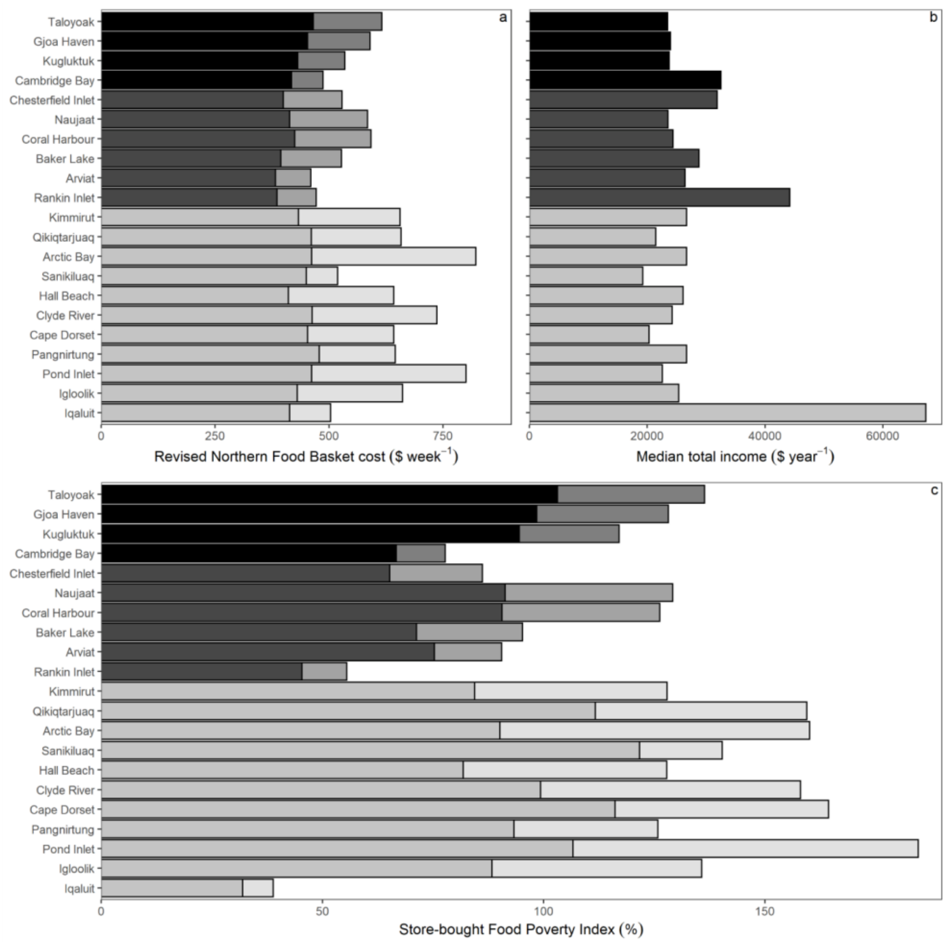

FIG. 4. Store-bought food poverty in Nunavut communities, based on (a) the weekly cost of a revised northern food basket (RNFB; \$ week^{-1}) reported for each community in 2016, including the discount provided by the Nutrition North subsidy (darker bar) or with this subsidy excluded (lighter bar), and (b) median total income (\$ y^{-1}). Expressing the cost of 52 RNFB as a percentage of median reported income generates (c) a store-bought food poverty index, which assumes a four-person household supported by a single reported total income.

Comparing indices highlighting country food wealth to those indicative of store-bought food poverty emphasizes a general pattern across Nunavut regions and communities—many smaller, more remote or more traditional Nunavut communities appear to offset store-bought food poverty with country food wealth, whereas the territorial capital of Iqaluit, and the regional capitals of Rankin Inlet and

Cambridge Bay have less country food wealth but greater affordability of store-bought food (Fig. 6). Communities that are partial exceptions to this pattern include Chesterfield Inlet and Arviat with higher than average store-bought food affordability and considerable country food wealth, and Gjoa Haven and to a lesser extent Sanikiluaq, which are characterized by low store-bought food affordability and limited country food wealth.

According to average energy and protein content of the consumed fraction of country food and its estimated store-bought food replacement value, a 1 kg serving of typical Nunavut country food has an energy value of \$13.19 kg^{-1} (or \$17.53 kg^{-1} excluding subsidy) and a protein value of \$30.17 kg^{-1} (or \$39.67 kg^{-1} excluding subsidy). Protein-replacement values and, in particular, protein-replacement values excluding the Nutrition North subsidy, are higher than most if not all previous estimates of local food value (Table 1).

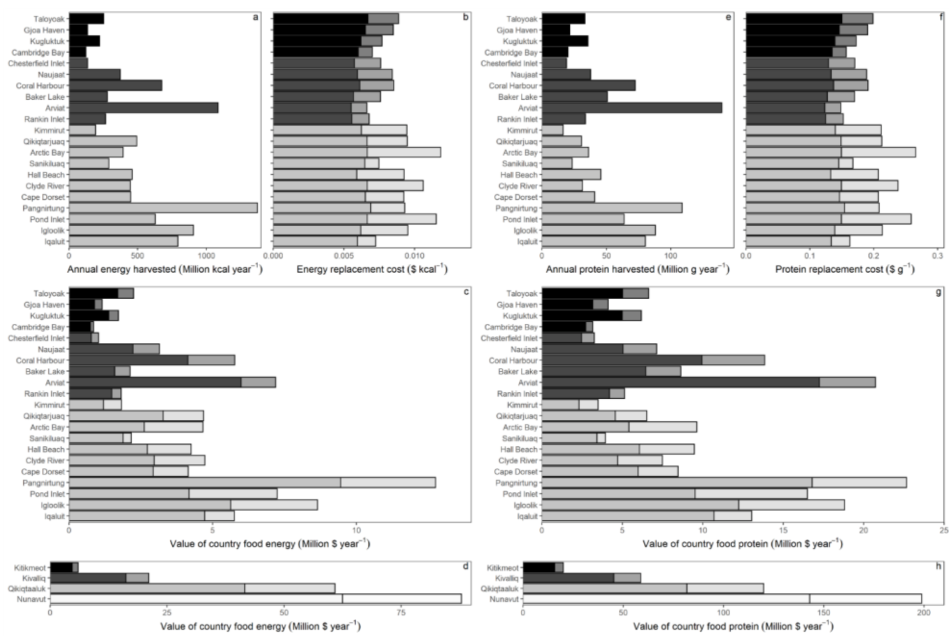

FIG. 5. Valuation of annual country food harvest across Nunavut communities and regions based on energy (a–d) and protein replacement (e–h). a) Annual energy harvested (million kcal yr-1) derived from reported country food harvest,

edible yield, and energy content of edible fraction. B) Store-bought food energy replacement cost, expressed as \$ $kcal^{-1}$, based on the cost and energy content of a revised northern food basket, including Nutrition North subsidy (darker bar) and excluding subsidy (lighter bar). C) Replacement value of country food energy by community (million \$ yr^{-1}), calculated as a product of (a) and (b), including (darker bar) and excluding (lighter bar) Nutrition North subsidy. D) Summed regional and territorial country food energy value (million \$ yr^{-1}). E–h) present equivalent information for protein replacement, including e) protein harvested (million g yr^{-1}), f) store-bought food protein replacement cost (\$ g^{-1}), g) country food protein value by community (million \$ yr^{-1}), and h) regional and territorial totals (million \$ yr^{-1}).

Based on an average country food value of \$39.67 kg yr^{-1} and 5 million kg yr^{-1} country food harvest across the territory, Nunavut's country food system annually harvests protein that would cost nearly \$200 million to purchase in grocery stores (Fig. 5h). In 2016, Nunavut reported \$2.27 billion in GDP, \$620 million of which was attributed to natural resource sectors. Comparing our \$150–200 million replacement value estimate to the \$3.5 million reported for the hunting, fishing, and trapping sector or to the Government of Nunavut (2021) estimated replacement value of \$35 million for the country food economy suggests the value of wildlife harvest to Nunavummiut and the Nunavut economy may be underestimated by two to three orders of magnitude.

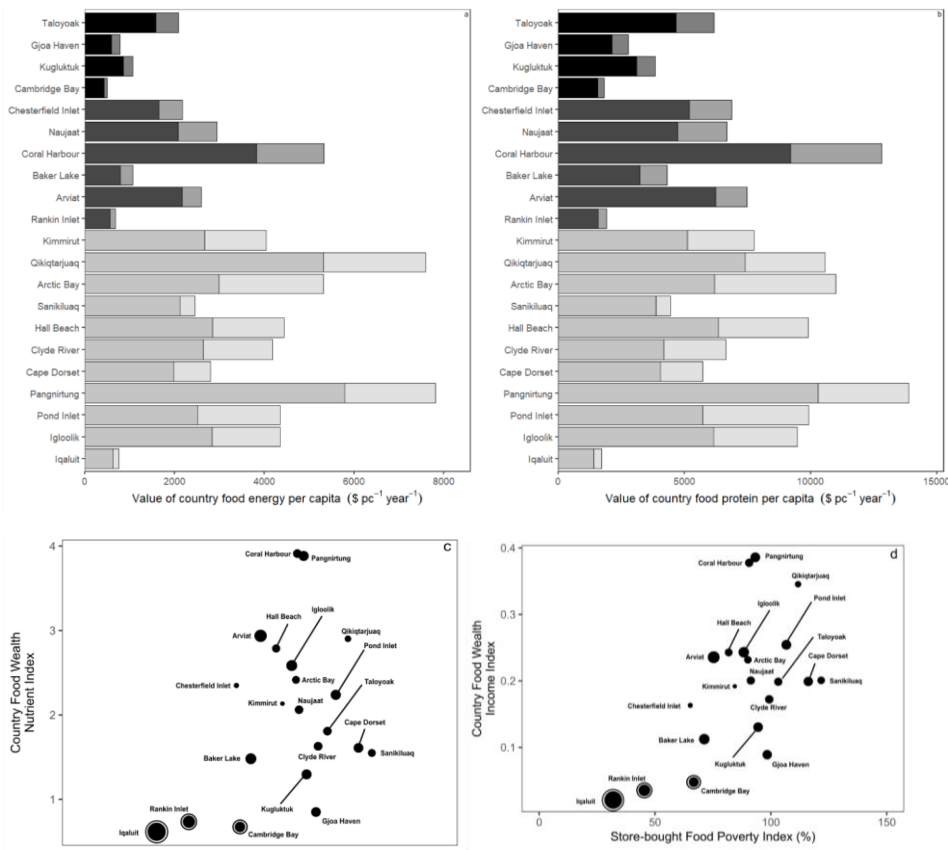

FIG. 6. Per capita valuation of annual country food harvest across Nunavut communities based on (a) energy and (b) protein replacement, and country food wealth and store-bought food poverty for Nunavut communities (c, d); size of symbol indicates population size and white outline indicates capitals (as in Fig. 1). The store-bought food poverty index reflects the cost of 52 store-bought food baskets (RNFB) expressed as a percentage of the median reported total income and is plotted in relation to two indices of country food wealth. (c) A country food wealth nutrition index focused here on harvested protein (g person^{-1} d^{-1}) expressed as a proportion or multiple of the recommended dietary allowance (RDA) for protein (g person^{-1} d^{-1}), and (d) a country food wealth income index focused here on the value of harvested protein ($ pc^{-1} yr^{-1}) expressed as a proportion of median annual reported income ($ yr^{-1}).

TABLE 1. Country food system valuations, expressed as 2016 $ kg-1, comparing our nutrient replacement-based valuations based on protein or energy (with or without the Nutrition North subsidy) to prior valuations based on mass replacement or exchange value.

Value ($ kg^{-1})	Basis of valuation	Region	Source
39.67	Protein replacement, local store-bought food cost, unsubsidized	Nunavut	Current study
35.52	Mass replacement, local store-bought food cost	Yukon	DeLury et al., 1975
30.17	Protein replacement, local store-bought food cost, subsidized	Nunavut	Current study
18.86	Mass replacement, local store-bought food cost	James Bay and Hudson Bay, Ontario	Berkes et al., 1994
17.61	Not clearly described in source	Alaska	O'Garra, 2017
17.53	Energy replacement, local store-bought food cost, unsubsidized	Nunavut	Current study
13.19	Energy replacement, local store-bought food cost, unsubsidized	Nunavut	Current study
17.81	Not clearly described in source	Nunavut	Wenzel, 2009
9.41	Mass replacement, local store-bought food cost	Fort Severn, Ontario	Pal et al., 2013
3.12	In community barter/exchange value	Banks Island, NWT	Usher, 1971

Discussion

Valuation of Nunavut's country food system, according to local prices of store-bought food required to replace harvested nutrients, indicates a territorial average replacement value of \$13 kg^{-1} for the energy and \$30 kg^{-1} for the protein contained in country foods. Values increase to \$18 kg^{-1} for energy and \$40 kg^{-1} for protein when store-bought food costs are not discounted by the Nutrition North subsidy programs. These valuations are higher than most financial values previously estimated for local food harvests (Usher, 1971; DeLury et al., 1975; Berkes et al., 1994; Wenzel, 2009; Pal et al., 2013) because they are more reflective of the energy and nutrient richness of country food (InterGroup Consultants Ltd., 2013) and the high and subsidized price of store-bought food in northern communities.

Scaling the \$40 kg^{-1} country food value across the totality of wildlife harvests documented during the five-year NWHS indicates the Nunavut country food system harvests protein worth \$198 million annually, dwarfing the \$3.5 million annual valuation applied to the hunting, fishing, and trapping sector by the Nunavut Bureau of Statistics. GDP-based valuation of natural resource sectors emphasizes the contributions of mining and oil and gas (> \$500 million in 2016, combined) to the Nunavut economy (GN, 2019), but the country food system may be more likely to generate wealth that stays in the territory and that is well-distributed across regions and households (Bernauer, 2019). Converting community-specific harvest data into nutrient yield indicates that the annual harvest of country food in Nunavut is sufficient to meet the RDA of protein for the entire population and about 50% of the population's energy requirements. Thus, our results converge with previous analyses of the NWHS, particularly Lysenko and Schott's (2019) demonstration of wildlife harvest contributions to food security and the importance of the mixed economy in the Nunavut food system.

The valuation approach described here, based on an Integration of data sources related to country food (harvest amounts, edible yield, and nutrient composition) and store-bought food (food basket costs, nutrient composition, and subsidization levels), has several important limitations. First, the NWHS harvest data represent reported harvests from 1996 to 2000. As is the case for all harvest surveys, reported harvest may not reflect actual harvest, and harvest levels are likely to change over time (Wenzel et al., 2016). For example, since the completion of the NWHS, most Nunavut caribou herds have declined dramatically, leading to caribou harvest restrictions (quotas or bans) and reduced caribou consumption, with presumed but poorly documented impacts on the rest of the Nunavut country food system (Kenny et al., 2018b). The socio-ecological system of Nunavut, specifically wildlife regimes, can mean that local food security is sensitive to both local ecology, but also regional harvest policies, which stresses the importance of long-term projects monitoring dietary change (Redwood et al., 2019). The population of Nunavut has also grown in this timeframe; the NWHS quotes the Inuit population of Nunavut at 22,947 in 1999 (Priest and Usher, 2004), while the 2016 Canadian census reported 30,140 Inuit residents of Nunavut (Statistics Canada, 2017). The increasing population poses the risk of further challenging food security in the region, requiring either increased total harvest levels or sharing less country food among more people if total harvest remains constant or declines. The complexity of the food system again underlines calls to ensure food security and wildlife management policy are treated in tandem, with health policy and wildlife management considered in relation to each other (Kenny et al., 2018b; Lysenko and Schott, 2019). Harvest surveys also exclude critical information on post-harvest processing, sharing, preparation, and consumption of food, which collectively define the extent and distribution of country food nutrition. Assumptions regarding edible yield fractions and nutrient composition of specific tissues have received considerable research attention and have been recently shown to yield estimates of intake that correspond well with food frequency surveys (Kenny and Chan, 2017). Nevertheless, the distinction between what is reported harvested and the actual food amounts and tissues consumed and by whom remains a key knowledge gap in harvest-based food valuations.

Data on the price and nutritional value of store-bought foods in northern communities has improved over time, but key uncertainties remain, including seasonal variation in the cost and availability of store-bought food, the consumer impact of store-bought food subsidies across a series of program transitions (Duhaime and Édouard, 2015; Galloway, 2017; St-Germain et al., 2019), and three issues related to the replaceability of harvested nutrients using store-bought food (see also Kenny et al., 2018c). The first replacement issue is whether energy and protein replacement should be valued separately (i.e., food value = protein value or energy value) as we have done here, or additively (i.e., food value = protein value + energy value), which would be more appropriate if the protein and energy content of country foods are replaced independently through the purchase of separate foods.

A second, related replacement issue involves the combination of store-bought food items used to substitute country food. Our valuation assumes the substitution occurs via the purchase of a RNFB, because this collection of items is intended to reflect healthy store-bought food and because price and nutritional data are available for these items. Actual substitutions may be more or less strategic. For example, if in-store food purchases target foods that are more nutritious (i.e., contain more protein and energy) and less expensive than the RNFB average, then our country food valuation may be an overestimate (because people will have obtained more store-bought protein and energy at less cost than we have estimated). Conversely, if store-bought foods are typically less nutritious or more expensive than the RNFB, then we may have underestimated the value of country food. The literature about traditional food systems tends to highlight the contribution these foods make to essential dietary nutrients and the relative nutrient richness of these foods over alternatives (Kuhnlein and Receveur, 2007; Rosol et al., 2016; Kenny et al., 2018a, b, c).

Third, our replacement valuation considers only energy and protein replacement and thus excludes consideration of all the additional macronutrients and micronutrients acquired through or associated with country food, such as iron, zinc, and potassium (Receveur et al., 1997; Kuhnlein and Receveur, 2007;

Blanchet and Rochette, 2008; Egeland et al., 2011; Rosol et al., 2016), as well as all the values of country food beyond nutrition, including sharing, knowledge, culture, well-being, and identity (Borré, 1991; Condon et al., 1995; Kuhnlein et al., 2004; Lambden et al., 2007). The non-nutritional benefits of country foods have been estimated to represent several multiples of their nutritional value (O'Garra, 2017), but are difficult to quantify, precisely because of their lack of substitutability and their irreplaceability. Country food is, in many and important ways, priceless.

This study emphasizes the country food wealth of Nunavut communities and the enormity of country food contributions to nutrition and food security in the region. Country food is also culturally relevant food, an essential attribute that is deliberately incorporated in the very definition of food security (FAO, 1996). Food affordability is a globally recognized barrier to food security, with food costs that exceed 80% of income indicative of severe food poverty (Lee et al., 2013). Averaged across Nunavut communities, the purchase of store-bought food for a family of four for one year (52 RNFB = $22,489) requires 81% of a single median income (Nunavut community average = $27,890). This store-bought food poverty index increases to 94% when averaged across Nunavut communities other than the regional and territorial capitals of Iqaluit, Rankin Inlet, and Cambridge Bay, where reported incomes are higher ($67,200, $44,000, and $32,540, respectively), food costs are lower ($21,486, $20,067, and $21,708, respectively) and the index therefore more favourable (32%, 45%, and 67%, respectively). The presented measures of food affordability are sensitive to the assumed four-person household supported by a single median income earned in a region where household crowding and unemployment are high (Minich et al., 2011). Our analysis is based on a 3:1-dependant:income ratio family unit and will be sensitive to fluctuation in this ratio caused by housing circumstances; increases in the ratio of dependents will cause lower food affordability as family income is stretched thinner. Lysenko and Schott (2019) have explicitly emphasized food security metrics that can capture the particularities of a mixed food system in Nunavut, combining traditional harvesting, food sharing, wage income, and store-bought food affordability. Improving measures of food poverty require reducing the price of store-bought food, increasing incomes, or both. The Nutrition

North federal subsidy program already reduces the cost of store-bought food in Nunavut by about 28%. In the absence of this subsidy program, the food poverty index averaged across all Nunavut communities would be 122% and that of Nunavut communities excluding regional capitals would be 133%. However, alternative measures of food poverty and food wealth are needed in Nunavut and other regions where store-bought food is not the only food, and reported incomes are not the only form of community and household wealth (see Lysenko and Schott, 2019 for further discussion of food poverty).

An Inuktitut word for country food, niqituinnaq, which translates as real food, emphasizes the primary importance of food that does not come from the store (Wenzel, 1991, 2016). Our results, including country food wealth nutrition and income indices, highlight the magnitude of country food wealth across Nunavut communities and the concentration of country food wealth within communities characterized by the most extreme store-bought food poverty. Importantly, the country food valuations we present here are gross values that do not incorporate the financial and equipment costs of harvest. Hunting in Nunavut is expensive, and financial barriers to country food access can be as important and severe as the financial barriers to store-bought food. Country food may be priceless, but it is not free; maintaining and improving access to country foods also requires financial resources. The availability of certain country food species is affected by natural variation in population levels, and food security planning must account for this. The literature indicates that communities consuming a diverse diet are best able to adapt to the loss or reduction in harvest levels of one species (Beaumier et al., 2015). Traditional knowledge across a range of harvested species has also been shown to assist climate change adaptation by permitting the harvest of alternative species when the abundance or access to a primary species declines (Ford et al., 2008; Wenzel, 2009).

The methods of country food valuation described here should be applicable to other regions within Inuit Nunangat and to the traditional and local food systems of Indigenous cultures living elsewhere in North America and across the globe. Several authors have now stressed the importance of describing Indigenous food security in a manner that accommodates the importance of local food alongside many other systematic elements contributing to household food security (Kenny et al., 2018b; Lysenko and Schott, 2019). Money does not define the country food system, but given the wealth country foods represent and the biocultural opportunity for sustained use of renewable resources for remote, northern regions, financial investment in the country food system, ranging from harvester income support to effective wildlife conservation, may be as or more effective than efforts focused on improving the affordability of store-bought food.

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Chapter 4 linkage

In the previous chapter, I investigated the Nunavut Wildlife Harvest Study (NWHS), along with price, income and nutrient data, to describe the replacement value of harvesting and the nutrients supplied by the harvest, while comparing this to the [in]affordability of store-bought foods. Chapter 4 combines methods developed in Chapter 2 (i.e., integration of harvest and food use surveys) and chapter 4 (i.e, assessment of local food nutritional adequacy and economic value) to estimate numeric, nutritional, and value gaps between reported food use in the 2000's and guaranteed levels of harvest levels established in the 1970's by the James Bay Northern Quebec Agreement for the Cree region of Eeyou Istchee and the Inuit region of Nunavik. This analysis offers a description of change over time, and an estimated value of that change.

Chapter 4: Estimated numeric, value, and nutritional gaps between guaranteed harvest levels and local food use in Nunavik and Eeyou Istchee

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Abstract

The rights of Indigenous Peoples to harvest wildlife for food has long been legally recognized across Canada, with some more recent environmental impact or land claim agreements specifying guaranteed levels of harvest. Tracking whether guaranteed harvest levels are or are not being realized is challenging but can be indirectly assessed using dietary recall studies. Here we compare reported food use in the Cree region of Eeyou Istchee and the Inuit region of Nunavik relative to guaranteed levels of harvest levels established in the 1970's by the James Bay Northern Quebec Agreement, to estimate numeric, value and nutritional gaps between what was guaranteed and food use reported three decades later.. Estimated total use declined by nearly 50% in both regions between the 1970's and the 2000's. Given substantial population growth during the same period, this reduction in total use translates to an 85% decrease in per capita use in Nunavik and a 74% decrease in per capita use in Eeyou Istchee. Reported use was sufficient to satisfy 100% of the population's protein requirements in the 1970's but in the 2000's provided for only 51% of recommended dietary allowances in Nunavik and 40% in Eeyou Istchee. This represents an estimated $20 million annual value gap between guaranteed levels of harvest established in the 1970's and food use reported in the 2000's, representing close to half a billion dollars of food not coming from the land and into communities in the last two decades. A major conclusion of this analysis is that information about local food systems is inconsistent, incomplete, and dated. However, given indirect evidence of dramatic change in the nature and extent of local food systems relative to legally-binding benchmarks, more and better information about these systems is an important regional, national, and international knowledge priority.

Introduction

Indigenous food systems are grounded in the culture of harvesting, consuming, and conserving local biodiversity for health and wellness (Kuhnlein & Receveur 1996; Kuhnlein, Erasmus & Spigelski 2009; Lemire et al. 2015; Kenny et al. 2018a). Reliance on local wildlife as a source of food and nutrition for people connects the abundance and distribution of wild plants and animals ((Kuhnlein & Humphries 2017; Kenny et al. 2018), the health of the people to the health of the land (Dudley et al., 2015), and subsistence economies and livelihoods (Wenzel 2000, Hickey at al. 2016). Better documentation of the importance of Indigenous food systems and a clearer understanding of the impacts of social and environmental change on these systems, including the many community benefits they generate, are widely described as a northern research priority requiring multidisciplinary approaches (CCA 2014; Little et al. 2021)

There are many challenges involved in communicating the extent, value, and evolution of local Indigenous food systems, many of which are related to the personal, protected, and interdisciplinary nature of the local livelihoods of Indigenous Peoples. Natural resource sectors like oil and gas, mining, forestry, and agriculture generate earnings and outputs that are quantifiable, similar to other economic sectors (Repetto et al. 1989). Wildlife harvesting is a key natural resource sector in many regions of the world, especially where human population densities are low and natural habitats are abundant, but is a special case in that it encompasses three forms of harvest activities differing widely in regulatory and reporting structures; i) commercial wildlife harvest, including fisheries and fur, for which the products of harvest are sold commercially and thus are quantified similar to other natural resource sectors, ii) recreational harvest associated with sport hunting and fishing, which can be monitored through license sales and may be subject to mandatory harvest reporting or voluntary harvest surveys, and iii) subsistence harvest by aboriginal rights holders, which requires no license, no mandatory reporting, and in most cases does not yield commercially sold products(Tober 1981; Craig et al. 1993; Hessami et al. 2021). As a result, subsistence harvest is not regulated, quantified, or monitored in the same way as the recreational or commercial harvest of wildlife. Among those participating in the subsistence economy, the system may be well known, quantified, communicated, and regulated, but for those operating outside the system it may resemble an informal, unreported, and unregulated local economy (Wenzel 2009; Rodon & Schott 2015; Natcher 2015; Lysenko & Schott 2019). In addition, local Indigenous food systems span culture, health, economy, and environment, whereas the methods used to describe them tend to be constrained to particular disciplinary approaches and interpretations (Usher & Wenzel 1987; Chan et al. 2006; CCA 2014; Cidro et al. 2015).

An important exception to the general condition of local Indigenous food systems not being systematically described can arise from negotiations surrounding mega-development projects, Indigenous self-governing agreements, or concerns over contaminant exposure and nutrition. Under these conditions, disclosure of information about local harvest, livelihoods, and food consumption is more likely to be understood by communities to contribute to the protection of local Indigenous food systems rather than their exploitation or infringement (Usher & Wenzel 1987; Furgal, Powell & Myers 2005; Angell and Parkins 2011; Thompson et al. 2019). These conditions can, at the same time, provide the funding and contribute to the alignment of the extensive researcher-community collaboration required to complete systematic harvest and food consumption surveys. This combination of necessary conditions required for the systematic description of local Indigenous food systems has not been consistently and sustainably present across most northern regions, at least not in the past, meaning that these systematic descriptions have tended to be region, time point, and purpose specific. The regional, period, and purpose specificity of these surveys has made it challenging to describe regional differences or similarities in local food use (but see Tremblay et al. 2020) and particularly difficult to assess change or consistent over time in local food use within the same region and especially across different regions.

Despite the paucity of systematic data on subsistence harvest and local food use, there are clear indications that local food use and food systems are changing, including a nutrition transition from reliance primarily on locally harvested food to store-bought food (Receveur, Boulay & Kuhnlein 1997, Kuhnlein et al. 2004, Little et al. 2020; Little et al. 2021). This nutrition transition has been described across many regions (Kuhnlein & Receveur 1996, Delormier & Kuhnlein 1999, Damman et al. 2008, Johnson-Down & Egeland 2013, Chee et al. 2019, Fernandez 2020). The high cost of store-bought food, combined with low incomes and limited access to wage economies, is a widely identified barrier to food security in northern regions. A dietary shift towards energy-dense, nutrient-poor, processed foods has been identified as contributing factor to high rates of obesity and diabetes in many northern regions (Kenny et al. 2018a; Huet, Rosol & Egeland 2012; Zotor et al. 2012; Kolahdooz et al. 2013). Widespread declines of key wildlife species, including many migratory and boreal caribou herds (Vors & Boyce 2009), as well as some marine mammals (Lesage 2021) and fish stocks (d'Amours & Dion 2019), have resulted in reduced harvest and, in some cases, harvest quotas or moratoria (Kenny & Chan 2017). Land use change, an economic shift towards wage economies, a transition to more time in community and less time on the land, changing community demographics, and the loss of Elders and experienced knowledge holders all create challenges to the integrity of local food systems (Batal et al. 2021). Despite all this change and these challenges, local food systems remain a culturally-prioritized, highly-valued, central contributor to daily life in northern communities.

The Cree territory of Eeyou Istchee and the Inuit territory of Nunavik comprise most of Northern Quebec, bordering James Bay and Hudson Bay to the east, Hudson Strait to the north, and Ungava Bay to the West. Non-Indigenous economic interests have operated in this region since 1668, when Fort Charles was founded as a trading post (now Waskaganish, previously called Fort St. Jacques, Fort Rupert and Rupert House as well; Francis and Morantz1983). In 1670 territory was parcelled into Rupert's Land by royal charter, granting the Hudson's Bay Company exclusive and monopolistic right to the territory. As such, the territory was never covered by Numbered Treaty. This territory was sold by the Hudson's Bay Company to Canada in 1870, and finally transferred from the North-West Territories to Quebec in 1912 as part of the *Quebec Boundaries Extension Act, 1912*. The Inuit and Cree populations living in northern Quebec were not signatories of any of these transfers, sales, and agreements, nor were they consulted. However, a section within the boundary extension agreement urged Quebec to recognise Indigenous rights within the transferred territory, and to negotiate treaties within the territory (Section 2c; Scott 2003). This would not be undertaken until the signing of the James Bay and Northern Quebec Agreement (JBNQA) in 1975. In November 1975, prompted by hydro-electric development envisioned by the James Bay Project, the Cree of James Bay, the Inuit of Nunavik, and the governments of Canada and Quebec signed the James Bay and Northern Quebec Agreement (JBNQA). The JBNQA created a new legal framework defining local self-government, land management, and protection of traditional ways of life in northern Quebec (Feit 1979;

Peters 1999; Rodon 2014). Section 24 of the JBNQA established a harvesting regime for Cree and Inuit lands, recognizing a co-management committee composed of Native and government members, referred to as the Hunting, Fishing and Trapping Coordinating Committee, reviews, manages, supervises, and regulates the regime.

Fundamental to the harvesting regime negotiated between the Cree, Inuit, and Quebec via the JBNQA is the idea of guaranteed harvest levels, a total count of animals coming off the land that may not be unilaterally modified. These counts were made by studies intended to quantify levels of harvesting of wildlife by the Cree and Inuit in northern Quebec. Section 24 of the JBNQA covers Hunting and harvesting, with Sections 24.1.14 and 24.4.30 explaining "harvest levels", measured in carcasses, and Section 24.6.2 specifying:

> *"The principle of priority of Native harvesting shall mean that in conformity with the principle of conservation and where game populations permit, the Native people shall be guaranteed levels of harvesting equal to present levels of harvesting of all species in the Territory."*

Because present levels of harvesting were documented as an annual number of animals harvested per species and were specified on a community-specific basis, the guarantee refers to a community-based quota of individual animals harvested, rather than a volume quota system (as is common in fisheries) or as a per capita quota that would allow for altered harvest levels as population size changes. The JBNQA harvest surveys conducted in the 1970's provide unique information about the regional nature of local Indigenous food systems, because they systematically document harvest levels in two distinct biocultural regions – the Cree region of Eeyou Istchee and the Inuit region of Nunavik – during the same time period and using similar methodology. These harvest surveys are also unique in that they established guaranteed levels of harvest, a legally-binding benchmark against which subsequent surveys can be compared. Although the JBNQA harvest surveys have never been replicated, food frequency surveys completed in Nunavik and Eeyou Istchee in the early 2000's provide a more recent assessment of local food use that can be compared against the guaranteed levels of harvest benchmark. These food frequency surveys arose from two independently conducted health surveys, the 2004 Qanuippitaa? How are we? Nunavik Inuit Health Survey (Bonnier-Viger et al. 2007) and the 2005-2009 Nituuchischaayihtitaau Aschii Environment-and-Health Longitudinal Study in Eeyou Istchee (Nieboer et al. 2013), both of which intended to assess the overall health of Indigenous populations, including contaminant exposures through consumption of local food species.

Here we integrate results from harvest and food frequency surveys spanning the biocultural regions of Nunavik and Eeyou Istchee and a 30-year interval since the signing of the JBNQA to assess numeric, nutritional, and value gaps in reported food use relative to guaranteed levels of harvest. To do so, we use cross-survey methods introduced by Kenny and Chan (2017), combined with valuation metrics and nutritional comparisons introduced by Warltier et al. (2021 [chapter 3 of this thesis]). These approaches allow us to estimate if reported food use in the 2000's appears consistent with guaranteed levels of harvest negotiated in the 1970's, and the value and nutritional gaps associated with estimated differences. This two-region and four-survey comparison offers a unique opportunity to communicate the extent, value, and evolution of local Indigenous food systems in relation to legally binding guaranteed levels of harvest.

Methods

Data

The following analyses are based on harvest surveys conducted in the 1970's in Eeyou Istchee (James Bay and Northern Quebec Native Harvesting Research Committee 1982; hereafter JBNQNHRC 1982) and Nunavik (JBNQNHRC 1988) and food frequency questionnaires conducted in the 2000's in Eeyou Istchee (Bonnier-Viger et al. 2007, Nieboer et al. 2011, Nieboer et al. 2013) and Nunavik (Rochette and Blanchet 2007, as reported in Lemire et al. 2015).

1970s Reported Harvest

The Wealth of the Land study reported harvest of the 32 species for each of the eight Cree communities included in the harvest study. The body size and consumed edible fraction of harvested species, as well as community population size were also reported by JBNQNHRC (1982), permitting estimation of annual reported harvest in individuals per year, edible kg per year, and edible kg per person per year. Populations used in analysis are 5-year averages from the period of the harvest studies.

The Inuit of Nunavik study reported harvest of the 40 species groups for each of the 13 Inuit communities included in the harvest study. Unlike the Cree harvest study (JBNQNHRC 1982), JBNQNHRC (1988) does not include estimates of the body size and consumed edible fraction of harvested species. Accordingly, edible yield mass for species harvested in Nunavik was obtained from Ashley (2002); for species with multiple masses reported in Ashley (2002), masses from the James Bay region were used. Combining information from these three sources permitted reporting annual reported harvest estimates for the 40 species categories in individuals per year, edible kg per year, and edible kg per person per year.

2000s Reported food consumption

The Nituuchischaayihtitaau Aschii Environment-and-Health Longitudinal Study in Eeyou Istchee (Nieboer et al. 2013) was conducted in during two- to four-week period during the spring and/or summer in Mistissini in 2005 (Bonnier-Viger et al. 2007), Eastmain and Wemindji in 2007 (Nieboer et al. 2011), Chisasibi and Waskaganish in 2008 (Nieboer et al. 2013), and Waswanipi and Whapmagoostui in 2009 (Nieboer et al. 2013).

The study component relevant to analysis presented here was an assessment of the intake frequencies of traditional foods. This assessment documented use across 49 local food categories representing different species (e.g., Category 22. Sturgeon) or species groups (e.g., Category 24. Red or white sucker) as well as different parts and cooking methods of a single species (e.g., Category 4. Moose meat dried; 5. Moose meat cooked; 6. Moose liver or kidney). Results from this survey are presented as a series of community-by-community tables (Tables A7.2A-D in Nieboer et al. 2013), with seasonal responses combined into annual totals representing the % of respondents reporting consumption of the food category and, if consumed, the days/month that it was consumed. To facilitate species comparisons, we summed food categories representing different parts or cooking methods of the same species, which reduced the number of species categories to 24. Then, focusing on the total population estimate, we multiplied the percent of respondents who reported consumption by total population to calculate the number of consumers of a species in a specific community. The number of consumers was multiplied by the day/ month consumed to estimate the total meals of a species consumed in a community. This was then multiplied by 12 to obtain a days/year estimate. Although portion sizes for all or some of the food categories appear to have been estimated as part of the 2005 Mistissini survey (Bonnier-Viger et al. 2007), these results were not included in Bonnier-Viger et al. 2007 or Nieboer et al. (2013). Accordingly, we calculated the average daily portion size across all local foods reported in Sheehy et al. (2013) and multiplied this 174 g average portion size by the days/year estimate to obtain a consumed kg per person per year (kg/p/y) estimate. These studies were not performed in the same year and thus community population at the time of sampling is reported.

The *Qanuippitaa? How are we?* Nunavik Inuit Health Survey was a cross-sectional study conducted in the fall of 2004 (August 27 to October 1) on a representative sample of the Inuit population (889 adults aged between 18 and 74 years old) present in the 14 communities of Nunavik (Rochette and Blanchet 2007). The country food portion of the questionnaire documented use across 49 local food categories representing different species (e.g., lake whitefish), species groups (e.g., trout and salmon), different parts and cooking methods within a single species (e.g., beluga mattaaq, beluga blubber, beluga meat), and preparation methods inclusive of multiple species (e.g., Pitsik made from Arctic char, brook trout or lake whitefish). Multiple tissues from a single species (e.g. caribou meat, liver, heart) were all merged into a “Caribou” category to estimate the available food per species. The questionnaire estimated consumption frequency of the different food items (days per year) as well as item-specific daily portion size (grams), allowing an estimate of annual consumption in kg per person per year (kg/p/y). Summary data from this food frequency questionnaire are published in Lemire et al. (2015), with survey results presented for three Nunavik regions (Hudson Bay, Hudson Strait, and Ungava Bay) and for Nunavik as a whole. However, results presented by Lemire et al. (2015) focus only on adult female respondents and the intake values presented in Table S4 are expressed per unit body mass of respondents (g consumed/kg body mass/year). We used reported adult female body masses from three regions (Lemire et al. 2015; Table 1) to re-express consumption values as kg per person per year in each of the three regions. Using these regional rates multiplied by the population of each community in a region gives an estimate of total community consumption by species. Community populations are taken from Levesque and Duhaime (2019). Per capita consumptions rates for communities in the same region are identical because reported use was regionally aggregated in Lemire et al. (2015).

Analysis

This analysis is based on the valuation methodology first described in Warltier et al. (2021). Modifications have been made for areas outside of the service area of Nutrition North Canada, using local reports on food costs for National Nutritious Food Basket (NNFB, Vinet-Lanouette and Godin 2017).

Energy and protein content for harvested and market foods were taken from the Canadian Nutrient File (CNF), or where data for harvested food was unavailable, CINE's Traditional Animal Foods database (parallel to Kenny et al. 2018b). Foods that appeared in neither database were assigned a value from the most closely related species for which data were available (Valita et al. 2018). Combined with total and per capita edible harvests these data allowed for an estimation of harvested nutrients on a total and per capita basis.

Harvested nutrients were assessed for adequacy using an average of Health Canada's Recommended Daily Allowances (RDAs) as described in previous research (Warltier et al. 2021). Annual per capita harvested nutrients were converted into daily amounts and compared to average RDA's of 2300 kcal/day and 47 grams of protein/day.

Nunavik communities are serviced by Nutrition North Canada (NNC) and the revised northern food basket (RNFB), the total nutritional content of which is presented in Warltier et al. (2021) allowing for the calculation of a price per kilocalorie and gram of protein in Nunavik. However, Eeyou Istchee is not serviced by NNC, thus regional nutritional costs needed to be derived from another source. Vinet-Lanouette and Godin (2017) report community costs for a Nutritious Food Basket, the contents of which are also reported. Total content analysis was performed with the assistance of the Canadian Nutrient File (CNF) database. Community specific unit values for energy and protein were derived from the community prices of baskets.

Using the NFB value of nutrients in Eeyou Istchee and the RNFB in Nunavik, an estimated cost to replace harvested nutrients was constructed for each community, presented both as a total and as a share per community member.

Results

There is a large numeric gap between guaranteed harvest levels established in the 1970's and use estimated from food frequency surveys conducted in the 2000's (**Figure 1**). This gap is present among four of the five major species harvested in Nunavik (**Figure 1B**), including approximately 1,500 less caribou, 300 less beluga, 1,200 less ringed seal, and 900 less bearded seal estimated to have been consumed annually in 2000's compared to the edible yield available from 1970's harvest. Arctic char is the only major species in Nunavik estimated to be consumed more in the 2000's than it was harvested in the 1970's. Numeric gaps are present for all five of the major harvested species in Eeyou Istchee (**Figure 1C**), including approximately 575 less moose, 10,000 less geese, 14,000 less beaver, 80,000 less whitefish, and 100 less caribou estimated to have been consumed annually in 2000's compared to reported harvests in the 1970's.

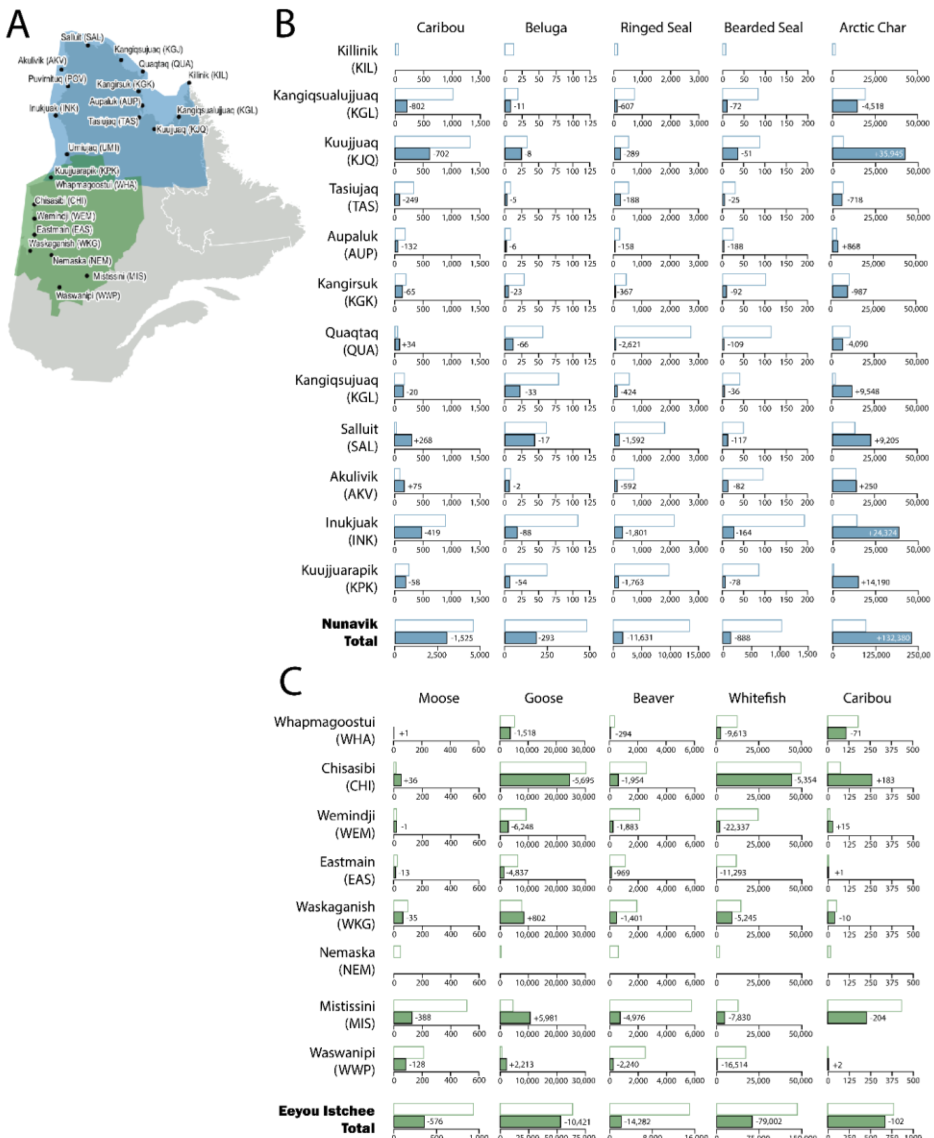

Figure 1. Numeric gaps between guaranteed harvest levels established in the 1970's and harvest numbers estimated from food frequency surveys conducted in the 2000's. **A.** Nunavik (blue area) and Eeyou Istchee (green area) communities and community abbreviations included in the analysis. **B.** Numeric gaps for Nunavik communities between guaranteed harvest levels established in the 1970's (open bars) and harvest numbers estimated from food frequency surveys conducted in the 2000's (blue bars). **C.** Numeric gaps for Eeyou Istchee communities between the 1970's (open bars) and the 2000's (green bars). Numeric data are presented for the top five species harvested in each region, based on edible yield estimates (kg/p/yr) from the 1970's harvest surveys. Numbers indicate the estimated

reduction (negative values) or increase (positive values) in total animals used from the 1970's period to the 2000's period. The three letter codes in brackets after community names are used as community identifiers in subsequent figures.

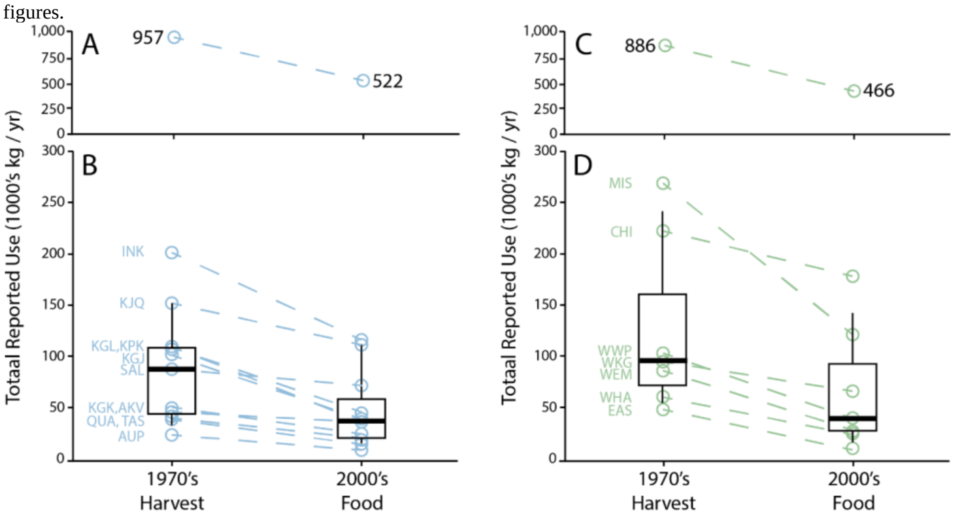

Figure 2. Estimated total wildlife use (kg/yr) in **A.** Nunavik as a whole, **B.** specific Nunavik communities, **C.** Eeyou Istchee as a whole, and **D.** specific Eeyou Istchee communities. Box plots in B and D indicate 10th and 90th quantiles (vertical line min and max), 25th and 75th quantiles (boxes), and median (thick horizontal line) values for community-level estimates. Community abbreviations are indicated in **Figure 1**.

Expressing estimated use from the two periods as total edible yield indicates Nunavik communities collectively harvested an edible yield of 957,000 kg/yr in the 1970's and consumed 522,000 kg/yr in the 2000's (**Figure 2A**), a 45% decrease. All Nunavik communities appear to be characterized by a decline (**Figure 2B**), with Salluit characterized by the smallest and Inukjuak the largest estimated decline. Eeyou Istchee communities collectively harvested an edible yield of 886,000 kg/yr in the 1970's and consumed 466,000 kg/yr in the 2000's (**Figure 2C**), a 47 % decrease. All Eeyou Istchee communities appear to be characterized by a decline (**Figure 2D**; noting Nemaska has no 2000's data), with Chisasibi characterized by the smallest and Mistissini the largest estimated decline.

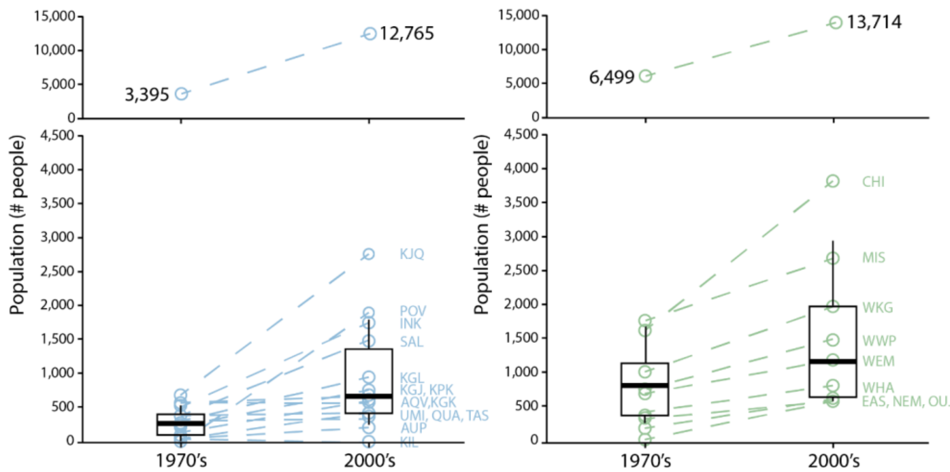

Figure 3. Population growth in northern Quebec between 1970's and 2000's, for **A.** Nunavik as a whole, **B.** specific Nunavik communities, **C.** Eeyou Istchee as a whole, and **D.** specific Eeyou Istchee communities.

Both Nunavik and Eeyou Istchee were characterized by substantial population growth between the 1970's and the 2000's (**Figure 3**). During this period, the total population of Nunavik increased from 3,339 to 10,545 people, an increase of 316%, while the total population of Eeyou Istchee increased from 6,649 to 13,714 people, an increase of 206%. In both regions, larger communities like Chisasibi and Kuujjuaq were characterized by the largest population growth, both in absolute numbers and in percentage increase.

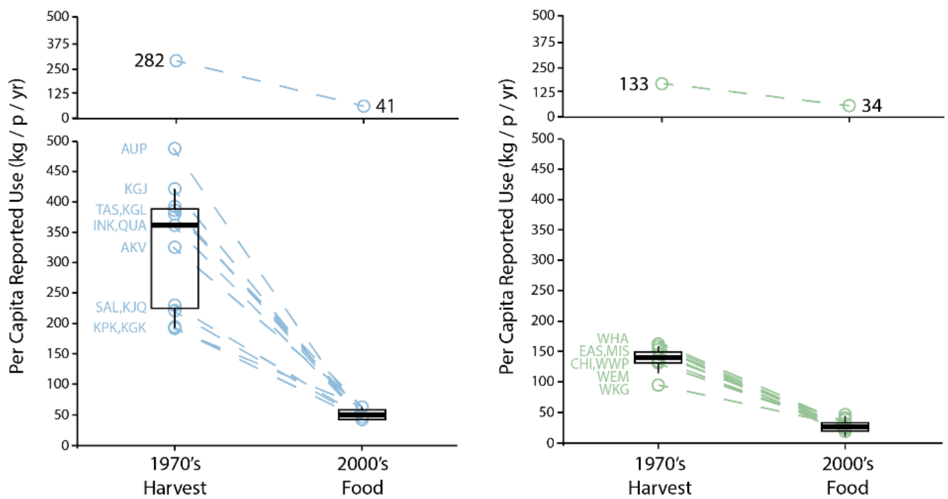

Figure 4. Estimated per capita wildlife use (kg/p/yr) in **A.** Nunavik as a whole, **B.** specific Nunavik communities, **C.** Eeyou Istchee as a whole, and **D.** specific Eeyou Istchee communities.

Expressing harvest and food use estimates from the two periods as per capita measures, which includes both the effect of declining numbers of animals used (**Figure 2**) and increasing population size (**Figure 3**), indicates a pronounced decline in per person local food use between the 1970's and 2000's in both regions and all communities (**Figure 4**). In Nunavik, there was an 85% decline between the 1970's per capita edible yield of 282 kg/p/yr and 2000's consumption of 41 kg/p/yr (**Figure 4A**). All Nunavik communities appear to be characterized by a dramatic decline (**Figure 4B**). In Eeyou Istchee, there was a 74% decrease between a 1970's per capita edible yield of 133 kg/p/yr and 2000's consumption of 34 kg/p/yr (**Figure 4C**). All Eeyou Istchee communities appear to be characterized by a dramatic decline (**Figure 4D**), albeit starting from a lower per capita value in the 1970's in Eeyou Istchee than in Nunavik.

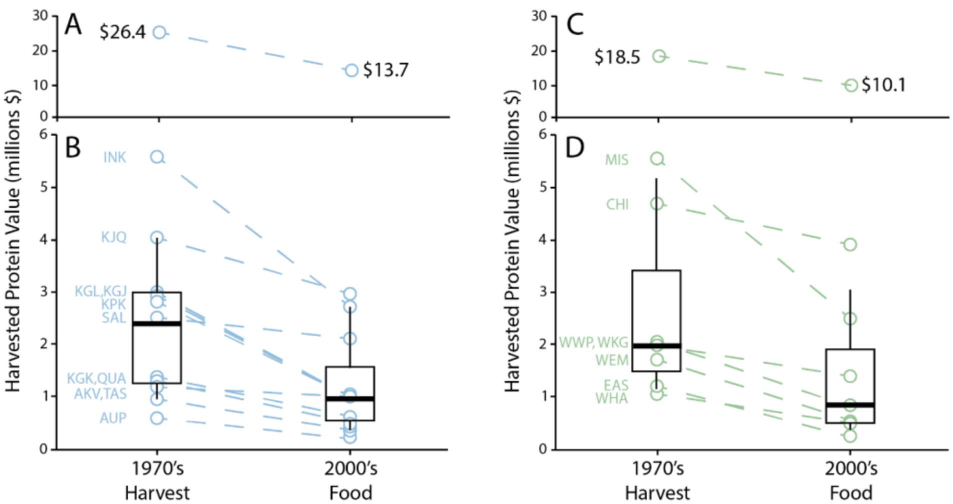

Figure 5. Replacement valuation (millions of dollars) of total protein harvested annually in the 1970's and consumed annually in the 2000's for **A.** Nunavik as a whole, **B.** specific Nunavik communities, **C.** Eeyou Istchee as a whole, and **D.** specific Eeyou Istchee communities.

The value gap between guaranteed levels of harvesting established in the 1970's and food use reported in the 2000's – estimated via the protein replacement value of store-bought food – is $12.7 million annually in Nunavik (from $26.4 million in the 1970's to 13.7 million in the 2000's, a 48% decline) and $8.5 million annually in Eeyou Istchee (from $18.5 million in the 1970's to $10.1 million in the 2000's, a 46% decline; **Figure 5**). These regional value estimates sum to a more than $20 million annual value gap across this part of northern Quebec. Given local food value declined during a period of population increase, local food value expressed per capita declined even more dramatically, from $7,776 to $1,073 per person per year in Nunavik (a 86% decline) and from $2,847 to $736 per person per year in Eeyou Istchee (a 74% decline). Regional and community-level differences in local food value reflected variation in the amounts of local food harvested (**Figure 2**) as well as substantial and in some cases regionally inconsistent community differences in store-bought food prices (**Figure 6**). For example, in Eeyou Istchee, harvest value is higher in Eastmain than in Whapmagoostui, despite Whapmagoostui having higher total reported harvest, because store-bought food costs are higher in Eastmain. Similarly, in Nunavik, Salluit's 2000's is closer to

Kuujjuaq and Inukjuak in estimated value than reported amount because store-bought food is more expensive in Salluit than in the two larger, more southerly communities.

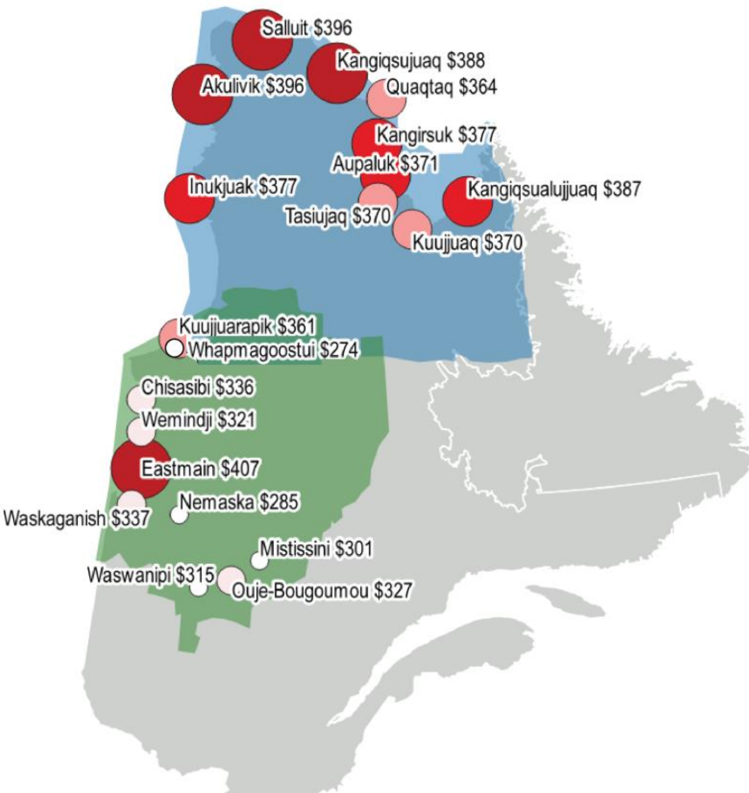

Figure 6. Weekly store-bought food basket costs in Nunavik (blue) communities and Eeyou Istchee (green) communities. Community dots are coloured and scaled to basket price.

Introducing nutrient composition information (energy content, in kcal/kg, and protein content, in g/kg, specific to the species and fractions consumed) into our per capita use estimates, then re-expressing these as daily values and relating them to recommended daily allowances (RDA's), indicates an emerging nutritional gap between amounts consumed in the 2000's and daily protein requirements (**Figure 7**). Edible yield from wildlife harvested in the 1970's was more than sufficient to meet the protein requirements of both regions and all communities but, by the 2000's, food consumption surveys indicate that protein requirements were no longer being met by local food sources in any community in Nunavik (**Figure 7B**) or Eeyou Istchee (**Figure 7D**). At a regional level, estimated protein intake via local food consumption reported in the 2000's surveys would have provided for only 51% of recommended dietary allowances in Nunavik and 40% in Eeyou Istchee (**Figure 7A-B**). Eastmain was the Eeyou Istchee community with the lowest estimated local food protein in the 2000's (10.4 g/p/d, 22% of RDA), while in Nunavik local food protein was lowest in Ungava Bay communities (24.7 g/p/d, 53% of RDA). Estimated energy intake from 1970's reported harvest in Nunavik and Eeyou Istchee was, respectively, 78% and 27% of a recommended daily allowance of 2300 kcal. Energy intake estimated from the 2000's food surveys declined to 8% of daily energy requirements in Nunavik and 9% in Eeyou Istchee.

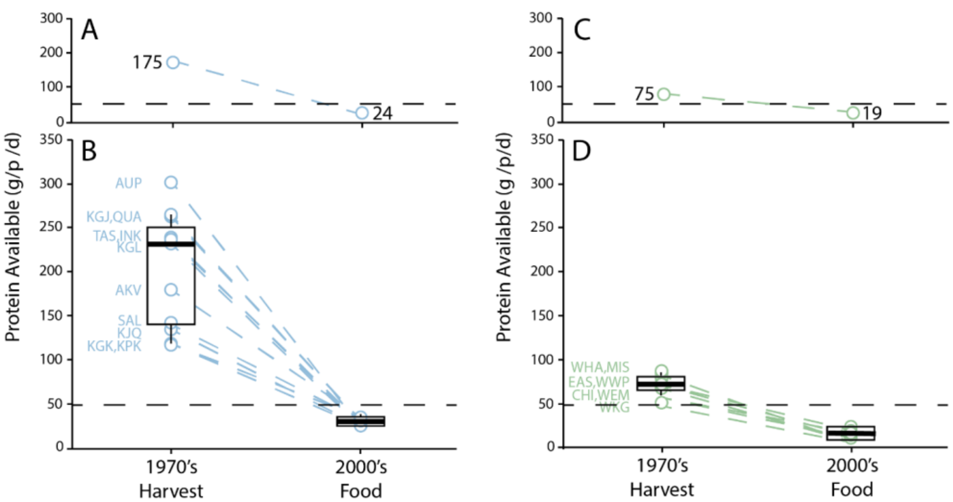

Figure 7. Estimated daily protein available based on 1970's reported harvest and 2000's food consumptionfor **A.** Nunavik as a whole, **B.** specific Nunavik communities, **C.** Eeyou Istchee as a whole, and **D.** specific Eeyou Istchee communities. The dashed black lines represent average recommended daily allowances 47 grams of protein per person.

Discussion

Our analysis estimates numeric, nutritional, and value gaps in reported food use relative to guaranteed levels of harvest across Eeyou Istchee and Nunavik using two data snapshots, one from the 1970's and another from the 2000's. Change is a major theme between these two time periods. The population of Eeyou Istchee has doubled (6,649 to 13,714) and the population of Nunavik has tripled (3,339 to 10,545) during a period when estimated total use declined by almost half (>45%). The synergistic effect of this population increase and total use decline is per capita use falling to less than 25% of 1970's levels in both regions. Our estimates of nutrient availability suggest that 1970's harvest levels did not supply adequate energy to the majority of communities but would have been sufficient to fulfil protein needs of all communities, whereas reported use in the 2000's was insufficient to satisfy either average energy or protein requirements. Valuation of reported local food use, based on the cost of protein replacement using store-bought food, indicates an estimated $20 million annual value gap between guaranteed levels of harvest established in the 1970's and food use reported in the 2000's, representing close to half a billion dollars of food not coming from the land and into communities in the last two decades.

When comparing local food use estimated with different survey methods (i.e., harvest vs. food recall surveys), it is important to acknowledge the limitations that may be present within each survey (Usher & Wenzel 1987; Naylor et al. 2023 [submitted]) and comparisons made between them (Kenny and Chan 2017). Beyond the numeric uncertainties and potential for recall errors or biases inherent in harvest and food use surveys, Indigenous food systems are highly complex socio-ecological systems and cultural practices (Delormier et al. 2009) defined by community livelihoods (Hickey et al. 2016; Warltier, Landry-Cuerrier, & Humphries 2021) The cultural and socio-ecological foundations and complexities of local food systems risk being lost in the numbers and simplification of reported use. Describing the value of these systems is challenged by difficulties describing collective wealth and well-being, quantifying trade-offs, and considering food systems as commodities (Lysenko and Schott, 2019). Feit's (1980) analysis at similar conclusions regarding the amounts, value, and nutritional adequacy of Cree harvest reported in the 1970's. Kenny et al. (2017) reported similar modest total energy contributions but significant contributions to daily protein and micronutrients in Inuit Health Survey data on traditional foods from Nunavut.

This analysis shows a significant decline in the adequacy (the ability to meet basic physical needs) of available and accessed nutrients entering communities in Nunavik and Eeyou Istchee. This analysis also implies that use levels have fallen below the legally guaranteed levels of harvest set out in the JBNQA. This decline is illustrative of the food security crisis that exists in many northern Indigenous communities. The loss of available nutrients from harvests must be at least partially compensated for by accessing local food stores, where food is expensive and often of low quality. The price of weekly store-bought food baskets varied from $274-407 across the regions, with a large community-to-community differences, including in the adjoining communities of Whapmagoostui ($274) and Kuujjararpik ($361). These differences could be driven by differing subsidy structures, ownership regimes, or other unaccounted for factors. The necessity and expense of store-bought food associated with the inaccessibility of traditional or country foods is a clear part of the "nutritional transition", but why access to traditional food system has apparently declined so much remains unanswered. Community members in the 2000's appear to be accessing less than 25% of harvests reported in 1970's when the guaranteed level of harvest was set. This is likely at least partially due to significant population increase (>200%) in both regions across the 30 years examined, but total estimated use has also fallen >45% in both regions. The cause of the decline in total use is unknown but appears to represent a dramatic decline in nutrients accessible to community members through traditional and country foods. Three potential barriers to accessing harvested foods are cost (and opportunity cost) of harvesting (economic accessibility), the ease and safety of accessing harvesting locations (socio-ecological accessibility), and changes in underlying abundance, distribution, and health of wildlife populations (availability). Equipment costs, and especially gasoline costs (Brinkman et al. 2014) are commonly reported barrier to accessing traditional harvesting, although hunting success is determined by more factors than availability of gasoline (Naylor et al. 2021a). Harvester support programs are a potential pathway to reduce financial barriers to traditional harvest (Pal, Haman, and Robidoux 2013). These support programs would help to alleviate barriers caused by access to harvesting but would not be able to address accessibility and availability issues caused by shifting underlying environmental conditions, like climate change. The vulnerability of Indigenous food systems to climate change is a major concern for local food security

(Naylor et al. 2021b), despite local adaptive capacity (Ford, Smit and Wandel 2006; Ford & Berrang-Ford 2009; Wenzel 2009; Ford et al. 2014) which has been overwhelmed by change in the past (Ford 2009). Synergistic effects of climate change and shifting range distributions of species is a concern in Nunavik, where beaver are damming arctic char rivers whose flow is already being altered by climate change (Neelin 2021). These challenges must be adequately addressed in future monitoring and reporting efforts. While causes of declining local food use are likely to be complex and multifaceted, the analysis presented here quantifies the numeric, economic and nutritional magnitude of this lost harvest, which requires compensation from non-local sources, including but not limited to the cost of replacing the harvested foods with store bought foods.

Future monitoring should improve on the limitations of the analyses presented here and be focused on informing action and adaptation. Additional food system monitoring has occurred, including through the 2017 Nunavik Health survey, *Qanuilirpitaa?*. The results of this most recent survey, which are just beginning to be published, appear to suggest an increase in consumption frequency of country food in 2017 relative to levels reported in the 2004 survey (Allaire et al. 2021). This is an important, recent result, which hints at the reversal of a possible declining trend in use described in this research. We are unaware of recent comprehensive food or harvest surveys from Eeyou Istchee. This possible reversal of trend in Nunavik, and the absence of comparable information from Eeyou Istchee, helps to highlight the importance of contemporary and regionally consistent monitoring efforts, especially since incomplete regional coverage, extended between-survey sampling intervals, and non-longitudinal sampling designs can hide important details, including regional-specificities, non-linear trends over time, and cohort effects. Darling at al. (2022) highlight the importance of data accessibility to avoid replication of sampling efforts, as inaccessible data are most often recollected. Further analyses could consider micronutrient intakes from harvested foods variation in the size and body condition of harvested animals. Feit (1980) estimated Cree harvests as contributing >50% of total recommended daily allowance (RDA) of most micronutrients. Lemire et al. (2015) strongly associate traditional food consumption to selenium and omega-3 polyunsaturated fatty acids (n−3 PUFA) intake in Nunavik. Kenny et al. (2018) found country foods to contribute >50% of iron, Bs 3, 6 & 12, and vitamin D intake across Inuit Nunangat. The present research uses constant body sizes within each dataset (but not across all datasets) to turn carcass harvest estimates into mass estimates. Prior research that has also relied on Ashley (2002) points out that edible mass estimates fail to account for natural variation in body size and condition (Kenny and Chan 2017). Future work could examine the sensitivity of results to variation in estimate edible mass per carcass and body condition.

Cree communities of Eeyou Istchee and Inuit communities of Nunavik will continue to navigate the appropriate balance between protecting Indigenous livelihoods and food systems while partnering in emerging economic opportunities. Incomplete information and indirect comparisons presented here suggest that guaranteed levels of harvest are no longer being realized in Nunavik or Eeyou Istchee, not on a total basis and much less on a per capita basis. Better, more direct, and more community-led documentation and monitoring of Indigenous food systems is a key knowledge gap in an increasingly connected and multi-sectoral world where, it seems, things need to be measured to matter. Assessing the impacts of past, present, and future development on Indigenous food systems and their many component parts is a substantial monitoring challenge. We hope that the methods presented here, including numeric, nutritional, and value estimations derived from a combination of harvest and food use data suggest possible approaches and necessary improvements that can guide community-based efforts aimed at documenting, protecting, compensating, and recovering Indigenous food security.

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Discussion:

This thesis presents a series of analyses based on snapshots of wildlife used for food by Indigenous Peoples across three regions and three decades. These analyses have relied entirely on pre-existing harvest and food use surveys, extended in meaning, interpretability, and applicability through additional nutrient and price information obtained from other pre-existing databases. Several of these analyses have relied on combining data from different survey methods widely separated in time. Key findings from this work include an integrated socio-ecological characterization of wildlife use across distinct regions and periods (chapter 2), a new method for valuing local food harvests (chapter 3), and, combining approaches developed in the first two chapters, an assessment of numeric, nutritional and value gaps between reported use and guaranteed levels of harvest (chapter 4). Situating the significance of this research requires looking both to the past, where it provides a comprehensive analysis of change over time and differences across regions in local food use, and to the future, where this work can inform better local food system documentation, monitoring, and valuation in a manner that can communicate the necessity and assess the effectiveness of local food security strategies.

Indigenous food systems are complex and multi-faceted systems that sit at a confluence of wildlife management, community health, and household economics. These systems are challenged by ongoing colonial processes, expanding frontiers of development, and the cumulative effects of climate change. The work presented here hopes to empower communities and regional organisations to better confront these challenges with local monitoring efforts that better communicate the complexity, vulnerability, and resilience of these Indigenous food systems. As expressed in chapter 3, if policy makers are to rely on the quantified and quantifiable, then avoiding discounting and marginalization of northern livelihoods requires a reproducible quantification and economic valuation of Indigenous food systems that communicates contributions to collective wealth and well-being, quantifies trade-offs, and contemplates compensation when the traditional economy is compromised. Indigenous communities are unlikely to find the conclusions in this dissertation new or novel, but rather as a re-expression of knowledge present in the history of these communities, their lived experiences, and the food they enjoy with one another. However, we hope the quantities and trends present in this re-expression help to communicate the nature and extent of these systems to a broader community of knowledge holders and decision-makers.

This work has found a systemic undervaluation of Indigenous food systems, both their financial value and their contributions to local food security. My estimates (chapter 3 and 4) suggest that an adequate level of protein was harvested in the 1970’s in Eeyou Istchee and Nunavik and in the 1990’s in Nunavut to meet nutritional requirements (assuming complete utilisation and sharing), but the amount of energy (kcal) harvested at that time was not sufficient to meet community’s needs in any of the three regions. Analysis of food recall data from the 2000s in Nunavik and Eeyou Istchee (chapter 4) suggests that protein needs are no longer being met by traditional food sources, contrary to guaranteed harvest levels established in the 1970s. The new methodology for estimating the cost to replace nutrients harvested in northern communities indicates that prior food system valuations have under-valued traditional food by one to two orders or magnitude (chapter 3), while historic value estimates from Eeyou Istchee appear quite accurate (chapter 4). Because of the reduction in total harvest in northern Quebec, the estimated value of the harvest has also fallen. This value deficit may represent a cumulative loss of close to half a billion dollars since the early 2000s. Despite this change in northern Quebec, analysis by ordination suggests that Inuit and Cree regions utilise a different assemblage of species and that these differences have been maintained over time, despite declining use concentrated in particular among fur-bearing species (chapter 2). Additional analyses from Nunavut highlight the financial inaccessibility of store-bought foods and a general state of severe store-bought food poverty (chapter 3), further contributing to food insecurity in the region.

As this thesis has described itself as “interdisciplinary” or “transdisciplinary”, the work presented must communicate with a plethora of literature across multiple fields. Although data used in this analysis have been rigorously collected and conditioned, concerns have been raised in the literature over the misappropriation of Indigenous harvest statistics, particularly as the data moves from the context it was collected in into more derived forms, without the broader understanding remaining intact (Usher & Wenzel

1987). However, additional research has indicated that harvest data and food recall data, while differing in survey method and exact results, can arrive at convergent results (Kenny & Chan 2017), justifying the direct comparison of these data. The valuation methodology proposed here may draw criticism as it seemingly reduces Indigenous food systems down to a financial value, simplifying a complex system to meet predetermined scientific thinking (Nadasdy 1999). This analysis further risks reducing a complex social-ecological system down to a single provisioning service and a single expression of value, processes which may arise out of and empower systemic power asymmetries instead of challenging them (Kosoy & Corbera 2010). However, this thesis is not the first work to commodify Indigenous food systems and this thesis has presented rigorous methodologies that may effectively communicate some of the substantial values of these systems. If nature is already being reduced into financialised services, then meaning may result from values that do not obscure or marginalise the contributions these systems make to the well-being of local communities. A pluralist vision of nature should be pursued, one which allows for multiple views and values of nature to be held simultaneously, which can help to link environment, development, and social change (Escobar 1999). Chapter 2 makes explicit reference to this in the discussion of cultural eating (Delormier, Frohlich, & Potvin 2009), where there is cultural mediation of what parts of nature become direct parts of the food system. Cree and Inuit food systems are both entirely representative of place, even if they represent shared landscapes differently through their own unique cultural lens. As chapter 2 concludes, these cultural differences are being maintained even as both food systems change over time. The literature has described this change largely through the lens of the "nutritional transition", where traditional harvesting systems are displaced or augmented by store-bought foods (Kuhnlein & Receveur 1996; Kuhnlein et al. 2004). This transition is characterised in some areas by decreases in consumption of local foods and has been linked to an increase in total energy intake and total energy from carbohydrates in Indigenous communities across Canada, increasing risk of metabolic diseases, such as diabetes (Receveur, O. Boulay, M. & Kuhnlein, H.V. 1997). Recent data suggests that these trends may be reversing and traditional food consumption rebounding, at least in Nunavik where recent surveys have been completed (Allaire et al. 2021). This reversal of trend may indicate that community programs focused on reinvigorating harvesting and local food traditions are succeeding, but recent data from other regions are lacking. The acute and chronic state of food insecurity in Northern Canada (Furgal & Seguin 2006; Tarasuk et al. 2013; Council of Canadian Academics 2014) has been a consistent underpinning of this work and hopefully this work aids in communicating and monitoring the varied contributions of local and store-bought food within contemporary Indigenous food systems. Ongoing responses to food insecurity include informal institutions, including food sharing and land-based learning (Harder & Wenzel 2012; Searles 2016), community scale initiatives, including community freezers and education programs (Organ et al. 2014; Hirsch et al. 2017), and interregional food security strategies (ITK 2021).

Future research should continue to assess the past, present, and future contributions of Indigenous food systems to the food security of northern regions, communities and households and how and who to best monitor Indigenous food systems. Chapters 3 and 4 conclude that Indigenous food systems can provide vital nutrients to communities at nutritionally significant levels, even if this provisioning appears to be declining over time. This work joins growing scholarship highlighting the importance of local Indigenous food systems as contributing to local food security (Ford & Berrang-Ford 2009; Douglas et al. 2014; Stephenson & Wenzel 2017; Kenny et al. 2018a). Given Chapter 4 provides evidence that local food use in northern Quebec is substantially less than guaranteed levels, ongoing monitoring of the status and drivers of Indigenous food system is a key northern knowledge priority. Similar to the analysis in chapter 4, emerging research advocates for using harvesting and food use information as tools in food system monitoring (Thompson et al. 2019; 2020; Thompson, Lantz, & Ban 2020). Indigenous food system monitoring, in particular, needs to support knowledge plurality (Rahman et al. 2019) and the self-determination of Indigenous communities, including their rights to data ownership, control, access, and protection (Darling et al. 2022).

This work highlights the importance of ongoing harvest and nutritional monitoring, showing how drastically estimated food use can change between surveys. The 30-year period between surveys in northern Quebec concealed a 75% decline in harvest availability to individual community members driven by a doubling of the population and a near halving of total harvest (Chapter 4). The same 30-year interval will soon have elapsed since the Nunavut Wildlife Harvest Study (Priest & Usher 2004) was completed, and it remains unknown whether similar declines in local food use are occurring in Nunavut. Any reduction in available nutrients from harvests must be at least partially compensated for by accessing store-bought food, which is expensive, and often of low quality, and often not effective at alleviating food insecurity (St-Germain, Galloway & Tarasuk 2019). The rights of Indigenous Peoples to harvest wildlife for food are legally protected across Canada, yet reported appears to be declining across many northern regions. This research offers methods capable of both estimating the magnitude of declines in local food use and constructing a potential valuation framework for constructing a minimum estimate for compensation based on the loss of accessible nutrients. This valuation exercise may also inform the prioritization and design of harvester support programs, helping them to play a more substantial and direct role in reducing the financial barriers limiting access to local food harvesting opportunities (Pal, Haman, & Robidoux 2013; Brinkman et al. 2014; Naylor et al. 2021a).

The vulnerability of traditional food systems to climate change is a major concern for the integrity of Indigenous food systems and the state of local food security (Naylor et al. 2021b). Local adaptive capacity is a key determinant of vulnerability to climate change (Ford, Smit & Wandel 2006; Ford & Berrang-Ford 2009; Wenzel 2009; Ford et al. 2014) and more effective food system monitoring could contribute to adaptive capacity under climate change. Spatial and temporal variation is and always has been a defining feature of ecological systems. Indigenous food systems are a complex social ecological system involving multiple species, seasons, habitats, harvest methods, and food preparation methods. The resilience of Indigenous food systems to environmental variation arises from their complexity, and from traditions that include harvest calendars, rotational harvesting, species substitutions, and food sharing traditions. In an era of accelerated climate change and cumulative impacts from more localized impacts, and at a time when Indigenous food systems are affected by local, provincial, federal, and international policy decisions spanning health, environment, and economy, better monitoring and communication of the status and change over time of local Indigenous food systems may be central to their protection and adaptive capacity.

The most important limitation of this thesis, which extends to Indigenous food systems across northern Canada, is a lack of recent, consistently documented, and continuously monitored information about these local food systems. This limitation may be overcome by more consistent monitoring, including over time and from region to region. However, this improvement in monitoring will not be achieved unless it is led by communities, supports their self-determination, and can be seen to have direct and tangible benefits for the strength and integrity of Indigenous food systems (Thompson et al. 2019; Thompson et al. 2020, Thompson, Lantz, & Ban 2020). Local communities should have control of information about their food systems, in adherence to OCAP principles (Schnarch 2004). Darling at al. (2022) highlight the importance of data accessibility to avoid replication of sampling efforts, as inaccessible data is most often recollected.

Effective monitoring of Indigenous food systems is best done by people with the greatest stake in and knowledge of these systems, the local communities themselves. Depending on the level of community participation, these monitoring efforts can take on a spectrum of forms from top-down researcher-led efforts, to organic, grassroots efforts envisioned and achieved by communities (Brammer et al. 2016). Monitoring Indigenous food systems is likely to require both scientific and traditional knowledge to disentangle the intersections of environment, wildlife population dynamics, and harvesting traditions (Gagnon et al. 2023). Supporting Indigenous food systems requires understanding the environmental, social, and cultural contexts of the North and valuing Indigenous self-determination (Ford et al. 2018; Wilson et al. 2020). Examples of the effectiveness of this understanding are provided by recent and emerging successes of co-management regimes, created through land claim agreements, in achieving evidence-based management decisions that situate Indigenous harvest rights, land rights, and management goals closer to the centre rather than the periphery of decision-making. (Kourantidou, Hoover & Bailey 2020; Scott 2020). The Indigenous Guardians program was launched in 2017 with federal funding mobilised to give communities a greater number of opportunities for stewardship over their territories (GC 2023; Indigenous Leadership Initiative, no date). Indigenous Guardians are extremely well positioned to support communities with land-based education programs, data collection and monitoring, protecting at risk species, habitat protection, and enforcement of local land and harvest practices. Monitoring and supporting the integrity of Indigenous food systems might be identified as a primary and coordinated goal of Indigenous Guardians from coast-to-coast-to-coast. Federal monitoring can be impeded by the slow adoption of new tools and paradigms due to unclear legal mandates, unclear guidelines, and institutional support and training (Kerr et al. 2021). The ineffectiveness, patchiness, and jurisdictional boundedness of federal or university-based monitoring approaches (Kerr et al. 2021), combined with the emergence of a national (in fact many nation) Indigenous Guardians network, creates both the need and the opportunity to empower Indigenous communities to monitor the systems they know best and live within (Thompson et al. 2019).

Northern research needs to achieve a balance between ensuring that research meaningfully engages local people and their knowledge while avoiding research duplication, fatigue, and invasion of privacy. This ongoing challenge is heightened in food systems research where research priorities, methods, and applications are focused on the lives, livelihoods, and health of people, yet topics often overlap with areas of natural, social, and health sciences research where much is already known and much has already been done or is ongoing (Usher & Wenzel 1987). Accordingly, this research made a concerted effort to identify relevant past research and datasets and to try to capitalize on this existing knowledge rather than proposing new and potentially redundant efforts. Over reliance on previous research risks offering nothing new and propagating the limitations of prior research, while too much reliance on contact with community representative organizations and too little time spent working with and listening to individual community members can leave communities feeling unheard and unengaged. The appropriate balance between too much and too little engagement remains a challenge and a work in progress. I have attempted to align this research with the existing priorities and initiatives of regional organizations to maximize research synergies and minimize redundancies. An important part in this process is ensuring that existing data gets analysed to its fullest extent and has the opportunity to live beyond the original report for which it was generated.

The 2014 Council of Canadian Academies state of knowledge report, "Aboriginal Food Security in Northern Canada" identifies the existence of numerous past surveys, but a lack of cross-cultural and over-time consistency in information about local food systems. We hope that our development of new methodological tools and our application of these approaches to single time point surveys completed in the past prompts further consideration of how information gaps about local food systems can be best addressed, while respecting and advancing the self-determination of the Indigenous people and nations who create these systems.

This research highlights the importance of long-term monitoring of Indigenous food systems, specifically monitoring current use in relation to guaranteed levels of harvest and ensuring proper metrics and valuation methods are used in this monitoring. Broader questions about suitable compensation for compromised food systems remain unanswered (Scott 2020). With the addition harvesting equipment costs, the values presented here could be expressed both as gross value (currently presented) and net value (harvest value – harvesting expenses). Only protein and energy are currently analysed for replacement value, but interest exists in, for example, examining the value of iron in harvests, as anaemia has been raised as a community concern, and B vitamins, which are vital in natal development. This analysis may also investigate how different nutritional constituents are considered, including whether the value of distinct constituents, should be considered separately or summed. Lastly, robust monitoring will be an important strategy as the North contends with climate change and cumulative impacts, with food systems affected not only by shifting species ranges and changes in abundance, but as harvesters must navigate shifting patterns in safety on the land, water, and ice.

Conclusions

This thesis contributes to the understanding of Indigenous food security in Canada by developing new methodologies to communicate the value of Indigenous food systems, comparing guaranteed harvest levels with contemporary use estimates, and comparing food system data collected in different times, places, and methodologies. Chapter 2 offers an integrated socio-ecological characterization of wildlife use across distinct regions and periods. In Chapter 3, I develop a new method for describing the nutrient replacement value of local food, estimate the contribution of local food to nutrient requirements, and examine the affordability of store-bought food in communities across Nunavut. This work is already being integrated into regional food security strategies. Chapter 4 examines change in local food use over time across Nunavik and Eeyou Istchee to assess numeric, nutritional, and value deficits of current harvests compared to guaranteed harvest levels. Combining approaches from Chapter 2 and 3 enables estimation of the value of unrealized harvest in northern Quebec in Chapter 4. Overall, my thesis highlights Indigenous food system as critical, valuable, and dynamic systems that warrant better assessment, monitoring and protection.

Although Indigenous communities understand the importance and dynamics of their food systems, articulating this importance beyond the people who rely on the food system can be challenging. The metrics used in this articulation, and the frequency with which these metrics are measured and updated, can help or hinder communication, co-management efforts, and the realization of historic and modern treaty rights. This thesis has shown how infrequent monitoring and guaranteed harvest levels that remain unassessed can conceal drastic changes in Indigenous food systems. Previous value estimates for Indigenous food systems were off by up to two orders of magnitude. Further, 30-year sampling intervals (from the 1970's to the 2000's), differing points of survey focus, and a lack of recent information obscure the assessment temporal trends in the nature and extent of Indigenous food systems in northern Quebec. Comprehensive harvest surveys often revolve around the settlement of land claims and the policy imperative to document the extent of a local economy that an emerging agreement is intended to protect. Subsequently, modern land claims become a major facet of wildlife management, as land claims often contain stipulations to undertake a monitoring program to establish guaranteed harvest levels, but these monitoring programs are usual a snapshot in time and download subsequent monitoring responsibilities onto regional organisations that are still building monitoring capacity (Usher 2003).

Despite the paucity of directly comparable information documenting change over time in subsistence harvests and local food use, available evidence is consistent with a near halving of harvests in northern Quebec that suggests Section 24 of the James Bay and Northern Quebec Agreement (JBNQA), which guarantees an explicit number of harvested animals to the Cree of Eeyou Istchee and the Inuit of Nunavik, has not been realized. A logical follow-up to the analysis presented here is to extend the approach to 2017 food recall data from Nunavik which is currently being published and made available (Allaire et al. 2021), to compare the most recently available results to the 2000's and 1970's use information analysed here. Unfortunately, there is no similar more recent information available from Eeyou Istchee.

Commented [MH3]: The new insert is fine, but the "Nevertheless..." sentence that follows no longer works because it is now disconnected from the previous thread. Turning it into a new paragraph and adding to the topic sentence might rescue it

Almost 30 years have elapsed since the Nunavut Wildlife Harvest Study, and the Inuit National Health Survey is set to commence in late 2023 (Qanuippitaa? National Inuit Health Survey 2021), a similar survey interval to northern Quebec. If the results of this upcoming survey suggest that local food use by residents of Nunavut has also declined by half, as appears to be the case in Nunavik and Eeyou Istchee, this will represent almost $100 million of nutrients that Nunavummiut must now be purchase from a store or face hunger. Applying analytical approaches included here to the three comprehensive food use surveys available for Nunavut – the 2004 Nunavut Wildlife Harvest Study, the 2007-2008 Inuit Health Survey, and the in progress Qanuippitaa? National Inuit Health Survey – represents a logical extension of the current analysis. Another potential extension of the analysis presented here is a focus on the seasonality of local Indigenous food systems, considering how the seasonality of harvest of local species relates to the seasonality of food purchases from stores. More needs to be known and monitored about Indigenous food systems throughout northern Canada to better assess and protect the integrity of these local food systems in support of Indigenous food security.

Continued dialogue with Indigenous communities and regional organizations will give this research the greatest chance to inform policy and decision-making processes supporting future monitoring efforts and food security initiatives. This thesis and the analysis presented here arose from encouragement by representatives of government and regional organizations in Eeyou Istchee (including the Cree Board of Health and Social Services) and in Nunavik (including Makivik and the Kativik Regional Government) to make better use of pre-existing harvest and food survey data prior to initiating new research projects. Having completed these analyses and building on ongoing contact, relationship, and collaboration with these organizations through my own work and through related work conducted by my thesis supervisor, my intention is to circulate summaries of chapters 2 and 4 to representatives of regional organizations in northern Quebec, including Makivik, Kativik Regional Government, Nunavik Hunting, Fishing and Trapping Organization, and Nunavik Regional Board of Health and Social Services in Nunavik and the Cree Nation Government, Cree Trapper's Association, and Cree Board of Health and Social Services in Eeyou Istchee. I also will communicate the results to the Hunting Fishing and Trapping Coordinating Committee, instituted in 1976 under the provisions of Section 24 of the JBNQA (and extended to include Naskapi representation in 1978 with the signing of the Northeastern Québec Agreement; NEQA). This approach to results sharing and request for organizational review and input, proposed here for chapter 2 and 4, was similar to the process my co-authors and I followed for chapter 3. Prior to submission for journal peer-review, the research in chapter 3 was presented at two academic conferences and was reviewed by several Nunavut organizations and food security authorities, who are identified in the acknowledgements of this chapter. These discussions directly led the opportunity to present this research to multiple Nunavut government agencies and at the Nunavut Poverty Reduction Roundtable. The results of Chapter 3 were reported on by Nunatsiaq News (Anselmi 2019) and have been included in ITK's Inuit Nunangat Food Security Strategy (ITK 2017). Similar results sharing from chapters 2 and 4 have already been initiated in Nunavik and Eeyou Istchee and I am hopeful the results will achieve organizational interest and eventual policy impacts similar to what has started to be realized with chapter 3 in Nunavut.

Data-based methods focused on secondary analysis of pre-existing data can offer a key first step to inform the identification of knowledge gaps and the prioritization of future research and policy initiatives. For subsequent research phases, knowledge co-production approaches offer the best opportunity to envision priorities and approaches for future Indigenous food systems research that are ethical, impactful, engaged, and respectful (Armitage et al. 2011; Norström et al. 2020). The next phase of this research needs to include regional organizations in the design and prioritization phase of the research. Discussion of the results of the secondary analysis presented here provides an excellent starting point for co-identification of research priorities based on both the strengths and the limitations of the analyses that are presented here. These partnerships, at the research development stage, are a vital tool to support community self-determination, for achieving meaningful community engagement, and for achieving research results that are locally valid, relevant, and impactful (Douglas et al. 2014; Brunet, Hickey & Humphries 2014b; Brunet, Hickey & Humphries 2016; Brunet, Hickey & Humphries 2017; Hovey et al. 2017; Lam et al. 2019).

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Appendices and Supplemental Materials

S2.1 Species and Taxonomic merges used in the RDA. Some food stuffs were removed from analysis.

Analysis	Eeyou Istchee 1970s	Nunavik 1970s	Eeyou Istchee 2000s	Nunavik 2000s
Char	Char	Arctic Char		Arctic Char
B.Bear	Black Bear		Bear	
Beaver	Beaver		Beaver.meat	
Beluga		Beluga		Beluga
Brant	Brant	Brant		
Burbot	Burbot		Burbot	
Geese	Canada Geese	Canada Geese	Goose	Geese
	Lesser Snow Geese	Snow Goose		
Caribou	Caribou	Caribou	Caribou	Caribou
Ducks	Ducks	Ducks	Other.ducks	
Walleye	Dore		Walleye	
Grouse	Grouse	Grouse		
Loons	Loons	Loons	Loon.or.Merganser	
Moose	Moose		Moose	
Pike	Pike		Pike	
Polar Bear	Polar Bear	Polar Bear		Bear
Ptarmigan	Ptarmigan	Ptarmigan	Ptarmigan..partridge..and.other.birds	Ptarmigan
Lagomorphs	Rabbit	Arctic Hare	Rabbit.meat	Hare
Seals	Seal	Bearded Seal		Seal
		Harbous Seal		
		Harp Seal		
		Ringed Seal		
Salmonids	Speckled Trout	Brook Trout	Speckled.trout	Salmonids
	Lake Trout	Lake Trout	Lake.trout	
		Salmon		
Whitefish	Whitefish	Whitefish	Whitefish	Lake whitefish
Cods		Cod		Arctic & Atlantic cod
Sturgeon	Sturgeon		Sturgeon	
Sucker	Sucker		Red.or.white.sucker	
Walrus		Walrus		Walrus
Sculpin		Sculpin		Other fish (mostly sculpin)
Auks		Murre		
		Guillemot		
Otter	Otter			
Lynx	Lynx			
Muskrat	Muskrat			
Porcupine	Porcupine			
Duck eggs		Duck eggs		
Landlocked Char		Landlocked Char		
Snowy Owl		Snowy Owl		
Dabblers			Dabblers	
Sea.ducks			Sea.ducks	
Igunak				Igunak
Blue mussels				Blue mussels
Clams				Clams
Scallops				Scallops
Pitsik				Pitsik
Other birds				Other birds
Bird eggs				Bird eggs
[Removed]				Fox
[Removed]				Seaweeds
[Removed]				Wild berries

S2.2, constraining set used for redundancy analysis, with regional and survey methodology labels

	Region	Survey
Great Whale.1970	Eeyou.Istchee	Harvest
Fort George.1970	Eeyou.Istchee	Harvest
Paint Hills.1970	Eeyou.Istchee	Harvest
Eastmain.1970	Eeyou.Istchee	Harvest
Rupert House.1970	Eeyou.Istchee	Harvest
Nemaska.1970	Eeyou.Istchee	Harvest
Mistassini.1970	Eeyou.Istchee	Harvest
Waswanipi.1970	Eeyou.Istchee	Harvest
Kuujjuarapik.1970	Nunavik	Harvest
Inukjuak.1970	Nunavik	Harvest
Akulivik.1970	Nunavik	Harvest
Salluit.1970	Nunavik	Harvest
Kangiqsujuaq.1970	Nunavik	Harvest
Quaqtaq.1970	Nunavik	Harvest
Kangirsuk.1970	Nunavik	Harvest
Aupaluk.1970	Nunavik	Harvest
Tasiujaq.1970	Nunavik	Harvest
Kuujjuaq.1970	Nunavik	Harvest
Kangiqsualujjuaq.1970	Nunavik	Harvest
Killiniq.1970	Nunavik	Harvest
Mailasi.1970	Nunavik	Harvest
WASKAGANISH.2000	Eeyou.Istchee	Recall
CHISASIBI.2000	Eeyou.Istchee	Recall
WHAPMAGOOSTUI.2000	Eeyou.Istchee	Recall
WASWANIPI.2000	Eeyou.Istchee	Recall
MISTISSINI.2000	Eeyou.Istchee	Recall
WEMINDJI.2000	Eeyou.Istchee	Recall
EASTMAIN.2000	Eeyou.Istchee	Recall
Kuujjarapik.2000	Nunavik	Recall
Inukjuak.2000	Nunavik	Recall
Akilivik.2000	Nunavik	Recall
Puvirnituq.2000	Nunavik	Recall
Salluit.2000	Nunavik	Recall
Kangiqsujuaq.2000	Nunavik	Recall
Quaqtaq.2000	Nunavik	Recall
Kuujjuaq.2000	Nunavik	Recall
Kaniqsualujjuaq.2000	Nunavik	Recall
Kangirsuk.2000	Nunavik	Recall
Tasiujaq.2000	Nunavik	Recall
Aupaluk.2000	Nunavik	Recall

Table S2.3: Results of permutational Bray-Curtis based MANOVA of a **transformed** socio-ecological dataset (constructed from four individual datasets over two cultural-regions and two data collection methodologies that are separated by several decades) constrained by 2 factors: cultural region, and data collection method. The selection of an interaction was deliberate.

	Df	Sum of Squares	R2	F	P<
Region	1	3.6463	0.62393	116.047	0.001
Survey	1	0.7267	0.12434	23.127	0.001
(interaction)	1	0.3399	0.05817	10.819	0.002
Residual	36	1.1312	0.19356		
Total	39	5.8441	1.0		

A permutational-MANOVA of the socio-ecological data, transformed by a Hellinger transformation to account for many “0” entries in the dataset. The second perm-MANOVA was performed to confirm that RDA selected constraining variables were significant, rather than for direction analysis.

TABLE S3.1. Estimated energy and protein content of Nunavut country foods, including tissue type and preparation method contributing most to edible fraction, and the Canadian Nutrient File food code (CNF; Health Canada, 2018) from which energy and protein content were obtained.

Common name	Scientific name	Tissue type[1]	CNF code[2]	Energy (kcal kg^{-1})	Protein (g kg^{-1})
Bivalves:					
Clams	*Mya truncata*	r	3109	860	146.7
Mussels	*Mytilus edulis*	r	3115	860	119.0
Fish:					
Whitefish	*Coregonus* spp.	r	3208	1140	190.0
Inconnu	*Stenodus leucichthys*	r	3234	2410	168.0
Char	*Salvelinus alpinus*	mr	3230	1030	195.0
Lake trout	*S. namaycush*	r	*3204*	1480	207.7
Grayling	*Thymallus arcticus*	r	5483	970	200.0
Cod	Gadidae spp.	r	*3194*	820	178.1
Turbot	*R. hippoglossoides*	r	3013	1860	143.7
Birds:					
Ptarmigan	*Lagopus* spp.	mr	5932	1280	240.0
White–fronted Goose	*Anser albifrons*	msr	*5215*	2700	191.1
Snow Goose	*A. caerulescens*	msr	*5215*	2700	191.1
Brant	*Branta bernicla*	msr	*5215*	2700	191.1
Canada Goose	*B. canadensis*	msr	5215	2700	191.1
Goose	*Branta*/*Anser* spp.	msr	*5215*	2700	191.1
Goose egg	*Branta*/*Anser* spp.	r	*89*	1850	138.7
Swan	*Cygnus columbianus*	msr	*5215*	2700	191.1
Swan egg	*C. columbianus*	r	*89*	1850	138.7
Duck	*Anas*/*Aythya* spp.	msr	*667*	2100	174.2
Eider	*Somateria* spp.	msr	X[3]	1215	123.0
Murre egg	*Uria lomvia*	r	*89*	1850	138.7
Mammals:					
Grizzly bear	*Ursus arctos*	mr	3565	1280	220.0
Polar bear	*U. maritimus*	mr	5835	1160	220.0
Muskox	*Ovibos moschatus*	mr	5831	1050	190.0
Moose	*Alces alces*	mr	3587	1240	220.0
Caribou	*Rangifer tarandus*	mr	3577	1220	225.0
Hare	*Lepus arcticus*	mr	X	640	215.0
Ground squirrel	*Urocitellus parryii*	mr	3598	1200	212.3

[1] Tissue types: r = whole raw, mr = meat raw, and msr = meat with skin.

[2] Italicized codes indicate values obtained from closely related species.

[3] For X, values were taken from Kuhnlein and Humpries (2017).

TABLE S3.2. Estimated energy (E) and protein (P) content of marine mammals with edible fraction components (EFC) and their assumed contributions (%) to total edible fraction and total nutrient content.

Common name	Scientific name	1st					2nd					3rd					4th					E (kcal/kg)	P (g/kg)
		EFC[1]	%	Code[2]	E	P	EFC	%	Code	E	P	EFC	%	Code	E	P	EFC	%	Code	E	P		
Walrus	*Odobenus rosmarus*	mu	60	5796	1710	330.0	mr	20	3647	1150	235.0	o	10	5904	9010	0	br	10	5791	7560	59.0	2903	250.9
Bearded seal	*Erignathus barbatus*	mr	70	5759	1210	250.0	o	20	5891	8990	5.6	br	10	5763	7700	7.0						3415	176.8
Hooded seal	*Cystophora cristata*			x																		2679	193.2
Harp seal	*Pagophilus groenlandicus*	mr	100	3645	1130	238.0																1130	238.0
Harbor seal	*Phoca vitulina*			x																		2679	193.2
Ringed seal	*Pusa hispida*	mr	70	5782	1260	230.0	ba	20	5779	8950	7.0	br	10	5778	8190	22.5						3491	164.7
Seal	Phocid spp.			x																		2679	193.2
Bowhead	*Balaena mysticetus*	mu	70	5906	4660	126.0	o	20	5907	9010	0.0	br	10	5905	8700	4.0						5934	88.6
Beluga	*Delphinapterus leucas*	mu	50	5766	1540	245.0	md	30	5769	3560	720.0	o	10	5768	8900	3.0	br	10	5764	7310	95.0	3459	348.3
Narwhal	*Monodon monoceros*	mu	70	5755	1320	225.0	md	20	5771	4250	110.0	br	10	5772	6570	91.5						2431	320.7

[1] EFC = edible fraction components: mu = muktuk raw, o = oil, br = blubber raw, mr = meat raw, ba = blubber aged, and md = meat dried.

[2] Code = the Canadian Nutrient File food code (Health Canda, 2018). For x, due to a lack of species-specific data, E and P values were estimated as the average of the three other seals (bearded, harp, and ringed) with available data.

TABLE S3.3. Country food harvest, store-bought food costs, and reported income for Nunavut communities. Italicized communities have reported harvest but lack publicly available store-bought food basket costs and reported incomes. Regional capitals are displayed in bold.

REGION / Community	Population	Country food total energy harvested (kcal yr^{-1})	Country food total protein harvested (g yr^{-1})	Country food available energy (kcal $pers^{-1}$ d^{-1})	Country food available protein (g $pers^{-1}$ d^{-1})	Store-bought food basket cost (\$ yr^{-1})	Median reported total income (\$ yr^{-1})	Store-bought food basket cost/income (%)	Store-bought food basket energy cost (\$ $kcal^{-1}$)	Store-bought food basket protein cost (\$ g^{-1})	Store-bought food basket unsubsidized energy cost (\$ $kcal^{-1}$)	Store-bought food basket unsubsidized protein cost (\$ g^{-1})
KITIKMEOT												
Umingmaktok	–	–	–	–	–	–	–	–	–	–	–	–
Bathurst Inlet	–	–	–	–	–	–	–	–	–	–	–	–
Kugaaruk	972	170,624,907	21,420,000	480.9	60.4	–	23,760	–	–	–	–	–
Taloyoak	1076	253,528,163	33,374,312	645.5	85.0	24,205	23,460	1.032	0.0067	0.1503	0.0089	0.1987
Gjoa Haven	1483	135,577,902	21,626,669	250.5	40.0	23,538	23,920	0.984	0.0065	0.1462	0.0085	0.1904
Kugluktuk	1610	223,068,892	35,795,761	379.6	60.9	22,431	23,740	0.945	0.0062	0.1393	0.0077	0.1725
Cambridge Bay	1746	122,407,898	20,173,396	192.1	31.7	21,708	32,540	0.667	0.0060	0.1348	0.0070	0.1571
KIVALLIQ												
Whale Cove	462	174,524,180	22,780,671	1035.0	135.1		25,260	–	–	–	–	–
Chesterfield Inlet	473	135,092,396	19,063,526	782.5	110.4	20,770	31,850	0.652	0.0058	0.1290	0.0076	0.1705
Naujaat	1069	373,380,781	37,809,625	956.9	96.9	21,482	23,520	0.913	0.0060	0.1334	0.0084	0.1887
Coral Harbour	1080	676,057,718	72,469,702	1715.0	183.8	22,083	24,370	0.906	0.0061	0.1371	0.0085	0.1911
Baker Lake	1997	279,690,325	50,747,258	383.7	69.6	20,489	28,760	0.712	0.0057	0.1272	0.0076	0.1701
Arviat	2772	1,086,673,078	139,675,510	1074.0	138.0	19,880	26,400	0.753	0.0055	0.1234	0.0066	0.1484
Rankin Inlet	2675	266,944,687	33,706,200	273.4	34.5	20,068	44,210	0.454	0.0056	0.1246	0.0068	0.1523
QIKIQTAALUK												
Grise Fjord	167	123,008,228	8,592,504	2018.0	141.0	–	–	–	–	–	–	–
Resolute Bay	210	121,782,456	9,086,338	1588.8	118.5	–	31,170	–	–	–	–	–
Kimmirut	450	192,764,989	16,472,009	1173.6	100.3	22,499	26,650	0.844	0.0062	0.1397	0.0094	0.2116
Qikiqtarjuaq	616	493,805,289	30,667,891	2196.3	136.4	23,966	21,450	1.117	0.0066	0.1488	0.0095	0.2124
Arctic Bay	876	393,950,688	36,299,724	1232.1	113.5	24,030	26,680	0.901	0.0067	0.1492	0.0118	0.2653
Sanikiluaq	887	290,263,696	23,576,857	896.6	72.8	23,390	19,220	1.217	0.0065	0.1452	0.0075	0.1675
Hall Beach	956	459,598,869	45,709,094	1317.1	131.0	21,358	26,110	0.818	0.0059	0.1326	0.0092	0.2073
Clyde River	1,127	445,330,267	31,499,172	1082.6	76.6	24,045	24,220	0.993	0.0067	0.1493	0.0106	0.2378
Cape Dorset	1,481	448,837,325	40,901,146	830.3	75.7	23,563	20,290	1.161	0.0065	0.1463	0.0092	0.2072
Pangnirtung	1,633	1,372,498,032	108,790,049	2302.7	182.5	24,866	26,660	0.933	0.0069	0.1544	0.0093	0.2083
Pond Inlet	1,663	628,046,553	63,856,474	1034.7	105.2	24,031	22,530	1.067	0.0067	0.1492	0.0115	0.2584
Igloolik	1,986	907,786,478	88,071,166	1252.3	121.5	22,373	25,340	0.883	0.0062	0.1389	0.0095	0.2136
Iqaluit	7,590	793,252,977	80,233,377	286.3	29.0	21,486	67,260	0.319	0.0060	0.1334	0.0073	0.1625

TABLE S3.4. Country food valuation for Nunavut communities. Italicized communities have reported harvest but lack publicly available store-bought food basket costs and reported incomes. Regional capitals are displayed in bold.

REGION Community	Population	Country food energy value ($ yr^{-1})	Country food protein value ($ yr^{-1})	Country food unsubsidized energy value ($ yr^{-1})	Country food unsubsidized protein value ($ yr^{-1})	Country food energy value per capita ($ pers^{-1} yr^{-1})	Country food protein value per capita ($ pers^{-1} yr^{-1})	Country food unsubsidized energy value per capita ($ pers^{-1} yr^{-1})	Country food unsubsidized protein value per capita ($ pers^{-1} yr^{-1})
KITIKMEOT:									
Umingmaktok	–	–	–	–	–	–	–	–	–
Bathurst Inlet	–	–	–	–	–	–	–	–	–
Kugaaruk	972	–	–	–	–	–	–	–	–
Taloyoak	1076	1,700,022	5,016,115	2,247,692	6,632,082	1,579.95	4,661.82	2,088.93	6,163.64
Gjoa Haven	1483	884,054	3,160,869	1,151,872	4,118,431	596.13	2,131.40	776.72	2,777.09
Kugluktuk	1610	1,386,107	4,985,586	1,716,856	6,175,234	860.94	3,096.64	1,066.37	3,835.55
Cambridge Bay	1746	736,127	2,719,250	857,724	3,168,430	421.61	1,557.42	491.25	1,814.68
KIVALLIQ:									
Whale Cove	462	–	–	–	–	–	–	–	–
Chesterfield Inlet	473	777,301	2,458,605	1,027,522	3,250,051	1,643.34	5,197.90	2,172.35	6,871.14
Naujaat	1069	2,222,010	5,043,399	3,143,581	7,135,131	2,078.59	4,717.87	2,940.67	6,674.58
Coral Harbour	1080	4,135,740	9,936,944	5,762,690	13,846,016	3,829.39	9,200.87	5,335.82	12,820.39
Baker Lake	1997	1,587,500	6,456,180	2,122,790	8,633,146	794.94	3,232.94	1,062.99	4,323.06
Arviat	2772	5,984,563	17,241,724	7,194,281	20,726,960	2,158.93	6,219.96	2,595.34	7,477.26
Rankin Inlet	2675	1,484,009	4,200,025	1,814,058	5,134,125	554.77	1,570.10	678.15	1,919.30
QIKIQTAALUK:									
Grise Fjord	167	–	–	–	–	–	–	–	–
Resolute Bay	210	–	–	–	–	–	–	–	–
Kimmirut	450	1,201,442	2,301,167	1,819,671	3,485,284	2,669.87	5,113.70	4,043.71	7,745.08
Qikiqtarjuaq	616	3,278,468	4,563,793	4,679,725	6,514,414	5,322.19	7,408.75	7,596.96	10,575.35
Arctic Bay	876	2,622,437	5,416,185	4,662,231	9,629,020	2,993.65	6,182.86	5,322.18	10,992.03
Sanikiluaq	887	1,880,746	3,424,129	2,169,088	3,949,091	2,120.34	3,860.35	2,445.42	4,452.19
Hall Beach	956	2,719,276	6,061,831	4,249,891	9,473,889	2,844.43	6,340.83	4,445.49	9,909.93
Clyde River	1,127	2,966,384	4,702,958	4,723,723	7,489,075	2,632.11	4,172.99	4,191.41	6,645.14
Cape Dorset	1,481	2,929,809	5,984,290	4,148,181	8,472,880	1,978.26	4,040.71	2,800.93	5,721.05
Pangnirtung	1,633	9,454,316	16,797,105	12,757,267	22,665,325	5,789.54	10,286.04	7,812.17	13,879.56
Pond Inlet	1,663	4,180,940	9,528,266	7,239,495	16,498,644	2,514.10	5,729.56	4,353.27	9,921.01
Igloolik	1,986	5,626,295	12,234,871	8,649,521	18,809,142	2,832.98	6,160.56	4,355.25	9,470.87
Iqaluit	7,590	4,721,494	10,704,087	5,751,174	13,038,474	622.07	1,410.29	757.73	1,717.85

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