AN EXPLORATION AND EXAMINATION OF APPROACHES AND METHODS USED TO BRING TOGETHER INDIGENOUS AND ENVIRONMENTAL SCIENCE KNOWLEDGE IN ENVIRONMENTAL RESEARCH

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ABSTRACT

An exploration and examination of approaches and methods used to bring together Indigenous and Environmental science Knowledge in environmental research

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The bringing together of Indigenous (IK) and Environmental science Knowledge (ESK) has garnered significant attention in environmental research. This intersection has been recognized for enhancing understanding of various contemporary environmental challenges. Despite its acknowledged importance, there remains a notable gap in understanding how these knowledge systems are brought together, specifically at the level of data analysis, presentation, and interpretation of results. Furthermore, even less is known regarding the appropriate and effective use of any one approach and method in its application. Therefore, this thesis was guided by the question, **'What approaches and methods have been used previously to bring together Indigenous and Environmental science Knowledge in environmental research, and what are the challenges and limitations of any one approach and method in practical application?'**

This question is investigated through the conduct of a systematic map and application of a case study scenario. A search protocol was developed and served as a guide for the conduct of a systematic map. This protocol detailed how articles focused on bringing together IK and ESK would be systematically gathered and analyzed (Chapter 2). The resulting systematic evidence base highlighted four main approaches used in the peer-reviewed literature to bring together IK and ESK, namely: (1) a narrative approach to mixing; (2) the use of statistical analysis; (3) use spatial overlap in GIS; and (4) mixing IK and ESK using illustrative figures (Chapter 3).

In order to gain a more in-depth understanding of the identified approaches and methods, their use was explored through the application of a case study scenario on environmental factors influencing Arctic Char (*Salvelinus alpinus*) growth in the Inuvialuit Settlement Region (Chapter 4). Although more data collection and analysis is needed to understand the relationship between environmental variables on Arctic Char growth in lakes surrounding Ulukhaktok, the attempt to link Indigenous Knowledge of lake ice change with Environmental science Knowledge on landlocked Arctic Char growth, coupled with insights informed from a review of relevant literature, led to the development of criteria that may be used in future research to test the identified approaches and methods.

This thesis makes contributions to the academic literature by documenting and examining the types of approaches used to bring together IK and ESK at the level of data analysis, offering insights into the complex and evolving landscape of linking IK and ESK in environmental research.

Keywords: Indigenous Knowledge, Environmental science Knowledge, Knowledge linking, Arctic, Arctic Char, environmental, freshwater ecology, environmental research

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A sincere thank you to the residents of Ulukhaktok for their invaluable contributions and shared knowledge. This study would not have been possible without the participation of community members, and I am greatly appreciative of their time and insights.

DEDICATION

To my friends, family and all of those who have supported me along the way.

TERMINOLOGY USED IN THE THESIS

Convergent parallel design**:** A *convergent parallel design* is a mixed-methods research approach in which both qualitative and quantitative datasets are collected and analyzed concurrently. The results from each method are then integrated for comprehensive interpretation (Creswell & Clark, 2017).

Data: For the purposes of this thesis, *data* is defined as information, or a representation of knowledge gathered through various research methods such as observations, interviews and questionnaires (Creswell & Creswell, 2018).

Data analysis: In this thesis, the *data analysis* process encompasses multiple stages, including refining raw data through cleaning and transformation, conducting thematic or statistical analysis, presenting results, analyzing the outcomes, and engaging in discussion to interpret findings and identify their broader implications (Creswell & Creswell, 2018).

Data transformation: For the scope of this study, *data transformation* is defined as the process of altering the nature of the data to facilitate linking with ESK/IK data, rather than solely organizing, and presenting data in a structured manner for the purposes of deriving insights (Fetters et al., 2013; Creswell & Clark, 2017).

Environmental science Knowledge**:** In this thesis, *Environmental science Knowledge,* is defined as a field of science, which is part of a broader system of knowledge that can be traced back to the philosophical traditions of ancient Egypt, India, China, and Greece, as well as the more recent Renaissance (Mazzocchi, 2006). This knowledge is represented by various models of inquiry, such as classical, hypothetico-deductive, and pragmatic approaches. Although it is often associated with Eurocentric worldviews and epistemologies (Aikenhead & Ogawa, 2007) and commonly referred to as "Western

Scientific Knowledge" within the environmental studies and sciences literature, the authors acknowledge that science is not inherently Western (Raju, 2009) and will use the term "Environmental science Knowledge" throughout.

Indigenous Knowledge: For the purposes of this thesis, *Indigenous knowledge,* as part of a larger system of knowledge, can be defined as "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relation of living beings (including humans) with one another and with their environment" (Berkes et al., 2000). According to Battiste (2013), Indigenous Knowledges are "diverse learning processes that come from living intimately with the land, working with resources surrounding that land base, and the relationships that it has fostered over time and place" (p.33). Indigenous Knowledge has also been commonly referred to as Traditional Ecological Knowledge, Local Ecological Knowledge and Indigenous Science in the academic literature (Cajete, 1999; Silvano & Begossi, 2005).

Knowledge: In this thesis, *knowledge* is defined as the understanding, interpretation, and meaning given to information, experiences and observations, encompassing various forms of knowing, such as knowing through science, Indigenous and community-based knowledge (Creswell & Creswell, 2018; Kovach, 2021).

***Knowledge linking*:** *Knowledge linking* has been commonly referred to in the academic literature as Knowledge bridging, merging, weaving and braiding (Johnson et al., 2016) and can occur at one or more stages of the knowledge production process. For the purposes of this study, knowledge linking can be broadly defined as any planned and/or purposeful undertaking of the bringing together of Indigenous and Environmental science Knowledge as represented by data generated through epistemological processes accepted within each knowledge system. This definition is inclusive of that put forth by Johnson et al. (2016) on co-production of knowledge, including Indigenous Knowledges, and by Alexander et al. (2021) when speaking of knowledge bridging. The focus in this paper is more specific than each of these though in that we examine this phenomenon at the stage of interconnected analysis of data originating from the two knowledge systems and therefore clarify our use of the term "linking" here.

***Linking Approach and method**:* For the purposes of this thesis, a *linking approach* refers to the general strategy used to link IK and ESK data (e.g., statistical analysis). On the other hand, a *linking method* refers to the specific technique used to facilitate linking (e.g., transformation of data).

***Qualitative data*:** For the purposes of this thesis, *qualitative data* typically consists of non-numerical information obtained through methods such as interviews, participant observations, or questionnaires. Qualitative data is often analyzed through qualitative research methods such as thematic analysis to identify themes, patterns and meanings within the data (Creswell & Creswell, 2018).

***Quantitative data*:** For the purposes of this thesis, *quantitative data* typically comprises of numerical data collected through methods like surveys, experiments, or measurements. Quantitative data is often analyzed through quantitative research methods such as statistical analysis to identify patterns, relationships, and trends within the data (Creswell & Creswell, 2018).

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CHAPTER 1:
Introduction

1.1 Linking Indigenous and Environmental science Knowledge in environmental research

The bringing together of data from Indigenous Knowledge and Environmental science Knowledge bases has attracted considerable attention in research due to its role in better understanding and assessing complex environmental and climate change impacts on the health and well-being of many wildlife species. Particularly relevant are those species that hold significant cultural, economic, and nutritional importance for Indigenous communities, Nations, and peoples worldwide. International agreements and policies have increasingly emphasized the importance of incorporating multiple knowledge systems, including IK, into conservation strategies, as evident in earlier years in the creation of the Brundtland Report, The Convention on Biodiversity, and Agenda 21 (Higgins, 1998; Tengö et al., 2017). Furthermore, it has long been considered imperative to recognize the role that active and equitable engagement of and partnership between non-Indigenous and Indigenous peoples and communities can play in advancing environmental research and decision-making, fostering inclusivity, and promoting collaboration between knowledge systems (McGregor, 2000).

Subsequently, when applied in certain contexts, the role of local and Indigenous Knowledge (IK) in wildlife management has been explored as a unique source of knowledge that has the potential to help address existing data challenges facing decision makers (Huntington et al., 2000; Arce-Ibarra & Charles, 2008; Russell et al., 2013; Eckert et al., 2018). For example, the cases of the freshwater fisheries of the Yucatan peninsula and the yelloweye rockfish have shown how IK is a significant source of knowledge, that, where applicable, has been drawn upon to provide information absent amongst existing Environmental science datasets.

The freshwater fisheries of the Yucatan peninsula in southern Mexico have been largely understudied, despite many inland fisheries and local Indigenous communities residing in this area and who rely on freshwater fishes for economic, traditional and dietary purposes. As a result, no Environmental science knowledge existed at the time of the study (Arce-Ibarra & Charles, 2008). Interviews and questionnaires were undertaken with local Indigenous communities in the area in order to better understand fish species that support local fisheries, local fishing methods and the seasonality and time of fishing. The local and Indigenous knowledge provided by local and Indigenous communities provided the means for an extensive assessment of the local freshwater fishery and can be used to address gaps in knowledge of local fisheries in the surrounding area for both governmental agencies and local communities (Arce-Ibarra & Charles, 2008).

The yelloweye rockfish (*Sebastes ruberrimus*) are fish vulnerable to exploitation and have important cultural and traditional value to many First Nations in British Columbia, Canada. Indigenous fishers from the Kitasoo/Xai'xais, Heiltsuk, Nuxalk, and Wuikinuxv First Nations of Bristish Columbia’s Central Coast have observed declines of rockfish due to a history of unrestricted large-scale commercial fishing and requested that research be conducted in the area. Traditional ecological knowledge (TEK) of the fishers was used in conjunction with existing ecological surveys to provide a comprehensive understanding of size and abundance of yelloweye rockfish over time. Interviews with Indigenous fishers, supported by existing ecological evidence, extended the historical baseline for yelloweye rockfish size, showing that yellow rockfish populations have experienced a significant decrease in overall length since the 1980s (Eckert et al., 2018). While more research is needed to investigate the relationship between large-scale commercial fishing and changes to yelloweye rockfish size and abundance in the study area, this work highlights the significant impact that knowledge held by Indigenous fishers can have on extending historical baseline information of fish life history (Eckert et al., 2018).

Together, the cases of the local freshwater fishery of the Yucatan peninsula and the yelloweye rockfish demonstrate the significant impact of bringing together Indigenous Knowledge and Environmental science Knowledge. The linking of IK and ESK datasets regarding fish life history has facilitated the creation of enriched datasets. These datasets offer a comprehensive understanding that can be used to inform conservation practices that align with and support local and Indigenous communities cultural, economic and physical health needs and priorities, while also contributing to the sustainability of marine and freshwater fishes in the environment.

To date, there have been numerous articles published in the field of environmental studies and sciences in studies attempting to bring together IK and ESK and they have used a variety of approaches and methods in their work. The processes involved in knowledge linking are complex and should not be viewed through a one-size-fits-all mindset (Bohensky & Maru, 2011; Johnson et al., 2023). This study recognizes that there are many levels of knowledge linking; different methods and approaches exist at each level; and that there is overlap between and among linking levels or phases. Various studies have explored knowledge linking across different stages of research, ranging from project design and collaboration, to research methodology and data collection. For example, researchers such as Thornton & Scheer (2012), Castelden et al. (2017), Stefanelli et al. (2017), and Henri et al. (2021) have focused primarily on identifying methods and approaches related to knowledge linking taking place at the level of project design and collaboration. Additionally, Castelden et al. (2017), Stefanelli et al. (2017), Alexander et al. (2019a,b, 2021), and Henri et al. (2021) have explored knowledge linking within the context of research data collection methods and methodological approaches as relates to water or terrestrial research and management. Bélisle et al. (2018) examined how common challenges to LEK (Local Ecological Knowledge) inclusion in ecological modelling have been confronted in the literature, while Stern & Humphries (2022) reviewed the methods used to weave experiential wildlife knowledge into quantitative, mixed methods analyses of population and habitat models. This thesis contributes to the literature by offering a comprehensive and critical analysis of the approaches and methods used to bring together Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) through data analysis drawn from multiple fields of environmental studies and sciences worldwide.

In support of the ongoing importance of fostering meaningful engagement of Indigenous Knowledge and Environmental science Knowledges in research, and in recognition of the complex nature of IK and ESK knowledge interaction, this thesis will be guided by the question, **'What approaches have been used previously to bring together Indigenous and Environmental science Knowledge in environmental research and what are the challenges and limitations of any one approach in its application?'.** It proposes to systematically review existing approaches methods for linking IK and ESK, as documented in peer-reviewed literature and will involve a critical assessment of the practical implementation of an approach and method through a case study scenario. The case study focuses on environmental conditions influencing growth variability of landlocked Arctic Char in the western Canadian Arctic. Given the cultural, economic and dietary importance of many marine and freshwater fishes to Inuit communities across the Canadian Arctic (Kristofferson & Berkes, 2005; Roux et al., 2011; Dewailly et al., 2001), and the need to understand species dynamics in the face of environmental and climate change, this case study illustrates how multiple knowledge systems can inform conservation and management practices that support and engage Indigenous communities needs and priorities.

1.2 Organization of manuscript-based thesis

This thesis consists of five chapters, with three chapters (2-4) written as standalone manuscripts. Chapter 2 has been accepted for peer-review publication and is currently in the process of being published, and Chapters 3 and 4 are going to be submitted for peer-review publication. This chapter (1) serves as the introduction to the thesis, providing relevant background information and context to this study. Chapters 2, 3 and 4 specifically address the main objective of the research. Chapter 5 is a summary and conclusion of findings presented in Chapters 2-4. All chapters (1-5) included in this thesis were conceptualized by Emma Pirie (EP) with primary guidance from, Dr. C. Furgal (CF). All chapters (1-5) were written by Emma Pirie. Guidance on otolith examination and analysis was provided by Dr. J. Knopp (Chapter 4). Review and comments for revision were provided by committee members Dr. T. Whillans and Dr. J. Knopp. Project and editing guidance were provided by Dr. C. Furgal.

Chapter 2: A systematic map protocol to identify the approaches and methods used to bring together Indigenous and Environmental science Knowledge in environmental research, presents the processes and procedures used to conduct a systematic map review of the ways in which Indigenous and Environmental science knowledge have been brought together at the level of data analysis in environmental research. General study characteristics such as year of publication, geographic location of study, and Indigenous groups from which IK was drawn, are also gathered in addition to linking approaches and methods.

Chapter 3: Results of a systematic map identifying the approaches and methods used to bring together Indigenous and Environmental science Knowledge in environmental research, presents the findings of the systematic map review. Specifically, it presents findings and interpretations on trends of publications over time, global spatial variation of identified studies, Indigenous groups from which IK was drawn in identified studies, as well as the identified approaches and methods used to link IK and ESK at the level of data analysis, presentation and interpretation of results.

Chapter 4: An illustration of the linkage of Indigenous and Environmental science Knowledge: Case study on environmental conditions and Arctic Char (Salvelinus alpinus) growth in the Inuvialuit Settlement Region, presents an attempt at linking pre-existing IK on observations of environmental conditions with ESK on Arctic Char growth rates in the Inuvialuit Settlement Region. The results of doing so led to the development of criteria to determine data readiness for linking and a better understanding of the challenges and limitations of attempting to link IK and ESK using the four approaches as identified from the systematic map review.

Chapter 5: Summary and conclusion, presents an overview of findings and implications of the work provided in Chapters 2-4.

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CHAPTER 2:

A Systematic map protocol to identify the approaches and methods used to bring together Indigenous and Environmental science Knowledge in Environmental Research

2.1 Introduction

The merging of data from Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) bases has become a topic of interest within academic research, natural resource management and Indigenous communities for some time (Turnbull, 2003). In the areas of natural resource management for example, the bringing together of IK and ESK datasets has raised considerable interest for its potential to increase understanding and provide insights into complex phenomena such as the effects of climate change and variability on wildlife health and distribution (e.g., Gagnon & Berteaux, 2009; Hauser et al., 2021). The recognition of the role of multiple knowledge systems in sustainable resource management and biodiversity conservation has led to various international agreements, such as The Brundtland Report, The Convention on Biodiversity, and Agenda 21, emphasizing the importance of engaging and incorporating knowledge held by Indigenous peoples for informed environmental policy and decision-making purposes (Higgins, 1998; Tengö et al., 2017). Effective wildlife and resource management practices require a holistic and accurate understanding of ecosystem dynamics and must reflect the needs of resource users involved/affected (Huntington, 2000; Gilchrist et al., 2005; Laidler, 2006; Russell et al., 2013). Acknowledging the role of actively and equitably engaging Indigenous peoples has been widely recognized in advancing environmental research and decision-making, fostering inclusivity and promoting collaboration between knowledge systems (McGregor, 2000).

Subsequently, there have been numerous articles published in the field of environmental sciences and studies attempting to link both Indigenous and Environmental science Knowledge (definitions found on pgs. v-vi). This study recognizes that there are many levels of knowledge linking and acknowledges that these levels or stages are not separate or mutually exclusive but may interact with one another and can exist in the same project in a mutually beneficial manner. Various studies have explored knowledge linking across different stages of research, ranging from project design and collaboration, to research methodology, and data collection (Figure 1a). For example, researchers such as Thornton & Scheer (2012), Castelden et al. (2017), Stefanelli et al. (2017), and Henri et al. (2021) have focused primarily on identifying methods and approaches related to knowledge linking taking place at the level of project design and collaboration. Additionally, Castelden et al. (2017), Stefanelli et al. (2017), Alexander et al. (2019a, b, 2021), and Henri et al. (2021) have explored knowledge linking within the context of approaches and methods for data collection as they relate to water or terrestrial research and management. Bélisle et al. (2018) examined how common challenges to LEK (Local Ecological Knowledge) inclusion in ecological modelling have been confronted in the literature, while Stern & Humphries (2022) reviewed the methods used to weave experiential wildlife knowledge into quantitative, mixed methods analyses of population and habitat models.

The current work extends this research to further explore the processes involved in linking IK and ESK, but specifically at the stage of data analysis, presentation and interpretation, and across multiple fields of environmental studies and sciences around the globe (Figure 1b).

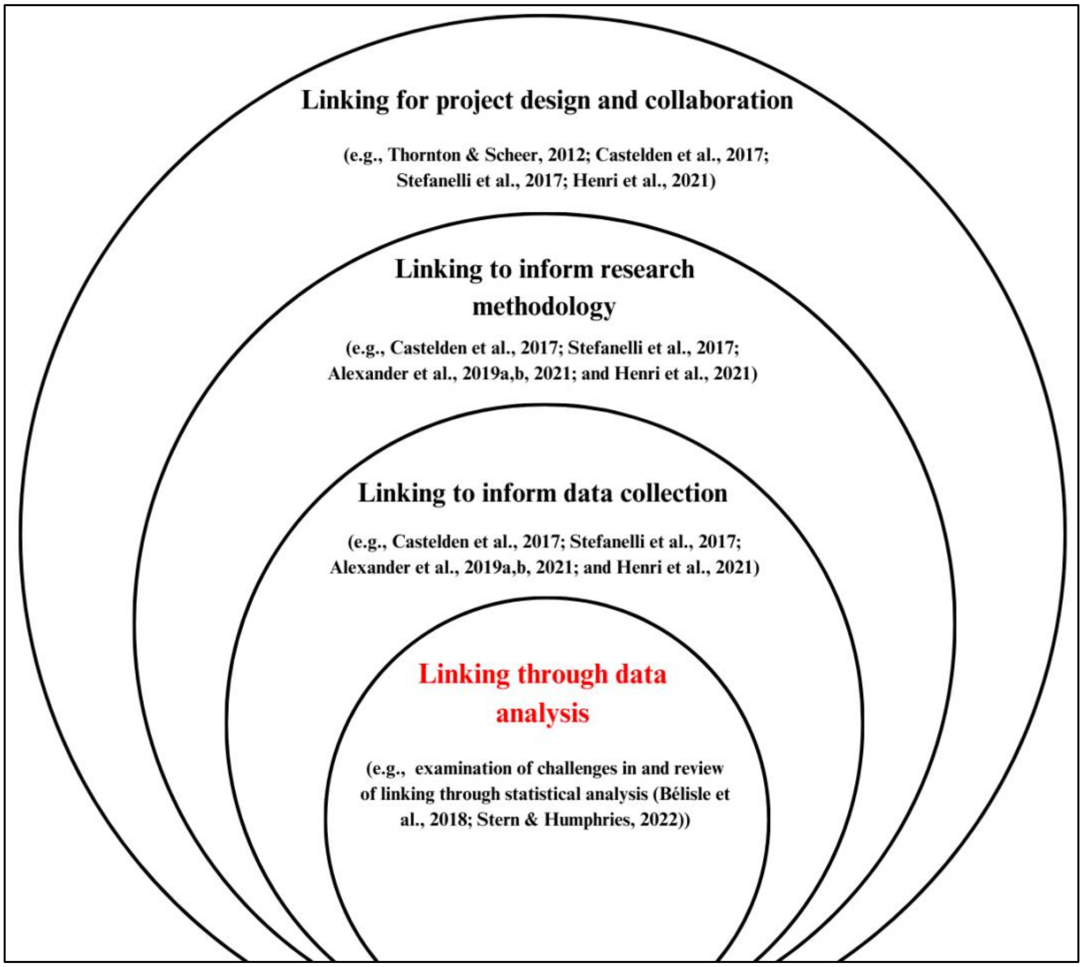

Figure 1a. Examples of work that have explored and examined aspects of knowledge linking at various stages of the research process.

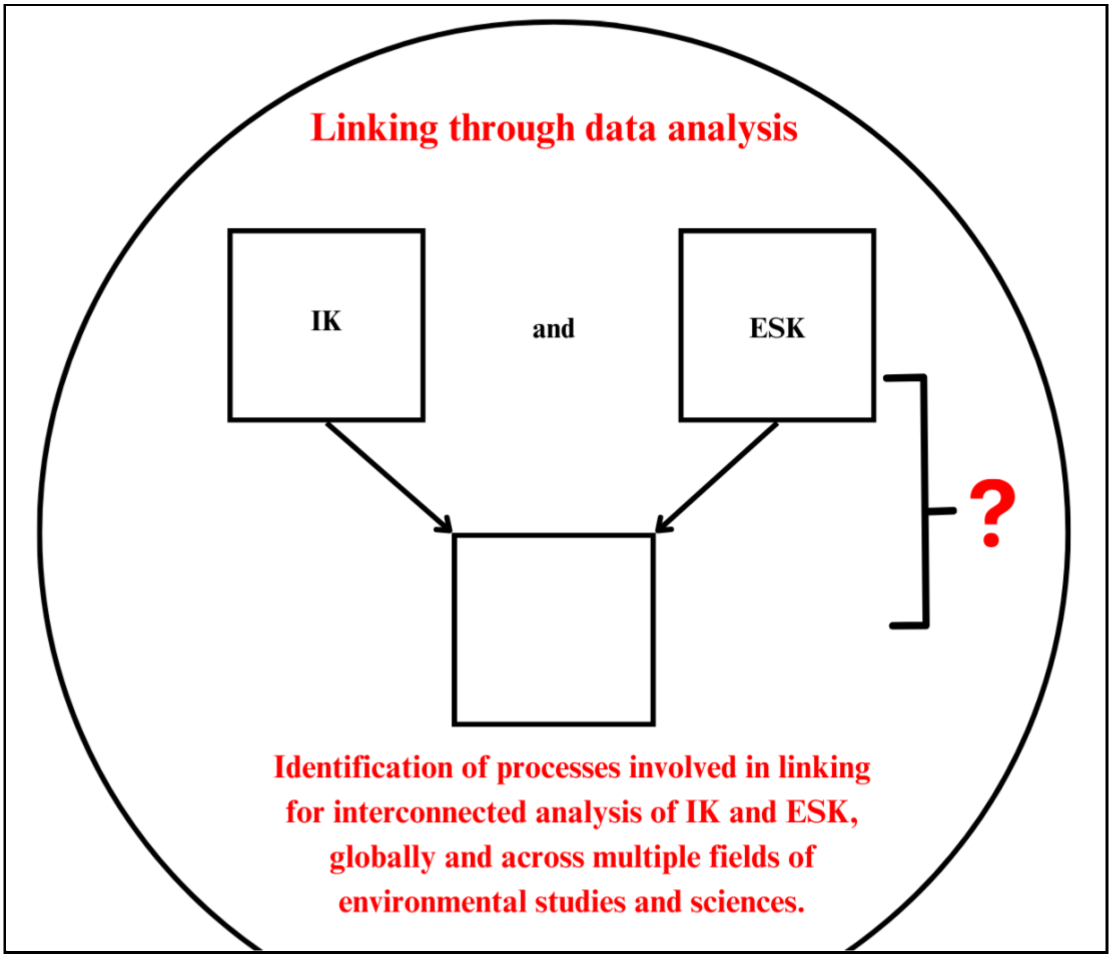

Figure 1b. Focus of the proposed review and its intended contribution to the literature.

Many different methodological approaches, methods and techniques have been developed and used in different regions around the world for the purposes of bringing together IK and ESK at various stages of the research process and this number continues to grow. The diversity highlights the complex nature of IK and ESK knowledge interaction in environmental research. In support of the ongoing importance of fostering meaningful engagement of both Indigenous and Environmental science Knowledges in research, and in recognition of the existence of multiple levels of knowledge interactions, the aim of this systematic map is to contribute to this existing body of literature and support ongoing research using or further exploring ways to bring together these knowledges to address important environmental challenges. This will be done by using a systematic mapping approach to identify and examine the approaches and methods used in published studies from around the globe that aim to bring together Indigenous and Environmental science Knowledges within the fields of environmental studies and sciences, with particular emphasis on methods and approaches used for data analysis, results, and interpretation/discussion stages of the research process.

2.2 Methods

2.2.1 Author Positionality

Emma Pirie is a non-Indigenous researcher who currently works alongside faculty and postdoctoral researchers at Trent University to identify research and monitoring projects involving Indigenous communities around the Laurentian Great Lakes in an effort to support Indigenous-led research and conservation efforts. Ms. Pirie is a graduate student and research assistant with Trent University's Indigenous Environmental Institute.

2.2.2 Systematic Maps

Systematic mapping approaches can be used to synthesize, categorize and classify all available evidence pertaining to a specific research question/objective (CEE, 2018). The systematic mapping protocol presented in this manuscript provides a transparent, replicable, standardized and systematic method to capture and synthesize evidence (Haddaway et al., 2016). This proposed systematic mapping protocol considers guidelines provided by CEE (CEE, 2018) and follows the standards of ROSES (i.e., adhering to and completion of ROSES form; Appendix 1: Chapter 2 - Supporting information 1) (Haddaway et al., 2018).

2.2.3 Primary research question and objectives

This work is guided by the question: What approaches and methods do peer-reviewed papers in the field of environmental studies and sciences use to bring together Indigenous

Knowledge (IK) and Environmental science Knowledge (ESK) during the data analysis, results and/or discussion stages of the research process? In this study, we will employ a systematic mapping approach to categorize and classify key aspects of existing research papers within the scope of our investigation. It is the intent of this protocol to outline the methodology for the conduct of a systematic map. In contrast to systematic reviews, our methodology will concentrate on organizing and thematically describing the available literature, without the need for data synthesis or evaluating the quality or validity of individual studies, as outlined by CEE (2018). This approach is particularly suited to the broad objectives and scope of our work. This method will allow us to provide a comprehensive overview of the research landscape, identifying general study characteristics (e.g., publication year, geographic distribution, focus of study etc.) and key approaches and methods used to bring together IK and ESK, specifically those used at the stage of data analysis, results and discussion in the research process.

2.2.4 Components of the research question

For this protocol and the resulting systematic map, identified and explored articles will include the following components, details of which are provided in Table 2:

- *Population*: Articles within the fields of environmental sciences and studies.
- *Study intent*: Articles which aim to bring together both Indigenous Knowledge and Environmental science Knowledge.
- *Geographic scope*: There will be no geographic limit applied to this search.

Table 1. Description of eligibility criteria

Population
In recognition of the growing diversity of literature available and considering the time constraints of this systematic map, our focus will be limited to peer-reviewed studies that focus on any aspect of ecological or environmental research. For the purpose of this review, ecological or environmental research will be defined broadly as any planned and/or purposeful

inquiry pertaining to the environment, including those studies examining the environment as a determinant of human health.
Study intent
Articles that purposefully and actively bring together Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) and present empirical results will be included. Specifically, we will consider articles that incorporate both IK and ESK components, offering empirical evidence to support the merging of IK and ESK datasets. Our inclusion criteria will be further refined to include papers that have employed some form of a convergent parallel design. Review papers and articles proposing frameworks for merging IK and ESK without accompanying empirical assessments will be excluded.
Geographic scope
The geographic context for this systematic map will include all geographic areas identified within the final capture.
Language
English.

2.2.5 Searching for articles

Using four online bibliographic databases (i.e., Web of Science, Academic Search Elite, International Bibliography of the Social Sciences, and Bibliography of Indigenous Peoples in North America), this search aimed to capture all relevant articles in the peer-reviewed literature that relate to the primary research question. The scope of this map report was limited to documents written in the English language as translation capacity is limited. Articles included will be limited to the range of database date coverage as well as the date of final capture.

2.2.5.1 Search string development

A list of keywords and synonyms informed by the primary research components were compiled in order to begin the development of a search string. The web-based search engine Google Scholar was used as an aid to scope out keywords and related synonyms. Various keywords and synonyms were compiled and combined using Boolean Operators (AND, OR, NOT) and wildcard characters in order to assess the sensitivity of possible search terms and combinations within the online bibliographic database, Web of Science. Search terms were separated into three groups, guided by the primary research components, and combined using Boolean Operators “AND” and/or “OR” and the proximity indicator “NEAR/#” (Appendix 1). Keywords were included if they resulted in the addition of any number of relevant sources relating to the primary research question. A list of benchmark articles (n=15; Appendix 1), identified through hand searching, was used to ensure relevance and comprehensiveness of the search string. These benchmark articles are representative of the diversity of parameters (i.e., Linking Indigenous Knowledge and Environmental science Knowledge within the fields of environmental studies and sciences) included in the search string protocol. Emphasis was placed on selecting articles that represent a diversity of various environmental fields, regions and topics of study. It is expected that the search protocol will capture the benchmark articles. If the benchmark articles are not captured with the search protocol, the search protocol will be revised or picked up by hand searching as necessary.

2.2.5.2 Bibliographic database searches

A total of four databases were searched for peer-reviewed articles in the English language. The final search string was developed in Web of Science and was standardized and adapted to each database. Search abilities and capacities for each database were considered when determining whether to include or exclude a database (e.g. the batch export function and capacity), the coverage and extent of research topics included in each database (e.g., disciplinary focus), and the range of publication dates included in the database. The search was conducted until no further relevant articles were found. The following databases will be searched using subscriptions from Trent University:

1. EBSCO*host* Academic Search Elite: a multidisciplinary database which offers full text for scholarly journals covering several areas of academic study including social sciences, sciences and humanities.
2. EBSCO*host* Bibliography of Indigenous Peoples in North America (BIPNA): a bibliographic database covering all aspects of Indigenous Peoples in North American culture, history, and life and including topics such as archaeology, multicultural relations, gaming, governance, legend, and literacy.
3. ISI Web of Science (Core Collection): multidisciplinary database consisting of various subject areas including science, social sciences, and arts & humanities.
4. ProQuest International Bibliography of Social Sciences (IBSS): a bibliographic database for social science and interdisciplinary research.

2.2.6 Screening articles and eligibility criteria

2.2.6.1 Screening process

Results from the online bibliographic databases will be exported into Endnote 20 and duplicates removed before stage 1 of the screening process. Remaining sources will then be screened in two stages: (1) at the level of title and abstract; and (2) full-text analysis.

(Stage 1): Title and abstract screening

The title and abstract for each study will be screened for relevance during stage 1. Any studies that fully or partially align with the inclusion criteria (see eligibility criteria below) will proceed to stage 2 of the screening process. Articles which do not align with the primary research question will be excluded at this level. To test the consistency of the screening process, the two reviewers, EP and CF, will independently screen the same subset of titles and abstracts (5%) and compare results. The selection of a subset of articles will be made by choosing articles from varying disciplines and publication years to ensure diverse representation. A training phase will be undertaken prior to the independent screening where the two reviewers will meet to practice, discuss and adapt the eligibility criteria on 100 test titles and abstracts.

(Stage 2): Full-text analysis

This stage will involve a manual search and review of entire articles. In order to ensure eligibility criteria are consistent across and applicable to captured articles, a subset of articles (10%) will be selected and screened independently by EP and CF. The selection of a subset of articles will take place by choosing articles from varying disciplines and publication years to ensure diverse representation. The two reviewers will meet to compare their results, discuss and adapt the eligibility criteria as necessary. Similar to stage 1, a training phase will be undertaken prior to the independent screening where the two reviewers will meet to practice, discuss and adapt the eligibility criteria on 50 test full texts. The goal of these meetings will be to ensure both reviewers have a clear understanding of the eligibility criteria and their application.

A list of excluded articles and reasons for exclusion at the level of full-text review will accompany the resulting systematic map report.

2.2.6.2 Eligibility criteria

A set of pre-established inclusion/exclusion criteria will be used to guide the screening process (Table 2). All inclusion criteria will need to be met in order for an article to be included in the final dataset.

2.2.7 Study validity assessment

It is not the intention of this systematic map to assess the validity of identified articles.

2.2.8 Data coding strategy

Following the full-text screening (stage 2), remaining studies will be exported from Endnote 20 into Microsoft Excel where they will be coded using a pre-established and standardized coding template (Appendix 1). The template was designed to reflect and capture key information about the articles based on multiple parameters, including:

(1) Bibliographic information

(2) Geographic location of study

(3) Discipline of study

(4) Methods used to collect IK and ESK

(5) Linking approach segments from the article

(6) Categorical identification of linking approach and method used in data analysis (informed by linking approach segment from the article)

(7) Location in the research process where evidence of linking is reported

(8) The study's stated intent or purpose of bringing together IK and ESK

In order to avoid misrepresentation of articles while coding, missing information regarding any of the parameters will be coded as Unspecified.

For extraction of information identifying the aim or goal of the linking of data from the IK and ESK datasets, as well as the analytical process used to link them (items 5, 6 and 8) – a comprehensive examination of each article will be conducted. This examination will include a thematic content analysis, wherein every section of the article, including captions and other details contained in figures and tables, will be reviewed. The identification and categorization of content pertaining to items 5 and 6 (above) will be guided by the following questions:

1) How is each individual dataset being analyzed?

2) How and where in the research process (and paper) are the results of individual dataset analyses being connected with each other? Is there anything that is being done to each dataset to facilitate interconnection (i.e., transformation of data before merged analysis)?

3) How and where are the linked results presented and interpreted in the paper?

Data from all included articles (i.e., each article remaining after full text screening) will be coded using the standardized coding template. A series of data coding sessions will take place between the primary reviewer, EP, and a secondary senior reviewer, CF. In the first session, coding will be tested on a sample of 15 articles during a face-to-face meeting. This meeting will ensure that each reviewer understands the metadata to be extracted from each article and any adaptations to this list. Following this, EP and CF will each independently code a test sample of 30 articles. They will then compare their interpretations of the extracted data. Discrepancies will be carefully examined and discussed, leading to any necessary adjustments to the coding strategy. In the final phase, EP will proceed to code all articles, with CF verifying any identified as being challenging or questionable to code. This process will be done to ensure the accuracy and consistency of the coded data.

2.2.9 Study mapping and presentation

Study characteristics (such as year of publication, geographic distribution, discipline of study) and approaches and methods used to bring together IK and ESK at the level of data analysis, results and discussion, will be coded, analyzed and presented through the application of a narrative synthesis approach, using thematic content analysis and descriptive statistics to synthesize study findings in a coherent narrative format (Saldana, 2021). Results of analysis will be presented in tables and figures and knowledge gaps and clusters will be highlighted through the use of a framework-based synthesis using structured matrices (Dixon, 2011; McKinnon et al., 2016; Alexander et al., 2019). The final output will include a published systematic map.

2.3 Discussion

This mapping exercise aims to produce a protocol and systematic map that will identify the approaches and specific methods used to bring together IK and ESK published scientific articles within the field of environmental studies and sciences, with particular emphasis on the level of data analysis, presentation of results and discussion stages of the research process. The growing methodological complexity that exists in bringing together these diverse knowledge systems, presents a unique opportunity to provide a categorization and classification of current approaches and methods used to bring IK and ESK together at the level of data analysis, presentation and interpretation. If we are to adopt appropriate approaches and methods in future research and decision-making and leverage the opportunities that arise from bringing together multiple knowledge systems pertaining to a particular issue, learning from any attempt is critical. By identifying and analyzing articles which have aimed to bring together IK and ESK, the results of this study will yield a unique resource for researchers and policy makers and support ongoing efforts that recognize the opportunities involved in engaging with multiple sources of knowledge in environmental research and management.

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CHAPTER 3:

Results of a systematic map identifying the approaches and methods used to bring together Indigenous and Environmental science Knowledge in environmental research

3.1 Introduction

3.1.1 Background

In the fields of environmental sciences and studies, the bringing together of Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) has become a subject of widespread interest and discussion, bridging diverse perspectives and expertise. Notably, this knowledge intersection has piqued interest for its potential in better understanding the impacts of climate change and variability on wildlife health and distribution (Gagnon & Berteaux, 2009; Hauser et al., 2021). In certain contexts, the role of local and Indigenous Knowledge (IK) in wildlife management has been explored as a distinct and valuable source of knowledge that has the potential to address existing data challenges encountered by decision-makers (Huntington et al., 2000; Arce-Ibarra & Charles, 2008; Russell et al., 2013; Eckert et al., 2018). For instance, cases such as the freshwater fisheries of the Yucatan peninsula and the yelloweye rockfish demonstrate how data originating from IK is a significant source of knowledge (Arce-Ibarra & Charles, 2008; Eckert et al., 2018). This knowledge plays an important role in informing datasets concerning the life history of important fish species to local and Indigenous communities and may be applicable for developing conservation strategies that align with and support local and Indigenous communities needs and priorities.

There has been a global push for the inclusion and recognition of knowledge held by Indigenous peoples to be implemented within environmental research and decision-making (Higgins, 1998; McGregor, 2000; Tengö et al., 2017). Moreover, numerous international mandates and policies have and continue to emphasize the importance of incorporating multiple knowledge systems, including IK and ESK, into conservation and management strategies. This has led to an increasing number of projects aimed at bringing together IK and ESK and the ways in which these knowledge are brought together continues to grow.

While there is broad acknowledgement of the potential benefits of bringing together Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) in environmental research, the full extent of doing so is not fully recognized, and many complex challenges exist (Gagnon & Berteaux, 2009; Bohensky & Maru, 2011; Furgal & Laing, 2012; Johnson et al., 2023). Moreover, the study recognizes that a uniform approach to knowledge linking may not be suitable (Johnson et al., 2023), in part due to the multiple levels and ways in which knowledge can be brought together during the research process (e.g., project design and collaboration, methodology, and data collection stages). For instance, some studies in the environmental peer-reviewed literature have explored ways in which knowledge linking takes place at level of project design and collaboration (Thornton & Scheer, 2012; Castelden et al., 2017; Henri et al., 2021). Specifically, Thornton & Scheer (2012) explored the successes and challenges in conducting collaborative work (i.e., relationship and trust-building) between local and traditional ecological knowledge (LTK) and science, with a focus on marine research and management. Additionally, studies by Castelden et al. (2017), Stefanelli et al. (2017), Alexander et al. (2019a,b,2021), and Henri et al. (2021) have explored aspects of knowledge linking within the context of research data collection methods and methodological approaches (e.g., community-based research, mixed methods, ethnography), particularly in water or terrestrial research and management. Bélisle et al. (2018) examined how common challenges to LEK (Local Ecological Knowledge) inclusion in ecological modelling have been confronted in the literature, while Stern

& Humphries (2022) reviewed the methods used to weave experiential wildlife knowledge into quantitative, mixed methods analyses of population and habitat models. This thesis adds to and extends beyond the current understanding of the processes involved in linking IK and ESK. By providing an in-depth exploration and examination of approaches and methods used globally and across multiple fields of environmental studies and sciences, this work aims to enhance understanding of the existing approaches and methods used to link IK and ESK at the level of data analysis, presentation and interpretation of results. Furthermore, through the application of a case study scenario to the identified approaches and methods, this thesis provides a critical analysis of any one approach and method in its practical application, thereby shedding light on the functioning and limitations of the identified approaches and methods used to link IK and ESK in environmental research.

3.1.2 Objective of the review

The intent of this review was to map all available existing peer-reviewed evidence pertaining to the research question: What approaches and methods have been used in studies that engage in the bringing together of Indigenous and Environmental science Knowledge within the fields of environmental studies and sciences?

The research question can be further broken down into the following three components:

1. *Population*: Articles within the fields of environmental sciences and studies.
2. *Study intent*: Articles which aim to bring together both Indigenous Knowledge and Environmental science Knowledge.
3. *Geographical scope*: There was no geographic limit applied to this search.

3.2 Methods

3.2.1 Systematic map protocol

This systematic map was conducted using a previously established mapping protocol and considered guidelines published by Collaboration for Environmental Evidence (CEE, 2018) and RepOrting standards for Systematic Evidence Syntheses (Haddaway et al., 2018; Appendix 2). A comprehensive overview of the systematic mapping protocol can be found in Chapter 2 of this thesis. However, methodological details relevant to the systematic mapping process are included here as well as in Appendix 2. No modifications were made to the protocol prior to conducting this map. The methodological details for this systematic map are outlined in the following sections.

3.2.2 Searching for articles

This systematic map used a standardized search string across four online bibliographic databases. Hand searching was performed by randomly scanning the reference sections of relevant peer reviewed articles. All searches were undertaken in June 2022.

3.2.2.1 Search string

Through a scoping exercise, a draft search string was developed based on a pre-established list of key words and synonyms informed by the primary research components (See Section 3.1.2). Database and platform-specific searches including the use of Boolean operators, database date range and language can be found in Appendix 2. A list of benchmark articles (n=15; Appendix 2) representing a diversity of subject disciplines and identified through hand searching, were used to ensure relevance and comprehensiveness of the search string.

3.2.2.2 Searches

Articles relevant to the review objectives were systematically searched through online bibliographic databases in English. The search was conducted using four online databases: ISI Web of Science Core Collection, EBSCOhost Bibliography of Native North Americans, ProQuest International Bibliography of Social Sciences, and EBSCOhost Academic Search Elite. Access to these databases was made possible through the Trent University Omni subscription. Detailed information about the search can be found in Chapter 2 of this thesis as well as in Appendices 1 and 2.

3.2.3 Article screening and study eligibility criteria

3.2.3.1 Screening process

The findings retrieved from the online bibliographic databases were transferred to Endnote 20 Referencing Software. Prior to commencing the two-tier screening process, duplicate entries were removed using Endnotes duplicate removal function. The screening process took place in two stages: at the level of title and abstract, and subsequently, through a manual search and review of full texts. During stage 1, all articles that fully or partially aligned with the eligibility criteria (See section 3.2.3.2) were included based on their title and abstract. The remaining articles then moved on to the next phase, which involved screening at the full-text level.

Prior to the screening process, a series of training sessions took place between the primary reviewer (EP) and the secondary senior reviewer (CF). The intent of these meetings was to ensure each reviewer understood the eligibility criteria. The primary reviewer screened all of the articles and met with the secondary reviewer on a regular basis (weekly) to discuss any challenging articles. When challenging articles did arise, both reviewers were in full agreement as to whether the article met the criteria to be considered eligible for the next round of screening.

3.2.3.2 Eligibility criteria

The article screening procedure followed predefined eligibility criteria outlined in Table 1. For articles to be included in the final dataset, they had to have met all specified inclusion criteria.

Table 1. Eligibility criteria

Population
Peer-reviewed articles that focus on any aspect of ecological or environmental research.
Study Intent
Peer-reviewed articles that purposefully and actively bring together IK and ESK and report empirical results to support the linking of IK and ESK datasets. Specifically, articles that have employed some form of a convergent parallel design will be included.
Geographic scope
All geographic areas identified within final capture.
Language
English.

3.2.3.3 Critical appraisal

It was not the intention of this systematic map to assess the validity of the articles captured.

3.2.3.4 Data coding strategy

Data from all included articles (i.e., each article remaining after full text screening) were coded using the standardized coding template (Appendix 2). For each article, information was extracted on (1) bibliographic information; (2) geographic location of study; (3) discipline of study; (4) methods used to collect IK and ESK; (5) approaches and methods used to link IK and ESK at the level of data analysis, results and discussion stages of the research process; (6)

location of the research process where merging is taking place; and (7) the articles stated intent or purpose of bringing together IK and ESK. The resulting data were compiled in Microsoft Excel software.

For extracting information such as the approaches and methods used to link IK and ESK data (item 5) and the articles stated intent or purpose for linking IK and ESK (item 7) – a comprehensive examination of each article was conducted, often concurrently. This examination involved thematic content analysis, wherein each section of the article was inspected including details from figures, and descriptions of processes involving the IK and ESK datasets throughout the article. When coding for the articles stated intent or purpose of bringing together IK and ESK, the abstracts and introductions were specifically targeted. Coding for both items involved the identification of specific themes, derived directly from direct quotes and excerpts found within the papers. Subsequently, these themes or codes were further grouped under overarching themes.

Prior to the coding process, a series of data coding sessions took place between the primary reviewer (EP) and the secondary senior reviewer (CF). The sessions aimed to ensure that the coding template was accurate and consistent in capturing data from included articles. In the first session, the coding template was tested on a sample of 15 articles during a face-to-face meeting. Following this, EP and CF independently coded a test sample of 30 articles and compared their interpretations of the extracted data. Careful examination and discussion addressed any discrepancies, and clarifications were incorporated into the coding strategy as needed. In the final phase, EP proceeded to code all articles. In instances where information from articles was difficult to extract and code within specific categories or labels in the coding template, EP engaged in discussions with CF to resolve these uncertainties. Through discussion, EP and CF consistently reached a mutual agreement on the appropriate placement and identification of codes.

3.2.3.5 Study mapping and presentation

In this study, we systematically coded and analyzed various study characteristics, including the year of publication, geographic distribution, and discipline of study. Additionally, as the central focus of this investigation, we examined the approaches and methods employed to link Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) at the level of data analysis, results, and discussion. Results were coded, analyzed, and presented through the application of a narrative synthesis approach, consisting of thematic content analysis and descriptive statistics (Saldaña, 2021). The presentation of results involved the use of tables and figures. In recognizing the nuanced and complex nature of knowledge linking, we intentionally maintained a clear distinction between the characterized approaches and methods, presenting them as distinct results in corresponding graphs. The final output includes a database of final included articles and their metadata.

3.3 Review findings

3.3.1 Literature searches and screening stages

Figure 1 provides an overview of the search and screening process used to identify included articles. The process began with 10,663 search results with 1,265 duplicates. Screening of titles and abstracts - based upon the eligibility criteria (Table 1) - resulted in the removal of 8,818 articles. This left 580 articles available for full-text screening; 3 of these were unobtainable (Appendix 2). At the full-text screening stage, 339 full-texts were excluded for not meeting the inclusion criteria. The main reasons for exclusion were Population (i.e., Non-Indigenous populations or lack of information regarding whether the research study included knowledge from Indigenous populations) and TEK / IK study (i.e., no ESK data was used / gathered alongside IK data for the purpose of linking). A complete list of excluded articles at full-text, with reasons for exclusion, can be found in Appendix 2. Full-text screening identified 238 articles that met all of the inclusion criteria. A further 3 were picked up through hand searching, met the inclusion criteria and were included. Thus, 241 articles were included in the systematic map in an accessible excel table containing meta-data and coding for final included articles (Appendix 2).

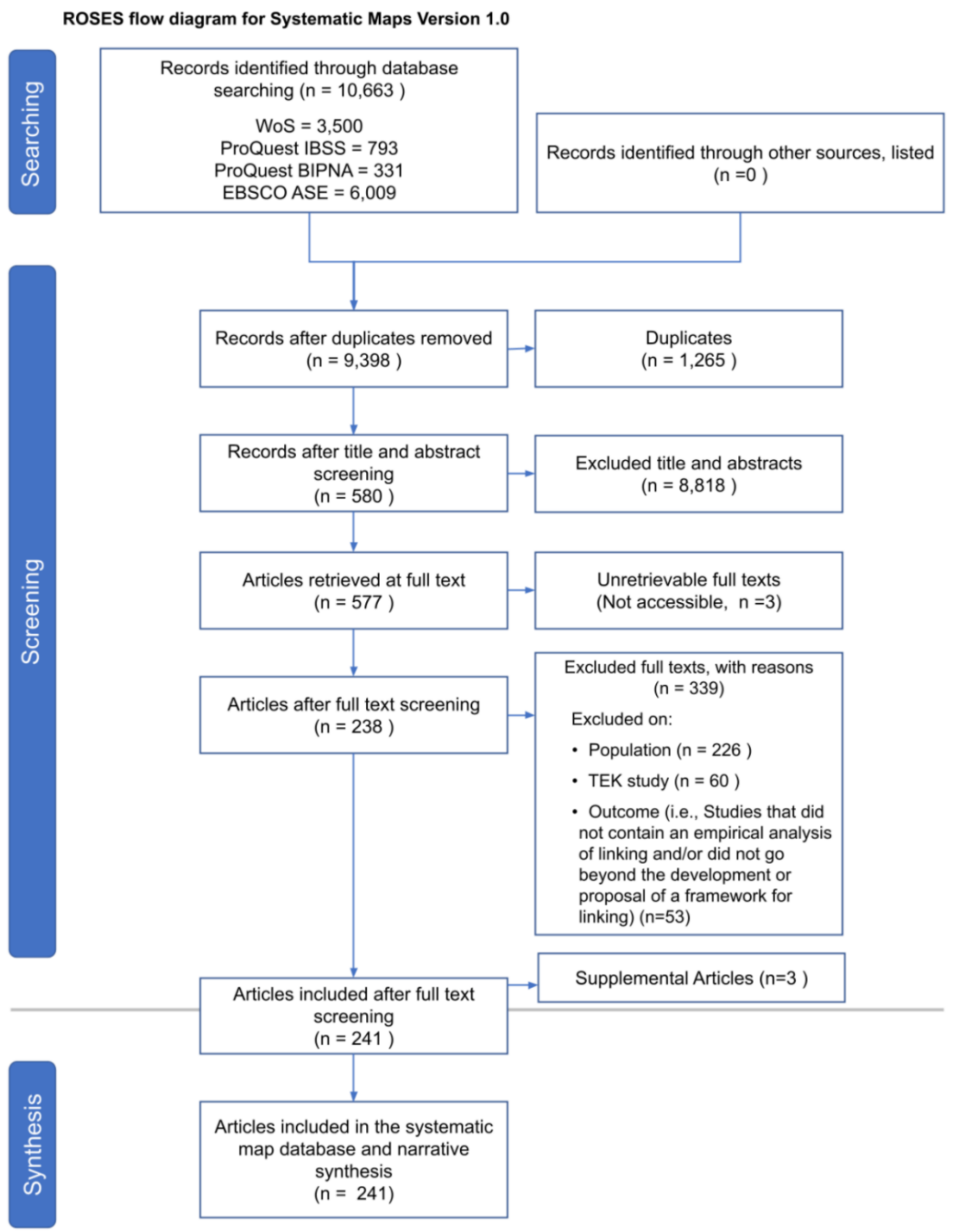

Figure 1. ROSES flow diagram for the systematic map

3.3.2 General study characteristics

The final identified articles covered a period from 1996 to 2022 with an increase in the number of articles published during the last 20 years (Figure 2).

In this map we observed a high number of articles about research that was conducted in Canada (52), followed by the USA and Brazil (28 and 19, Fig. 3). Few articles took place in countries such as Kenya (9), Mexico (7), India (6) and even less in Vietnam (3), Finland (1) and Venezuela (1). Note that an article could include multiple study locations.

A significant portion of the articles provided explicit information regarding the Indigenous group involved in the research (86%). Among these, the predominant Indigenous group from which Indigenous Knowledge (IK) was derived was the Inuit (13%). Note that an article could include more than one Indigenous group.

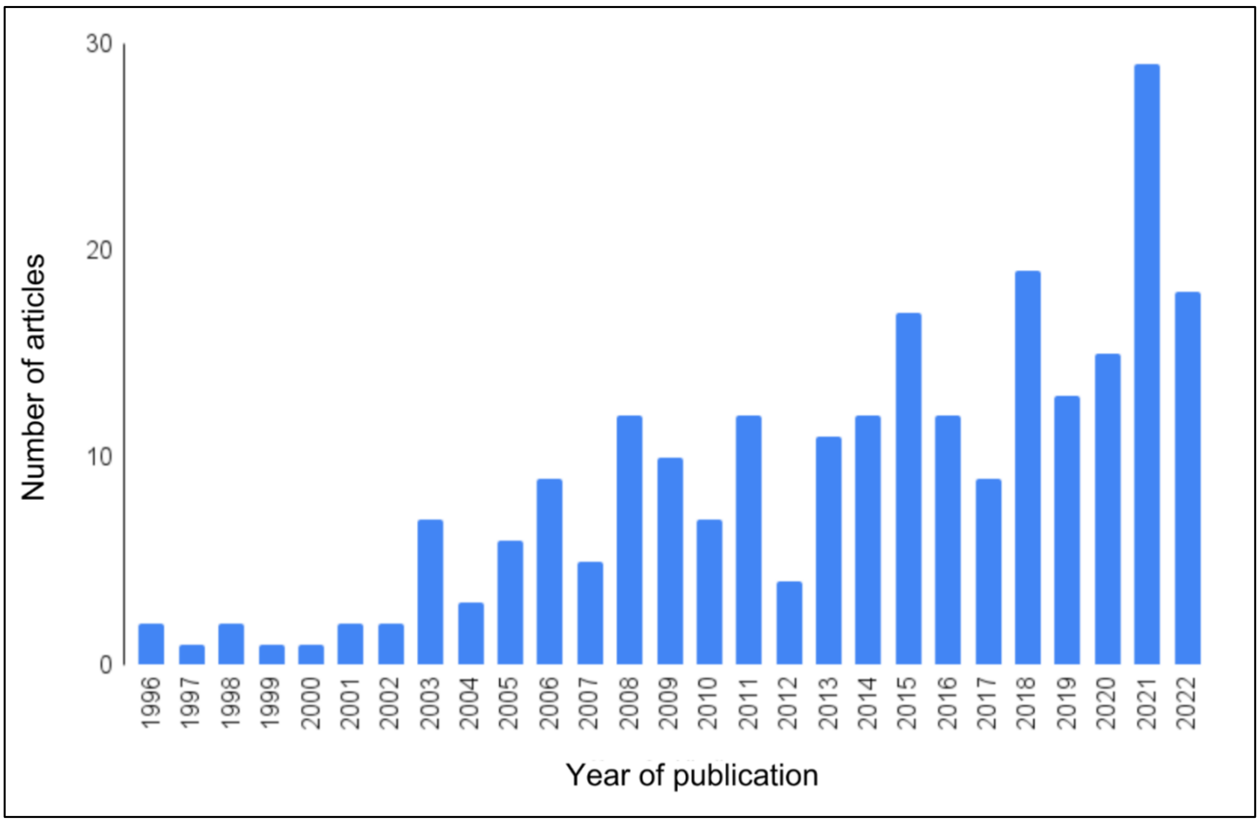

Figure 2. Articles included in the systematic map distributed by year of publication

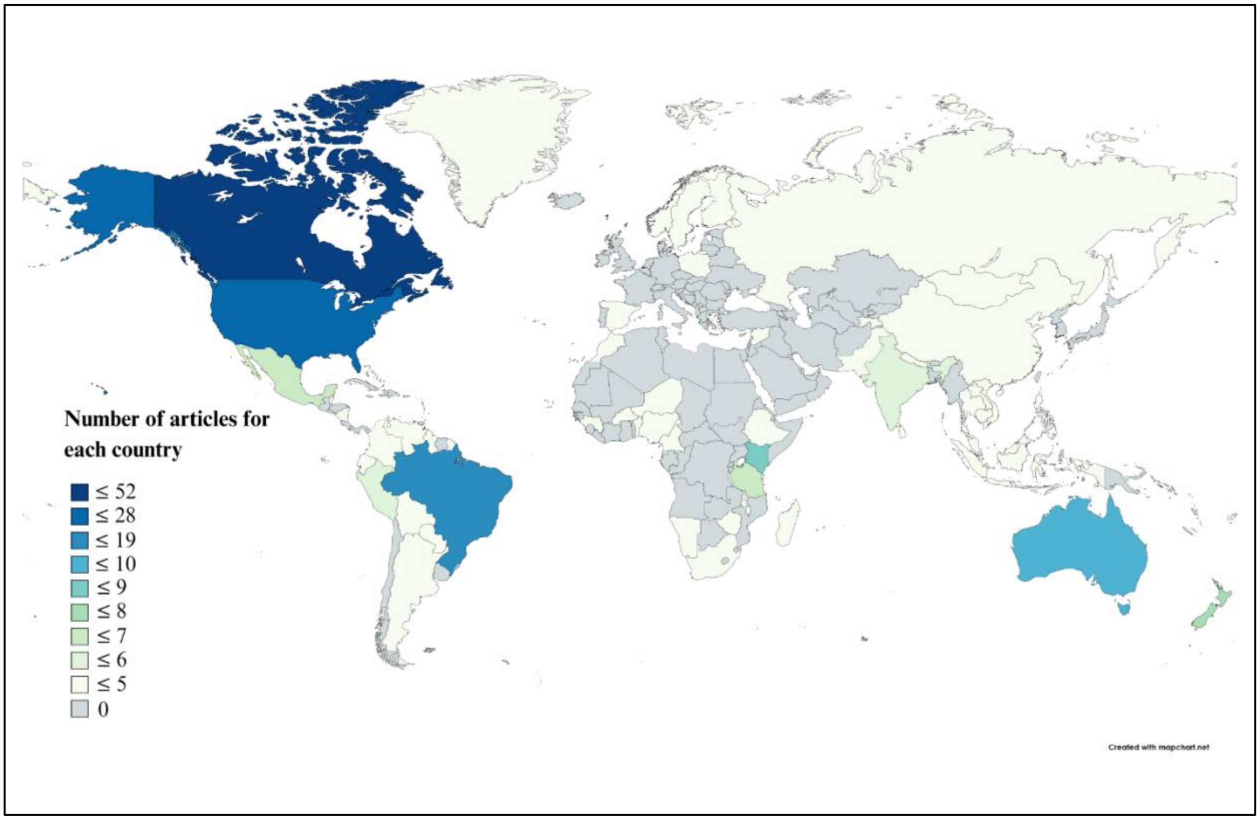

Figure 3. Geographic distribution of study location

Table 2. Indigenous groups identified in the systematic map

Indigenous group	Number of articles (n=241)
Inuit	28
Iñupiat	10
Caiçaras	8
Māori	8
Cree	7
Kalikoqu	6
Kazukuru	6
Saikile	6
Vuragare	6
Yupik	6
Bantu	4
Dene	4
Kitasoo/Xai’xais	4

Aleut	3
Heiltsuk	3
Métis	3
32 other Indigenous groups (i.e., Aché, Nuxalk, Sámi, Xhosa)	2
151 other Indigenous groups (i.e., Adja, Digo, Mossi, Tlingit, Wichí)	1
Unspecified	33
Inclusion of more than one group	47

3.3.3 Methodological approaches and methods for data linking

Reported purpose / intent for bringing together IK and ESK

This map aimed to explore the purpose and intent of articles linking IK and ESK by characterizing the specific aims of each article, as detailed in Section 3.2.3.4. Table 3 provides an overview of the diverse purposes and intents identified for linking IK and ESK, along with the corresponding total number of articles in each category.

Of the final identified articles, nearly three quarters stated that the intention of linking IK and ESK was to fill a gap in understanding (168 out of 241). A quarter of the articles highlighted the intention of linking IK and ESK to assess the quality of IK (59 out of 241). Within this subset of articles, 30% explicitly aimed to use ESK to assess the validity of IK (18 out of 59). Other stated purposes for linking IK and ESK included exploring differences between the two knowledge bases and understanding the reasons behind these differences (7%), identifying and describing the diversity of knowledge within IK (6%), and evaluating / assessing IK for scientific understanding (4%).

To offer a deeper insight into the purposes and intents behind linking IK and ESK, we present specific examples drawn from the final articles in this map. For instance, in the category ‘using both IK and ESK to fill gap in understanding,’ we cite the work of Service et al. (2014) who stated, “Our aim was to amalgamate indigenous and western scientific evidence of grizzly bear (*Ursus arctos horribilis*) records and detail a potential range shift on the central coast of British Columbia, Canada". To exemplify the category characterized as 'bringing together IK and ESK to assess the quality of IK', we draw on the work of Tsuji (1996) who states, 'In this paper, I examine the validity of Cree traditional ecological knowledge through a case study of the Sharp-tailed grouse…it is clearly shown that Cree traditional knowledge (with respect to the case study of the Sharp-tailed grouse) is factual (when taken as a whole) when compared to the scientific literature'.

Note that just under a quarter of identified articles included multiple purposes for linking IK and ESK (17%).

Table 3. Reported purpose / intent for bringing together IK and ESK

Reported purpose / intent of linking	Number of articles (n=241)
Using both IK and ESK to fill gap in understanding	168
Assess quality of IK	59
Explore differences between IK and ESK and why they exist	16
Identify and describe diversity of knowledge within IK base	15
Identify opportunities for complementarity with ESK	13
Assessment of IK for scientific understanding	10
Assess quality of ESK	2
Testing IK hypothesis	2
Inclusion of more than one purpose / intent	40

Type of linking approach used

In this study, our central focus was on understanding the processes and techniques used in articles aimed at linking Indigenous Knowledge (IK) and Environmental science Knowledge (ESK), specifically doing so at the level of data analysis. Such processes were characterized, labeled, and categorized (see Section 3.2.3.4 for data coding process) as approaches and methods used for linking these knowledge bases (Fig. 4). Figure 4 provides a representation of the distribution of approaches used to link IK and ESK across the identified articles. In total, this systematic map identified four different approaches used to bring together IK and ESK in the peer-reviewed environmental research literature and at the level of data analysis. The main approach used was statistical analysis (171/241 articles), followed closely by the use of narrative (163/241 articles). The two other approaches included the use of knowledge visualization at the spatial (i.e., spatial overlap in GIS) and conceptual level (i.e., use of illustrative figure) (46/241 and 2/241 respectively).

To provide a more detailed understanding of these approaches, we present specific examples from the articles. For instance, Pitman et al. (2011) demonstrated the use of statistical analysis as an approach to link IK and ESK stating, ‘To analyze how closely Cashinahua predictions of abundance and rarity corresponded to the data collected in the five tree plots we used a 232 contingency table analysis based on Fisher’s exact test.’ Another approach, characterized by the use of spatial overlap in GIS, was employed in the research conducted by Alexander et al. (2011). They detailed how IK narratives and weather station temperature data (e.g., ESK) were spatially linked: ‘A geographic information system (ArcView GIS 9.3.1; Esri, Redlands, California) was used to overlay the locations of the narratives with temperature changes from 1970 to 2004 and with data from peer-reviewed studies documenting physical and biological climate-related changes’.

Note that a single article could have used one or a combination of the aforementioned approaches and methods.

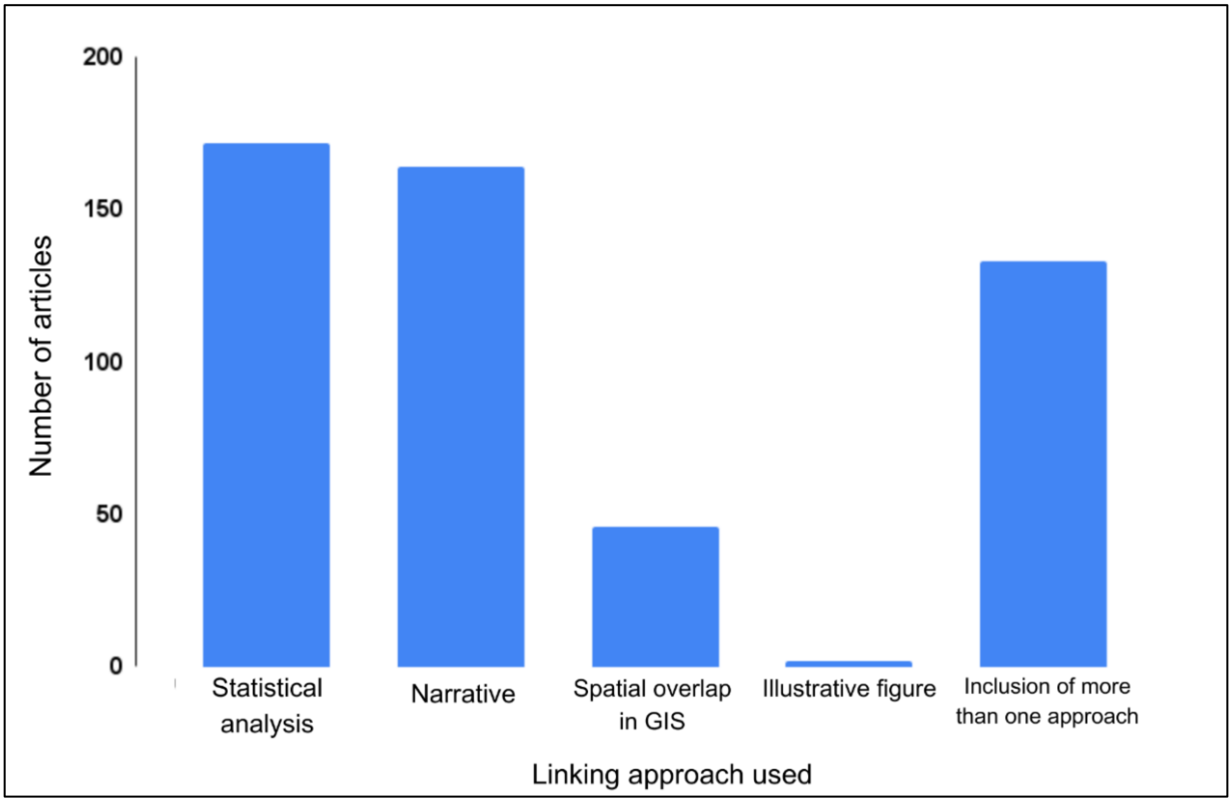

Figure 4. Type of linking approach used

Methods used for linking

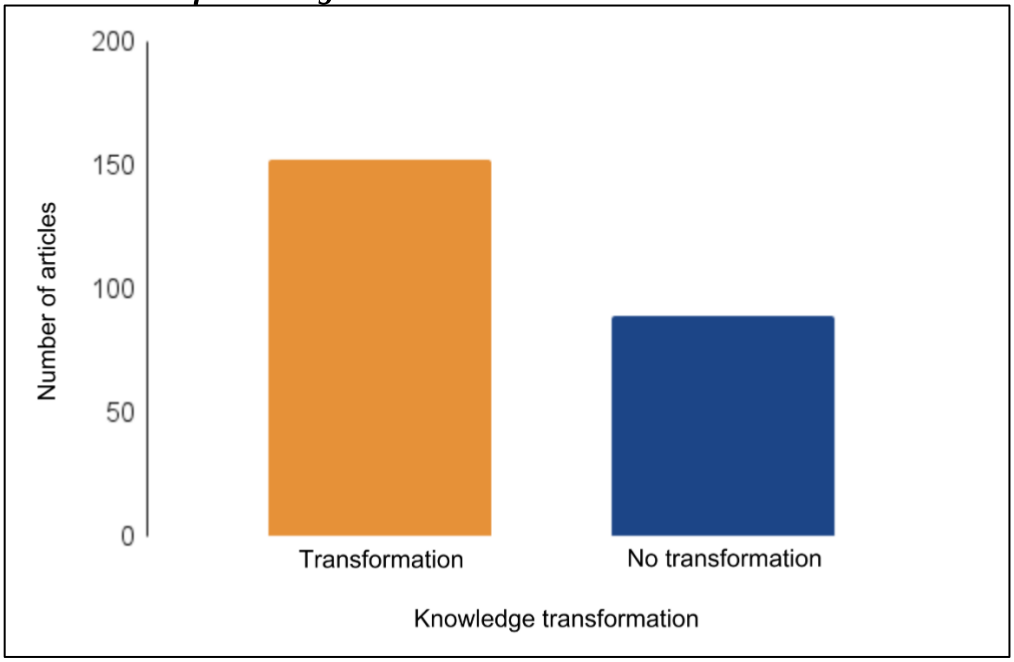

Figure 5. Methods used for linking (i.e., knowledge transformation)

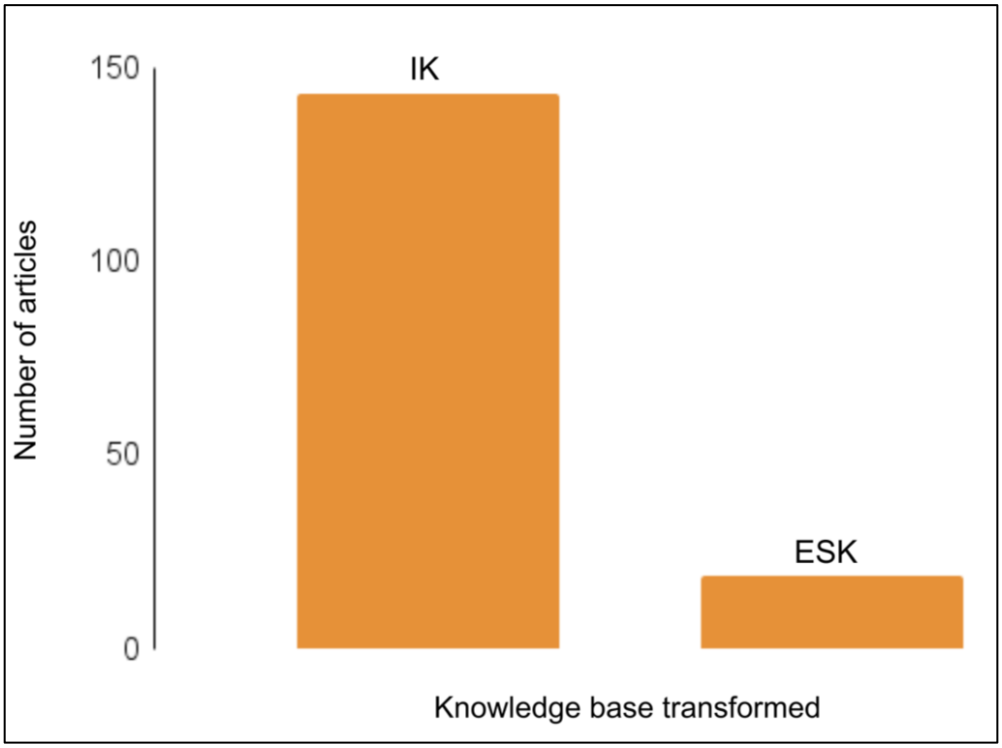

Figure 6. Knowledge base transformed

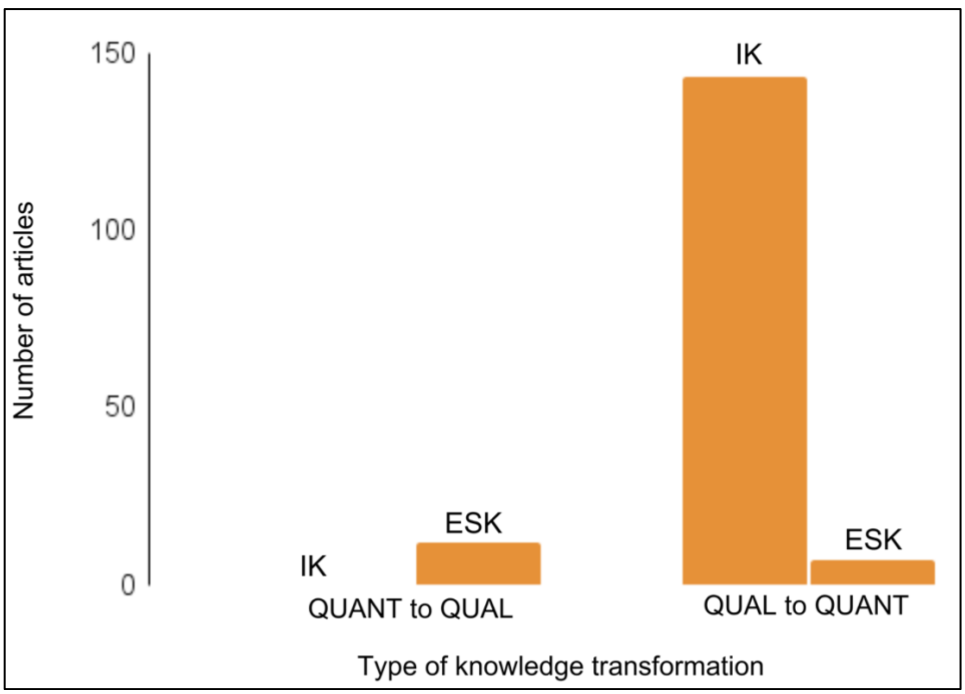

Figure 7. Type of knowledge transformation taking place

Within each linking approach, as detailed in Figure 4, we identified associated methods (refer to Sections 3.2.3.4 and 3.2.3.5 for data coding process). Within any chosen approach, a method involves the purposeful transformation of either or both gathered IK and ESK datasets, converting qualitative data to quantitative or vice versa for the purposes of linking. Note that not all articles performed a transformation, as illustrated in Fig. 5.

In total, 63% of articles performed a transformation on the gathered data (152 out of 241), while 37% of articles did not (89 out of 241), as illustrated in Figure 5. Among the articles that performed a transformation (152 out of 241), nearly all (94%) did so on the IK dataset (143 out of 152), whereas approximately 12% performed a transformation on the ESK dataset (19 out of 152) (Fig. 6). Note that an article could have transformed one of the gathered IK or ESK data, or both in the same instance.

All articles that transformed an IK dataset (143 out of 152) did so to convert qualitative IK data into a quantitative form (Fig. 7). An illustrative example is found in the work of Joshi et al. (2013) where they detailed their approach: 'Data collected from the individual interviews and focus groups were compiled. Data analysis was based on the frequency and percentage of responses. Responses for ''yes'', ''no'', and ''don't know'' were converted into percentages to assess the proportion of individuals perceiving or not perceiving change. The official data published by the Pakistan Meteorological Department (PMD) (Chaudhary and others 2009) was used to validate the results through analysis of observed trends in meteorological values.' In this instance, the transformation of qualitative IK data to a quantitative form was conducted for use in a statistical analysis approach to linking, alongside previously gathered quantitative ESK data.

On the other hand, the transformation of ESK data (19 out of 152) was predominantly aimed at converting data from a quantitative to a qualitative form (12 out of 19), with fewer instances involving a change from qualitative to a quantitative form (7 out of 19) (Fig. 7). An example of transforming quantitative to qualitative data can be seen in the work of Gichangi et al. (2015). To link quantitative ESK data with qualitative IK data, they converted quantitative ESK temperature data to a qualitative format, as demonstrated by the following passage: "To contrast the perceptions of farmers on the nature of past seasons with scientific data, the seasons were classified into two categories, based on the deviation from the long-term mean. Seasons within excess of 25% of the long-term mean were classified as good and those with rainfall less than 25% below the long-term mean as poor." In this case, the transformed ESK data was then used in conjunction with qualitative IK through a narrative approach. Note that a single article could have transformed both IK and ESK datasets, or just one.

Evidence of linking

Concurrently with identifying the approaches and methods used, the locations in an article where evidence of linking occurred was noted and coded for. This was undertaken in an attempt to better understand and explore how many articles had reported on the ways in which they brought together IK and ESK datasets. While the majority of identified articles reported on the outcomes and interpretations of linking the two knowledge bases (81% and 99% respectively), just over half of the articles (63%) reported on and provided details regarding how the two knowledge bases were connected within the research process. It is important to note that evidence of linking could have appeared in multiple sections of the article.

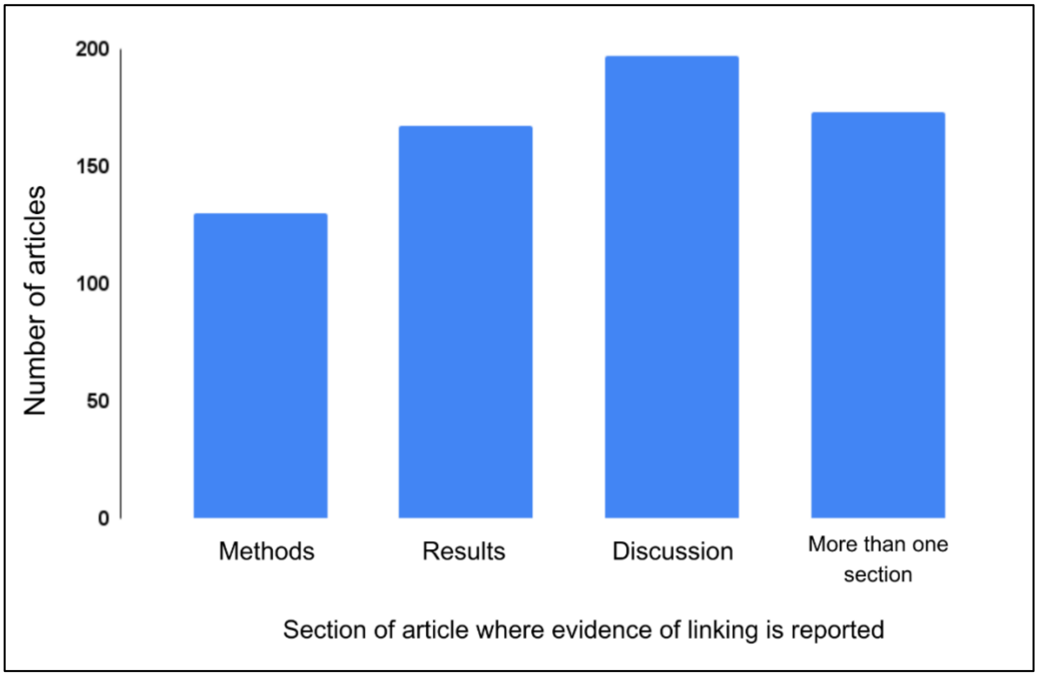

Figure 8. Evidence of linking

3.4 Discussion

3.4.1 Evidence gaps and insights

This map sheds light on significant gaps in evidence and provides valuable insights into the linking of IK and ESK within environmental research. A notable trend is the increase in the number of articles aiming to link IK and ESK over time (Fig.2). This observed trend aligns with findings reported by Bélisle, et al. (2018), Alexander et al. (2021) and Stern & Humphries (2022), and suggests a substantial and growing body of literature. Additionally, the results from this map illustrate widespread global linking of IK and ESK in environmental research (Fig. 3), a similar observation to those found in the works of Bélisle et al. (2018) and Stern & Humphries (2022).

The inclusive and widespread representation of knowledge from multiple Indigenous peoples / groups / Nations / tribes, as detailed in Table 2, contributes additional depth to our understanding. The increase in publications suggests not only a growing interest but also an increase in the number of approaches and methods used to link IK and ESK at the level of data analysis in environmental research. This trend is further underscored by the involvement of multiple countries and Indigenous peoples in the undertaking of knowledge linking, signaling the potential for an increased use and variety of approaches and methods in the field of environmental research in the future.

The primary objective of this study was to present a comprehensive overview of the methodological characteristics found in articles captured within this systematic map. Table 3, along with Figures 4 to 8, collectively illustrates these characteristics. Notably, there exists a wide array of purposes and intents for linking, as evidenced in Table 3. The most prevalent aim, identified in nearly three-quarters of articles, was to link IK and ESK to fill a gap in understanding. Another prevalent objective, identified in one-quarter of articles, was linking with the aim of assessing the quality of IK in relation to ESK (24%). While not as common as the intention to link knowledges to fill gaps in understanding, the focus on the examination of IK quality brings into question the implications of doing so, drawing parallels to similar discussions and reviews in regard to the associated challenges, ethics, and inherent power imbalances related to knowledge linking (Agrawal, 1995; Nadasdy, 1999; McGregor, 2009; Bohensky & Maru, 2011). The assumption that alignment between content from one knowledge base (e.g., IK) and another (e.g., ESK) implies truth and signifies quality has significant implications, particularly concerning epistemological considerations. As knowledge coming from IK and ESK systems have distinct epistemologies or ways of knowing, adopting such an assumption may lean towards a positivist stance, potentially overlooking the validity inherent in each system (Berkes, 2018). Further complexity emerges when considering the quality of information derived from IK, particularly in research settings. This assessment primarily revolves around the methodologies used to gather IK, often relying on social science research methods (Furgal & Laing, 2012). Consequently, assessing IK quality through its relation to ESK may lack coherence and highlights the importance of recognizing the standards and methodologies used to gather 'data' or representations of knowledge coming from IK systems. Collectively, these issues highlight the need to acknowledge and better understand the complexity and nuance existing in linking IK and ESK in environmental research.

This systematic map has identified four major approaches, as depicted in Figure 4. Among these, statistical analysis and narrative emerge as frequently employed approaches for linking. Furthermore, each approach encompasses a variety of methods, as outlined in Figures 5, 6 and 7. The use of one or a combination of approaches and methods in any single article highlights the nuanced and complex nature of the knowledge linking process at the level of data analysis.

Lastly, an important gap emerged from this systematic map. Notably, just over 60% of articles in this systematic map articulated how they intended to connect the two knowledge bases (Figure 8), indicating a lack of explicitness in detailing the linkage of knowledge bases in the research process. Without a clear understanding of the methods employed, replicating these studies becomes challenging. Therefore, this gap highlights the need for increased transparency and methodological rigor in future research efforts to enhance the clarity and reliability of knowledge linking in environmental studies.

3.4.2 Limitations of the methods used

While the methods employed in this systematic map facilitated a thorough exploration of the approaches and methods used to linking Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) in environmental research, we acknowledge and recognize its limitations. These limitations are specifically related to (1) language, (2) search terms used, (3) eligibility criteria, and (4) coding and screening processes.

Firstly, it is important to note that the articles included in this map are limited to the English language. Expanding the range to include a broader spectrum of languages used worldwide could have increased the comprehensiveness of our search. However, constraints such as limited resources impacted the scope of our map, potentially introducing biases by focusing on some countries and/or Indigenous populations while neglecting others.

We recognize that the choice of search terms inherently influences the search outcome. To mitigate potential bias, we rigorously tested and incorporated a diverse set of search terms and keywords in our string. For instance, in the third parameter of our search string, ‘knowledge linking’, our goal was to include a multitude of commonly used keywords and synonyms associated with knowledge linking in an attempt to retrieve a wide scope of relevant papers. Furthermore, the resulting approaches and methods do not extend beyond the predefined boundaries of the eligibility criteria used in this map. While this facilitated the identification of articles that fell within the scope of the primary research objective, it may not have fully captured or represented approaches and methods that were not exclusively employed at the level of data analysis, particularly within the context of environmental research.

Lastly, while efforts were made to ensure consistency and reliability through a systematic approach to screening and coding, we recognize the inherent levels of subjectivity involved in these processes. Variations in interpretations related to included articles and extracted data may exist and have the potential to impact the resulting evidence base.

3.4.3 Limitations of the evidence base

In addition to the methodological limitations, it is important to recognize and address the limitations within the evidence base. The articles included in this map are confined to those published in the peer-reviewed literature. While an exhaustive search ideally involves incorporating grey literature, constraints such as resource availability and time, imposed limitations on the scope of our investigation. Therefore, it is important to acknowledge that the approaches and methods identified in this map are derived solely from the included articles, excluding those found in the grey literature as well as those not picked up by the search string, as mentioned above in Section 3.4.2. Additionally, as coding was primarily based on the data presented in the articles, the resulting approaches and methods resulting in this map were confined to what was explicitly reported. Thus, we acknowledge the possibility of other approaches and methods not captured here, highlighting the need for future research to explore a more extensive range of sources and perspectives as well as increased transparency regarding documentation and reporting of approaches and methods used at the level of data analysis.

In addition, concerning reported intents and purpose for linking (Table 3), it is important to note that assessing the quality of articles was beyond the scope of this systematic map. Consequently, further research is needed to determine whether the outcomes of the articles in this systematic map align with their purported intent and purpose for linking.

3.5 Conclusion

Despite the recognized advantages of linking IK and ESK in environmental research, the complex nature of knowledge linking poses substantial challenges (Gagnon & Berteaux, 2009; Furgal & Laing, 2012; Bohensky & Maru, 2011; Johnson et al., 2023). The inherent complexity and multiple levels at which knowledge linking can take place, coupled with the growing global emphasis on linking IK and ESK in environmental research, provides a unique opportunity to research how knowledge has been brought together analytically.

Furthermore, it has long been considered imperative to recognize the role of active and equitable engagement of the knowledge held by Indigenous peoples in advancing environmental research and decision-making. This recognition is pivotal for fostering inclusivity and encouraging collaboration between knowledge systems (McGregor, 2000). Emphasizing the significance of incorporating both IK and ESK in an effective and accurate manner is crucial for representing both knowledges comprehensively while upholding their integrity. This highlights the broader goal of achieving a respectful and collaborative approach to linking IK and ESK within the environmental research landscape.

This systematic map sought to offer a comprehensive understanding of existing approaches and methods used to link IK and ESK at the level of data analysis in environmental research, revealing key insights and identifying evidence gaps. The findings highlight the need for further in-depth investigations on the linking of IK and ESK at the level of data analysis. For example, conducting empirical tests on the approaches and methods identified in this systematic map would help to facilitate a more in-depth exploration of the processes involved in linking IK and ESK in environmental research.

3.5.1 Implications for research

Previous studies by Thorton & Scheer (2012), Castelden et al. (2017), Stefanelli et al. (2017) Alexander et al. (2019a, b,2021), Henri et al. (2021), have significantly advanced our understanding of knowledge linking, focusing primarily on different stages of linking such as project design and collaboration, research methodology and data collection. Similarly, studies by Bélisle et al. (2018) and Stern & Humphries (2022), have touched upon the methodological processes of linking during data analysis, with their focus primarily centered on the challenges of applying statistical analysis to link IK and ESK. To the best of our knowledge, this paper stands as the first comprehensive systematic map, aiming to explore, identify and provide an overview of the approaches and methods employed globally to link IK and ESK at the level of results, analysis, and discussion stages of the research process. Together, the results of this systematic map highlight the nuance and complexity involved in knowledge linking and prompt a critical examination of approaches and methods used to link IK and ESK at the level of data analysis and their implications for the knowledge systems involved. These findings contribute to advancing understanding of knowledge linking and may guide future research endeavours that may lead to effective strategies for knowledge linking in environmental research.

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CHAPTER 4:

Linking Indigenous Knowledge and Environmental science Knowledge datasets: Case study on environmental conditions and Arctic Char (*Salvelinus alpinus*) growth in the Inuvialuit Settlement Region

4.1 Introduction

4.1.1 Background

The merging of datasets from Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) holds significant importance in advancing environmental research needs and priorities for researchers, natural resource managers and Indigenous communities around the world. This endeavour has been increasingly conducted for its potential to better understand marine and freshwater ecosystems, for which there is oftentimes limited Environmental science Knowledge or Indigenous Knowledge data available (Thornton & Scheer, 2012). By bringing together data from IK and ESK, researchers aim to enrich understanding and provide new directions for future studies. For instance, Silvano & Begossi (2005) conducted a study comparing information gathered from local Indigenous fishers with published biological data. They found that both sources of knowledge oftentimes aligned, while in other instances they diverged. These discrepancies prompted further investigation and hypothesis testing, highlighting the value of linking IK and ESK in environmental research.

However, it is important to note that linking IK and ESK in environmental research is not without significant challenges (Gagnon & Berteaux, 2009; Furgal & Laing, 2012; Bohensky & Maru, 2011; Johnson et al., 2023). In work conducted by Gagnon & Berteaux (2009), they found that differences and similarities between knowledge sources were not necessarily due to the mismatch between knowledge sources, but rather by the spatial, temporal and conceptual scales at which the information was gathered. This finding prompts a deeper investigation into the ways in which IK and ESK are brought together, specifically when bringing together IK and ESK through data analysis. While previous studies by Thorton & Scheer (2012), Castelden et al. (2017), Stefanelli et al. (2017) Alexander et al. (2019a,b,2021), Henri et al. (2021), Bélisle et al. (2018) and Stern & Humphries (2022), have advanced our understanding and approach of knowledge linking for project design and collaboration, research methodology, and data collection, this thesis aims to extend current understanding of the processes involved in merging IK and ESK by examining the approaches and methods used to link IK and ESK at the level of data analysis, presentation and interpretation of results.

This chapter provides a critical examination of the approaches and methods identified through the systematic map (Chapter 3). By linking existing IK and ESK data within a case study framework, this work aims to better understand the challenges and limitations in using any one approach. Specifically, the linkage between IK and ESK data in a case study focusing on environmental conditions influencing growth variability of landlocked Arctic Char (*Salvelinus alpinus*) in the western Canadian Arctic is explored. This particular case study was selected for its unique characteristics. Firstly, the IK and ESK data associated with it were previously gathered with the explicit intention of linking them, reflecting a proactive approach towards knowledge linking (Knopp, 2017). Moreover, these datasets had not been previously analyzed or linked, presenting a unique opportunity to explore the practice of knowledge linking. Furthermore, marine and freshwater fishes, like Arctic Char, are valuable to many Inuit communities across the Canadian Arctic, serving important cultural, economic, and dietary roles (Kristofferson & Berkes, 2005; Roux et al., 2011; Dewailly et al., 2001) and there is evidence to suggest that changes in environmental conditions have a variety of effects on the health of Arctic Char (Larsson & Berglund, 2005; Knopp, 2017; Caza-Allard et al., 2021; Harris et al., 2022).

This process was guided by the question: What approach and method could be used to link the existing IK and ESK data? Subsequently, for each approach and method (i.e., use of statistical analysis; narrative; spatial overlap in GIS and illustrative figure) various characteristics needed for linking to occur were identified and criteria developed. The development of characteristics and criteria was informed and guided by a review of relevant literature. Following this, the existing IK and ESK case study data was applied to the criterion. This was done to identify which approach and method could be used given the responses to criteria. The IK and ESK data were then linked using the appropriate approach and method. The selection of this case study not only offers a valuable opportunity for understanding knowledge linking at the stage of data analysis, but also contributes to the development of practices that support and engage Indigenous ways of knowing that align with and prioritize the needs of the communities. The outcomes of this work will aid in identifying challenges and enhancing clarity with respect to the ways in which IK and ESK are linked in academic and environmental research.

4.2 Methods

4.2.1 Part 1: IK and ESK Case Study

The case study used in this thesis was part of a larger study (i.e., Knopp, 2017) aimed at linking Inuit Knowledge and Observation and Scientific Knowledge and Observations to better understand Arctic Char (*Salvelinus alpinus*) growth and variability. As part of this former project, the following research question was investigated:

"Does local environment and climate affect the growth of landlocked Arctic Char, and if so which environmental and biological parameters show predictable relationships such that they can be used to monitor char?"

Inuit Knowledge, or more specifically Inuvialuit Knowledge and Observation (IKO) was gathered alongside Scientific Ecological Knowledge and Observation (SEKO) to examine if local climate and environment affect landlocked Arctic Char growth (Knopp, 2017).

For the purposes of this thesis, Indigenous Knowledge (IK) will be used to encompass Inuvialuit Knowledge and Observation (IKO); similarly, Environmental science Knowledge (ESK) will be used to encompass Scientific Ecological Knowledge and Observation (SEKO).

4.2.2.1 Case study context

Ulukhaktok (formerly Holman, or Holman Island) is a small, primarily Inuit community situated on the western coast of Victoria Island in the Inuvialuit Settlement Region, in the Northwest Territories. The name, Ulukhaktok (Olokhaktok), stems from the Inuinnaqtun language, meaning "where there is ulu material," a reference to the copper used to craft a semi-circular Inuit knife, the ulu, which remains an important tool for traditional food preparation (Chambers, 2010). Throughout its history, Inuit residents of Ulukhaktok, the Ulukhaktokmiut, have experienced changes to lifestyle, shaped by historical pressures and continual environmental shifts (Ford, 2008; Collings, 2011; OHTC et al., 2016).

Despite these changes, the Ulukhaktokmiut maintain and uphold their traditional hunting and fishing practices of the lands and waters through modern-day practices, and continue to work towards the careful use and preservation of important local resources (Usher, 2002; OHTC et al. 2016). Among these resources, the anadromous and landlocked Arctic Char (*Salvelinus alpinus*) holds particular significance, serving as important cultural, economic, and dietary sources for

Ulukhaktokmiut (OHTC et al., 2016; Lea et al., 2023). The establishment of the Inuvialuit Final Agreement (1984) coupled with the decision of members of the community to remain part of the NWT rather than becoming part of Nunavut, and the formulation of community conservation plans, have been instrumental in addressing the evolving needs of the community of Ulukhaktok. These choices stem from a recognition of the changes in community lifestyle and the importance of collaborative efforts to uphold traditional practices and way of life and maintain local resources for future generations (OHTC et al., 2016).

Understanding marine and freshwater ecosystems remains a significant challenge, particularly in remote areas where comprehensive scientific data collection and observation are lacking (Thornton & Scheer, 2012). This knowledge gap is particularly concerning given the rapid environmental and climate changes occurring worldwide, notably in Arctic and subarctic regions. These changes have profound impacts on the marine and freshwater species which hold deep economic, cultural, and nutritional significance for Indigenous communities living in Arctic regions. Many Inuit communities continue to uphold traditional hunting practices and rely on locally harvested foods throughout Inuit Nunangat (Tremblay et al., 2020), the homeland of Inuit in Canada. In particular, the harvesting of Arctic Char (*Salvelinus alpinus*) continues to play an important part in the economy, culture and health of Inuvialuit living in the Inuvialuit Settlement Region (ISR) (Knopp, 2010; Ayles et al., 2016; Reist et al., 2018), one of the four regions that make up Inuit Nunangat.

Arctic Char are a circumpolar fish species whose geographic range includes the areas surrounding the northernmost communities in the ISR (Knopp, 2010; Reist et al., 2018). The formerly collected data and knowledge used for this research focused on the Indigenous Knowledge of Inuvialuit living in Ulukhaktok (see Figure 1 for study location). The importance of Arctic Char to Ulukhaktok, and other Inuvialuit communities, combined with a lack of long-term scientific data of this species, highlighted the necessity for long-term community-based monitoring for sustainable management of Arctic Char (Knopp, 2010; OHTC et al., 2016). This includes the bringing together of IK and ESK data for a more holistic understanding of the potential impacts of changing environmental conditions on Arctic Char growth.

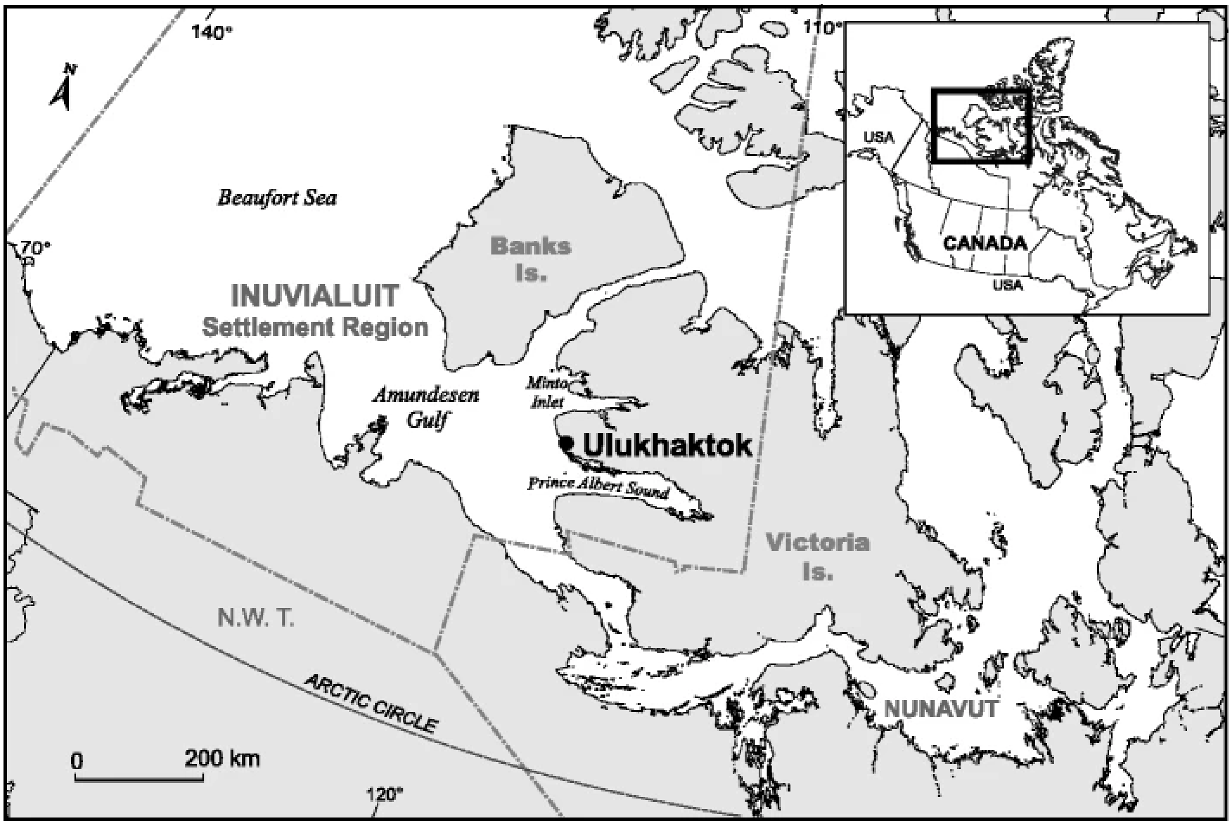

Figure 1. Map of case study community location, Ulukhaktok, Inuvialuit Settlement Region, Northwest Territories. (Map Source: Pearce et al., 2011; https://doi.org/10.1007/s10745-011-9403-1).

The critical examination of the types of approaches used to link IK and ESK datasets in environmental research, as identified in Chapter 3, will look at the variables: IK perceptions of lake ice changes and ESK Arctic Char growth rates, and will be guided by the question: ‘What is the relationship between lake ice conditions and landlocked Arctic Char growth?’. The variable

IK perceptions of changes to lake ice was chosen because lake ice met most of the criteria required in order to link with existing ESK data.

4.2.2.2 Indigenous and Environmental science Knowledge data collection

4.2.2.2.1 Collection of Indigenous Knowledge data

The IK dataset was originally collected by Dr. Jennie Knopp through semi-structured interviews. During the summer of 2010, interviews were conducted with local community members from the community of Ulukhaktok in the Inuvialuit Settlement Region. Interviews focused: historical and baseline conditions of fish habitat and fishing pressures; current local knowledge regarding Arctic Char and fish in the area surrounding the community; fish condition and numbers; and local environmental conditions including temperature, precipitation, weather, permafrost and erosion, aquatic environment and fish habitat, and invasive species and changing species composition. Background information (e.g., gender, place of birth, year of birth, whether the interviewee is still an active fisher and hunter etc.,) was also gathered during the interview process. Participatory mapping was conducted to complement the information gathered from interviews. Community consultations, update meetings and validation workshops were conducted. Ethical considerations were addressed by the original researcher during the data collection process, and as such, all research involving Indigenous Knowledge was carried out under Trent University Research Ethics Board Approval with approval from the Olokhaktomiut Hunters and Trappers Committee.

4.2.2.2.2 Collection of Environmental science Knowledge data

The formerly collected ESK dataset was obtained through biological field sampling methods conducted in the summer of 2010 by local assistants and Dr. Jennie Knopp. Arctic Char from Ikahavik Lake were captured in August of 2010 through the setting of floating and sinking multimesh gillnets with a total length of 120 m and 20 m bar mesh sizes: 10 mm (110/2 twine), 19 mm (110/3), 33 mm (110/3), 45 mm (210/2), 55 mm (210/3) and 60 mm (210/3); net depth = 1.8 m (Knopp, 2017). Arctic Char were sampled for a variety of parameters including fork length, standard length, weight, sex, and identification of parasites and stomach contents. Sagittal otoliths were extracted from the captured fish. The otoliths were then embedded in epoxy resin, sectioned, and photographed at Trent University by Dr. Jennie Knopp and several research assistants. Ethical considerations were addressed by the original researcher during the data collection process and as such, all fish were cared for in accordance with the Guide to the Care and Use of Experimental Animals and following Trent University Animal Care Committee Approvals as well as the Department of Fisheries and Oceans Canada Animal Use Protocol approvals. The meat of fish captured for study and otolith removal was provided to community members for consumption.

4.2.2.3 Indigenous Knowledge and Environmental science Knowledge data analysis

4.2.2.3.1 Analysis of Indigenous Knowledge data

Audio recordings of the semi-directed interviews (n=13) were obtained along with the digital copies of the written transcripts, a copy of the interview guide, and additional notes made by the original researcher. Transcripts of the interviews were verified by listening to the audio and confirmed correct transcription in the typed version. Digital copies of the maps used throughout the interview process were also obtained and the mapped information (e.g. hunting locations, areas travelled, location of birth) were organized and collated into Microsoft Excel to facilitate analysis.

Interviews were coded using thematic content analysis to look at patterns of reported observations among respondents. This process included examining the interview transcriptions to identify common themes and possible insights (Creswell & Creswell, 2018; Saldaña, 2021). All coded information was organized and documented in Microsoft Excel.

4.2.2.3.2 Analysis of Environmental science Knowledge data

The original live sampling field data sheets containing parameters like fork length, weight and sex of the sampled Arctic Char (n=42), were digitized using Microsoft Excel. Sagittal otoliths, previously embedded, sectioned, and photographed via microscope, were used for age determination and to back-calculate size at age of individual fish. Photographs of the otolith sections were imported into the digital image analysis software, Image J, where the age of the fish at capture was determined by counting the number of distinct otolith annuli, representing annual growth rings (DFO, 2019). Once age was determined, measurements were taken to be used in the back-calculation process. First, to measure the total length of the otolith (in mm), a transect was placed at the center of the primordium, to the last full year of growth (Stevenson & Campana, 1992). The next transect line was positioned from the same location on the primordium and stretched to the end of the nucleus, representing the first year of growth. This process was repeated for each year of growth. The resulting measurements were then used in combination with the known fork length for each sampled fish to determine the length of fish prior to capture. Back-calculated values were then used to construct a von Bertalanffy growth curve. This was done in R (version 2023.12.1+402 using the package "FSAdata" (Ogle, 2019)).

4.2.2 Part 2: Linking IK and ESK data using the case of environmental variables and Arctic Char growth

The process of linking the existing IK and ESK case study data was initially guided by the question: What approach and method could be used to link the existing IK and ESK data? (Fig. 2). The approaches and methods identified from the systematic map (i.e., narrative, statistical analysis, spatial overlap in GIS, and illustrative figure) were chosen, because to the best of our knowledge, no other approaches and methods used to link IK and ESK datasets have been identified in papers published peer-reviewed journals. A comprehensive understanding of the nature of the available data as well as the parameters associated with each approach and method for linking was also required. The parameters and functionalities of the linking approaches and methods were identified through an in-depth analysis of examples from the articles included in the systematic map. Informed by a relevant review of literature, this process was further guided by the questions:

1. What is needed to conduct each approach?
2. What should be known about the data?
3. What is important to factor in for trust and confidence in results?

Recurring themes or patterns from relevant literature regarding the key attributes or characteristics deemed important for linking datasets were identified and compiled. Specifically, attributes / characteristics utilized by various approaches and methods in the literature for linking datasets were extracted and included. Through an analysis of the compiled linking characteristics criteria were formed. This took place by assigning weight or value to the list of characteristics based on what was found to be important or necessary for linking to occur through each approach and method. The existing IK and ESK datasets were then applied to the criteria and the appropriate approach and method was used to link the datasets.

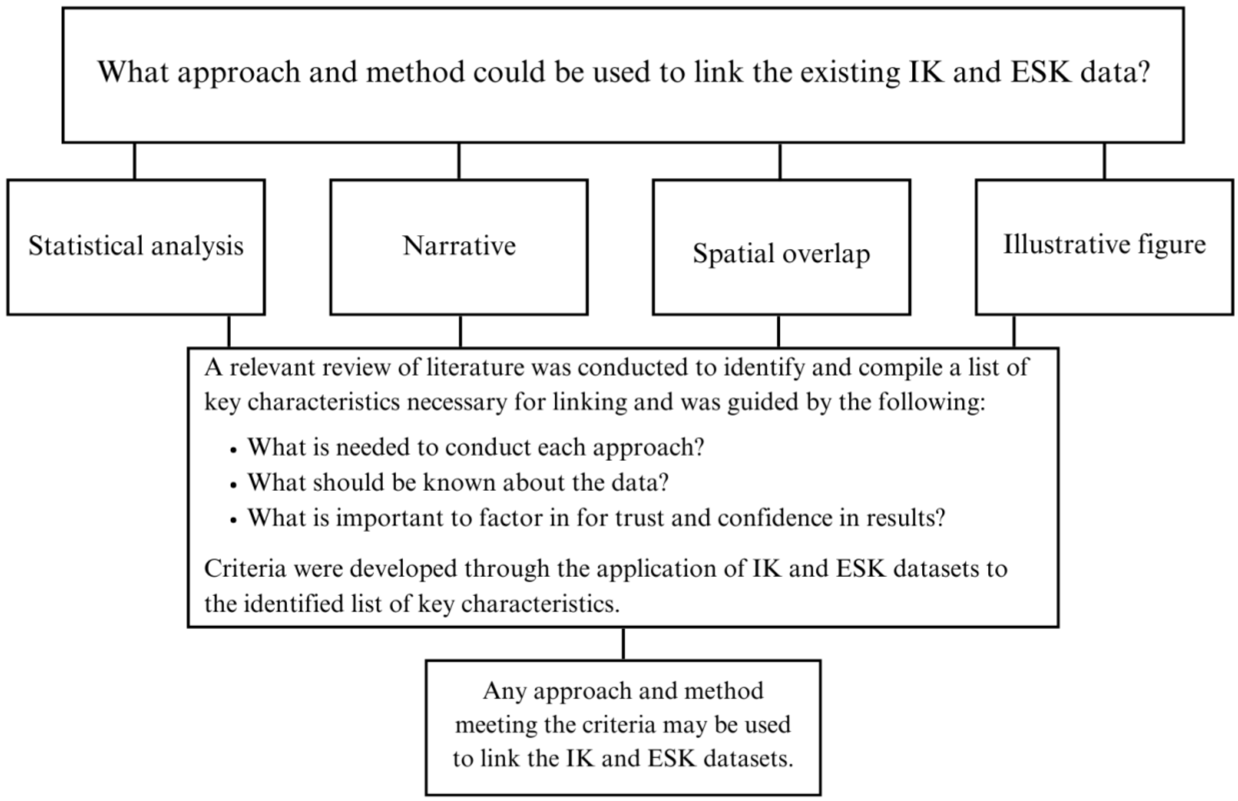

Figure 2. Overview of the steps taken in the development of characteristics and criteria to determine data readiness for linking and choosing an approach and method.

4.3 Results

4.3.1 Characteristics and attributes of linking and application of case study data

In total, ten major parameters were identified and used to guide the approach selection process. They include:

- spatial scale
- temporal scale
- conceptual scale
- what needs to be done to link datasets generally
- data transformation
- credibility / trustworthiness

- significant contributions
- ethical
- data collection practice
- dataset reliability and validity

The suitability of the data for each linking approach and method was assessed. Examples from the literature from which the functionalities and parameters of each approach and method were drawn can be found in Appendix 3. When the criteria outlined in the decision-making table were applied to the existing IK and ESK datasets, a merged narrative was identified as the most appropriate approach to use, whereas statistical analysis, spatial overlap in GIS or illustrative figure were not (Table 1).

Table 1. Decision-making table for choosing a linking approach.

		Statistical analysis		Narrative		Spatial overlap in GIS		Illustrative figure	
Row #	**Parameter**	**ESK Dataset**	**IK Dataset**	**ESK Dataset**	**IK Dataset**	**ESK Dataset**	**IK Dataset**	**ESK Dataset**	**IK Dataset**
For use of an approach and method (rows 1-5)									
1	Spatial scale	✔	✔	✔	✔	✔	✔	✔	✔
2	Temporal scale	✔	✔	✔	✔	✔	✔	✔	✔
3	Conceptual scale	✔	✔	✔	✔	✔	✔	✔	✔
4	What needs to be done to link datasets (in general)	✔	✔	✔	✔	✔	✔	✔	✔
5	Data transformation	✔	✖	✔	✔	✖	✖	✖	✖
For trust and confidence in linking results (rows 6-10)									
6	Credibility / trustworthiness			✔	✔				
7	Significant contribution			✔	✔				
8	Ethical			✔	✔				
9	Data collection practice			✔	✖				
10	Dataset validity & reliability			✖	✖				

Responses to each linking parameter can be found in Table 2 and are explained in more detail in the following paragraphs. Examples are also provided to illustrate the criteria development process.

Table 2. Developed criteria and application of available IK and ESK data, where (n) represents the number of otoliths used for growth estimation (ESK) and number of interview respondents who spoke directly to changes in lake ice (IK).

	IK AND ESK PARAMETERS AND CRITERIA FOR LINKING	**ESK otolith data (n=42)**	**IK lake ice (n=8)**
1	**SPATIAL SCALE**	Ikahavik Lake	50km within region of community and lake (3); 70km within region of community and lake (2); 175km within region of community and lake (1); 200km within region of community and lake (1); 240km within region of community and lake (1)
2	**TEMPORAL SCALE**	1987-2010	1944-2010(1);1947-2010(1);1955-2010(2);1959-2010(1);1969-2010(1);1977-2010(1);1985-2010(1)
3	**CONCEPTUAL SCALE**	growth rates of land-locked Arctic Char	perception of environmental change
4	**WHAT NEEDS TO BE DONE TO IN ORDER TO LINK DATASETS (IN GENERAL)** A) Does the researcher have access to the data in its raw/original form? (interview transcripts, physical maps, sampling field data sheet etc.)	A) Yes B) Numerical data	A) Yes B) Narrative data

	B) What is the type of data? (numerical/quantitative, narrative/qualitative)		
5	**DATA TRANSFORMATION** A) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its initial accuracy and precision? B) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its integrity/meaning? C) Can the data be transformed (qual-quant, quant-qual) so that it is in a 'useable' form and format such that it lends itself to analysis in combination with other variable(s) in the combined dataset? D) Can the data be transformed into a recognized and widely accepted scale? E) Can the data be transformed in a way that allows for linking to address the established research question or objective?	A) Yes B) Yes C) Yes D) Yes E) Yes	A) No B) Yes C) No D) Yes E) No
6	**CREDIBILITY / TRUSTWORTHINESS** A) Did the researcher provide a positionality statement? B) Did the research provide a thick and detailed description of data collection procedures? C) Does the researcher explain engagement with community from beginning to end?	A) Yes B) Yes C) Yes	A) Yes B) Yes C) Yes
7	**SIGNIFICANT CONTRIBUTION** A) Does the research build upon existing work (is this backed up via a thorough review of literature?) (qual, quant)	A) Yes	A) Yes

8	**ETHICAL** A) Did the researcher provide detail on how ethics was approached? (i.e., going through a research ethics board or advisory committee) (qual, quant)	A) Yes	A) Yes
9	**DATA COLLECTION PRACTICE** A) Did the researcher spend enough time to gather interesting and significant data? (qual, quant) B) Is the context or sample appropriate given the goals of the study? (qual, quant) C) Did the researcher use appropriate procedures in terms of how the data was collected (field note style, interviewing / sampling practices, and analysis procedures)? (qual, quant) D) Were data collection tools (questions, surveys, interview protocols, sampling methods, and analysis procedures) applied consistently across all participants/observational points? (qual, quant)	A) Yes B) Yes C) Yes D) Yes	A) Yes B) Yes C) Yes D) No
10	**DATASET VALIDITY & RELIABILITY** A) Is the dataset complete, or missing data points? (qual, quant) B) Did the researcher use member reflections to ensure internal validity of results? (qual) C) External validity – were the sample results generalised? (quant)	A) Missing (n=20 or 32%) C) Yes	A) Missing (n=5 or 38%) B) Yes

11	**FOR A NARRATIVE APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative, B complete; row 5: at least C and E must be affirmative for approaches and methods requiring IK transformations only): A) Is there any IK data that could be mixed with ESK data? If affirmative response to A), the following approach or combination of approaches may be used: 1. Qualitative IK and quantitative ESK results are presented in sequence. The two sets of results are brought together and interpreted via a merged narrative. Interpretation involves a comparative and/or complementary analysis. 2. Qualitative IK and quantitative ESK results are brought together via a merged narrative. Interpretation of merged datasets takes place via a merged narrative and involves a comparative and/or complementary analysis. 3. Transformation of a quantitative ESK variable into a qualitative form. IK and transformed ESK results are brought together and interpreted via a merged narrative. Interpretation involves a	A) Yes	A) Yes

	comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
12	**FOR A STATISTICAL ANALYSIS APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative, B complete; row 5: at least C and E must be affirmative): A) Is there any transformed quantitative IK data that could be mixed with quantitative ESK? If affirmative response to A), the following approach or combination of approaches may be used: 1. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in a regression analysis. The transformed variable is used in a complementary way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis.	A) No	A) No

	2. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in a correlation analysis. The transformed variable is used in a comparative way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. 3. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in percent agreement and disagreement calculations. The transformed variable is used in a comparative way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
13	**FOR A SPATIAL OVERLAP IN GIS APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A	A) No	A) No

	affirmative, B complete; row 5: at least C and E must be affirmative): A) Is there any qualitative or transformed quantitative IK data that could be mixed with ESK quant or qual? If affirmative response to A), the following approach or combination of approaches may be used: 1. Transformation of a qualitative IK variable into a quantitative form. Results are brought together via knowledge visualization at the spatial level. The transformed variable is used in a comparative and/or complementary way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
14	**FOR AN ILLUSTRATIVE FIGURE APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A	A) No	A) No

	affirmative B complete; row 5: at least C and E must be affirmative): A) Is there any qualitative IK data that could be mixed with qualitative or quantitative ESK data? If affirmative response to A), the following approach or combination of approaches may be used: 1. Qualitative IK and qualitative ESK results are brought together via knowledge visualization at the conceptual level. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
15	**FOR BRINGING IN ADDITIONAL DATASETS** A) Do other datasets exist that can be combined to enhance or enrich the dataset? B) Is the researcher aware of the nature of the spatial, temporal, conceptual scales and what is available in the dataset to then be connectable?		

	C) Is there at least one scale in overlap? If affirmative responses to A), B) and C), proceed to adding on another column beside the original variable and fill out rows 1-14 for incoming variable.		

Spatial, temporal and conceptual scales *(rows 1-3)*

Gagnon & Berteaux (2009) emphasized the necessity of identifying and recognizing the spatial, temporal, and conceptual scales of each dataset when linking IK and ESK. They found that disagreements between knowledge sources were often attributed to differences in the extent of overlap across these scales during data collection, and not necessarily due to differences in content provided derived from various knowledge bases. This highlights the critical importance of assessing scale overlap to ensure meaningful linking of knowledge sources.

The determination of scales involved the following: (1) identification of variables in each dataset (i.e., core concepts, geographic and time-related variables); (2) establishment of inclusion criteria (i.e., development of criteria based on primary research question and available data points); (3) identification of units of measurement (e.g., time units, units of spatial measurements). Definitions for the scope of each scale used in this process can be found in Table 3. Table 4 outlines the inclusion criteria that were applied in order to identify the spatial, temporal and conceptual scales of the existing datasets. To identify variables, an exploration of dataset characteristics was conducted, involving a review of interview transcripts and participatory mapping data for IK, and field/biological data collection sheets for ESK. Inclusion criteria were shaped by initial research questions and the interview guide as well as core concepts, geographic variables and time-related variables for IK and ESK datasets. All information was extracted and compiled into Microsoft Excel. Measurement units were identified and standardized across datasets.

Table 3. Definitions of scales of operation

Scale of operation	Definition
Spatial	includes the extent, scope, or resolution of the geographical area covered by the dataset
Temporal	includes time range or duration over which the data is collected or measured (i.e., time-related variables or dimensions like dates or intervals)
Conceptual	includes underlying concepts or dimensions that the dataset aims to capture (i.e., key concepts or variables)

Table 4. Inclusion criteria for identifying scales of operation for IK and ESK datasets

	Inclusion criteria	
Scale of operation	**ESK**	**IK**
Spatial	Data points with information about where the fish were caught	Responses from individuals living near the lake or those who have travelled to the lake or its surrounding areas
Temporal	Data points that cover the entire lifespan of fish, from the time it was born until the time of catch	Responses that draw from individuals' personal experiences, observations, and memories within their own lifetime
Conceptual	Data points that include information about the species of fish and which provide quantitative details about the fish (e.g., age, length, weight)	Responses focusing on experiences or observations related to specified environmental or ecological parameters

The spatial, temporal and conceptual scale of the IK and ESK datasets are listed in Table 2. Based on the results, there is high overlap between the IK and ESK datasets. Specifically, the spatial scale of the IK data overlaps with that of the ESK data while also providing a broader geographical coverage. Similarly, the temporal scale of IK aligns with that of the ESK data while also encompassing a broader time span. The conceptual scales of IK and ESK were overlapping, but only indirectly, as ESK data focused on growth rates of Arctic Char and IK data focused on perceptions of environmental changes (Table 2).

General dataset characteristics *(row 4)*

To decide which approach to use, general attributes of the dataset need to be known (i.e., what form and format does the data exist in, what type of data exist). For the case study data, the raw data was available in its original form. The IK data was gathered and reported in qualitative terms while the ESK data was gathered and reported in quantitative terms.

Data transformation *(row 5)*

The inclusion of the category 'data transformation' was guided by insights from the convergent parallel design employed in mixed methods research (Teddlie & Tashakkori, 2009; Creswell & Clark, 2017), as well as examples of linking approaches and methods extracted from papers identified in the systematic map. This decision was influenced by the recognition that data transformation is a common practice in research that integrates qualitative and quantitative data and is a method that is widely employed by articles that link IK and ESK datasets in environmental research. The following questions were included in assessing the datasets ability to be transformed:

A) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its initial accuracy and precision?

B) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its integrity/meaning?

C) Can the data be transformed (qual-quant, quant-qual) so that it is in a 'useable' form and format such that it lends itself to analysis in combination with other variable(s) in the combined dataset?

D) Can the data be transformed into a recognized and widely accepted scale?

E) Can the data be transformed in a way that allows for linking to address the established research question or objective?

As reported in Table 1, the IK data is listed as being unable to maintain its accuracy and precision, however, the overall meaning can be maintained. An example to illustrate this concept is detailed below in the response by community member, David Kuptana:

Original narrative:

"Right now (August) the ice in the lakes are starting to melt earlier, cuz of the weather. We've been having really weird weather in May. That's when the -- no April. April, that's when the ice really melted. That's the first time I've ever seen that in April."

Narrative data converted to ordinal data:

"Perceived change in melting of lake ice: no change (0), little change (1), moderate change (2), a lot of change (3)"

While the transformation maintains the general meaning that David Kuptana observed a noticeable change in the timing of lake ice melting, there is a loss of the original nuance and specific details present in the narrative. However, the transformed data could still potentially be used, which is why question A) under data transformation does not require an affirmative response. Conversely, to link IK and ESK data, both need to be in compatible useable forms and formats. For example, to perform a correlation analysis with the existing IK and ESK datasets, the IK data would need to be transformed into a numerical form. It was possible to transform the

IK data into binary form (i.e., Yes (1) and No (0), but this would be the extent of the transformation and its use in a logistic regression for example, would not provide much insight, in addition to having a small sample size, it is reasonable to speculate that assumptions associated with the chosen statistical model would be violated. Attempting to transform qualitative IK interview responses into continuous data also proved to be somewhat problematic. For example, it was not possible within this study, for reasons of time and scope, to obtain lake ice cover for Ikahavik Lake. Had this been possible, there was potential to use this data to create an appropriate scale as was done in Ferguson et al. (1998). Additionally, attempting to link the available IK and ESK datasets using spatial overlap in GIS also proved to be unsuccessful due to the inability of both datasets to be transformed to the same format (i.e., spatially). While the IK data is presented in map form, gathered through participatory mapping, the available ESK lacks this spatial representation. These are some examples that showcase the decision to weigh question C) more heavily than question A) for example, because C) does need to have an affirmative response if an approach and method which requires a transformation is going to be used.

The data also needs to be transformed in a way that allows for linking to address the established research question. For example, drawing on the work of Davies et al. (2020) the parameters needed to use an illustrative figure were identified. The authors used an illustrative figure to compare IK perceptions of benthic habitat characteristics with ESK habitat characteristics. In the case of the existing IK and ESK data on environmental variability and Arctic Char growth, an illustrative figure was deemed not appropriate to use, largely in part due to its inability to answer the research question through conceptual visualization. This prompted question E) ‘Can the data be transformed in a way that allows for linking to address the established research question or objective?' to become a necessary criterion to be met when assessing which approach and method may be used.

Data quality *(rows 6-10)*

In recognition of the potential impacts of data quality on the robustness and trustworthiness of results and interpretations (Onwuegbuzie & Daniel, 2003; Tracy, 2010; Larson-Hall & Plonsky, 2015; Kwak & Kim, 2017; Creswell & Creswell, 2018), as well as the alignment and linkage of datasets (Sandelowski et al., 2009; Teddlie & Tashakkori, 2009; Creswell & Clark, 2017), measures for data quality were included as relevant and important characteristics to take into account when linking. The resulting characteristics (Table 2, rows 6-10) include: credibility and trustworthiness; significant contribution; ethical; data collection practice; and dataset validity and reliability. While the characteristics in rows 1-5 are necessary for being able to apply an approach and method, the content included in rows 6-10 are useful for ensuring that the outcome or results of linking are trustworthy. If a dataset is deemed as being inadequate for linking, an additional dataset may be brought in provided one exists and has at least one scale (spatial, temporal or conceptual) in overlap with the existing data.
Affirmative responses were found regarding both datasets on the following characteristics: credibility / trustworthiness; significant contribution, and ethical (Table 2). In the category 'data collection practice' it was found that the IK data collection practices were not applied consistently across all participants (e.g., when participants were in pairs, both participants were not explicitly asked to reply to the same questions and give their feedback.). With respect to 'dataset validity & reliability' all were missing at least one data point or response from interview participants.

Although a merged narrative approach was deemed appropriate to use in this case, responses to criteria in rows 6-10 illustrate that there exist issues regarding the trust and confidence in linking results. For example, the methods used to gather IK were inconsistently applied and not all interview questions were explicitly posed to each participant, resulting in missing 30% of responses. This in turn influences the reliability and validity of the dataset, as explored by Huntington (1998), Creswell and Creswell (2018), Furgal and Laing (2012), and Martinez-Levasseur (2017). These authors report on the impact of variations in data collection practices on accurately reflecting the information coming from a knowledge base. Therefore, although the IK and ESK data were linked through a merged narrative, to have trust and confidence in the linking results (i.e., there exists a link between changes in lake ice and the growth rates of landlocked Arctic Char in the context of the case study data), additional datasets are necessary to better explore and answer the research question of study. Thus, row 15 was added as a parameter to take into account should the available datasets be deemed as inadequate for linking. Specifically, this prompted the development of criteria for bringing in supplementary datasets, a process illustrated through a set of guiding questions presented in Table 1:

A) Do other datasets exist that can be combined to enhance or enrich the dataset?

B) Is the researcher aware of the nature of the spatial, temporal, conceptual scales and what is available in the dataset to then be connectable?

C) Is there at least one scale in overlap?

4.3.2 Linking the IK and ESK case study data through a merged narrative approach

4.3.2.1 Indigenous Knowledge perceptions of environmental change in the area surrounding Ulukhaktok NT

A total of 13 local community members were interviewed. The analysis of IK interviews revealed information on local climate, environment, and associated changes, some of which included changes to ocean ice, lake ice, air temperature, rainfall and permafrost melt. Also identified were perceptions of changes in fish population, fish health and competing invasive species. For the purpose of this analysis, IK perceptions of changes to lake ice were analyzed. In total, 8/13 respondents shared their observations and perceptions of changes to lake ice, while 5/13 did not comment on changes to lake ice. Of the 8 respondents who commented, all reported having noticed changes in the time of lake freeze over periods (i.e., ice is forming later and melting sooner) when compared to past years.

4.3.2.2 Environmental science Knowledge Arctic Char age and growth rates from Ikahavik Lake, Ulukhaktok NT

A total of 42 landlocked char otoliths were examined to determine the age of the fish at capture. The age of fish ranged from 10 to 23 years, with 15 being the most common (6 out of 42). A large majority of the fish (76%) fell into the range 10-18 years, while a smaller number of fish (i.e., n=10) fell into the range 19-23 years in age. Growth increments determined from back-calculation for char captured in August 2010 from Ikahavik Lake allowed for the determination in annual growth of individual char, with the earliest year of growth determination in 1987. The von Bertalanffy growth curve was estimated for the number of char included in the capture and back-calculated datasets (n=42) (Figure 3). The von Bertalanffy growth parameters (with 95% CI) for Arctic Char from Ikahavik Lake (2010) were $L\infty$=575, K=0.11, and t0 = -1.13, where $L\infty$

represents the asymptotic length, or maximum length a fish could reach in its lifetime; K or Brody growth rate coefficient represents the rate at which the fish will reach $L\infty$; and t0 is the age of fish when growth began, or when average length was zero.

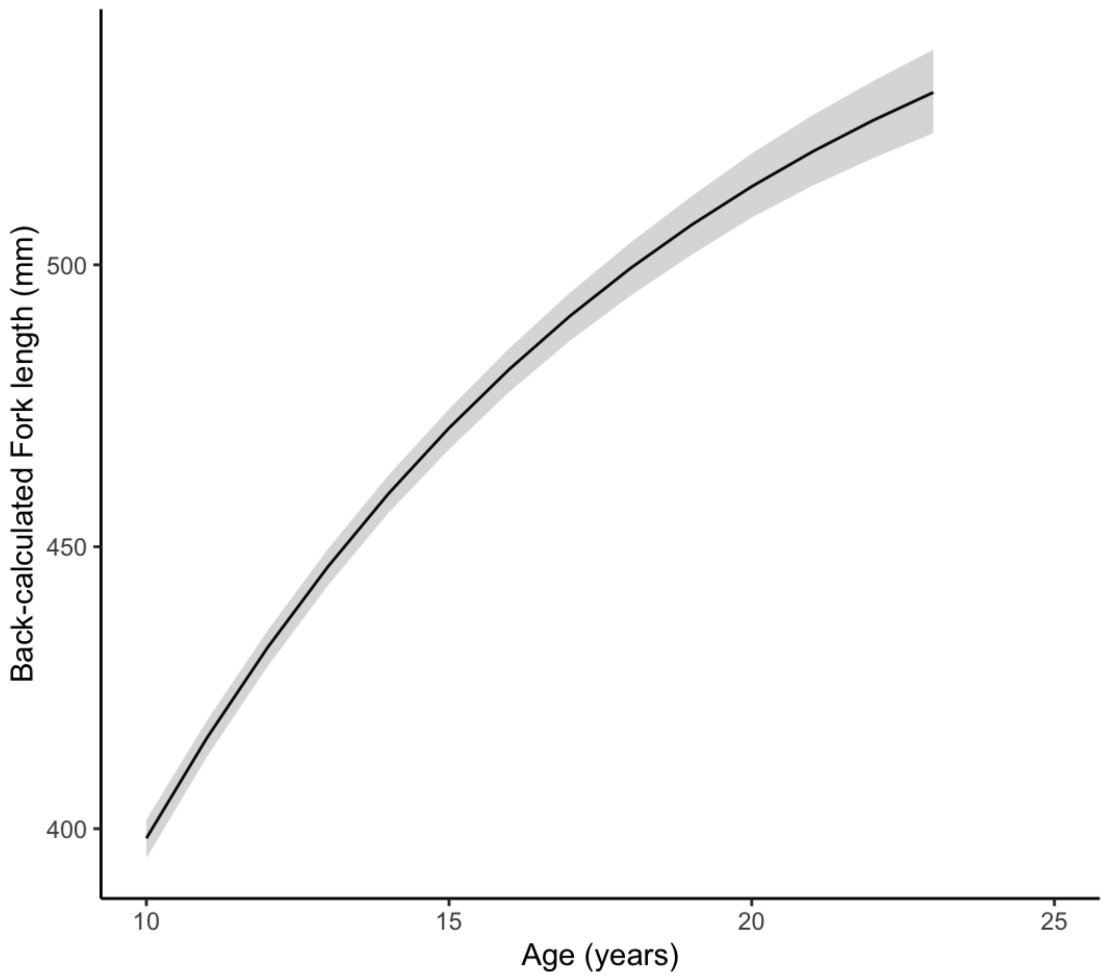

Figure 3. Von Bertalanffy growth curve with 95% confidence intervals for Arctic Char sampled in Ikahavik Lake in 2010 (n=42). The size and age of char were analyzed using otolith back-calculation. The growth parameters estimated from the curve are as follows: ($L\infty$) = 575, (K) = 0.11, and (t0) = -1.13.

4.3.3.3 Environmental conditions and Arctic Char growth

Evidence indicates that changes in environmental conditions may impact Arctic Char health and condition (Larsson & Berglund, 2005; Caza-Allard et al., 2021; Harris et al., 2022). In this study, IK perceptions of environmental change, and SK Arctic Char growth were gathered and analyzed. Among the respondents who commented on lake ice changes (8 out of 13), all reported observing a shift in the timing of lake ice freeze dates within their lifetime, notably, lake ice forming later and melting earlier in the season. From the ESK dataset, a von Bertalanffy growth curve was estimated for the number of char to determine the growth rate of the char included in the study (n=42). The von Bertalanffy growth parameters were found to be comparable to landlocked Arctic Char whose growth was shown to be positively influenced by prolonged ice-free periods and growing degree days (Knopp, 2017), suggesting the growth rates described here potentially represent elevated growth rates.

In this case study, insights from IK observations indicating an extended lake ice-free period along with Arctic Char growth rates comparable or similar to those influenced by longer ice-free periods and growing degree days (Knopp, 2017), suggest a potential link between changes in lake ice and the growth rates of landlocked Arctic Char. This is supported by Larsson & Berglund (2005) and Budy et al. (2014), who propose that Arctic Char may experience enhanced growth during longer ice-free periods. Their work highlights the significance of an elongated ice-free period in extending the growing season of char, resulting in increased growth rates over time.

4.4 Discussion

4.4.1 Key insights and challenges

Results of this work provide insight into the linking of IK and ESK datasets in environmental research. This section focuses on areas of future research identified by the author of this thesis through the systematic map review and critical analysis presented and methods to be used to increase understanding of knowledge linking in environmental research. They include: (1) inclusion of community reports and grey literature; (2) conducting interviews with Indigenous scholars and practitioners to better understand the appropriateness of data transformations; (3) implementation of QA/QC (quality assurance and quality control) measures on the existing systematic map database (Chapter 3).

The outcome of this work provides a conceptual understanding of the approaches and methods being used to link IK and ESK datasets in environmental research. Further exploration and examination would increase understanding of the challenges and limitations, especially when applied to in multiple contexts. This process may involve the incorporation and application of a variety of different types of IK and ESK data. A valuable addition to this refinement would be a comprehensive assessment of what constitutes ‘successful’ linking, drawing on insights from existing literature. These identified characteristics could be integrated into the established set of criteria or adapted as variations. The challenges and reflections presented here underscore the complexity of linking IK and ESK datasets and highlight the importance of continuous refinement and exploration to further explore and understand the appropriateness and effectiveness of the approaches and methods being used.

This work supports insights put forth by Gagnon & Berteaux (2008) and Furgal & Laing (2011) such that the linking of IK and ESK case study data would not have been possible if the data was not comparable across at least one of the spatial, temporal, and conceptual levels. Thus, researchers aiming to link IK and ESK need to be aware of the spatial, temporal and conceptual scales at which the data exists and ensure that there is at least one scale in overlap before continuing with the linking process. Furthermore, assessments of individual dataset quality are important to factor in when interpreting the weight of confidence and trustworthiness of the linking results. The findings presented in this work are supported by others **(**Huntington (1998), Creswell and Creswell (2018), Furgal and Laing (2012), and Martinez-Levasseur (2017). Critical issues identified included challenges related to IK data collection practices and dataset validity and reliability (for both IK and ESK data) and the resulting implications on the trustworthiness of linking results.

This current work showed that some approaches (i.e., statistical analysis, spatial overlap in GIS, and use of an illustrative figure) were not appropriate to use because they required certain transformations that could not be performed given the nature of the data. More work is needed to better understand the use and appropriateness of data transformations for the purposes of linking data from IK and ESK in environmental research.

4.4.2 Limitations of the study

It is important to recognize and address the limitations of this study. Firstly, it should be acknowledged that the way in which back-calculation was performed may be too simplistic and may not be an accurate reflection of fish growth (Stevenson & Campana, 1992). Moreover, to have better trust and confidence in measurements of fish age, an additional reviewer would be required to review the subset of otoliths for quality control of aging.

Additionally, a major challenge in using merged narrative given the nature of the data, was that the connection between Arctic Char growth rates and changes to lake ice was inferred by the researcher, rather than explicitly identified by the participants, potentially affecting the accuracy of the linking results.

The approaches and methods included in this study are directly derived from the articles included in the systematic map, which are confined to those published in the peer-reviewed literature and written in the English language. Thus, the identified approaches and methods may not represent the entirety of existing methodologies for linking Indigenous Knowledge (IK) and Environmental science Knowledge (ESK), and additional approaches and methods may exist beyond the scope of this study. Additionally, it is crucial to acknowledge that the exploration and examination of approaches and methods conducted in this study is preliminary in nature. While the systematic map provides valuable insights into the existing landscape of linking IK and ESK data, the critical examination conducted represents an initial exploration of characteristics to consider when attempting to link pre-existing IK and ESK datasets. Future research would benefit from further examination and empirical testing of approaches and methods to better understand and ultimately assess the effectiveness, appropriateness, and potential limitations of the identified approaches and methods.

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CHAPTER 5:

Summary and Conclusion

5.1 Summary and contributions

The bringing together of multiple knowledge sources, such as Indigenous Knowledge (IK) and Environmental science Knowledge (ESK), is a topic of considerable interest and significance in the field of environmental sciences and studies. For instance, in natural resource management contexts, the merging of data from IK and ESK has captured attention for its potential to enhance understanding and offer insights into complex phenomena, such as the impacts of climate change and variability on wildlife health and distribution (Gagnon & Berteaux, 2009; Hauser et al., 2021). Despite widespread recognition of the potential benefits arising from merging IK and ESK datasets, navigating the complex processes involved in knowledge linking presents substantial challenges (Bohensky & Maru, 2011; Gagnon & Berteaux, 2009; Furgal & Laing, 2012; Johnson et al., 2023). Furthermore, knowledge linking operates across multiple levels, each requiring distinct approaches and methods, making a one-size-fits all strategy unsuitable (Johnson et al., 2023). The inherent complexity involved in knowledge linking, coupled with an increased interest in and global push for the inclusion of IK within environmental research and decision-making, provides impetus to explore and examine previous approaches and methods used to bring IK and ESK together.

This thesis contributes novel research to the field of environmental science and studies in several ways. Through conducting a systematic map, this work provided a comprehensive understanding of existing methods and approaches used to bring together IK and ESK datasets in the environmental research literature. Particular emphasis was placed on identifying the types of approaches and methods used to merge IK and ESK datasets at the level of data analysis, presentation and interpretation. Building on the results of the systematic map, this work furthered the understanding of approaches and methods for linking by exploring their application on a pre-existing IK and ESK dataset concerning lake ice condition and growth of landlocked Arctic Char in the Inuvialuit Settlement Region. During this process, criteria were developed to determine data readiness for linking, and the available dataset was applied to the criteria to identify a suitable approach for linking. Through this initial application of IK and ESK data, the research provides a better understanding of what information is needed when attempting to link pre-existing IK and ESK datasets, offering key insights and recommendations for further exploration in the linking of IK and ESK in environmental research. Specifically, this work allows for the identified approaches and methods to be repeated in a wider context.

5.2 Considerations and recommendations for future research

It is important to acknowledge the methodological limitations inherent in the study. In the systematic map, the exclusive focus on articles written in the English language introduces potential biases, and there is recognition of the need for a more inclusive approach to language diversity in future research. Similarly, limitations extend to the systematic map evidence base, with a confined focus on peer-reviewed literature due to resource constraints. Community voices and engagement may add elements to the types of approaches used to link IK and ESK data and as such, the inclusion of community reports and theses found in the grey literature would be beneficial to include in future work to provide a more comprehensive identification of the types of approaches being used to link IK and ESK data in research. Additionally, the inherent subjectivity in systematic screening and coding emphasizes the need for and importance of transparent documentation in future research to enhance reliability and replicability. More extensive and widespread contributions and investigations into the evaluation of approaches and methods would be beneficial to gain a more comprehensive understanding of the nuanced processes associated with linking IK and ESK at the data analysis level in environmental research.

The evaluation of success of knowledge linking attempts was not included in this study. Such evaluation would require deeper understanding of the meaning of successful knowledge linking in environmental experiences. This may involve a systematic review and meta-analysis of environmental research literature with an aim to assess the quality of the approaches and methods used, providing insights into 'successful' knowledge linking across various contexts. In conclusion, while the systematic map and preliminary evaluation offer valuable insights, they serve as a foundation for future in-depth investigations and refinement of methodologies in the ongoing pursuit of linking IK and ESK at the level of data analysis in environmental research.

This study makes a significant contribution to the understanding of knowledge linking between Indigenous Knowledge (IK) and Environmental science Knowledge (ESK) at the stage of data analysis in environmental research. The findings highlight approaches that may guide future work while aiming to maintain the integrity of data from original knowledge sources. Future research could benefit from including community reports, interviews, and communication with Indigenous scholars and practitioners. Informed by perspectives from interviews with Indigenous practitioners and scholars, implementation of QA/QC (Quality Assurance/Quality Control) measures on the existing map database (Chapter 3) will be essential to learn more about what constitutes 'successful linking' in regard to linking data from IK and ESK in research.

5.3 References

Bohensky, E. L., & Maru, Y. (2011). Indigenous knowledge, science, and resilience: What have we learned from a decade of international literature on "integration"?. *Ecology and Society*, *16*(4). http://dx.doi.org/10.5751/ES-04342-160406

Furgal, C., & Laing, R. (2012). A synthesis and critical review of the traditional ecological knowledge literature on narwhal (*Monodon monoceros*) in the Eastern Canadian Arctic. DFO Can. Sci. Advis. Sec. Res. Doc, 131.

Gagnon, C. A., & Berteaux, D. (2009). Integrating traditional ecological knowledge and ecological science: a question of scale. *Ecology and Society*, *14*(2).

Hauser, D. D., Whiting, A. V., Mahoney, A. R., Goodwin, J., Harris, C., Schaeffer, R. J., ... & Zappa, C. J. (2021). Co-production of knowledge reveals loss of Indigenous hunting opportunities in the face of accelerating Arctic climate change. *Environmental Research Letters*, *16*(9), 095003. DOI: 10.1088/1748-9326/ac1a36

Johnson, L. R., Wilcox, A. A., Alexander, S. M., Bowles, E., Castleden, H., Henri, D. A., ... & Orihel, D. M. (2023). Weaving Indigenous and Western ways of knowing in ecotoxicology and wildlife health: a review of Canadian studies. *Environmental Reviews*. https://doi.org/10.1139/er-2022-0087

APPENDIX 1: Chapter 2 - Supporting Information

Supporting Information 1 – ROSES *pro forma* for systematic map protocols

A version of the *Reporting standards for Systematic Evidence Syntheses* (ROSES) *pro forma* for systematic map protocols is available upon request.

Supporting Information 2 – Search terms and strategies

Below are the search terms and strategies that will be applied to the search through ISI Web of Science (Core Collection), EBSCO*host* Academic Search Elite, ProQuest International Bibliography of Social Sciences and EBSCO*host* Bibliography of Indigenous Peoples in North America. Note that the asterisks (*) is a search engine wildcard character used to broaden search through use of truncations or variations of the word (e.g., assess* includes assess, assessment, assessments, assessing), quotation marks (“”) are used to capture exact phrases, and proximity operators (NEAR/#) are used to join and find specified terms within a specified number of words of each other.

Search strategy 1- ISI Web of Science (Core Collection)

Topic search (TS) in Web of Science includes: title, abstract, keywords, keywords plus. The following restrictions will be applied: advanced search, English language, document type: article, all years (1900-2022).

Proposed search string
TS= ((Indigenous OR traditional OR local) NEAR/2 (know*) AND (scien* OR ecolog*) AND

(assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) NEAR/4 (know* OR evidence* OR information* OR data* OR observation* OR understanding*))

Search strategy 2- EBSCOhost Academic Search Elite

Everything except full text (noft) in Academic Search Elite includes: title, abstract and keywords. The following restrictions will be applied: advanced search, English language, document type: article, all years (1888-2022).

Proposed search string
noft= ((Indigenous OR traditional OR local) N5 (know*) AND (scien* OR ecolog*) AND (assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) N5 (know* OR evidence* OR information* OR data* OR observation* OR understanding*))

Search strategy 3- ProQuest International Bibliography of Social Sciences

Everything except full text (noft) in International Bibliography of Social Sciences includes: title, abstract and keywords. The following restrictions will be applied: advanced search, English language, document type: article, all years (1951-2022).

Proposed search string
noft= ((Indigenous OR traditional OR local) NEAR/2 (know*) AND (scien* OR ecolog*) AND (assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) NEAR/4 (know* OR evidence* OR information* OR data* OR observation* OR understanding*))

Search strategy 4- EBSCOhost Bibliography of Indigenous Peoples in North America

Everything except full text (noft) in Bibliography of Indigenous Peoples in North America includes: title, abstract and keywords. The following restrictions will be applied: advanced search, English language, document type: article, all years (16th c.-2022).

Proposed search string
noft= ((Indigenous OR traditional OR local) N5 (know*) AND (scien* OR ecolog*))

Supporting Information 3 – Benchmark list of candidate studies for inclusion

Abbreviated Citation	Full Citation
Aswani & Hamilton 2004	Aswani, S., & Hamilton, R. J. (2004). Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (Bolbometopon muricatum) in the Roviana Lagoon, Solomon Islands. *Environmental conservation*, *31*(1), 69-83.
Ban et al., 2017 Bevilacqua et al., 2016	Ban, N. C., Eckert, L., McGreer, M., & Frid, A. (2017). Indigenous knowledge as data for modern fishery management: a case study of Dungeness crab in Pacific Canada. *Ecosystem Health and Sustainability*, *3*(8), 1379887. Bevilacqua, A. H. V., Carvalho, A. R., Angelini, R., & Christensen, V. (2016). More than anecdotes: fishers' ecological knowledge can fill gaps for ecosystem modeling. *PLoS One*, *11*(5).
Chalmers & Fabricius 2007 Fraser et al., 2006	Chalmers, N., & Fabricius, C. (2007). Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: can local ecological knowledge add value to science?. *Ecology and Society*, *12*(1). Fraser, D. J., Coon, T., Prince, M. R., Dion, R., & Bernatchez, L. (2006). Integrating traditional and evolutionary knowledge in biodiversity conservation: a population level case study. *Ecology and Society*, *11*(2).
Gagnon & Berteaux 2009	Gagnon, C., & Berteaux, D. (2009). Integrating traditional ecological knowledge and ecological science: a question of scale. *Ecology and Society*, *14*(2).

Gilchrist et al., 2005 Hallwass et al., 2013	Gilchrist, G., Mallory, M., & Merkel, F. (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society*, *10*(1). Hallwass, G., Lopes, P. F., Juras, A. A., & Silvano, R. A. (2013). Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers. *Ecological Applications*, *23*(2), 392-407.
Huntington et al., 2004 López-Arévalo et al., 2011	Huntington, H., Callaghan, T., Fox, S., & Krupnik, I. (2004). Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. *Ambio*, 18-23. López-Arévalo, H. F., Gallina, S., Landgrave, R., Martínez-Meyer, E., & Muñoz-Villers, L. E. (2011). Local knowledge and species distribution models' contribution towards mammalian conservation. *Biological Conservation*, *144(5),* 1451-1463.
Newman & Moller 2005 Pennesi et al., 2012	Newman, J., & Moller, H. (2005). Use of Matauranga (Maori traditional knowledge) and science to guide a seabird harvest: getting the best of both worlds?. *Senri Ethnological Studies.* Pennesi, K., Arokium, J., & McBean, G. (2012). Integrating local and scientific weather knowledge as a strategy for adaptation to climate change in the Arctic. *Mitigation and Adaptation Strategies for Global Change*, *17*(8), 897-922.
Salomon et al., 2007	Salomon, A. K., Tanape Sr, N. M., & Huntington, H. P. (2007). Serial depletion of marine invertebrates leads to the decline of a strongly interacting grazer. *Ecological Applications*, *17*(6), 1752-1770. Smith, B. M., Chakrabarti, P., Chatterjee, A., Chatterjee, S., Dey, U. K., Dicks, L. V., ... & Basu, P. (2017). Collating and validating indigenous and local knowledge to apply multiple knowledge systems to an environmental challenge: A case-study of pollinators in India. *Biological conservation*, *211*, 20-28.

Smith et al., 2017 Service et al., 2014	Service, C., Adams, M., Artelle, K., Paquet, P., Grant, L., & Darimont. (2014). Indigenous Knowledge and Science unite to reveal spatial and temporal dimensions of distributional shift in wildlife of conservation concern. *PLoS one*, *9*(7).

Supporting Information 4 – Coding Template

The following section contains the coding template used for this systematic map.

1. Provide the reference for the paper

2. Provide the year of publication

3. Identify the term used for Indigenous Knowledge (IK) system in the paper *(may include more than one)*

4. Did the paper include data or information represented from Indigenous knowledge?
   a) Yes
   b) No
   c) Unspecified

5. Identify the Indigenous group as stated in the paper *(may include more than one)*

6. Identify the term used for Environmental science Knowledge (ESK) in the paper *(may include more than one)*

7. What are the papers disciplinary subject focus? *(may include more than one)*
   a) Ecology
   b) Human ecology
   c) Physical geography
   d) Human ecology
   e) Chemistry
   f) Other
   g) Unknown / Unspecified

8. What is the geographical scope of the paper by country? *(may include more than one)*

9. What is the geographical scope of the paper by latitudinal zone? *(may include more than one)*
   a) Arctic
   b) Subarctic
   c) Temperate
   d) Subtropical
   e) Tropical
   f) Other:
   g) Unknown / Unspecified

10. What is the geographical scope of the paper by biome and landform? *(may include more than one)*
    a) Tropical and subtropical forests
    b) Tropical and subtropical grasslands, savannas and shrublands
    c) Temperate forests
    d) Temperate grasslands, savannas and shrublands
    e) Mediterranean Forests, woodlands and scrubs
    f) Montane grasslands and shrublands
    g) Deserts and xeric shrublands
    h) Boreal forests / Taiga
    i) Tundra
    j) Mangroves
    k) Coastal and marine
    l) Freshwater
    m) Other:
    n) Unknown / Unspecified

11. What is the species / object of study? *(may include more than one)*
    a) Bird
    b) Mammal
    c) Fish
    d) Reptile
    e) Amphibian
    f) Invertebrate
    g) Soil and substrate
    h) Vegetation
    i) Water, snow and ice
    j) Weather and climate
    k) Other:
    l) Unknown / Unspecified

12. What is the species name? *(may include more than one)*

13. Provide the method(s) used to gather IK *(may include more than one)*
    a) Questionnaire
    b) Participant observation
    c) Historical records
    d) Participatory mapping
    e) Interview and focus group
    f) Workshop
    g) Informal discussions
    h) Unspecified review of the literature
    i) Literature review
    j) Other:
    k) Unknown / Unspecified

14. Provide the method(s) used to gather ESK
    a) Ecological field survey/assessment
    b) Satellite image classification
    c) Historical records
    d) Interview
    e) Unspecified review of the literature
    f) Literature review
    g) Other:
    h) Unspecified / Unknown

15. What is the temporal nature of gathered IK and ESK? *(may include more than one)*
    a) Old
    b) New
    c) Both

16. Provide the linking approach segments as stated in the paper
    a) excerpt copy and pasted from paper

17. What section of the paper is evidence of linking reported in? *(may include more than one)*
    a) Methods
    b) Results
    c) Discussion

18. Provide a categorical interpretation of the linking approach and method used in the paper (as stated in #16) *(may include more than one)*
    a) Use of narrative
    b) Use of statistical analysis
    c) Use of spatial overlap in GIS
    d) Use of illustrative figure
    e) Other:
    f) Unspecified / Unknown

19. Provide the aim / purpose for linking segments as stated in the paper
    a) excerpt copy and pasted from paper

20. Provide a categorical interpretation of the aim / purpose for linking (as stated in #19) *(may include more than one)*
    a) Using both IK and ESK to fill gap in understanding
    b) Assess quality of IK
    c) Explore differences between IK and ESK
    d) Identify and describe diversity of knowledge with IK base
    e) Identify opportunities for complementarity with ESK
    f) Assessment of IK for scientific understanding
    g) Assess quality of ESK
    h) Testing IK hypothesis
    i) Other:
    j) Unspecified / Unknown

APPENDIX 2: Chapter 3 - SUPPORTING INFORMATION

Supporting Information 1 – ROSES *pro forma* for systematic maps

A version of the *Reporting standards for Systematic Evidence Syntheses* (ROSES) *pro forma* for systematic map protocols is available upon request.

Supporting Information 2 – Literature Searches

This section provides information pertaining to relevant components of the literature search (i.e., search string, restrictions, returns) for each bibliographic database used.

ISI Web of Science (Core Collection)

Note: Topic search (TS) in Web of Science includes: title, abstract, keywords, keywords plus.

Search string	**Restrictions**	**Returns [date]**
TS= ((Indigenous OR traditional OR local) NEAR/2 (know*) AND (scien* OR ecolog*) AND (assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) NEAR/4 (know* OR evidence* OR	• Database temporal coverage (1900) to date of final capture / All years • Language: English • Document type: Article	3,500 [June 1, 2022]

information* OR data* OR observation* OR understanding*))		

EBSCOhost Academic Search Elite

Note: Everything except full text (noft) in Academic Search Elite includes: title, abstract and keywords.

Search string	**Restrictions**	**Returns [date]**
noft= ((Indigenous OR traditional OR local) N5 (know*) AND (scien* OR ecolog*) AND (assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) N5 (know* OR evidence* OR information* OR data* OR observation* OR understanding*))	• Database temporal coverage (1888) to date of final capture / All years • Language: English • Document type: Article	6,009 [June 1, 2022]

ProQuest International Bibliography of Social Sciences

Note: Everything except full text (noft) in International Bibliography of Social Sciences includes: title, abstract and keywords.

Search string	**Restrictions**	**Returns [date]**
noft= ((Indigenous OR traditional OR local) NEAR/2 (know*) AND (scien* OR ecolog*) AND (assess* OR appl* OR bridg* OR bring* OR blend* OR coproduc* OR collaborat* OR combin* OR complement* OR corroborat* OR compar* OR contrast* OR contribut* OR connect* OR correlat* OR converg* OR evaluat* OR hybrid* OR inclu* OR integrat* OR interact* OR incorporat* OR link* OR match* OR merg* OR synerg* OR synthes* OR triangulat* OR use* OR using* OR valid*) NEAR/4 (know* OR evidence* OR information* OR data* OR observation* OR understanding*))	• Database temporal coverage (1951) to date of final capture / All years • Language: English • Document type: Article	793 [June 1, 2022]

EBSCOhost Bibliography of Indigenous Peoples in North America

Note: Everything except full text (noft) in Indigenous Peoples in North America includes: title, abstract and keywords.

Search string	**Restrictions**	**Returns [date]**
noft= ((Indigenous OR traditional OR local) N5 (know*) AND (scien* OR ecolog*))	• Database temporal coverage (16th c.) to date of final capture / All years • Language: English • Document type: Article	331 [June 1, 2022]

Supporting Information 3 – Benchmark Papers

This section contains the bibliographic information for the 15 benchmark papers used in the systematic map, serving as a means to evaluate the comprehensiveness of the search strategy

Citation	Link
Aswani, S., & Hamilton, R. J. (2004). Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental conservation, 31*(1), 69-83.	https://www.researchgate.net/publication/231964938_Integrating_indigenous_ecological_knowledge_and_customary_sea_tenure_with_marine_and_social_science_for_conservation_of_bumphead_parrotfish_Bolbometopon_muricatum_in_the_Roviana_Lagoon_Solomon_Islands
Ban, N. C., Eckert, L., McGreer, M., & Frid, A. (2017). Indigenous knowledge as data for modern fishery management: a case study of Dungeness crab in Pacific Canada. *Ecosystem Health and Sustainability, 3*(8), 1379887.	https://www.tandfonline.com/doi/full/10.1080/20964129.2017.1379887
Bevilacqua, A. H. V., Carvalho, A. R., Angelini, R., & Christensen, V. (2016). More than anecdotes: fishers' ecological knowledge can fill gaps for ecosystem modeling. *PLoS One, 11*(5).	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0155655
Chalmers, N., & Fabricius, C. (2007). Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: can local ecological knowledge add value to science?. *Ecology and Society, 12*(1).	https://www.jstor.org/stable/26267835

Fraser, D. J., Coon, T., Prince, M. R., Dion, R., & Bernatchez, L. (2006). Integrating traditional and evolutionary knowledge in biodiversity conservation: a population level case study. *Ecology and Society, 11*(2).	https://www.jstor.org/stable/26265998
Gagnon, C., & Berteaux, D. (2009). Integrating traditional ecological knowledge and ecological science: a question of scale. *Ecology and Society, 14*(2).	https://www.researchgate.net/publication/42766148_Integrating_Traditional_Ecological_Knowledge_and_Ecological_Science_A_Question_of_Scale
Gilchrist, G., Mallory, M., & Merkel, F. (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society*, *10*(1).	https://www.jstor.org/stable/26267752
Hallwass, G., Lopes, P. F., Juras, A. A., & Silvano, R. A. (2013). Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers. *Ecological Applications*, *23*(2), 392-407.	https://pubmed.ncbi.nlm.nih.gov/23634590/
Huntington, H., Callaghan, T., Fox, S., & Krupnik, I. (2004). Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. *Ambio*, 18-23.	https://pubmed.ncbi.nlm.nih.gov/15575178/
López-Arévalo, H. F., Gallina, S., Landgrave, R., Martínez-Meyer, E., & Muñoz-Villers, L. E. (2011). Local knowledge and species distribution models' contribution towards mammalian conservation. *Biological Conservation*, *144(5)*, 1451-1463.	https://www.researchgate.net/publication/232361194_Local_knowledge_and_species_distribution_models'_contribution_towards_mammalian_conservation
Newman, J., & Moller, H. (2005). Use of Matauranga (Maori traditional knowledge) and science to guide a seabird harvest: getting the best of both worlds?. *Senri Ethnological Studies.*	https://www.researchgate.net/publication/255574077_Use_of_Matauranga_Maori_Traditional_Knowledge_and_Science_to_Guide_a_Seabird_Harvest_Getting_the_Best_of_Both_Worlds
Pennesi, K., Arokium, J., & McBean, G. (2012). Integrating local and scientific weather knowledge as a strategy for adaptation to climate change in the Arctic. *Mitigation and Adaptation Strategies for Global Change*, *17*(8), 897-922.	https://www.researchgate.net/publication/257623201_Integrating_local_and_scientific_weather_knowledge_as_a_strategy_for_adaptation_to_climate_change_in_the_Arctic
Salomon, A. K., Tanape Sr, N. M., & Huntington, H. P. (2007). Serial depletion of marine invertebrates	https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/06-1369.1

leads to the decline of a strongly interacting grazer. *Ecological Applications*, *17*(6), 1752-1770.	
Smith, B. M., Chakrabarti, P., Chatterjee, A., Chatterjee, S., Dey, U. K., Dicks, L. V., ... & Basu, P. (2017). Collating and validating indigenous and local knowledge to apply multiple knowledge systems to an environmental challenge: A case-study of pollinators in India. *Biological conservation*, *211*, 20-28.	https://www.sciencedirect.com/science/article/pii/S0006320717307309
Service, C., Adams, M., Artelle, K., Paquet, P., Grant, L., & Darimont. (2014). Indigenous Knowledge and Science unite to reveal spatial and temporal dimensions of distributional shift in wildlife of conservation concern. *PLoS one*, *9*(7).	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0101595

Supporting Information 4 - Screening

A version of the list of articles excluded at the full-text level, along with accompanying rationales for exclusion is available upon request.

Supporting Information 5- Coding template

Refer to Appendix 1: Chapter 2 - Supporting Information 6 for the coding template used.

Supporting Information 6- Systematic map database

An online version of the final systematic map database is available upon request.

APPENDIX 3: Chapter 4 - Supporting Information

Supporting Information 1- Criteria to determine data readiness for linking

	IK AND ESK PARAMETERS AND CRITERIA FOR LINKING	ESK_data1	IK_data1
1	**SPATIAL SCALE**		
2	**TEMPORAL SCALE**		
3	**CONCEPTUAL SCALE**		
4	**WHAT NEEDS TO BE DONE TO IN ORDER TO LINK DATASETS (IN GENERAL)** A) Does the researcher have access to the data in its raw/original form? (interview transcripts, physical maps, sampling field data sheet etc.) B) What is the type of data? (numerical/quantitative, narrative/qualitative)		
5	**DATA TRANSFORMATION** A) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its initial accuracy and precision? B) Can the data be transformed (qual-quant, quant-qual) in a way that maintains its integrity/meaning? C) Can the data be transformed (qual-quant, quant-qual) so that it is in a 'useable' form and format such that it lends itself to analysis in combination with other variable(s) in the combined dataset? D) Can the data be transformed		

	into a recognized and widely accepted scale? E) Can the data be transformed in a way that allows for linking to address the established research question or objective?		
6	**CREDIBILITY / TRUSTWORTHINESS** A) Did the researcher provide a positionality statement? B) Did the research provide a thick and detailed description of data collection procedures? C) Does the researcher explain engagement with community from beginning to end?		
7	**SIGNIFICANT CONTRIBUTION** A) Does the research build upon existing work (is this backed up via a thorough review of literature?) (qual, quant)		
8	**ETHICAL** A) Did the researcher provide detail on how ethics was approached? (i.e., going through a research ethics board or advisory committee) (qual, quant)		
9	**DATA COLLECTION PRACTICE** A) Did the researcher spend enough time to gather interesting and significant data? (qual, quant) B) Is the context or sample appropriate given the goals of the study? (qual, quant) C) Did the researcher use appropriate procedures in terms of how the data was		

	collected (field note style, interviewing / sampling practices, and analysis procedures)? (qual, quant) D) Were data collection tools (questions, surveys, interview protocols, sampling methods, and analysis procedures) applied consistently across all participants/observational points? (qual, quant)		
10	**DATASET VALIDITY & RELIABILITY** A) Is the dataset complete, or missing data points? (qual, quant) B) Did the researcher use member reflections to ensure internal validity of results? (qual) C) External validity – were the sample results generalised? (quant)		
11	**FOR A NARRATIVE APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative, B complete; row 5: at least C and E must be affirmative for approaches and methods requiring IK transformations only): A) Is there any IK data that could be mixed with ESK data? If affirmative response to A), the following approach or combination of approaches may be used: 1. Qualitative IK and quantitative ESK results are presented in		

	sequence. The two sets of results are brought together and interpreted via a merged narrative. Interpretation involves a comparative and/or complementary analysis. 2. Qualitative IK and quantitative ESK results are brought together via a merged narrative. Interpretation of merged datasets takes place via a merged narrative and involves a comparative and/or complementary analysis. 3. Transformation of a quantitative ESK variable into a qualitative form. IK and transformed ESK results are brought together and interpreted via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
12	**FOR A STATISTICAL ANALYSIS APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative, B complete; row 5: at least C and E must be		

	affirmative): A) Is there any transformed quantitative IK data that could be mixed with quantitative ESK? If affirmative response to A), the following approach or combination of approaches may be used: 1. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in a regression analysis. The transformed variable is used in a complementary way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. 2. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in a correlation analysis. The transformed variable is used in a comparative way in analysis. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. 3. IK and ESK datasets are brought together via the transformation of a qualitative IK variable into a quantitative form for use in percent agreement and disagreement calculations. The transformed variable is used in a comparative way in analysis. Interpretation of merged results		

	takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
13	**FOR A SPATIAL OVERLAP IN GIS APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative, B complete; row 5: at least C and E must be affirmative): A) Is there any qualitative or transformed quantitative IK data that could be mixed with ESK quant or qual? If affirmative response to A), the following approach or combination of approaches may be used: 1. Transformation of a qualitative IK variable into a quantitative form. Results are brought together via knowledge visualization at the spatial level. The transformed variable is used in a comparative and/or complementary way in analysis. Interpretation of merged results		

	takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis. • For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
14	**FOR AN ILLUSTRATIVE FIGURE APPROACH TO MIXING OF RESULTS** • Based on data presented in rows 1-5 (responses to rows 1-3 must be complete; row 4: A affirmative B complete; row 5: at least C and E must be affirmative): A) Is there any qualitative IK data that could be mixed with qualitative or quantitative ESK data? If affirmative response to A), the following approach or combination of approaches may be used: 1. Qualitative IK and qualitative ESK results are brought together via knowledge visualization at the conceptual level. Interpretation of merged results takes place via a merged narrative. Interpretation involves a comparative and/or complementary analysis.		

	• For trust and confidence in linking results the following should exist: (1) rows 6-8: affirmative responses; (2) row 9: affirmative responses; (3) row 10: A) minimal missing data, B) and C) affirmative responses required. If a dataset is assessed as being inadequate for linking, then affirmative responses are required for row 15.		
15	**FOR BRINGING IN ADDITIONAL DATASETS** A) Do other datasets exist that can be combined to enhance or enrich the dataset? B) Is the researcher aware of the nature of the spatial, temporal, conceptual scales and what is available in the dataset to then be connectable? C) Is there at least one scale in overlap? If affirmative responses to A), B) and C), proceed to adding on another column beside the original variable and fill out rows 1-14 for incoming variable.		

Supporting Information 2- Application of available IK and ESK dataset to criteria

A version of the final application of the full IK and ESK dataset is available upon request.

Supporting Information 3- Examples of linking from the literature and linking of the IK and ESK case study data

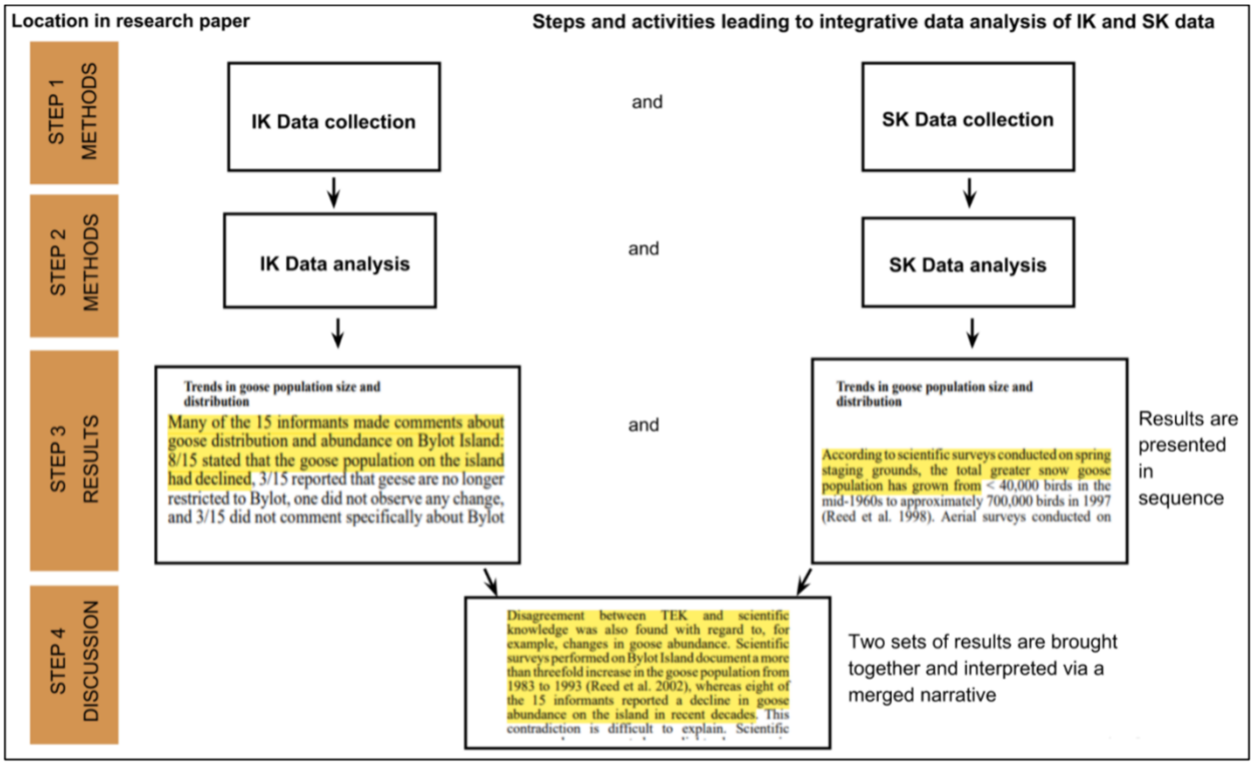

Figure 1. Use of narrative to link IK and ESK on goose population size and distribution from the work of Gagnon & Berteaux (2009).

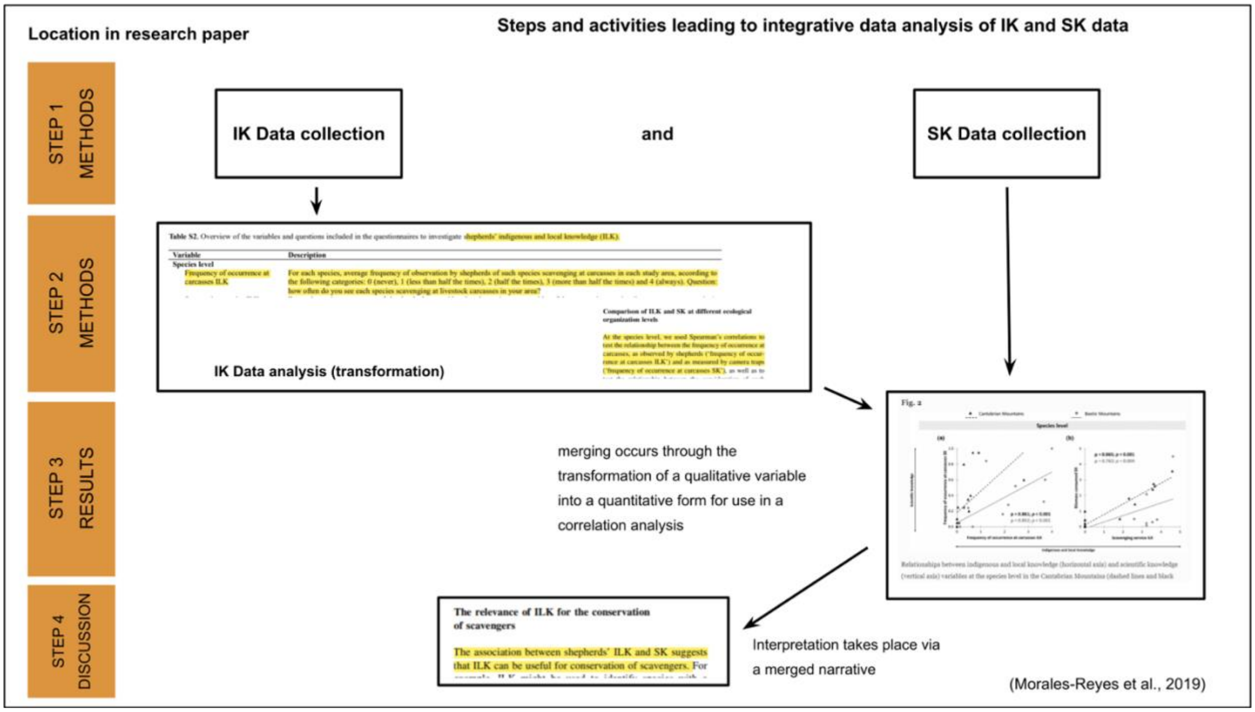

Figure 2. Use of statistical analysis to link IK and ESK data on behaviour of various scavenger species from the work of Morales-Reyes et al (2019).

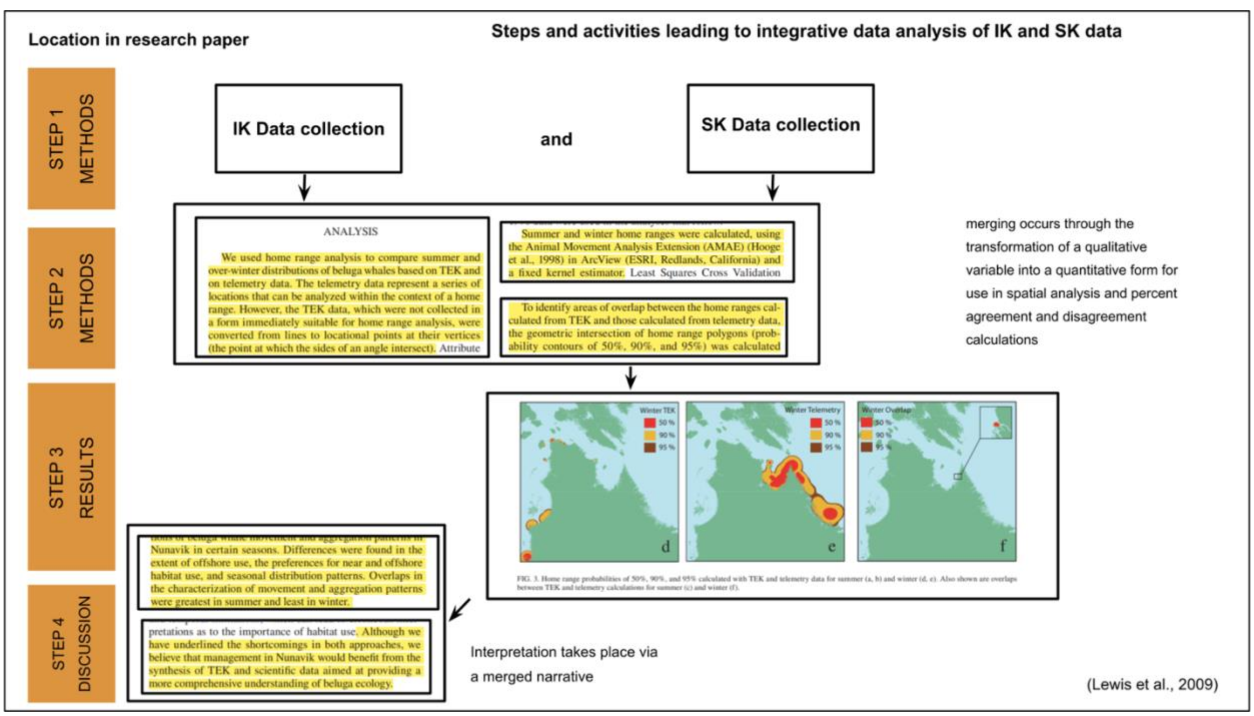

Figure 3. Use of spatial overlap to link IK and ESK on beluga whale summer and winter distribution from the work of Lewis et al. (2009).

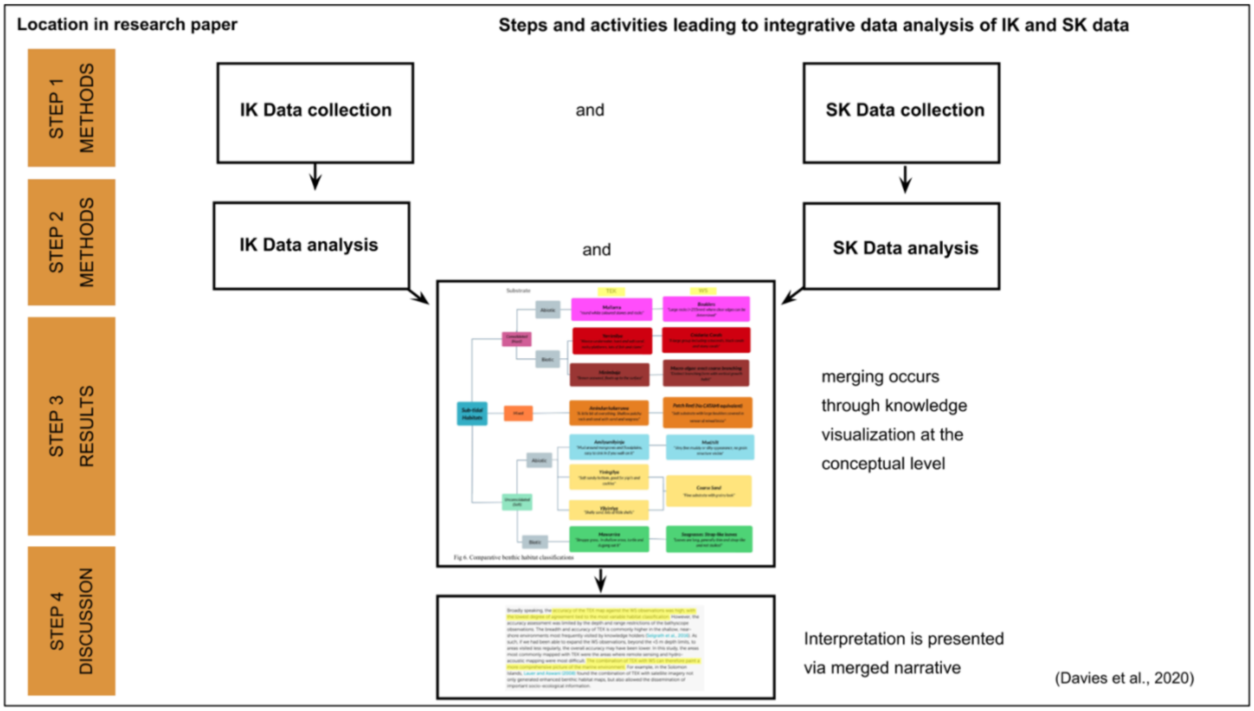

Figure 4. Use of illustrative figure to link IK and ESK on benthic habitat characteristics from the work of Davies et al. (2020)

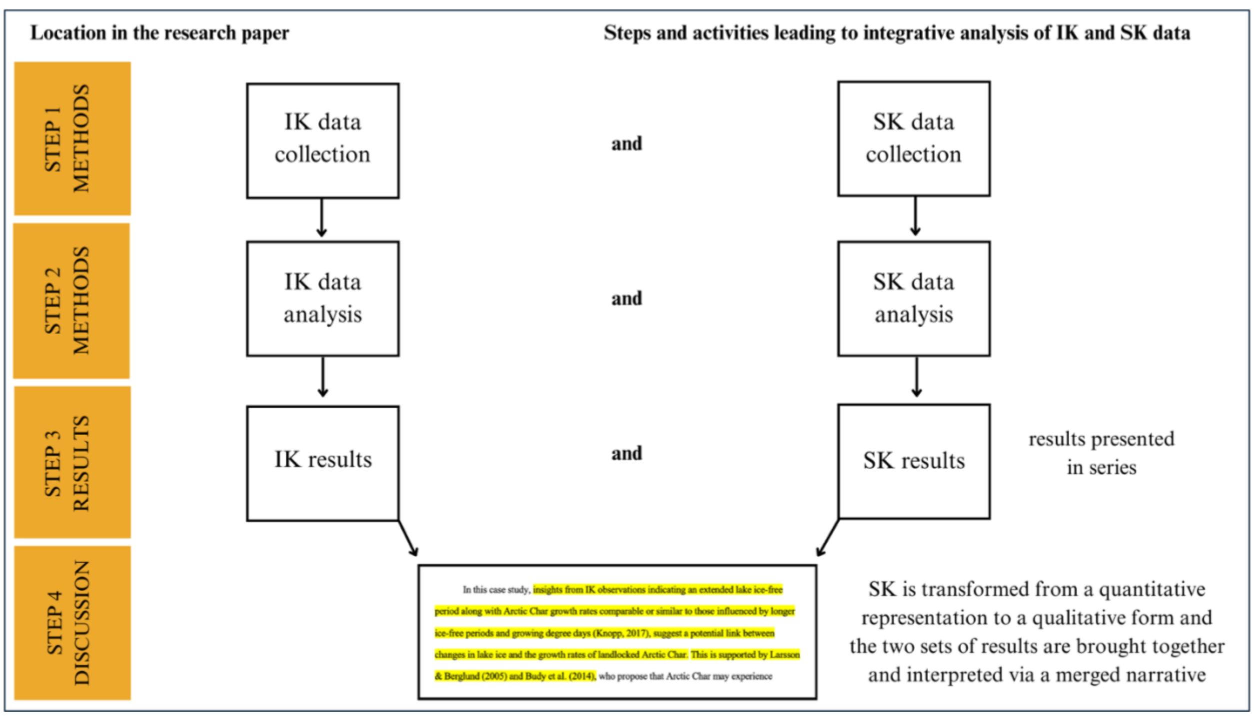

Figure 5. Use of merged narrative to link the IK and ESK case study data on environmental conditions and Arctic Char growth.