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REVIEW ARTICLE

A leverage points perspective on Arctic Indigenous food systems research: a systematic review

Silja Zimmermann[1,2] · Brian J. Dermody[1,2] · Bert Theunissen[3] · Martin J. Wassen[2] · Lauren M. Divine[4] · Veronica M. Padula[4] · Henrik von Wehrden[5] · Ine Dorresteijn[2]

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Abstract

Arctic food systems are increasingly challenged by rapid climate change, loss of food security and subsequent weakening of food sovereignty, and destabilization of Indigenous practices. Despite growing scientific knowledge on Arctic food systems, Indigenous communities continue to struggle with a plethora of sustainability challenges. To develop a systemic understanding of these challenges, we performed a systematic review of 526 articles published between 1998 and 2021 on Arctic Indigenous food systems. We used the leverage points framework to structure our analysis to understand to what extent the existing Western scientific body of literature provides the necessary knowledge to understand the food system characteristics that give rise to the current sustainability challenges. We combined deductive qualitative and inductive quantitative approaches to identify gaps in the systemic understanding of Arctic Indigenous food systems. We characterized existing research across the four levels of systemic depth—parameters, feedbacks, design, intent—and identified promising directions for future research. Our analyses show that research on food systems is clustered within six main domains, we term environmental contaminants, diet and health, food security, food culture and economy, changing socio-ecological systems and marine and coast. Based on our analysis, we identify three directions for future research that we believe to be of particular importance to enable sustainability transformations of Arctic Indigenous food systems: (i) the decolonization of research practices, (ii) acknowledging the significance of systemic interdependencies across shallow and deep leverage points, and (iii) transdisciplinary action-oriented research collaborations directing transformative system interventions.

Keywords Sustainability challenges · Transformation · Food security · Food sovereignty · Circumarctic

Handled by Erik Mathijs, Katholieke Universiteit Leuven, Belgium.

✉ Silja Zimmermann
s.zimmermann@uu.nl

1 Centre for Complex Systems Studies, Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands

2 Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands

3 Descartes Centre for the History and Philosophy of the Sciences and the Humanities, Utrecht University, Budapestlaan 6, 3584 CB Utrecht, The Netherlands

4 Aleut Community of St. Paul Island Ecosystem Conservation Office, St. Paul, Pribilof Islands, AK, USA

5 Institute of Ecology, Faculty of Sustainability and Centre of Methods, Leuphana University, Universitaetsallee 1, 21335 Lueneburg, Germany

Introduction

Arctic Indigenous food systems face a myriad of sustainability challenges (Nilsson and Evengard 2015). Unhealthy consumption of non-traditional or non-wild foods and food insecurity are widespread problems in Indigenous communities across the Arctic region (Little et al. 2021; Kenny et al. 2018; Walch et al. 2018; Odland et al. 2016; Kuhnlein et al. 2009, 2004). The challenges are manifold and entail competing demands for land, food and fuel provision, environmental degradation, loss of biodiversity, loss of culture, and power centralization in market structures (Lemke and Delormier 2017). Additionally, established structures of settler colonialism persist in many aspects of Indigenous life, hindering the attainment of a sovereign food system (Snook et al. 2020; Whyte 2016). Global trends such as accelerating climate change are placing even more challenges on the environment from which Indigenous communities derive much of their food (IPCC 2022; Panikkar and Lemmond 2020; Macdonald et al. 2003). For example, in Canada, Indigenous households experience food insecurity at a rate that is more than double that of the national average, driven by high food costs, unemployment, and low income (Council of Canadian Academies 2014). In Alaska, climate change reduces the accessibility of traditional or subsistence resources, as ice conditions on rivers, lakes, and seas become less predictable (Brinkman et al. 2016), and in Russia, high temperatures jeopardize Indigenous people's food security through forest and tundra fires on dry lichen pastures, forcing reindeer herders to change their nomadic routes and practices (Bogdanova et al. 2021).

Food systems encompass the entire range of actors and activities involved in the production, processing, distribution, and consumption of food products (Nguyen 2018). These are interlinked through feedback mechanisms and processes, creating the circumstances from which the complex challenges outlined above arise. Indigenous food systems are unique in that they are peculiarly defined through long-established socio-cultural–ecological linkages that give rise to a context-specific culture intimately tied to the local environment (Gao and Erokhin 2020). Over the last decades, there has been increasing attention on Arctic Indigenous food systems, but although some challenges faced by local communities have improved over time (Adamou et al. 2020), many issues persist.

There is growing recognition that transformative change is needed to resolve the challenges Indigenous communities across the Arctic face today (Spring et al. 2018; Blay-Palmer et al. 2014). Deep-rooted colonial influences are at the center of many of these issues, and there is recognition that Indigenous communities need to exercise sovereignty over their food systems to improve Indigenous health and well-being and adaptability to current and future challenges (Kanatami 2021; ICC-AK 2020; Whyte 2016; Nilsson and Evengard 2015).

In terms of approaches to understanding Arctic Indigenous food challenges, the value of an integrated food system approach has increasingly been recognized (Ingram 2011; Ericksen et al. 2010), whilst complexity science approaches have been shown to be well suited to capture the dynamics of socio-ecological systems (Bodin et al. 2019; Janssen et al. 2006). Additionally, transdisciplinary modes of research have been shown to take account of interlinked socio-ecological sustainability issues by bridging science and society (Sellberg et al. 2021; Brandt et al. 2013). Inclusion of Indigenous knowledge systems is crucial to reflect on prevalent colonial practices (Hill et al. 2020) and help understand complex issues as Indigenous worldviews are often more holistic in scope than Western worldviews (Reid et al. 2020; Heke et al. 2018; Martin 2012; Abgar et al. 2009). Hence, the concept of knowledge co-production is becoming best practice in the pursuit of decolonizing scientific approaches and a respectful engagement with Indigenous peoples (Yua et al. 2021; Hill et al. 2020).

In recent years, there have been efforts to evaluate to what extent scientific literature (Riechers et al. 2021; Dorninger et al. 2020) and management projects (Burgos-Ayala et al. 2020) have promoted transformative change in the context of sustainability. To do so, Donella Meadows' (1999) leverage points has been used as an analytical framework to identify levels of change ranging from shallow, superficial changes to deeper systemic changes. Meadows proposed a set of 12 places to intervene in a system with increasing order of effectiveness, to find so-called leverage points (LP) and initiate system-wide transformative change (Meadows 1999). Abson et al. (2017) then matched those LP with four system levels (parameters, feedbacks, design, intent) (Abson et al. 2017). Shallow system levels (parameters and feedback) coincide with shallow LP, and deep system levels (design and intent) mirror deep LP. The parameter level covers the relatively mechanistic characteristics policymakers typically target, such as the structure of material stocks and flows or taxes and subsidies (LP 10–12). The feedback level includes the interactions between elements that drive internal system dynamics, such as positive and negative feedback loops (LP 7–9). The design level refers to the social structures and institutions that manage those feedbacks and parameters (LP 4–6), and the intent level encompasses the underpinning values, goals, and world views of actors that shape the emergent direction to which a system is oriented (LP 1–3) (Abson et al. 2017). Inherent to this framework is the presumption that the four system levels are hierarchically nested and constraining—that is, deep system levels may inhibit changes at shallow levels (Abson et al. 2017). A leverage points perspective on sustainability has been proposed to have several key advantages (Fischer and Riechers 2019). It provides an especially suitable lens for this paper because it can help inform how different system levels interact, reinforce or constrain one another and why specific interventions may or may not enable transformations towards more sustainable states (Fischer et al. 2022).

Adopting a leverage points perspective (Abson et al. 2017; Meadows 1999), we investigate which levels of systemic depth and levers previous research on Arctic Indigenous food systems have focused on and identify promising directions for future research for the transformation of these systems. We focus on existing empirical research of Arctic Indigenous food systems with the goal of examining to what extent the available Western scientific knowledge contributes understanding of how to foster Arctic food systems transformation. We formulate four main objectives from this goal: (i) give an overview of the main methodological approaches that have been applied, (ii) explore which system levels current research targets, (iii) outline the main thematic research clusters and whether interactions among those levels are recognized, and (iv) based on our findings, provide recommendations for future research to contribute to Arctic Indigenous food systems transformation.

Methods

Data collection

Our systematic review of empirical Arctic Indigenous food systems research follows the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) framework (Moher et al. 2009). Following a scoping exercise informed by the author team's prior knowledge, search terms were arrived at that returned articles related to our research question and with a geographical and topical scope (Table 1). The search terms were combined using the Boolean operator "OR". Indigenous group names were chosen based on the Arctic Human Development Report (Einarsson et al. 2004). For the terms Arctic and subarctic, we did not use a specific definition, but included all articles that self-identified as contributing to Arctic and subarctic research. The resulting search string (Appendix A) is not case sensitive and was applied to Scopus and Web of Science databases on 11 July 2022. We took into account publications from January 1998 to December 2021 that include these terms in either their title, abstract or keywords. We consider socio-ecological research as particularly relevant in an Indigenous context. We chose January 1998 as the review start point because the socio-ecological systems research gained momentum following the publication of Berkes and Folke (1998). Our review was aimed at empirical research only, and therefore review papers, books, conference papers, and reports were excluded from the search.

The identified articles were screened for eligibility on three successive levels. First, duplicates were removed. Second, titles and abstracts were screened, and the number of eliminated records was recorded. Reasons to eliminate an article included lacking a solid link to Arctic Indigenous food systems research, lack of access to their full text, or the full text only being available in a language other than English (Appendix C). In case of uncertainty, we chose inclusion over exclusion. Third, the remaining articles were assessed based on a full-text review, and the number of excluded articles was reported, together with the motives for exclusion. The first author (SZ) and the last author (ID) of this paper first reviewed ten randomly selected articles independently and compared their results to refine the coding scheme. After resolving potential uncertainties, the first author (SZ) continued as the single reviewer. The initial search yielded 1847 eligible articles. After removing duplicates and screening titles and abstracts, 584 articles were included for full-text assessment. During the full-text assessment, another 58 articles were excluded since these did not meet one or more of the inclusion criteria (Table 1; Appendix C). Ultimately, 526 peer-reviewed scientific papers were selected for further analysis (Fig. 1).

To provide an overview of the main methodological approaches applied (objective (i)) and explore which system levels current research targets and whether interactions among those levels are recognized (objective (ii)), we first analysed the literature base with a qualitative deductive approach. The final selection of articles (Appendix D) was investigated using a qualitative coding scheme. Our coding scheme was used to identify the geographic scope, the methodological and scientific approach, the food systems dimensions, and the system levels and interventions explored in the literature (Table 2). Second, we organized the literature into

Table 1 Search terms and inclusion criteria used for the systematic literature review in Scopus and Web of Science databases

Databases	Scopus, Web of Science
Primary question	To what extent does previous research on Arctic Indigenous food systems provide knowledge across the different levels of systemic depth?
Search terms	arctic, subarctic, Indigenous, native, aboriginal, first nation, ahtna, aleuts, alutiiq, chipewyan, chukchi, deg, dena'ina, dogrib, dolgans, enets, evens, evenks, eyak, gwich'in, hän, hit'an, holikachuk, inuit, inupiat, inuvialuit, kalaallit, karelians, kaska, kets, kereks, khanty, komi, koryaks, koyukon, kuskokwim, mansi, nenets, nganasans, saami, sami, sakha, selkups, slavey, tagish, tanana, tanacross, tlingit, tutchone, yakuts, yukagirs, yupik, yup'ik, food, subsist
Inclusion criteria	Type: peer-reviewed original scientific articles Published: January 1998–December 2021 Language: English Access: access to full text Geographical scope: Arctic or subarctic scope Content: solid link to Arctic Indigenous food systems research

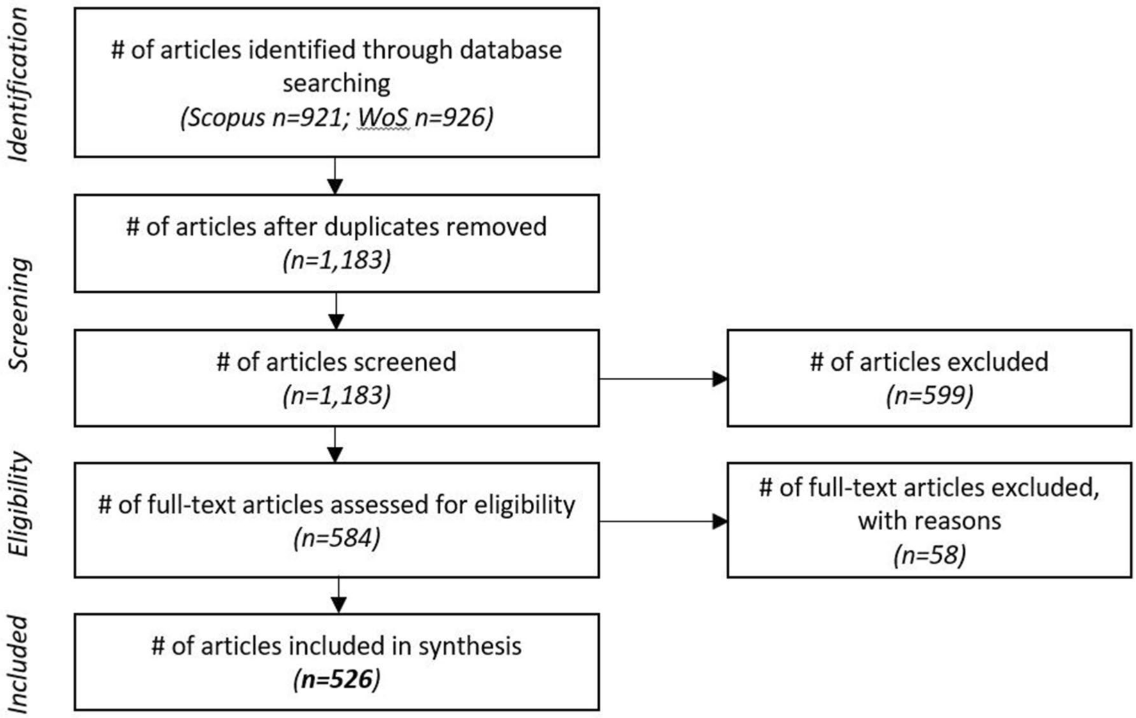

Fig. 1 The systematic review process using the PRISMA framework proposed by Moher et al. (2009)

Table 2 Twenty-six (26) variables were identified as a coding scheme from 526 selected articles on Arctic food systems, which were then grouped into six broader categories

I. *Geographic scope*	III. *Scientific approach*	*VI. Intervention*
01. Study area	10. Disciplinary approach	18. Intervention
II. *Method*	11. Problem/solution oriented	19. Leverage points
02. Datatype	IV. *Food system*	20. Interaction
03. Datatype IK	12. Food system dimension	21. Type
04. Participatory approach	13. Food security (FAO)	22. Monitoring
05. Co-design	14. Food security (ICC-AK)	23. Outcomes
06. Co-production	15. Food sovereignty	24. Temporal scale
07. Co-production dimension	V. *System level*	25. Primary executers
08. Complexity science	16. System level	26. Transformative potential
09. Complexity approach	17. Interaction	

Note, variable 17 indicates whether an article pays attention to the interactions between different levels of systemic depth, variable 20 specifically explores whether the interactions between the different levels of systemic depth are recognized in the paper

thematic clusters, applying an inductive quantitative multivariate analysis (objective (iii)). The inductive clustering approach allowed us to assess the thematic foci of the selected literature to date; the methods used in these themes; the food systems dimensions considered; and, finally, the systemic depth level of food system interventions enforced. Combining these two approaches allowed us to identify gaps in the systemic understanding of Arctic Indigenous food systems and formulate promising directions for future research (objective (iv)).

Qualitative coding scheme

Our qualitative coding scheme comprised 26 variables (denoted by numbers 01–26; Table 2) within six categories (denoted by Roman numerals; Table 2). The variables under category II were designed to inform objective (i), the variables under category V to inform objective (ii). First, we documented the geographic scope of each article. We then documented the methodological approach taken and specifically paid attention to the utilization of methods associated with complex system studies, participatory research approaches and transdisciplinary collaborations. We noted the aspects of the food system addressed and the system levels targeted. Lastly, we analysed food system interventions and their transformative potential.

The variables were either categorical, ordinal, or dummy variables. Dummy variables were coded binary (0 or 1), and ordinal variables were coded on a scale from 0 to 2. Code 0 was given if a subject was not considered, 1 if it was briefly mentioned, and 2 if it was a fundamental part of the article. Dummy variables are exhaustive and mutually exclusive (02–06, 08, 15, 17, 18, 23, 24; Table 2), whereas multiple entries are possible for categorical and ordinal variables (01, 07, 09–15, 16, 19–22, 25, 26; Table 2). For example, while a study's datatype may or may not include Indigenous knowledge (IK) (variable 03), an intervention can target multiple leverage points simultaneously (variable 20). A definition of each variable is given in the supplementary material (Appendix B). The coding scheme was applied by hand using Microsoft Excel.

Quantitative clustering approach

To characterize the existing research base across the four levels of systemic depth further, we applied an inductive quantitative multivariate analysis of the selected corpus of literature (objective (iii)). We identified dominant clusters within existing Arctic Indigenous food systems research. Of the 526 publications, five were excluded because they were unavailable in a computer-readable format, leaving 521 articles for the multivariate analysis. First, we created an initial word list comprising all unique words. Second, we removed pronouns, articles, abbreviations, and place names that we assumed indicate author affiliations, leaving us with 2955 words. Based on these words, we created a words by paper corpus, which contains all individual papers as columns and all words as lines. Thus, this table contains the information which words are written in which paper. We then used a detrended correspondence analysis (DCA) on the final word matrix to identify gradients in the vocabulary used across different publications (function decorana; library vegan). We used a DCA, since it does not create arch effects as is typical with correspondence analysis, yet is able to deal with abundance data. We then applied agglomerative hierarchical cluster analysis using Ward's method (function agnes; library cluster). Agglomerative hierarchical clustering is a bottom-up approach that builds a hierarchy of clusters (Borcard et al. 2011). We chose Ward's method, because it has a lower tendency to create steep steps that leads to more equal group sizes (Wesche and von Wehrden 2011). We used an indicator species analysis to identify suitable indicator words for the clusters designated by the cluster analysis. All analyses were carried out in R Studio (Team 2021). After the analyses, we described each cluster based on the qualitative coding scheme and a representative quote from the literature associated with the cluster. To synthesize our results, we used a Sankey diagram to illustrate the connections between the identified clusters and the variables from our qualitative coding scheme.

Results

Qualitative coding scheme

In the following, we present the results of our qualitative coding scheme. The numbers in parentheses refer to the specific variable indicated in Table 2 and Figs. 2, 3, and 4 and in brackets in this section. When one percentage value is given in parenthesis, this relates to a specified dummy or categorical variable. Two values within parentheses relate to an ordinal variable, where the first value refers to the proportion of articles in which the subject is briefly mentioned (coding scale: 1), and the second value refers to the share of articles in which the issue is a fundamental part of the article (coding scale: 2).

Of the articles considered, over half of the research on Arctic Indigenous food systems was conducted in Canada (59%), followed by the USA (18%) and Russia (12%) [01.] (Fig. 2). Few articles have a circumarctic perspective (4%) or study locations in Greenland (10%) and Fennoscandia (2%). Most articles ground their research on quantitative data (54%), some used qualitative data (26%), and even fewer studies had mixed data types (20%) [02.]. Twenty percent (20%) of the articles included IK [03.]. Within 21% of the articles, a participatory approach was taken [04.]. Considerably few studies were co-designed by researchers and local community members (9%) [05.]. Knowledge co-production across Western scientific and Indigenous belief systems was fostered in 8% of the studies and between Western scientific and other stakeholders' belief systems in 3% of all articles [06.]. However, a closer look shows that not all four dimensions of knowledge co-production (Norström et al. 2020) are equally considered. Of the studies that apply the concept of knowledge co-production, all are context based (100%), 55% explicitly recognize multiple ways of knowing and doing, 91% articulate clearly defined goals, and 86% allow for ongoing learning among actors [07.]. Seven percent (7%) of all articles use methods associated with complexity science [08.]. Thereof, most take a systems thinking perspective (73%), whereas a smaller number apply some form of network analysis (28%), socio-ecological modelling (23%) or agent-based modelling (3%) [09.].

Most articles choose disciplinary (80%) over inter- or multidisciplinary approaches (19%), and 10% of the publications are transdisciplinary [10.]. Most studies are problem

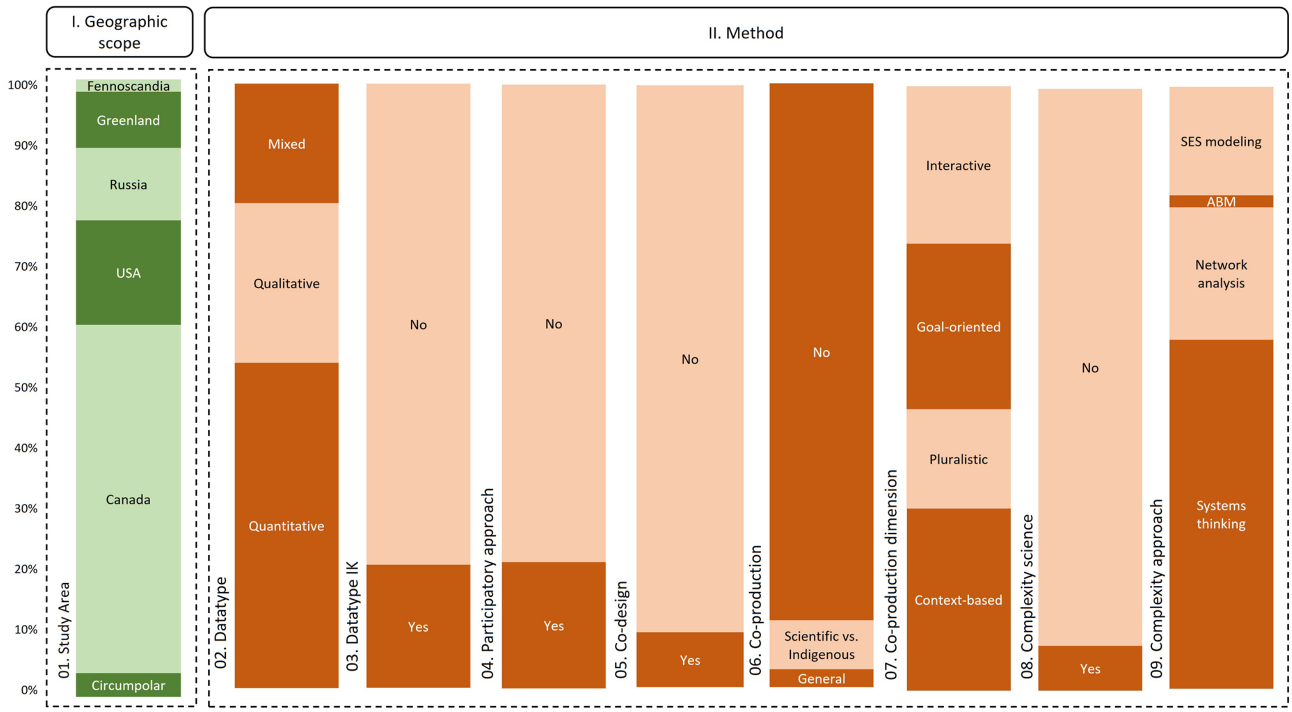

Fig. 2 Stacked bar plots show the proportions of all classes within their variable for two categories: I. Geographic scope and II. Method (see Table 2). Each variable category is indicated with the same shades of colour and within a dotted box. The stacked bar plots represent the results of all papers on Arctic Indigenous food systems on which full-text assessment was carried out ($n=526$). The stacked bar plot of variable 7 refers only to the articles that apply knowledge co-production ($n=44$), the stacked bar plot of variable 9 refers to articles that use complexity science ($n=39$)

oriented (93%) rather than solution oriented (18%) [11.] (Fig. 3).

Most articles focus on the food system's consumption (16%; 60%) or production (14%; 37%) dimensions. The processing (16%; 9%) and distribution (14%; 13%) of food are less frequently addressed in the literature [12.] (Fig. 3).

Referring to the definition of food security by the Food and Agriculture Organization (FAO) that comprises four pillars of food security (availability, accessibility, utilization, stability), most research targets the utilization pillar (15%; 63%). Food availability (19%; 24%), food accessibility (16%; 33%), and the stability of the food system (19%; 29%) are studied less [13.]. The Inuit Circumpolar Council Alaska (ICC-AK) adds two more pillars to their definition of food security: culture (28%; 18%) and decision-making power and management (13%; 12%) [14.]. The concept of food sovereignty is addressed by only a small proportion of the literature (6%; 4%) [15.] (Fig. 3).

Concerning the four levels of systemic depth by Abson et al. (2017), most studies address the parameter level of Arctic Indigenous food systems (12%; 75%). Less research aims at the system's design (12%; 28%) or intent (13%; 22%) level. Research on feedback level is scarce (10%; 10%) [16.]. Twenty-seven percent (27%) of the reviewed articles look at interactions between two or more system levels [17] (Fig. 3).

Seven percent (7%) of all reviewed articles include food system interventions [18.] (Fig. 4). Thereof, most interventions aim at the design (29%; 47%) or intent level (16%; 37%) of the food system. Fewer interventions target the parameter level (5%; 26%). No interventions had the main focus at the feedback level (3%; 0%) [19.]. An example of a food system intervention at parameter level is the provision of freezers to a community in Nunatsiavut, Canada (Organ et al. 2014). Interventions on design and intent level often involve policy changes (Couture et al. 2012) or educational approaches (Brox et al. 2003), respectively. Interactions between the targeted levels of systemic depth are studied for 29% of the interventions [20.] (Fig. 4).

Most interventions are via educational efforts (79%). Technological interventions (35%) and legislative interventions (32%) are less common [21.]. Intervention outcomes are monitored for 71% of all food system interventions [22.]. Thereof, most interventions are reported to lead to the creation of new knowledge (26%; 53%) and sometimes result in a shift of values or paradigms (16%; 16%). Other described outcomes are increased collaboration or co-management (16%; 42%), new technologies (8%; 29%), increased food security (24%; 55%), or food sovereignty (13%; 16%) [23.] (Fig. 4).

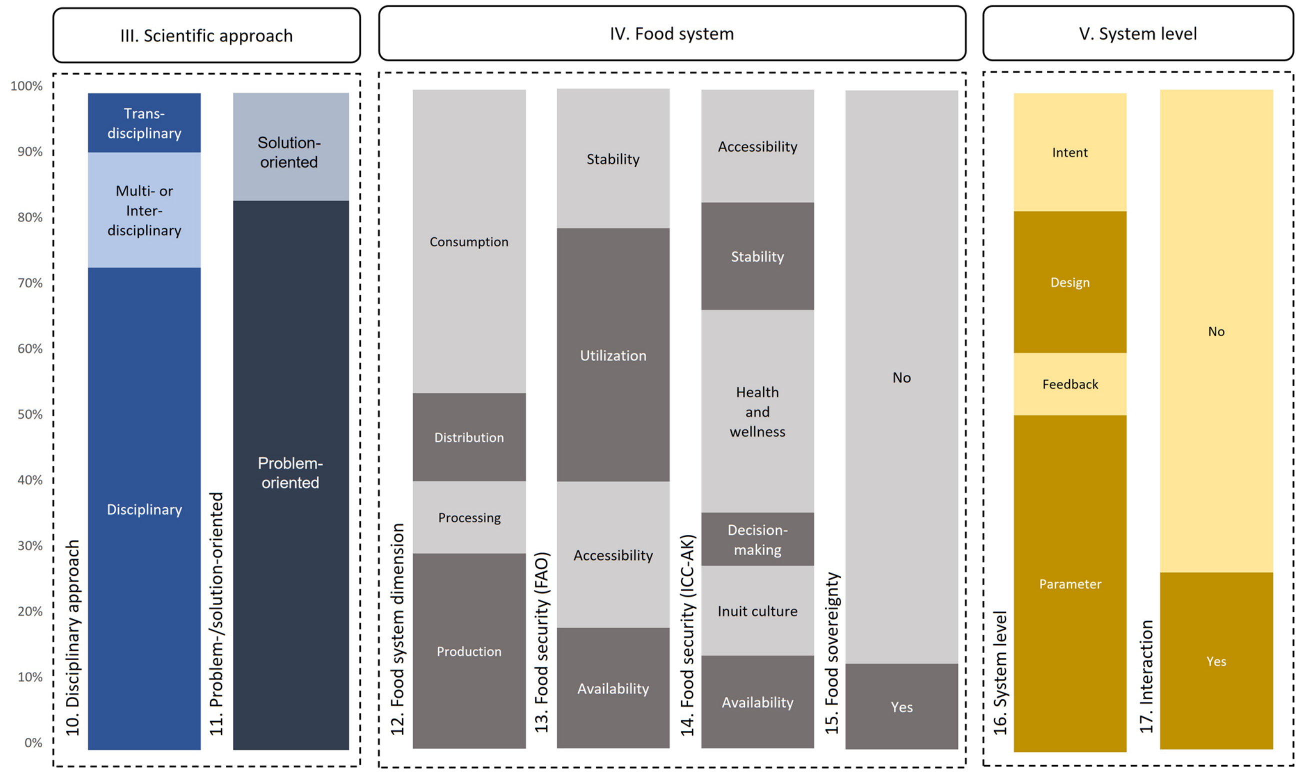

Fig. 3 Stacked bar plots show the proportions of all classes within their variable for the following categories: III. scientific approach, IV. food system, and V. system level (see Table 2). Each variable category is indicated with the same shades of colour and within a dotted box. The stacked bar plots represent the results of all papers on Arctic Indigenous food systems on which full-text assessment was carried out (*n* = 526)

Seventy-six percent (76%) of the interventions are long term as opposed to short term (24%) [24.]. Interventions are typically carried out by scientists (76%) and local communities (74%). Policymakers are the primary executors of 13% of the interventions [25.]. An intervention's transformative potential is stressed for 5% of all interventions [26.] (Fig. 4).

Quantitative clustering approach

The DCA identified clear gradients in the vocabulary used across the literature. We interpret the first ordination axis as describing a gradient from food system-centred towards health-centred articles (Fig. 5; *x*-axis). #The second ordination axis describes a gradient from a human-centred to an environment-centred focus (Fig. 5; *y*-axis). The cluster analysis identified six distinct research clusters within the literature, with an agglomerative coefficient of 0.84. Correlation coefficients indicate the explanatory power of the significant indicator words for the different clusters and are listed in the supplementary material (Appendix E). We named the clusters according to the themes identified as significant indicator words. In the following, each of the six clusters will be discussed. We start each section with a compilation of relevant quotes.

Environmental contaminants cluster (*n* = 147)

> Persistent organic pollutants […] bioaccumulate in the biota and biomagnify in the food web. The arctic populations, […], with traditional food intake […], have a relatively high POP exposure. […] Human exposure to most legacy POPs is […] decreasing in many Arctic populations, reflecting both transition from traditional to more imported westernized diet and reduced contaminant concentrations in the marine mammals. […] However, […] it is still important to investigate and report the levels and adverse effects of the POPs, due to their long half-life and persisting high concentrations in the Arctic populations (Long et al. 2021, p. 2).

Publications in this cluster highlight the contamination of Arctic environments and traditional food sources. Empirical research typically addresses food chain bioaccumulation of contaminants in tissues of Arctic marine mammals (Bolton et al. 2020; Lockhart et al. 2005) or blood contaminant levels

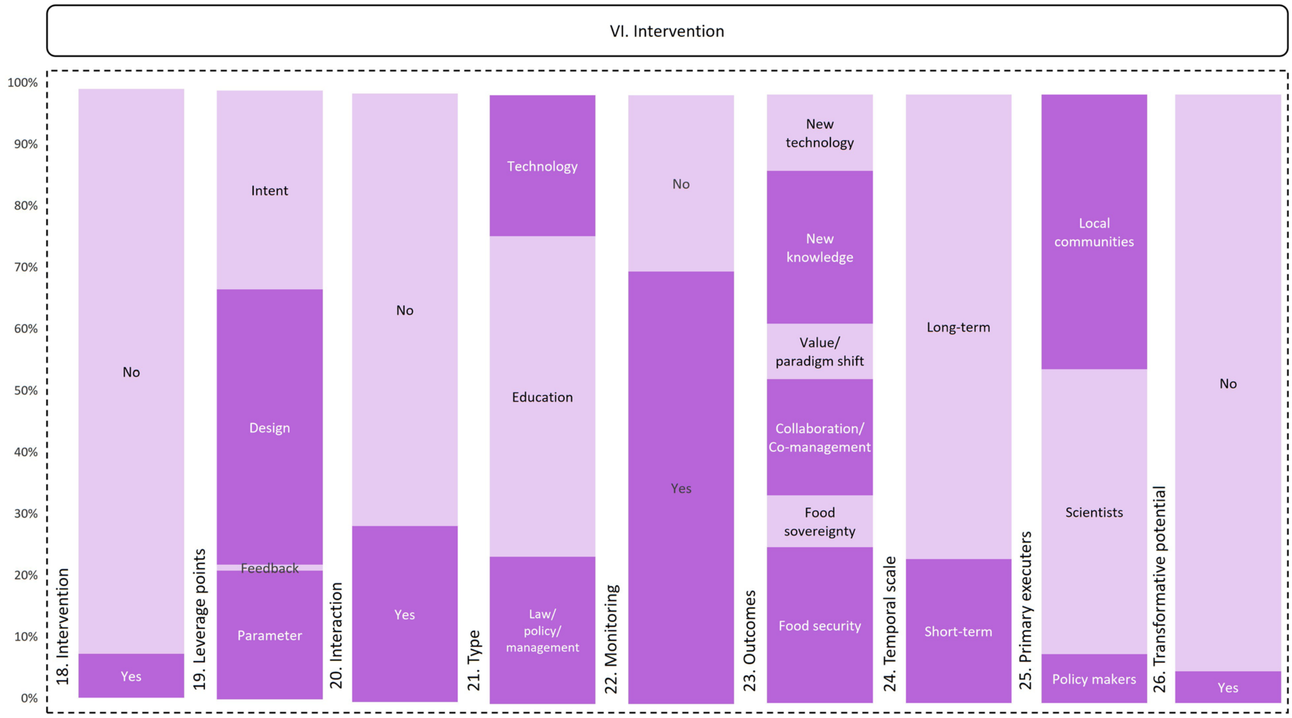

Fig. 4 Stacked bar plots show the proportions of all classes within their variable for category VI. Intervention (see Table 2). The variable category is indicated with the same shade of colour and within a dotted box. The stacked bar plot for variable 18 represents the results of all papers on Arctic Indigenous food systems on which full-text assessment was carried out ($n=526$). The stacked bar plots for variables 19–26 refer only to the articles on Arctic Indigenous food systems that included food system interventions ($n=38$)

of Indigenous Peoples (Adamou et al. 2020; Dudarev et al. 2004). Health effects associated with the consumption of contaminated foods are discussed (Bank-Nielsen et al. 2019; Dallaire et al. 2013). The literature reflects the general agreement that contaminants were especially problematic in past decades. Since environmental inputs of pollutants are more strictly regulated, respective indicators in Arctic populations show decreasing trends too. However, due to long half-lives, bioaccumulation and long-range atmospheric transport, contaminants remain a concern in the Arctic. In this context, achievements and shortcomings of the Stockholm convention on persistent organic pollutants (POPs) are also discussed (Sorokina 2019). Decreasing trends of contaminants in Indigenous peoples' blood levels also indicate a dietary transition from traditional to highly-processed store-bought foods (Binnington et al. 2016a, b; Quinn et al. 2012), associated with cultural loss and additional health risks (Binnington et al. 2016a, b). A smaller body of research on the accumulation of radionuclides (Skuterud and Thorring 2015; Bossew et al. 2000) and other pollutants in caribou (Garry et al. 2018) is also situated in this cluster.

Methodological approaches in this domain are typically quantitative (97%) and often include the sampling of faunal tissues to examine the consumption dimension (7%; 93%) of the food system. Parts of the literature also look at how food processing affects contamination levels (Chan et al. 2001). Regarding food security, most research concentrates on the pillars of utilization (5%; 95%) and health and wellness (5%; 95%), respectively. However, some articles focus on stability (7%; 18%), investigating temporal trends of environmental contaminants (Long et al. 2021; Lockhart et al. 2005). Studies aim explicitly at the parameter level of the food system (1%; 99%). Interactions between system levels are seldom investigated (8%). The literature associated with this cluster includes four food system interventions, of which three target the parameter and design levels and one the intent level of the food system. The interventions on parameter and design level include a ban on the use of lead ammunition (Couture et al. 2012). The intervention on intent level is advice on dietary habits and lifestyle given to 7th graders in a community in northern Norway (Brox et al. 2003).

Diet and health cluster ($n=89$)

> Consumption of traditional foods is associated with better diet quality and dietary adequacy […]. Efforts should be made to promote good nutrition […] through encouraging the use of traditional foods; however, harvesting adequate amounts of these foods may not be feasible for many families. Therefore, […] appropri-

Fig. 5 Ordination scales resulting from a detrended correspondence analysis (DCA) with most significant indicator words of six Ward's research clusters. Each of the six clusters has a different colour. Unreadable overlapping words were slightly shifted to enable readability. More significant indicator words are listed in Appendix E

ate strategies are needed to also promote the use of non-traditional foods that are affordable and of high-nutritional quality" (Sheehy et al. 2015, p. 450).

Research in the diet and health cluster predominantly addresses Arctic Indigenous diets and associated health effects. Empirical studies often evaluate dietary adequacy by monitoring dietary patterns (Sheehy et al. 2015; Kuhnlein et al. 2008) or assessing nutrient intakes (Sharma et al. 2013). Different socio-economic (Erber et al. 2010; Hopping et al. 2010; Mead et al. 2010) and lifestyle factors (Petrenya et al. 2019; Kolahdooz et al. 2013) as dietary indicators are evaluated. Further, the transition from nutrient-rich traditional to nutrient-poor imported foods observed across many communities is discussed (Sheehy et al. 2013; Egeland et al. 2011; Sharma et al. 2009). Though this dietary transition is often described to mitigate contaminant exposure, the cultural benefits of traditional foods are understood to outweigh its risks.

Existing research in this domain is primarily disciplinary (97%) and uses quantitative approaches (76%), such as clinical examinations and food consumption frequency recordings. Twenty percent (20%) of the research situated in this cluster takes mixed approaches. Studies show a strong focus on the consumption dimension (4%; 96%) of the food system, directed towards aspects of physical health. Most research targets the parameter level (2%; 93%) of the food system. Interlinkages between different system levels are rarely explored (9%). Nine of the articles associated with this cluster address food system interventions, most of which were initiated by the Healthy Foods North (HFN) program. The HFN programme aims to increase healthy dietary habits and physical activity in Canadian First Nation communities and targets the design and intent level of the food system through educational efforts and multi-institutional partnerships (Pakseresht et al. 2015; Mead et al. 2013; Sharma et al. 2010).

Food security cluster (*n* = 71)

> The cost of food in remote, predominantly Indigenous, communities of northern Canada is extremely high. […] For several decades, Inuit have indicated that they cannot afford to purchase sufficient food to meet their family's needs. This is reflected in the very high rates of food insecurity, and the extreme disparity […] in food secu-

rity status among Inuit, relative to the general Canadian population […] (Kenny et al. 2018, p. 39).

The Food security cluster represents literature on both problems and solutions regarding the food security of Arctic Indigenous communities. Of particular focus are the role public health policies (Fournier et al. 2019a, b; Suk et al. 2004), food programmes (Galloway 2017; Ford et al. 2013, 2012; Lardeau et al. 2011) and the food environment more generally, play in affecting accessibility and availability of healthy food (Fournier et al. 2019a, b; Watson et al. 2018). Many studies also address contaminants and associated food safety concerns. Yet, unlike the two previous clusters, the focus is not solely on individual parameters but also the design (Fillion et al. 2014; Suk et al. 2004) and the intent (Tyrrell 2006; Poirier and Brooke 2000) level of the food system. Therein, the role of media communication in the local perception of health risks is investigated (Boyd et al. 2019; Krummel and Gilman 2016). Moreover, not only physical but also mental and spiritual health aspects regarding the food safety concerns of Arctic communities are addressed (Bordeleau et al. 2016; Pufall et al. 2011).

In terms of methodological approaches, qualitative (45%), quantitative (27%), and mixed (28%) approaches are used in this cluster. Participatory approaches are used by almost half of the studies (48%) and about a third of the article methods include IK (31%). Although the majority of the studies situated in this cluster remains disciplinary (65%), multi- and interdisciplinary (35%) and transdisciplinary (21%) approaches can also be found. What is particularly distinctive for this cluster is that research on all pillars of food security is present. Therein, most research again focuses on the consumption dimension (18%; 72%) of the food system, however, other dimensions, such as food production aspects (23%; 48%), are also captured. Furthermore, articles do not only inspect the parameter level of the food system (25%; 59%), but also the design (20%; 50%) and intent levels (24%; 34%). Interactions across system levels are considered in 35% of the literature in this cluster and most often between the design and parameter level. For example, one study investigates the biophysical impact of a Euro-Canadian agrarian initiative on the food system of Fort Albany First Nation by comparing soil properties between a cultivated area and an undisturbed forest area (Spiegelaar and Tsuji 2013). Thirteen papers include interventions to the food system, most of which aim at deep system levels to improve food security through, for example, a community-driven toolkit for decision-makers that reflects shared values about healthy eating (Fournier et al. 2019a, b).

Food culture and economy cluster (*n* = 74)

Expressions of longing […] for "a taste of fish" are more than the desires of the stomach; they express also desires of and for the social. When a mother gingerly guides her daughter's hands as she teaches her to cut salmon, quietly acknowledging that now she knows how her own mother felt, and when a father takes his sons fishing, they each cultivate among their children relationships with living relations and ancestors, and with humans and salmon, that are paramount to a way of life (Voinot-Baron 2020, p. 6).

The food culture and economy cluster concentrates on the effects of globalization and development on local economies, and food cultures are frequently researched in this group (Wu 2020; Parshukov et al. 2018; Dinero 2007). In particular, this is illustrated by the example of food sharing networks along kinship lines (Ready 2018; Ready and Power 2018; Collings et al. 2016). Indigenous ways of knowing and doing are discussed in the context of community adaptation and resilience towards socio-economic change. Human migration as a response to change is also addressed (Berman 2021, 2009). Additionally, research on terrestrial subsistence practices, such as reindeer herding (Terekhina et al. 2021; Atkinson 2020) or the use of plants by Indigenous peoples (Norton et al. 2021; Whitecloud and Grenoble 2014; Black et al. 2008), is located in this cluster. Therein, Indigenous values towards traditional foods and subsistence practices are highlighted (Green et al. 2019). Overall, great emphasis is placed upon IK and its potential to help communities cope with change is recognized (Ziker et al. 2015; Takakura 2012).

Methodological approaches in this cluster are primarily qualitative (49%) or mixed (34%) and often include ethnographical fieldwork, interviews, and Indigenous methodologies such as storytelling. Quantitative complexity approaches, such as network analysis, are used to explore food sharing networks. The literature comprises disciplinary (59%), often anthropological studies, multi- and interdisciplinary work (39%), and some transdisciplinary approaches (9%). Research in this domain typically focuses on the production (19%; 47%) and distribution (16%; 26%) dimensions of the food system. Therein, risks of losing knowledge and skills around the production of traditional foods and food distribution through sharing practices are addressed. Moreover, cultural values and skills around traditional foods and subsistence practices are discussed in light of Indigenous food security.

Research in the food culture and economy cluster is evenly distributed across the parameter (15%; 54%), design (23%; 53%) and intent (24%; 51%) levels of the food system. Literature that addresses the food system's feedback level (16%; 23%) corresponds to the part that uses complexity science approaches and reports on food sharing networks. Almost half of the studies inspect interactions between different system levels (49%). As such, this cluster second most often addresses the feedback level and interactions between the different system levels (Berman et al. 2004; Kruse et al. 2004). Moreover, this cluster includes four food system interventions targeting the design and intent level of the food system, including a cross-cultural plant workshop and a filmmaking project to capture Indigenous values in subsistence harvesting (Atkinson 2020; Green et al. 2019; Cuerrier et al. 2012).

Changing socio-ecological systems (SES) cluster (*n* = 86)

> While climate-driven challenges for Arctic social-ecological systems are not new—across the circumpolar Arctic, survival has always demanded an ability to cope with high-risk, unpredictable resources and environmental change—they generate fundamental questions about how best to design future-oriented management, planning and mitigation efforts (Desjardins et al. 2020, p. 246).

Research in this cluster shares an interest in climate and environmental change within Indigenous food systems and understands them as socio-ecological systems. Moreover, a strong focus on vulnerability, resilience and adaptation within the changing Arctic is reflected by the vocabulary used in this domain (Naylor et al. 2021; Pearce et al. 2010; Ford et al. 2009; Berkes and Jolly 2002). Climate-driven challenges have always characterized Indigenous life in the Arctic (Desjardins et al. 2020). Most communities have learned to adapt and proven the ability to cope with such changes (Fawcett et al. 2018), yet, accelerating climate change (Hauser et al. 2021) and increasingly multifaceted and interwoven issues (Ready and Collings 2020) create a yet unknown level of uncertainty. Research, therefore, investigates how IK can inform monitoring and co-management efforts to cope with these challenges in the future (Ostertag et al. 2018; Herrmann et al. 2012; Parlee et al. 2005).

Many studies take qualitative (62%) or mixed (30%) approaches and consider IK (47%). Few studies have a quantitative database (8%). Participatory approaches are common (33%), and 20% of the studies follow knowledge co-production practices. Where methods from the complexity sciences are used (22%), those are primarily systems thinking or socio-ecological modelling, e.g. in the context of adaptation and community resilience (Fauchald et al. 2017; Brinkman et al. 2016). Most articles represent disciplinary research approaches (63%), yet, multi- or interdisciplinary work (37%) can also be found in this cluster. As indicated by the share of research that includes IK and participatory practices such as knowledge co-production, transdisciplinary research (16%) is also situated in this group.

Research on the food production dimension is at the core of this cluster (8%; 74%). In this context, we perceive a strong ambition towards food availability and accessibility, acknowledging its importance for the food security of Arctic Indigenous communities in the literature (Brinkman et al. 2016). The stability of these pillars is discussed against the background of climate-induced environmental changes.

Research in this cluster is balanced across the system levels parameter (28%; 51%), design (14%; 59%) and intent (23%; 49%). Additionally, research targeting feedbacks (21%; 23%) within Arctic Indigenous food systems is best addressed in this cluster. The same applies to interactions between different system levels (51%), as a systems perspective on Arctic Indigenous food systems encourages recognizing interactions and dependencies across system levels (Parlee et al. 2018; Brinkman et al. 2016).

The literature further comprises five interventions aiming at deep leverage points. Among those interventions are a co-produced video to document IK of climate change and explore potential contributions of IK to climate change research (Berkes and Jolly 2002) and a GIS-based GeoPortal that combines manually entered observations with base maps (Herrmann et al. 2012).

Marine and coast cluster (*n* = 54)

> Changes in sea ice affect hunters directly by changing access and altering the utility of ice as a substrate for hunting, (and) […] indirectly by altering the distribution, timing, behaviour and local abundance of marine mammals. These effects do not occur in isolation, but as a suite of factors that combine to alter hunting behaviour and success (Huntington et al. 2016, p. 3).

The marine and coast cluster shows a clear focus on marine and coastal elements of Arctic Indigenous food systems. Empirical research addresses different aspects of subsistence practices within the marine environments in, predominantly, North America. Traditional foods in focus include marine mammals (Regehr et al. 2021; Ashjian et al. 2010), anadromous fish species (Steiner et al. 2019; Fechhelm et al. 2007), and seabirds (Lovvorn et al. 2018). The literature in this cluster also pays special attention to the role of ice and snow in marine-centred Arctic Indigenous food systems (Callaghan et al. 2012; Beck et al. 2010). Also situated in this cluster is research on foodsheds or ice cellars and their architectural features (Maslakov et al. 2020; Gerlach and Loring 2013).

Research associated with this cluster is primarily disciplinary (80%). Most databases are quantitative (56%), yet qualitative (22%) and mixed methods approaches (22%) also exist. Some articles in this cluster include IK in their database (30%) or use participatory approaches (20%). Only three studies used complexity approaches. This cluster's two most important characteristics are its focus on the wider marine environment and the regional focus on North America. However, the correlation coefficients indicating the significant words for this group are the lowest among all clusters, meaning an overall weaker explanatory power (Appendix E).

Furthermore, there is a strong focus on the production dimension (20%; 57%) of the food system. However, there is no clear focus on one of the food security pillars. Most research targets the parameter level (17%; 72%) of the food system, followed by the design (13%; 20%) and feedback (13%; 15%) levels. The intent level (6%; 11%) is barely addressed. 26% of the articles also look at interactions between different system levels (Steiner et al. 2019; John et al. 2004). Finally, the cluster contains three articles that include food system interventions as climate change adaptations. Specifically, they merge Indigenous knowledge with modern technology to improve ice cellar performance, assess the communities' vulnerability to food security problems and provide ice trail maps to a community in Barrow, Alaska (now: Utqiagvik) (Druckenmiller et al. 2013; Brubaker et al. 2011a, b; Brubaker et al. 2011a, b).

Synthesis results

The Sankey diagram (Fig. 6) shows that most research focuses on the production and consumption dimensions of Arctic Indigenous food systems and that the vast majority of research targets biophysical health and nutrition aspects of Indigenous food security in the Arctic.

Most clusters were characterized by a focus on the parameter level of Arctic Indigenous food systems. For example, the clusters environmental contaminants and diet and health almost exclusively focus on food system parameters. Research on parameter level then mainly addresses the consumption dimension of the food system, which is primarily associated with research regarding the health and wellness food security pillar. The design level is addressed second most often, followed by the intent and feedback levels. Especially, the clusters changing socio-ecological systems, food culture and economy, and food security contribute to the understanding at the design level. The highest share of research efforts that target the intent level of the food system is situated in the cluster food culture and economy. The research assigned to the clusters food culture and economy and changing socio-ecological systems considers all four system levels in the most balanced way. Moreover, those two clusters contain the largest share of research at

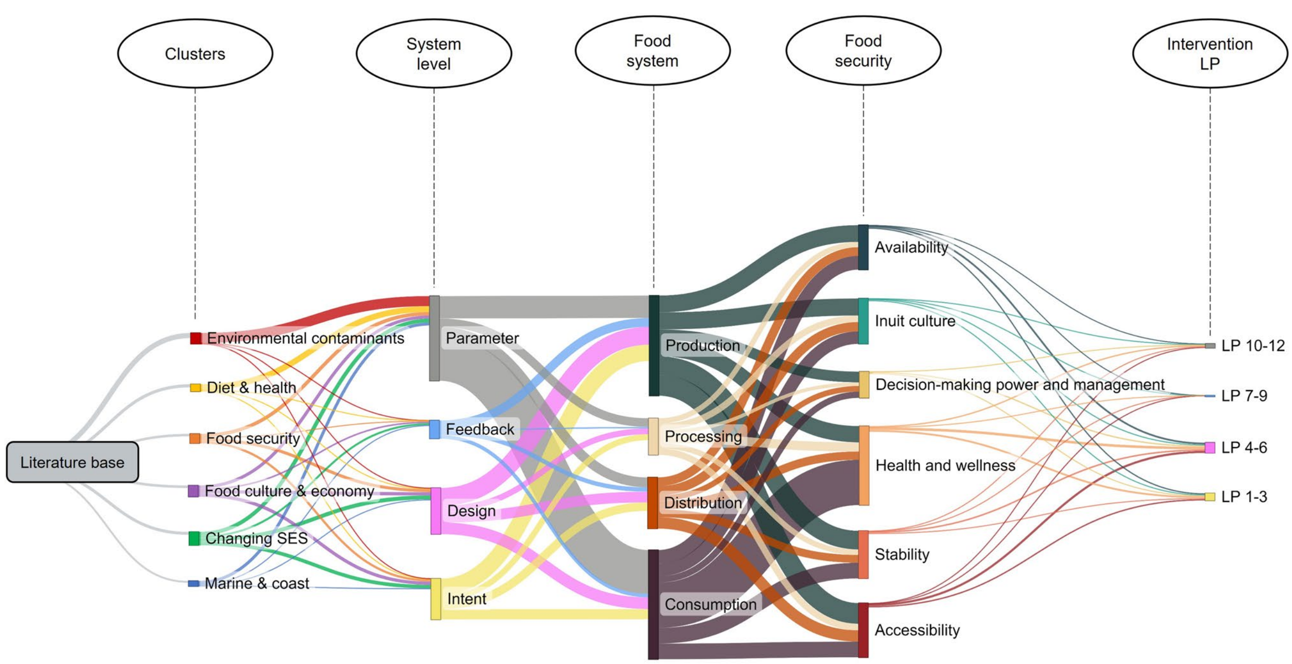

Fig. 6 Sankey diagram showing connections between clusters from the clustering approach and the variables from the qualitative coding scheme. Due to multiple possible categories for most variables and the coding scale ranging from 0 to 2, there is an imbalance in in- and outflows for most variable categories. The coding scale for ordinal variables (ranging from 0 to 2) was accounted for in the calculation of the variable flows. The categories under the food security variable refer to the definition of food security by the Inuit Circumpolar Council. The leverage points addressed by the interventions correspond to their according system level illustrated with the same colour in the system level variable

the feedback level. While most research addresses the very shallow parameter level, most food system interventions are typically directed at deep leverage points.

Discussion

Over the past decades, research on Arctic Indigenous food systems has provided a remarkable expansion and diversification of knowledge. Arctic Indigenous food systems have continuously received more attention, as evidenced by increased publication rates since 1998 (Appendix F). New scientific knowledge has been created, especially on specific food system parameters, such as contaminant levels in traditional foods or related health indicators across Indigenous communities. Additionally, awareness of the value of Indigenous knowledge, in itself and alongside Western scientific knowledge, has grown in recent years (Wheeler et al. 2020; Ford et al. 2016a, b; Ford et al. 2016a, b). Nonetheless, based on our analysis, we identify three important gaps in the current knowledge base that may hinder transformative change. From these gaps, we identify directions for future research that we believe can bring the scientific community closer to having the requisite knowledge to foster system-wide transformations towards sustainability.

Knowledge gaps across the existing literature base

The first gap we identify in the current knowledge base is that most research is conducted *about* rather than *within* Arctic Indigenous food systems. Approximately, one-fifth of all articles in this review included IK (Fig. 2, [03.]) or participatory approaches (Fig. 2, [04.]), and few studies used knowledge co-production approaches (Fig. 2, [06.]). Some studies intended to be participatory, but a uniform definition of what that implies does not exist to date. Thus, there is a risk of creating a research environment where predominantly Western scientific concepts are applied to Arctic Indigenous food systems that may be inapplicable to local contexts. Like the FAO definition of food security (Nguyen 2018), such concepts often fail to grasp aspects relevant to Arctic Indigenous realities. The definition of food security by the ICC-AK provides an excellent example of a co-created formalization that captures food security indicators relevant to Arctic Indigenous people (ICC-AK 2015). However, our review showed that such concepts are underrepresented in existing research despite their relevance (Fig. 3, [14.], [15.]). Research on Arctic systems has tended to overlook issues that are of particular importance from Indigenous perspectives. This was evident across the reviewed contaminants literature, in which most studies conclude by recommending safe consumption guidelines to Indigenous communities instead of appealing to the sources of pollution. Other examples are standard surveys to estimate food insecurity, which have proven unsuitable for mixed economies, as they typically focus on monetary food access but neglect the non-monetary exchange of food items and sharing within Indigenous communities (Teh et al. 2017).

Second, we found that past scientific studies have tended to focus on components of Arctic Indigenous food systems in isolation, thereby neglecting to address systemic root causes of complex sustainability challenges and the relevance of interlinkages across system levels (Fig. 3, [17.]; Fig. 6). Although the value of such research approaches for understanding specific system parameters is beyond question, we also need to acknowledge the urgency to understand sustainability challenges across all system levels and recognize the deep systemic origins of many food system issues in the Arctic. Food system challenges might originate from the mindset or paradigm underlying the system or the institutions that structure it. Consequently, the actions to resolve these challenges are also constrained by such (Abson et al. 2017; Ready 2016). Food security in the Arctic, for example, is deeply rooted in structural injustices compromising the rights of Indigenous communities to access food resources or control other processes leading to food security (Nilsson and Evengard 2015). Our review identified most knowledge gaps on the systems feedback level (Fig. 3, [16.]). This observation has already been made for the case of marine pollution, where it has been found that pollution is primarily studied as a technical problem rather than a systemic socio-ecological issue (Riechers et al. 2021). Filling these gaps is urgent as many Arctic food system challenges increase in complexity and develop to span different social and ecological subsystems (Stephen 2018). Doing so presents a challenge as feedbacks in complex systems emerge due to the system's structure and are difficult to address directly (Larrosa et al. 2016; Rotmans and Loorbach 2009).

Third, while the number of multi-, inter-, and transdisciplinary research projects has increased over the last decades, most research has to date been disciplinary (Appendix F; Fig. 3, [10.]). In-depth, disciplinary research is indispensable for a fundamental system understanding. Yet, in a complex system's context, it can lead to complex interrelationships not being recognized, a risk well illustrated by the distance between some of the thematic research clusters identified through our quantitative analysis (Fig. 5). For example, the clusters environmental contaminants and diet and health focused on shallow levels of systemic depth. They were distinctively separated from other clusters. This showed a lack of recognition of how environmental change, for example, might be linked to food contaminants and highlights a lack of interdisciplinary work on understanding such system interdependencies. Equally, the fundamental systemic causes of the sustainability challenges addressed in these clusters may be overlooked.

Promising directions for future research

From formulating these three knowledge gaps across the existing literature base, we continue by identifyg three directions for future research that we believe to be of particular importance to enable effective sustainability transformations. In doing so, we hope to inspire the future research agenda in Arctic Indigenous food system research to create new contextual knowledge and work towards transformative change.

Decolonization of research practices

Inclusive approaches that bridge Western and Indigenous knowledge systems continue to be underrepresented in Arctic Indigenous food system research (Fig. 2, [03.], [04.], [05.], [06.]). The need for plurality in understanding sustainability transformations through the active engagement of IK holders in research processes has recently been formulated (Lam et al. 2020). We extend this call for research on Arctic Indigenous food systems and encourage future scholars to reflect on their research approaches, strive for a plurality of knowledge and actively contribute to the decolonization of research practices. Existing abstractions are not necessarily applicable to Indigenous contexts in the Arctic, but Indigenous counterparts exist for many Western concepts (ICC-AK 2015). Actively engaging Indigenous voices throughout research processes will facilitate the recognition of multiple knowledge systems and inform scientific practices to help them become sensitive to the needs and desires of marginalized groups and non-human actants. Following the principles of knowledge co-production can help to systematically reflect on power positions and sources of inequity (Norström et al. 2020). Thereby, co-created research processes can support decolonization and initiate actions relevant to Indigenous communities to leverage their ability to influence transformational change.

Acknowledging systemic interdependencies

Arctic Indigenous food systems are often tightly linked, complex and adaptive socio-ecological systems (Naylor et al. 2021, 2020; Stephen 2018) characterized by feedbacks across multiple interlinked scales that amplify or dampen change (Fischer et al. 2022). At times of increasingly pressing sustainability challenges, we see immense potential in recognizing interactions between shallow and deep system levels. The resilience of socio-ecological systems is contingent upon the combination of changes on different system levels, as shown, for instance, for interactions between ecological and governance changes in a fisheries-dependent Sami community in the Norwegian Arctic (Broderstad and Eythórsson 2014). A promising direction for future research is to specifically address such interconnections to understand constraining behaviour between system levels and find effective leverage points in these compound systems. Complexity approaches hold considerable potential to address such complex interdependencies (Sayles et al. 2019), but they are not widely used (Fig. 2, [08.]). For example, network analysis of subsistence food flows has proven suitable to represent interdependencies between ecological and social system properties in Alaskan Indigenous communities facing economic and environmental changes (Baggio et al. 2016). Another study has shown agent-based computational models (ABMs) as appropriate to generate projections of how economic and climatic changes might affect resource harvests and well-being in an Arctic Canadian community (Berman et al. 2004). We strongly believe that future research projects that utilize complexity science methods to understand complex interactions within Indigenous socio-ecological systems offer a valuable addition to the existing literature.

Inter- and transdisciplinary action-oriented research collaborations

The sustainability challenges of Arctic Indigenous food systems demand integrated knowledge rooted in an interactive research mode that unites science and society to jointly approximate solutions. Our analysis has identified six research clusters, of which some are visibly separated from each other (Fig. 5). The health-centred literature on environmental contaminants and diet and health is detached from other, more food system-centred literature. The human-centred food security cluster is disconnected from environment-centred literature. We encourage interdisciplinary attempts to bridge the gaps between these groups to achieve a holistic system understanding. Moreover, we emphasize the need to focus on action-oriented research collaborations and advance a transdisciplinary research agenda for the Arctic region. Our review of existing literature shows high leverage to plan and implement the food system interventions needed for transformative change where Indigenous and Western scientific knowledge is brought together in inter- and transdisciplinary action-oriented settings. Examples are the development of a locally-driven tool kit for non-Indigenous researchers and practitioners to support healthy food environments in a Canadian Arctic community (Fournier et al. 2019a, b) or a film project that communicates Indigenous values in subsistence harvesting to practitioners in research management (Green et al. 2019). There is immense potential in such partnerships that aim at effective system interventions to leverage real-world change (Abgar et al. 2009). Collaborations between the research clusters that also integrate IK may help to inform traditional research approaches to embrace complexity and interrelatedness. Complex system studies can provide a common language and a way of thinking that facilitates inter- and transdisciplinary collaboration (Berkes and Berkes 2009). We believe complexity sciences' integrative nature offers a potentially fruitful platform for transdisciplinary partnership in an Indigenous context. Specifically, co-produced complex approaches provide promising prospects to foster just and sustainable transitions within Arctic Indigenous food systems.

Limitations

In this review, we focus on contemporary Arctic Indigenous food systems and exclude articles that address historical system states. An important future research endeavour is to account for the histories of these complex systems to uncover deeper characteristics from which the system emerged and understand their temporal dynamics. We also want to stress that we did not consider grey literature, review papers, books, conference papers and reports, yet information, including documented IK, on effective food system interventions (Fig. 4), certainly exists outside of peer-reviewed articles. Also, we focused exclusively on the Western scientific literature base that appeared in the conventional literature databases (Scopus and Web of Science) and not on Indigenous literature. Additionally, many of the studies considered in this review were published before the onset of current debates about the decolonization of research practices or participatory science. The findings presented here are not to be understood as a critique of past research projects but rather as recommendations for future research endeavours. Furthermore, as we are seeking to contribute to effective transformations in Arctic Indigenous food systems with our research, but confine our recommendations to leverage points that could be actioned by research, a brief reflection on the relationship between science and society is needed here. We are aware that we identified scientific knowledge gaps and recognize the limitations to how the academic community can contribute to societal change. We acknowledge that to enable true leverage we must go beyond the mere co-production of knowledge, but re-structure institutions and include other stakeholders (Abson et al. 2017).

Conclusions

Arctic Indigenous peoples are increasingly facing complex sustainability challenges to their food systems. To contribute to the effective resolution of such challenges and ultimately the transformation of these socio-ecological systems towards sustainability, we set out to review the existing literature about Arctic Indigenous food systems. Using the leverage points framework, we characterized current knowledge across the four levels of systemic depth to assess to what extent the scientific community has the necessary system knowledge to foster transformative change in Arctic Indigenous food systems. Based on our findings from the combination of a deductive qualitative with an inductive quantitative approach, we have outlined the strengths and weaknesses of recent research, its foci and approaches. We formulated three knowledge gaps within the existing research base that need to be addressed to enable Arctic food systems to transform to a more sustainable state. Based on these gaps, we propose promising directions for future research that we believe hold the potential to develop the new contextual knowledge needed to work towards transformative change. We propose future research inquiries to reflect on traditional scientific approaches and actively contribute to the decolonization of research practices. We further emphasize the significance of interlinkages between shallow and deep leverage points as essential to meet increasingly complex sustainability challenges and encourage inter- and transdisciplinary research collaborations in action-oriented settings. We specifically suggest co-produced complexity approaches as promising to leverage just and sustainable transitions within Arctic Indigenous food systems.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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