Carrying Capacity Surveillance: Indicators and Frameworks for Equitable Sustainability

Lars Hallstrom, Stacey Haugen, Payton Grant,

Timi Emiloju

Authors

Lars K. Hallstrom, PhD – Professor of Political Science at the University of Lethbridge and Director of the Prentice Institute for Global Population and Economy
Stacey Haugen, BA, MA – Project Manager for the Prentice Institute for Global Population and Economy
Payton Grant – Research Assistant for the Prentice Institute for Global Population and Economy
Timi Emiloju – Research Assistant for the Prentice Institute for Global Population and Economy

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Background: Growing awareness of human-driven environmental impacts, population growth, and socio-economic inequities have led to increased engagement with the concept and measurement of the Earth's carrying capacity. The persistence of substantial inequities between populations, places, and environments, and awareness of the implications of population growth has corresponded to unprecedented collection and access to (usually digital) data across all three traditional dimensions of carrying capacity: physical-ecological, socio-demographic, and political-economic (Coccossis 2001). As the intersections between population-growth, economically-driven resource development, environmental decline and health have been increasingly acknowledged (Hancock 2011; Parkes et al 2019), such data must also increasingly factor in these relationships as components of a larger whole or system (the integration imperative – see for example Hallstrom et al. 2016, Gilingham et al. 2016). This system has numerous and significant positive and negative feedback loops, and the subsequent realization that the relationship of human actions and ecological systems to carrying capacity is not simply one of measurement. Rather, that relationship speaks to critical social questions of equity, equality and public policy-making at local, regional, national and international scales (Gibson et al 2005).

Objectives: The objective of this project was to assess the state of knowledge and usage of integrated carrying capacity measurement approaches primarily within Canada, but also globally, with a particular emphasis upon the linkages between ecological change, socioeconomic, demographic and health impacts. This included an articulation of the strengths and gaps in the carrying capacity assessment and frameworks literatures, and the identification of better practices in support of improved data, measurement, the state, scope and biases of how carrying capacity is measured, and policy uptake and performance at local, regional and provincial levels in Canada.

Methodology: Utilizing a scoping review method, this project examined the academic, grey and policy literatures to understand what is being measured, and how, in order to better understand the operationalization of metrics that inform carrying capacity. This project synthesized not only the scope and methods of such initiatives, but in particular sought to connect that evidence to questions of how, and why, those assessment frameworks might support: (a) evidence-informed policy and decisions; and (b) performance change within public policy itself. As a result, particular emphasis is placed upon frameworks that draw from data based at the intersection of: social/community-based indicators; ecological change; and population and public health changes.

Results: The scoping review uncovered two bodies of literature: one of applied examples of integrated carrying capacity frameworks, in which the relationships between population, consumption, and limits to growth were assessed through differing methods, and a second on theoretical and methodological approaches to integration. Ecologically related themes, issues, and data were the most common across the literature, regardless of type, scale or scope, while socio-demographic and economic themes were rarely included. Despite widespread conceptual support for improved integrated indicators the literature, methods or theories of integration were relatively weak on substantive, practice-based approaches to integration. While the theoretical

literature contends that improved integration between social, economic and environmental goals is needed within government policy-making in the Anthropocene (the population and consumption "footprint"), there is little uptake by government leaders or policy-making. Overall the literature reflects a broad lack of knowledge concerning general or population/national-level carrying capacity (as the literature tends to focus on specific human or non-human populations in defined environments or locations), a lack of uniform and consistent indicator measurement and data collection (while many indicators are being measured across Canada and the globe, there is a lack of uniformity between the indicators being used), and few practical solutions to improve integration between data, measurement and decision-making (for example, only six Canadian studies were identified as having the best potential to measure the integrated and complex relationship between Canadian society and the environment in a holistic manner).

Key Messages:

- There is a clear bias toward the application of carrying capacity to ecological issues and data. Other sectors are significantly under-represented, with the least attention given to economic elements of limits to growth.
- Despite increased theoretical and methodological support for improved integration within and across indicators, data sets, and measurement frameworks, the mechanisms, and political support, to put this into practice are lacking within Canada and globally.
- The funding and disciplinary structures of science and social science in Canada may limit studies involving integrated indicators which account for the ecological, economic, socio-demographic, and health impacts of carrying capacity.
- The lack of applied studies means that very little is known about environmental carrying capacity and society in Canada, beyond knowledge about specific human and non-human populations in defined and bounded contexts.
- The few projects that integrate ecological, economic, socio-demographic, and health impacts of carrying capacity, are largely non-academic, community-based efforts. While integrated, these studies are lacking in methodological rigor, resulting in questionable findings.
- Indicators are often presented as integrated in the text, description, and theoretical assumptions provided, however, further analysis reveals that few are actually measuring data across ecological, economic, socio-demographic and health themes. Despite claims of integration, the indicators are in fact more singular or at the best bi-sectoral.

1.0 Introduction

Despite the increasing scope, volume and availability of data-driven initiatives to track the growth and changes that comprise the Anthropocene, the layering of assessment methodologies, sector-specific considerations, and a tendency to focus upon local or regional case studies for measurement and evaluation presents significant challenges for linking public policy, decision-making and practitioner perspectives with such data. In addition to broader technocratic gaps that emphasize interpretation by others, rather than interaction between policy-makers and data, the growing complexity of data provision, intersectoral affect, and jurisdictional barriers present roadblocks for the understanding, modeling and use of environmental, community, economic and health data. This creates a fundamental challenge for the frameworks and models that seek to better understand and predict the footprint and impact of human action and consumption upon social, ecological, economic, institutional and health systems.

In this context, the principal research question driving this study was: How can the data within these frameworks be best measured, interpreted, and used to both understand the "state" of carrying capacity data and measurement but also leverage policy performance as a response? Beyond this question, however, is one of functionality, namely "what works, for whom, and why?" This project specifically sought to understand the program logic and theories of change that have informed both integrated and sector-specific data initiatives, their respective uptake, and to develop a theoretically informed understanding of how successful implementation and usage is defined, modified and reflected by end-users. This will, through the knowledge mobilization activities, become another step toward improved and increased knowledge to action (K2A) through: (1) converting data to knowledge (D2K), (2) applying knowledge to influence performance (K2P).

Using a scoping review method, this review assessed the state of knowledge and usage of integrated carrying capacity measurement approaches (Arksey and O'Malley 2005). This project inventoried, catalogued, and assessed the Canadian and international-based indicator, thresholds and data-based initiatives (operationalized to include metrics, indicators, frameworks and models) from 109 studies focused on understanding and tracking change (both positive and negative) as well as current state assessments of carrying capacity. Such initiatives are found in actions such as sustainable development measurement (indicators), cumulative impacts, biodiversity thresholds, state of our community reports, specific ecological research, and theoretical approaches to integration.

Utilizing a broadly comparative method, this project positioned that inventory and inter-sectoral catalogue against three core research questions:

1. How do contemporary data collection and measurement initiatives select, aggregate and represent key performance measures that link:
    - social,
    - ecological,
    - economic, and,
    - population health changes?
2. How do such initiatives rise to the integration imperative, and specifically the modeling or representation of change (both positive and negative) within, and across, related sectors?
3. How are such initiatives positioned to inform decision-making and action, whether across private, public or third sectors?

The central goal of this review is to better conceptualize what is being measured, by whom and for what purposes, in order to inform the performance of public policy as it relates to the impact of human populations upon ecosystems, social systems and economic systems, both within Canada and beyond.

1.1 Background and Context

Carrying capacity is a concept used by a wide range of disciplines from ecology to anthropology to engineering. The theoretical simplicity and generic applicability of carrying capacity has contributed to a combination of a wide range and scale of studies. For example, within ecology alone, carrying capacity is utilized from studies at the cellular level to wildlife management to shellfish aquaculture (Chapman and Byron 2017). Across the various uses of carrying capacity, four major types of carrying capacity have been identified: (1) as a mechanical attribute of manufactured item or systems; (2) as a feature of living organisms and ecological systems; (3) as *K,* the limit of population increase in organisms; and (4) as the number of humans the earth can support (Sayre 2008). Since its inception, carrying capacity has often referred to an optimal or normative limit, aspiring to "idealism, stasis, and numerical expression" (Sayre 2008, p121). However, while carrying capacity is often "conceived as *ideal, static, and numerical"* these characteristics have become "…increasingly untenable as the concept was extended to systems of larger scale, greater variability, and lesser human control" (Sayre 2008, p120).

These understandings, assumptions, and uses of carrying capacity persist to the present, despite critiques that question carrying capacity as an objective measure, the ability of practitioners to measure carrying capacity outside of bounded, small systems, and the representation of complex interrelations between humans and their environment as static, quantifiable, predictable and controllable (Sayre 2008). The limitations of carrying capacity have led scholars to argue against the use of the concept as *a priori* within research studies. For example, Mote, Rivas and Kalnay (2020, p658) argue that "human population change should be modeled with dynamic equations that represent real mechanisms, interactions, feedbacks, and parameters in the coupled Earth–Human System. This bidirectional coupling of Earth System models with Human System models can be used to derive human Carrying Capacity *a posteriori* from the mechanisms, variables, and

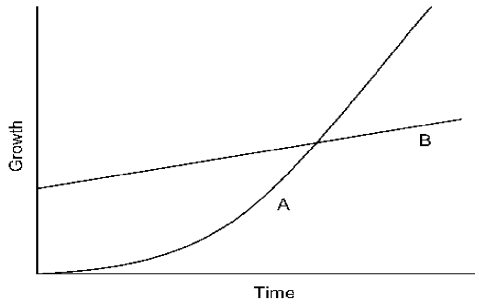
parameters found in the real coupled Systems. Carrying Capacity should be determined as a product of a dynamic model, not prescribed as an *a priori* equation."

Overall, there is limited consensus about what carrying capacity means, how it should work, how it should be framed and considered as a policy tool, and whether or not it has normative and empirical utility to policy makers and practitioners. The discursive and theoretical understandings and frameworks of carrying capacity shape how, even if it is implicit, indicators and measurement are selected and utilized, because they are driving different assumptions about carrying capacity. Below, the history and theoretical evolution of the concept is briefly outlined. This helps position the results of the scoping review, which point to significant gaps and bias in the operationalization and application of carrying capacity.

1.1.1 What is Carrying Capacity?

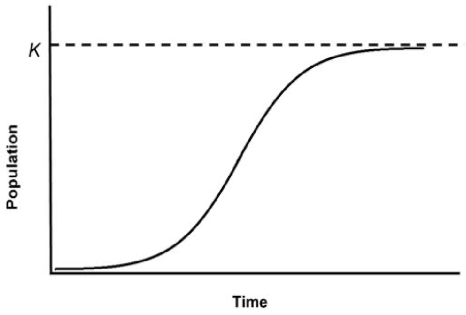
Definitions of carrying capacity are based on an assumption that there are both structural and functional limits to population and growth. Carrying capacity can be described as "a derivation of the most fundamental question in all of conservation: how much can we use the environment without spoiling it?" (Manning 2007). The underlying assumption generally tends toward the prediction that continued exploitation or consumption of resources will result in unacceptable and potentially catastrophic environmental degradation. Most discussions and conceptions of carrying capacity usually tied to population growth originate from *An Essay on the Principle of Population* (Malthus 1986). Malthus argued that while human population growth is exponential, food production is limited to arithmetic growth. Food supply presents a simple yet fundamental limit to population growth (Manning 2007).

Figure 1.0: Malthus's Model of Exponential Population Growth (A) Versus Arithmetic Growth of Food Resources (B)



This model was refined as a mathematical formulation of carrying capacity: population grows slowly at first, then faster and faster until it reaches "K" which represents environmental or ecosystemic limits (Manning 2007). Developed by Verhulst (1838), this equation was first published by Pearl and Reed (1920) and sparked interest in assessing and applying the concept of carrying capacity in wildlife management and ecology more broadly (Manning 2007, p13-4).

Figure 2.0: Logistic Population Growth Curve



Following the growth of both environmental social consciousness, as well as different environmental movements through the 1960s and 70s (Dryzek 2013). Malthus' ideas about limits to growth became foundational to environmental management, as did increasing awareness of ecological degradation, economic growth, and rapidly expanding populations (Seidl and Tisdell 1999). Popular books published during this time, such as *The Limits to Growth* (Meadows et al. 1972), *How Many People can the Earth Support*? (Cohen 1995) and *The Population Bomb* (Ehrlich 1969), all posed the possibility (and probability) of how not just the growth of a population, but the consumptive profile of that population, coupled with technical innovation and economic growth, could exceed the ability of the planet to support that population. In the course of doing so, that consumptive profile would also generate significant environmental, economic, and social inequities between, and within, nation-states and their populations. As the concept was used and modified, primarily within ecology-related fields, many forms of carrying capacity were identified, ranging from economic carrying capacity to cultural carrying capacity. Studies of applied ecology began to use the concept in relation to the management of specific habitats or ecosystems and the management of tourism. In human ecology, carrying capacity has been utilized to analyze the interactions between individuals, environment and society (Seidl and Tisdell 1999).

Although carrying capacity has long-standing roots in the study of ecology, economics and political science, as discussed above (Malthus 1986), there is increased awareness of human-driven environmental impacts (Gillingham, Halseth et al. 2016), population growth, economic inequities, and the sustainability of the Anthropocene beyond the 21st Century. Over the decades, understandings of carrying capacity evolved and it became widely accepted that the concept is a normative and value-laden idea that is mediated by social, institutional and cultural issues (Manning 2007). Decisions about human carrying capacity are deeply normative and political. While much importance has been placed on the term and idea of carrying capacity, attempts to apply the concept in various ways, to ecosystems and socio-economic sectors, have been challenging and often unsuccessful (Seidl and Tisdell 1999).

1.1.2 Theories of Carrying Capacity

The carrying capacity literature attempts to describe and account for the interactions between population dynamics, population size, growth, density, size, age and sex composition, etc., and the environment. Traditionally, efforts to understand the interactions between population

dynamics and the environment have often sought to "reduce environmental change to a mere function of population size or growth" (de Sherbinin et al. 2007, p346). This is particularly true in the study of ecology, where carrying capacity is focused on the quality and management of an ecosystem, including pressures and limits on that ecosystem, and corresponding population numbers. However, when applied to human activities, carrying capacity becomes more complex, influenced by ecological dynamics, values and culture, and institutional and management practices (Seidl and Tisdell 1999).

To account for this complexity, a number of theories have emerged to describe contemporary perspectives, including: neo-Malthusianism; the Boserupian hypothesis; Cornucopianism; political ecology; and, cultural Boserupianism. While there are other theories, this project is focusing on the above five because they are popular within the literature and appear throughout the literature analyzed within this review.

Neo-Malthusianism

Neo-Malthusians, adherents of Malthus' theory, believe that human populations, due to exponentially increasing fertility rates, will outstrip Earth's resources. While a dominant paradigm in the field, neo-Malthusianism has been criticized for being too focused on biological/ecological underpinnings, and overlooking cultural adaptation, technological advancements, and other institutional and trade arrangements which allow populations to grow beyond local capacity. Neo-Malthusianism underpins much of the academic work on Canadian carrying capacity, including the IPAT formulation in "which environmental impacts (I) are the product of population (P), affluence (A), and technology (T)—is implicitly framed in neo-Malthusian terms, although not all research using the identity is Malthusian in approach" (de Sherbinin et al. 2007, p348). One reason that population is such a popular measure of the human dimension of environmental change is that the data is readily available, and projections and models are reasonably reliable (de Sherbinin et al. 2007).

The Boserupian Hypothesis

The Boserupian hypothesis contends that agricultural production increases with population growth because of intensification of agricultural production, due to greater labour and capital inputs. This hypothesis understands technology as endogenous to the population-resource condition, while Neo-Malthusianism sees it as exogenous (de Sherbinin et al. 2007).

Cornucopianism

Cornucopian theories argue that human ingenuity and market substitution will avert future ecological crises. Market failures and the development and use of inappropriate technologies are more to blame for environmental degradation than population growth (de Sherbinin et al. 2007).

Political Ecology

Political ecology sees population and environment linked through the common root cause of poverty, which stems from economic imbalances between rich and poor countries. For example,

land degradation can be understood as stemming from a poor farmer's lack of access to credit and technology rather than a symptom of population growth (de Sherbinin et al. 2007).

Cultural Boserupianism

This project describes cultural Boserupianism as the theoretical and *a priori* assumption that the Anthropocene is a given and thus an endogenous variable. Cultural Boserupianism asserts that human beings are going to hit some kind of barrier or limit to the Earth's carrying capacity, whether through population, consumption, or production, and treats development as exogenous to carrying capacity. The literature operating within this theory is working to change or alter human behaviour at the population scale, in order to respond to the new normal of the Anthropocene.

1.2 Project Objectives

This project examined how different approaches to measuring integrated carrying capacity are being used in Canada and across the globe. The primary objective was to not only synthesize the evidence about the populations, consumption and thresholds implicit to the limits of growth (Meadows, Meadows et al. 1972), but ultimately to position that knowledge in support of how responses to systems-level changes (such as climate change) are designed, implemented and assessed. Through the comprehensive scoping review and resulting inventory, this project critically assessed the state of knowledge and usage of integrated carrying capacity measurement approaches in Canada and internationally.

This project was, therefore, focused on several intersecting knowledge synthesis objectives**:**

- Synthesis Objective (SO) 1: Evaluate whether and how relevant indicator frameworks reflect balance or bias in meeting ecological, socioeconomic/demographic and health goals;
- SO2: Assess the factors that facilitate implementation and uptake by policy actors in the Canadian context, with a particular focus upon application at the meso-level (regional and comparable jurisdictions);
- SO3: Identify best practices for learning system development (e.g. data and indicator collection, use, policy performance and phase 2 data and indicator collection); and,
- SO4: Mobilize knowledge to influence the knowledge, use and refinement/innovation of inter-sectoral carrying capacity indicator frameworks, indices and indicator suites via extant knowledge networks.

2.0 Methods

Utilizing a scoping review approach, this review focused on knowing what is measured, and how, in order to better understand the operationalization of concepts and metrics that inform how the research and policy communities frame and utilize carrying capacity. The scoping review was based on the framework outlined by Arksey and O'Malley (2005) and involved six stages: (1) Identifying the research question; (2) Identifying relevant studies; (3) Study selection; (4) Categorizing the studies; (5) Summarizing and reporting findings; and (6) Consulting. After identifying, cataloguing and analyzing 109 relevant academic and non-academic studies from Canada and across the globe, this project further analyzed six of the Canadian studies that had the best potential to measure the relationship between Canadian society and the environment. The six studies provide an inventory of over 400 indicators and functionally provide a topography of data in Canada across multiple dimensions and sectors.

2.1 Inclusion/Exclusion Criteria

This study has focused upon the analysis of English language peer-reviewed academic and non-academic studies published in the last 10 years. Relevant materials were identified from **Google, Google Scholar, JSTOR, Scopus**, and various **University databases**. This scoping review took a comprehensive approach to environment, community and health data, indicator and similar framework-based strategies by including relevant literature of all sorts. Both quantitative and qualitative studies were considered, as well as research from a variety of sources including, but not limited to, peer-reviewed academic journals, dissertations and theses, conference papers, government documents, organizational reports, and handbooks. Because of its broad scope, this project identified a large number of studies in the initial search results, approximately 200, before narrowing that number to 109 studies using the inclusion criteria described below.

While this project focused on Canadian materials (as per the SSHRC Guidelines for these grants), data was also collected regarding comparator states, defined as OECD countries with similar economies to Canada, and the broader international community. Because the purpose of a scoping review is to broadly search the literature, a number of search terms were used in varying sequences, including, but not limited to: Earth's human carrying capacity; measuring carrying capacity; carrying capacity assessment; global health and carrying capacity; ecological and health carrying capacity frameworks; carrying capacity in Canadian cities; sustainable development in Canada; social carrying capacity; ecological footprint analysis; social sustainability framework; Canadian health index; population health in the Anthropocene; measuring social determinants of health; carrying capacity and human health; health equity and carrying capacity; and, cultural carrying capacity.

Once an initial database was established, duplicate studies were removed. This resulted in the inclusion of 109 studies. Inclusion criteria included:

- English language
- Published in the last 10 years
- Theoretical, methodological, or practical approaches to the measuring of carrying capacity, the Anthropocene, and/or sustainability across sectors and themes, with

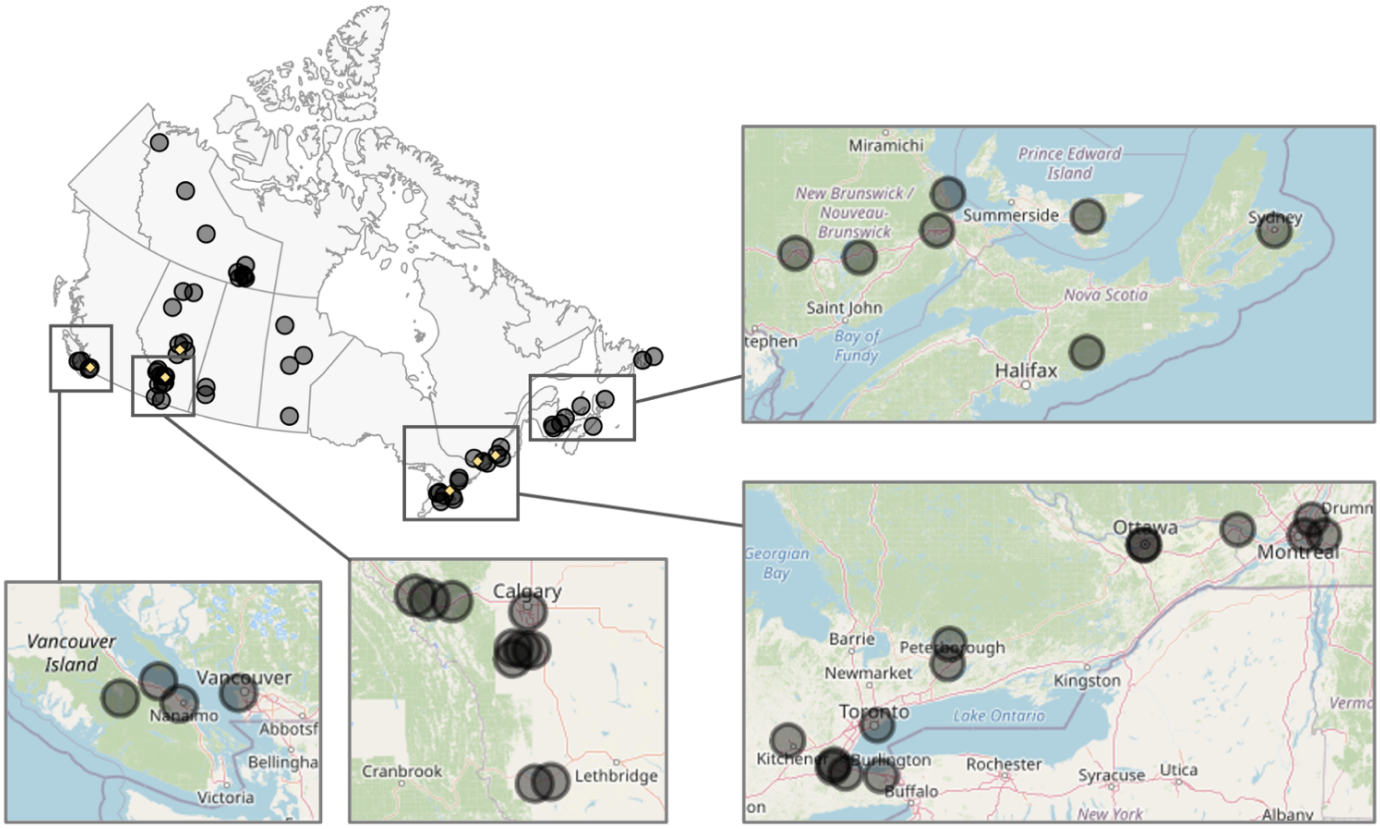
particular attention to articles and studies describing integration across multiple themes of carrying capacity, such ecological, health, socio-demographic, and/or economic themes.

- Peer-reviewed articles in scholarly journals and grey literature (non-academic studies) of all types including, but not limited to, organizational reports, community-based studies, and government documents

2.2 Geographic Distribution of Included Studies

A simple map, provided below, demonstrates the geographic distribution of the included Canadian studies. This map provides a visual overview of where studies on carrying capacity are taking place in Canada (see a full list of the reports by study location in the Appendix). The map demonstrates broader patterns of potential bias, and locates the areas where gaps in and across carrying capacity studies are prevalent. For example, in Figure 3.0, there are clusters of studies in key areas of ecological importance such as Banff in Alberta, Vancouver Island in BC, and the St. Lawrence Seaway in Ontario. The map demonstrates an urban bias, as well as a lack of study locations in the north and rural areas across the country, such as northern Ontario.

Figure 3.0: Canadian Study Locations



2.3 Analytic Strategy

The scoping review resulted in the identification and final inclusion of 46 Canadian, 7 relative comparator, and 56 international studies. After finalizing the 109 relevant studies, they were categorized by source and catalogued. Additional variables included the year published, authors, funding organization, and geographic focus, to provide ease of storage and citation of the studies. Identifying data included: geographic location (Canadian, relative comparator, or international); title/author/year; the scale of analysis (local, regional, national, global in focus); the themes of carrying capacity addressed (whether ecological, health, socio-demographic, and/or economic themes, or some combination of these four); and the focus/intention provided for the research (if the literature addressed general theoretical or methodological knowledge of carrying capacity measurements, and/or carrying capacity modelling, frameworks, metrics, indicators, data collection, or a combination). The inventory and analyses also included the parameters for the data and data sets being used or referenced, including the source of the data. For studies where data was utilized and could be accessed, the sectoral themes (whether ecological, health, socio-demographic, and/or economic themes, or some combination of these 4) of the data used was charted. Across all included studies (n=109), 26 were non-academic (grey literature) studies and 83 were academic (peer-reviewed) articles. Geographically, the majority of all studies, 56, were international in scope, while Canadian (n=46) and relative comparator studies (n=7) accounted for a smaller proportion. Table 1.0 illustrates the geographic distribution and form of this literature. Most peer-reviewed articles were international while the majority of grey literature studies were Canadian. Relative comparator studies accounted for a small portion of academic and grey literature.

Table 1.0: Carrying Capacity Literature by Subject and Location

	Canadian Studies	Relative Comparator Studies	International Studies
Peer-Reviewed, Academic Studies	28 (60.9%)	6 (85.7%)	49 (87.5%)
Non-Academic Studies	18 (39.1%)	1 (14.3%)	7 (12.5%)
Total	46	7	56

Given the knowledge synthesis goals and objectives noted above, a key issue was to assess the ways in which Canadian research and policy-relevant work had measured the relationship between Canadian society and the environment. Six studies were identified that fit this description and measured integrated carrying capacity across the five pillars of sustainability, which include social, environmental, health, community, and policy dynamics. These six studies, and the 418 indicators included within them, do not represent a complete inventory of indicators, but rather are examples of the measurement of integrated, holistic carrying capacity in Canada. Every indicator was then assessed in terms of if indicators were single or aggregated measures, how indicators were being calculated and measured, the level of data collection and temporal unit used, and integration of each indicator across environment, health, community, economic, and policy themes. Through this process and the analysis, this project concludes that while many indicators are being measured within and across sectors in Canada, they are not necessarily that useful when considered as a collective. This is largely due to the lack of uniformity of, and patterns of differentiation between, the indicators being used.

3.0 Results

The scoping review identified 109 academic and non-academic studies relevant for inclusion and analysis. The results of the analysis of these studies are divided into two sections: literature, indicator and data analysis, and representing and validating results. The first section details the results of the extensive scoping review through study charting and cataloguing, and analysis and comparisons of the literature, indicators, and data across geographic location and thematic. The second section provides an overview of the results through a citation network analysis and consultation process. A citation network analysis enables researchers to identify key articles and scholars that have shaped a particular topic, and shows how the literature relates through referencing. Citation Gecko is utilized to show the connections between the citations of the inventoried materials and the papers which have cited the inventoried articles. The citation network analysis demonstrates that the articles and authors are not very connected, meaning that the literature is quite siloed and there is a significant lack of integration and cross over within the carrying capacity literature. The literature that is generally compartmentalized and well referenced is not well linked into other research or projects of similar form or context. Lastly, the consultation process validates the results and final conclusions through virtual interviews and focus groups with experts and practitioners in the field.

3.1 Literature, Indicator, and Data Analysis

3.1.1 A Literature Review of Carrying Capacity

The Canadian literature on carrying capacity (n=46 studies) collected through this scoping review covers a broad range of topics, subject matter and study type. Within the Canadian literature, 60.9% (n=28) are peer-reviewed academic articles and 39.1% (n=18) are non-academic studies. Thematically, the majority of the Canadian studies address ecology in some way (n=33), fewer are socio-demographic in theme (n=31), and health (n=23) and economics (n=16) are represented the least. Within and across these themes, there are a number of clusters and patterns that appear.

Environmental and ecological topics are particularly presented in the academic literature and range in subject matter from studies at the cellular level, for example the effects of temperature on population rates in a phytoplankton species (Bernhardt, Sunday, and O'Connor 2017), to air quality, such as the contrasts in nitrogen dioxide and mortality in Canadian cities (Crouse et al. 2015), to animal species, for example the reintroduction of plains bison in Banff National Park (Steenweg et al. 2016). Coastal areas and sea life are particularly represented in this literature through studies of shellfish aquaculture (Guyondet et al. 2015) and the Fisheries Research Network (Mussells and Stephenson 2020).

In the academic literature, health and social determinants of health are studied at the local level, for example, through a community study in Hamilton, Ontario (Wilson et al. 2009) and a study comparing socio-economic factors and health outcomes in Manitoba (Chateau et al. 2012). At the national level, studies consider variations in health outcomes in rural areas (Lavergne and Kephart 2012) and an analysis of the of the community and health effects of natural resource development projects (Gillingham, Halseth et al. 2016). Studies more broadly considering human

health in the Anthropocene include articles addressing health psychology (Bernard 2019), an eco-social approach to public health (Hancock 2015a), human health through the framework of "One Planet" cities (Hancock, Desai, and Patrick 2020), and health equity and planetary health through Indigenous knowledge systems (Ratima et al. 2019).

There is also a cluster of academic literature addressing carrying capacity and sustainability in built infrastructure and land-use, particularly in cities. One study offers a sustainability assessment of urban communities through rating systems (Berardi 2013), another looks at a sustainability assessment tool for existing buildings (Mahmoud, Zayed, and Fahmy 2019), and another is focused on a sustainability assessment of the residential land use in Montreal (Vega-Azamar et al. 2016).

The grey literature is less defined by discipline or subject matter, and instead seeks a more holistic approach to sustainability or carrying capacity. Often, the studies utilize the United Nations Sustainable Development Goals (SDGs) as a model or framework. For example, a number of the studies consider the implementation and adoption of the SDGs within particular cities, such as Calgary (Keough 2020) and Winnipeg (PEG 2019), across particular populations, such as Indigenous peoples (NCCAH 2018), or within the Canadian population as whole (Waterloo 2016). Other non-academic studies provide outlines or models that Canadian communities can adopt to progress national SDG implementation, see for example "Generating SDG: Empowering Canadians through Sustainable Development" (Ho and Runnalls 2018), "Progressing National SDG Implementation" (Kindornay and Gendron 2020), and "Policy and Data Gap Assessments to Inform 2030 Agenda Implementation in Canada" (BCCIC 2019).

3.1.2 A Typology of Carrying Capacity

Canadian Carrying Capacity

The Canadian literature (n=46) collected within this review can be categorized into three of the theories described in the introduction: neo-Malthusianism (n=3); political ecology (n=36); and, cultural Boserupianism (n=7).

The three studies classified as neo-Malthusianism are found in the study of ecology and focus on the interactions of nonhuman species with their environment. These articles are oriented toward the micro-level and unit of analysis and are located within the academic literature. In each case, the research is geographically restricted, based on a single and specific species within a specific ecosystem or sub-system and are largely focused on understanding variables that directly affect species populations. One article was focused on estimating the bison carrying capacity (given the potential habitat available) in Banff National Park (Steenweg et al. 2016). Another article examined the effects of climate change on shellfish, specifically the carrying capacity of St. Peter's Bay in Prince Edward Island for mussel aquaculture (Guyondet et al. 2015). The last article looked at the carrying capacity of a phytoplankton species based on changes in temperature (Bernhardt, Sunday, and O'Connor 2017). Neo-Malthusianism is not widely applied to broader population dynamics in Canada because, like other developed countries, the fertility rate is decreasing, and population growth is not a problem which needs solving.

Seven studies are consistent with the theoretical assumptions of cultural Boserupianism. These studies all assert that humankind is operating within the age of the Anthropocene, meaning that humans are drastically and permanently impacting the Earth's carrying capacity, which is limited. For example, the authors of *Health in the Anthropocene* (2020, p6) are "concerned with how humanity can learn to live well within the ecological constraints of a finite planet. [The authors] propose that this will not occur without fundamentally disrupting dominant feedback loops within our social-ecological systems; it is a process that can only be accomplished by radically reorienting our political economies, our cultures, and our communities." The studies in this group start from the assumption that humans must learn to live within the constraints of the Anthropocene. For example, Hancock, Desai and Patrick (2020, 184) discuss a framework for "one planet living" which combines ecological footprint analysis ("which relates consumption of resources to the amount of productive land and sea on the planet") with the number of planets it might take to support different lifestyles. Another example argues that humans need to rethink their approach to the determinants of health in the Anthropocene, as the current focus on population health has largely become "ecologically blind" (Hancock 2015a). Hancock (2015, 252) contends that "we need to rebalance population health promotion to provide a much greater focus on the ecological determinants of health, and on the eco-social interaction."

The majority of the studies (n=36) fit into the theoretical frame of political ecology, largely understood through conceptions of sustainable development. Defined in the literature as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," sustainable development assumes that humans can push the limits of carrying capacity (Tanguay et al. 2010, p407). Sustainable development asserts that because humans can use problem solving to push the limits of carrying capacity, often through improving equity, the economy can continue to grow, and consumption can continue to increase. The literature contends that "development must be equitable (interaction between the economic and social dimension), livable (correspondence of the environment to social needs, which can refer to the concept of quality of life) and viable (economic development must abide by the supportive capacity of the ecosystems, and depletion of non-renewable resources must be avoided)" (Tanguay et al. 2010, p407). Authors in this group rely on discussions of environmental standards and pressures and equity considerations, rather than understanding the Earth's carrying capacity as a universal constraint or limit. In this understanding, adaptation and resilience play a role in moving the limits to increasing population and consumption (including absorptive capacity) outward.

The sustainable development literature is diverse. At the national level authors analyse the inequities between rural and urban sustainability research (Lowery, Dagevos, and Vodden 2020), and overarching inequities within Canadian society through the United Nations 2030 Agenda for Sustainable Development (PEG 2019). One study explains the focus on equity, stating that "ending poverty goes hand in hand with strategies that build economic growth and address a range of social needs, including education, health, social protection and job opportunities, while tackling climate change and providing environmental protection" (PEG 2019, p3). At a municipal level, projects such as the State of our City Calgary (2020) and the Peg (2019) in Winnipeg, attempt to explain and measure sustainable development within and across specific Canadian cities. Other sustainability literature is focused on the sustainability of specific types of

infrastructure, specifically stormwater systems (Upadhyaya, Biswas, and Tam 2014) and assessments of the built environment (Berardi 2013).

When viewed as a collective, there are broader trends that appear. Notably, the academic literature in Canada tends to take place at the micro and/or meso level, is very ecological and biodiversity focused in subject matter and data, and is largely driven by disciplinary factors rather than broader concerns about anthropogenic effects. This finding presents a challenge for broader, systems level understandings of carrying capacity in Canada. Academic research is not only more methodologically sound and rigorous than grey literature, it is also funded by the government at a large scale. Funding systems may be failing to make crucial connections between local and global processes, as a challenge for such focused academic researchers is "to understand how changes at the local and national scale relate to global-scale changes and how, in turn, their research can inform policies and programs at these lower scales that will attenuate environmental impacts at all levels" (de Sherbinin et al. 2007, p364).

International Carrying Capacity

Beyond the Canadian literature, this project also categorized the international literature as a way to contextualize the findings within the same typology. The literature collected from international sources (n=64) includes both general international literature (n=57) and literature collected from relative comparator countries (n=7). All five categories in the typology are touched upon by the international literature. Some of the distinctions between certain categories, particularly between Boserupianism and Cornucopianism, and between political ecology and cultural Boserupianism, are blurred in the international literature, and thus the studies are categorized within the category they best fit.

The most densely populated category was political ecology (n=21). There were two major clusters of studies in this group: one which deals broadly with the sustainability impacts of global health as it relates to carrying capacity, and the other which deals with urban and regional sustainable economic development. Looking at the first cluster of studies, emphasis is on the SDGs in developing countries and globally, with special attention paid to vulnerable populations across the globe. The social determinants of health are studied frequently in this cluster as a way to measure whether or not health systems are sustainable. For instance, the "Indicator and Monitoring Framework for the Global Strategy for Women's, Children's and Adolescents' Health" (2016) focuses on strategies for access to care and preventative measures. This cluster of political ecology looks at the ways in which complex systems like health and wellness feed into economic imbalance and inequity.

The second cluster in political ecology deals mainly with sustainable economic development in regional and urban centres, particularly where the limits of development are concerned. Many studies, particularly in extremely urban areas like that of mainland China, are focussed on the consumption needs of increasingly large urban areas while best addressing the need to scale back environmentally harmful practices, like the use of fossil fuels (Su, Xue, and Liang 2019, Swiader 2018, Mascarenhas et al. 2010). This is quite similar to themes found in culturalist Boserupian studies, however here, the focus is mainly on population behaviour adjustment than on economic development (de Sherbinin et al. 2007).

Within the neo-Malthusian literature (n=15) there are studies focused solely on ecological issues of carrying capacity and issues related to human population as a whole. For example, Gotmark, Cafaro, and O'Sullivan (2018, p851) assert:

> Halting population growth is essential to mitigating global climate change, avoiding a mass extinction of Earth's species, feeding millions of malnourished people in the developing world, limiting freshwater withdrawals from natural ecosystems while providing sufficient water for human and wildlife populations, and in general staying within the limits of prudent human use of the biosphere

The international literature brings an element of community to the otherwise very ecologically dominated sphere of neo-Malthusian areas about population carrying capacity. The ecologically themed literature is mainly focused on specific habitats such as coastal recreational waters (Di Dato et al. 2019) and the island and mainland habitat in Xiamen City (Qian et al. 2015) and their ecological capability to sustain life.

The culturalist Boserupian literature (n=13) assumes humans have already exceeded the Earth's limits and must learn to live within the constraints of the Anthropocene (de Sherbinin et al. 2007). Food systems and agriculture are analyzed closely here, especially with regards to their respective sustainability's. Schader et al. (2014) identify six different sustainability assessment systems to look at agriculture and food sustainability systems, and aim to adjust the way sustainability is measured in general, as well as harmonize food systems sustainability assessment tools (Schader et al. 2014). Where some literature, particularly political ecological literature, assumes that working toward sustainable development can help mitigate the negative impacts of hitting Earth's carrying capacity, cultural Boserupianism assumes humankind is already existing in the Anthropocene (Frugoli et al. 2015, 2011).

Cornucopian theories of carrying capacity in the international literature (n=10) recommend the use of certain theories and systems of assessment (human ingenuity) to solve problems of capacity and push limits (Wulf et al. 2019; Lane 2014). They particularly focus on assessing and adjusting the pre-existing indicators of sustainability, and answering still-remaining questions about the nature of sustainability across sectors.

Finally, Boserupian theories of carrying capacity (n=5) are the least common in the international literature group. However, even those studies that could be considered Boserupian are fairly loosely connected to the true Boserupian hypothesis. The studies that do fit into the traditional Boserupian theories of carrying capacity address very small environments that are often not associated with the natural world. For instance, the research done into sustainability for buildings in urban areas (Bragança and Castanheira 2014) is Boserupian in nature, but has little to do with the broader carrying capacity of Earth itself. There are, however, certain Boserupian elements to the study of how energy systems can be adapted to their populations in a more sustainable way (Chen and Li 2018).

3.1.3 Data Location and Accessibility

Given the emphasis of this project on measurement approaches to carrying capacity, this project also inventoried and assessed the data underlying both academic and grey literature work.

A large number (n=47) of the studies do not consider any specific data or data sets. Rather, these studies provide general knowledge regarding the subject and study of carrying capacity in a variety of disciplines or put forward ways and systems of understanding and/or measuring carrying capacity through frameworks, rating systems, governance strategies or other means. For example, one study develops a model for sustainable development that can be used to improve public policy and private sector decision-making (Bassi et al. 2019), while another study puts forward a First Nations data governance strategy (FNIGC 2020). The majority of these articles are peer-reviewed, academic articles (n=39). For example, one academic article provides a review of the concept and use of environmental carrying capacity in the spatial management of cities (Swiader 2018), another reviews the research literature and concepts of urban ecosystem carrying capacity (Xu and Xiaodong 2012), and another provides a sustainability rating system (Poveda 2014).

A similar number of studies (n=45) use publicly available data sets, such as those from Statistics Canada or regional and community health surveys (within 32 academic studies and 13 non-academic studies). For example, a study on the data challenges in First Nations communities utilizes data sets from the Canadian census, vital statistics offices and regional health surveys (McBride 2016). Others source data from the United Nations Statistics Division (NCCAH 2018), the Canadian community health survey (Lavergne and Kephart 2012), the Australian Bureau of Statistics (Lane 2014), and the Global Footprint Network, United States Department of Agriculture, and the World Wide Fund for Nature (Lawn 2013).

A smaller set of studies (n=16) rely upon proprietary data sets that are not available to the public. These are often academic studies (n=11) that involved primary data collection. For example, see "Inuit Traditional Ecological Knowledge (TEK), subsistence hunting and adaptation to climate change in the Canadian Arctic" (Pearce et al. 2015), "A new method for tourism carrying capacity assessment" (Castellani, Sala, and Pitea 2007), and "A model to assess fundamental and realized carrying capacities of island ecosystem" (Honghua et al. 2016). For the grey literature (n=5), this often means they have collected surveys or interviews from citizens and they only report summary results from these activities (see for example the State of Our City 2020).

One remaining study (an academic article) did not actually identify where they obtained their data sets. The authors of this article, "Development of sustainability assessment tool for existing buildings," do not list their data source (Mahmoud, Zayed, and Fahmy 2019).

The table below demonstrates which types of data are being used by academic and non-academic studies. Nearly half of all studies collected (n=47) did not utilize any data, while 62 studies used some kind of data. Across the studies, publicly available data was used in significantly more studies (n=45) than proprietary data (n=16).

Table 2.0: Use/Availability of Data by Research Source

	No Data	Proprietary Data	Publicly Available Data	Unknown Data Source	Total
Academic Articles	39 (47%)	11 (13.3%)	32 (38.6%)	1 (1.2%)	83 (100%)
Grey Literature Studies	8 (30.8%)	5 (19.2%)	13 (50%)	0 (0%)	26 (100%)
Cumulative	47 (43.12%)	16 (14.68%)	45 (41.28%)	1 (0.92%)	109 (100%)

Table 3.0 demonstrates that nearly half of all of the Canadian studies do not utilize any data sets (n=21), while 25 studies use data of some type. Publicly available data is also very important in the Canadian literature, as 15 studies use this type of data in some way.

Table 3.0: Use/Availability of Data by Research Source – Canada only

	No Data	Proprietary Data	Publicly Available Data	Unknown Data Source	Total
Academic Articles	15 (53.6%)	5 (17.9%)	8 (28.6%)	0 (0%)	28
Grey Literature Studies	6 (33.3%)	5 (27.8%)	7 (38.9%)	0 (0%)	18
Cumulative	21 (45.65%)	10 (21.74%)	15 (32.61%)	0 (0%)	46 (100%)

3.1.4 An Inventory and Analysis of Carrying Capacity Data Sets

A primary objective of this review is to understand first the sectoral, and then integrative, dynamics of the Canadian and relevant international carrying capacity/indicators literatures. This project distilled the literature in two parts in an effort to identify integration in both the literature overall and the specific data sets used.

First, the broad thematic goals and subject matter of the studies were identified. The title, abstract, and general description of each study were used to determine whether it addressed ecological, health, socio-demographic, or economic themes of carrying capacity, or a mix of these four. Since some studies approach carrying capacity from an integrated perspective, and address multiple themes, the total count of studies in the tables below is greater than 109 (see Table 4.0). In the table below, it is apparent that the majority of the studies (n=91) address the

ecological theme of carrying capacity in some way, while the economic theme is only accounted for in 40 studies.

Table 4.0: Literature Theme Frequency by Study Location

	Ecological Theme	Health Theme	Socio-Demographic Theme	Economic Theme	Total
Canadian Studies	33 (32.04%)	23 (22.33%)	31 (30.1%)	16 (15.53%)	103 (100%)
Relative Comparator Studies	7 (58.33%)	0 (0%)	3 (25%)	2 (16.67%)	12 (100%)
International Studies	51 (43.6%)	22 (18.8%)	22 (18.8%)	22 (18.8%)	117 (100%)
Cumulative %	91 (39.22%)	45 (19.4%)	56 (24.14%)	40 (17.24%)	232 (100%)

Next, this project looked specifically at the data used within each study. The themes (whether ecological, health, socio-demographic, and/or economic themes, or some combination of these 4) of the data used in each study were charted. Because some studies utilize integrated data sets, which address multiple themes, the total count of studies in the tables below is greater than 109.

However, when the themes of the data utilized within these studies was examined, it was apparent that the content within the data do not necessarily align with the thematic categories. For example, a significant body of the literature claims to examine economic dimensions of carrying capacity (n=40), yet only 25 items actually include economic data or indictors (see Table 5.0). For, example, in the international article “Sustaining Human Carrying Capacity: A Tool for Regional Sustainability Assessment” the authors contend that interactions between ecological, social and economic phenomena are important for progressing regional sustainability (Graymore, Sipe, and Rickson 2010). However, later in the article, when the authors put forward a framework for “sustaining human carrying capacity,” the focus is on ecological and social measurements, and the economic aspect is largely absent. The authors identify data availability as one significant limitation to the expansion of their framework and measurement of all aspects of equity, demonstrating the importance of data collection and availability (Graymore, Sipe, and Rickson 2010).

Table 5.0: Data Usage by Theme and Study Type

	Ecological Theme		**Health Theme**		**Socio-Demographic Theme**		**Economic Theme**		**Total**
	Academic	Grey Lit	Academic	Grey Lit	Academic	Grey Lit	Academic	Grey Lit	
Canadian Studies	9	11	4	10	6	12	4	8	64
Relative Comp-arator Studies	3	1	2	0	4	1	3	0	14
Inter-national Studies	25	2	13	5	8	4	7	3	67
Total	51 (35.17%)		34 (23.45%)		35 (24.14%)		25 (17.24%)		145

Table 6.0 (below) shows a breakdown of the themes of the content within the data sets across all of the studies included in the study. This table accounts for the theme of each data set present in the studies, including the themes of integrated data sets. The most frequent data set theme utilized in the studies was ecological, while data sets that integrated ecological/health/economical themes and health/economical themes were used the least. Across both academic and non-academic studies, single or bi-sectoral data set themes are more common than data sets integrated across three or more themes, demonstrating a lack of integration within the literature. Overall, economics is by far the least accounted for theme, across studies, indicators and data sets.

In order to demonstrate the difference between the themes accounted for in the literature, broadly defined, and the themes of the content of the data sets specifically, a comparison of the themes is provided in the Appendix (8.3). This table compares the themes present within the data sets and the broader literature themes of the studies in Canada. This break down is particularly important because it shows that there are discrepancies between what the literature was purporting to measure and what the data was actually measuring.

Table 6.0: Literature and Data Set Themes Present in Canadian Studies

	Number of Studies by Literature Theme	Percentage of Studies by Literature Theme	Number of Studies by Data Set Theme	Percentage of Studies by Data Set Theme	Ratio of Literature Theme to Data Set Theme
Ecological Theme	33	32.04%	20	31.2%	165%
Health Theme	23	22.33%	14	21.9%	164.29%
Socio-demographic Theme	31	30.1%	18	28.1%	172.22%
Economic Theme	16	15.53%	12	18.8%	133.33%
Total	103	100%	64	100%	

Tables 14.0 and 15.0 in the Appendix account for the same thematic comparison in the relative comparator and the international literature. Across these three tables, in almost every instance, more themes are accounted for within the studies (in some cases, almost twice as much) than is actually being measured or analyzed. The tables demonstrate that while much of the literature appears integrated and it seems as though they are measuring across multiple themes, the data sets used are often not integrated. The indicators being used are much more siloed and singular, because the data sets used are not integrated across multiple themes.

While more indicators are measured in the grey literature, these studies are not subjected to the same standards as academic work. For example, community organizations conducting some of these studies and writing the reports, such as Sustainable Calgary (2020), can face different challenges. For example, because non-academic studies may not have access to the same resources, academic expertise, or academic review processes and standards, non-academic studies can face challenges with methodological rigour, analytic capacity, reporting and review.

3.1.5 Indicator Themes and Analysis

The Canadian studies (n=46) were analyzed in order to determine how Canadian research and policy-relevant work was measuring integrated carrying capacity and the relationship between Canadian society and the environment. Six reports were identified as best measuring integrated, holistic carrying capacity in Canada across the five pillars of sustainability, which include social, environmental, health, community, and policy dynamics. These six studies were chosen for a number of reasons. Within the Canadian literature, only a small group of studies included

indicators and measurements, as some were instead focussed on designing carrying capacity models or frameworks. While 18 studies were identified as focussed on the measurement of indicators, 12 were excluded because of their narrow scope or because they did not measure the indicators that they discussed. These studies either proposed indicators for future study or talked about the process of measuring certain indicators, but did not actually conduct any measurements themselves. The remaining six studies are focussed on indicators, measure at least one of the five pillars of sustainability (environment, health, community, economy, and policy), and study the indicators they discussed in the report. These reports do not represent an inventory of all indicators used to measure all aspects of carrying capacity, rather they are an example of how integrated, holistic carrying capacity is being best measured in Canada.

1. 2019 Our City: A Peg Report on Winnipeg and the Sustainable Development Goals (PEG 2019)
2. Canada 2030: An Agenda for Sustainable Development (Kindornay et al. 2015)
3. How Are Canadians Really Doing? The 2016 CIW National Report (Waterloo 2016)
4. Learning From the Census: The Socio-economic Factor Index (SEFI) and Health Outcomes in Manitoba (Chateau et al. 2012)
5. 2020 State of Our City Report (Keough 2020)
6. Achieving a Sustainable Future: A Federal Sustainable Development Strategy For Canada, 2019 to 2022 (Canada 2019)

These studies provide an inventory of 418 indicators, the majority of which are unique to each study. Each indicator was assessed individually after being categorized by sector (environment, health, community, economy, and policy). Aggregated indices were separated into their individual parts. For example, measurements of "greenhouse gases" were separated into the specific gases that were included, such as methane and carbon dioxide. Additional data documented for each indicator include the geographical level of data collection (was data collected at the national, regional, or local level?), the temporal unit of collection (was the data cross-sectional, longitudinal, etc.?), and finally whether or not the indicator fit into more than one sector (primary AND secondary sectors were considered here). Among the five sectors, there were 37 indicator groups ranging from community focussed themes like "education" and "infrastructure," to environment focussed groups like "climate and temperature" and "household impacts." A full list of the indicator groupings is available in the Appendix (8.4).

A number of general findings were identified across the indicators. Overall, the grey literature contributed most to this inventory, both in terms of sheer number of measures identified, but also, they were much farther reaching, as well, often covering much more per report than academic sources, which often only studied a small number of indicators, sometimes in one or two per report. Several indicators were found multiple times throughout the broader group of 418:

- 27 indicators were labelled "self-reported" or "self-assessed". These were usually survey responses to do with the health sector. These were often "self-reported physical/mental health" or another similar measure.
- Indicators assessing aid (as ODA or OOF) occurred 8 times

- Indicators measuring income (demographic-based low-income measures) occurred 4 times
- Emissions data (CO2, CH4, N2O, NO2, SO2) were all present in 4 data sets
- Measurement of body-mass index (BMI) occurred 3 times

This project examined the sector trends, single or aggregated nature, methods of measurement and calculation, scale and location, temporal data trends, and the presence of asset and liability measures across the 418 indicators.

Sector Trends

The most significant number of indicators was in the environmental sector, with almost all authors having at least some indicators measuring environmental variables. In total, environmental indicators made up 179 of the total number of indicators. The next most populated sector was the community theme, with 106 indicators, then economy, which had 94. After this, there was a steep drop off, with the health sector sitting at 28 indicators, and then the policy sector, with 16.

In the environment sector, most indicators (44.63%) fit into the subsector of "water/air/land quality and wildlife." The remaining 55.37% primarily fit into conservatory efforts (12.43%), and presence of harmful chemicals (14.69%). For the health sector, "overall health," at 28.57%, was largely measured through self-reported survey-type questions, while the community sector's most common subsector was "social capital," at 47.16%. The economic sector was largely measuring "the broader market," at 41.49% (which included things like market basket measure, GDP), while policy was mostly measuring "democratic process," at 42.86%. The most common subsector was social capital, in the community sector (n=50), followed by broader market measures in the economic sector (n=39) and water quality and wildlife in the environmental sector (n=33). A table of these results is available in the Appendix (8.5).

Single and Aggregated Indicators

While the majority of the indicators were single measures (for example, emissions of CO or O3) a number of indicators were aggregated or calculated indices. The table below shows the number of indicators that were considered single (one indicator measuring one thing) or aggregate (many indicators measuring the same thing). As Table 7.0 shows, the majority of indicators were single (82.1%, n=343), but aggregated indices were not uncommon.

Table 7.0: Number of Single and Aggregated Indicators

	Frequency	Percent
Single	343	82.1%
Aggregate	75	17.9%
Missing	0	0%
Total	418	100%

Methods of Measurement and Calculation

The majority of the indicators used count data or a ratio of some sort. There were other methods, particularly calculation of means, and, for economic variables, measurements in currency (dollars) or percentage of GDP, however, these were in the minority. The majority of calculations were also either a count or a ratio of some sort.

Table 8.0: Methods of Measurement for Indicators

Methods of Measurement	Frequency	Percentage
Count data	160	38.28%
Ratio	156	37.32%
Other (GDP, proprietary indexes, yes/no surveys, etc.)	73	17.46%
USD/CAD/Other currencies	29	6.94%
Total	418	100%

Scale and Location

Most indicators were drawn from nationwide surveys, or data from Canada as well as other countries. Locally, two cities, Calgary and Winnipeg, were also represented in every sector, due the State of Our City report and the Peg report respectively. Minority indicator groups in these tables were regional and provincial indicators and "other," which included indicators that were measured globally, indicators that were measured by industry, and indicators that were measured in countries other than Canada.

Table 9.0: Number of Indicators by Sector and Location

Primary Sector	Local	Regional	National	Other	Total
Environmental	18	19	93	45	175
Health	3	4	14	6	27
Community	18	2	81	4	105
Economy	20	0	60	0	80
Policy	0	1	9	3	13
Total	59	26	257	58	400

The majority of the "other" category were areas where local, regional and national data were collected, but the specific localities are not mentioned in the literature. There was no Canadian data that focused exclusively on rural areas. There are 18 missing values, due to variable error.

Temporal Data

In addition to questions of content and scale, indicators were also assessed from a temporal standpoint. Specifically, the temporal nature (cross-sectional, longitudinal, time series) and frequency of collection for each indicator was catalogued. Most reports mentioned that their data was collected in yearly surveys, such as the Census and other national reporting surveys.

Table 10.0: Number of Indicators by Sector and Temporal Measurement

Primary Sector	Hourly	Daily	Monthly	Annually	Every 5 Years	Other	Total
Environment	14	3	4	153	1	0	175
Health	0	0	0	20	4	0	24
Community	0	1	0	99	2	3	105
Economy	0	0	0	80	0	0	80
Policy	0	0	0	9	1	1	11
Total	14	4	4	361	8	4	395

As seen in the table above, the majority of data, across all sectors, was collected annually, with environmental data also being collected at a more granular level (hourly, daily, monthly). Some indicators (8.61%, n=34) were measured using other units of time, primarily in the environmental sector, where several (n=14) indicators were measured on a continuous basis, noted and reported as hourly. These indicators primarily dealt with the monitoring of certain chemicals in air and water. There are 23 missing values, due to variable error.

Asset and Liability Measures

Many indicators were "asset measures," meaning they are measuring positive attributes and assessing strengths, like community faith in the democratic process or productive capabilities. As seen below, asset measures were the largest proportion of the economy and policy sectors. Liability measures are indicators that focus on measuring negative or harm impacts. These were especially common in the environment sector. Some indicators fit in neither category, and were primarily survey response questions meant to assess the landscape of a measure, such as self-rated health or life expectancy. These were the largest proportion of the health sector.

Table 11.0: Asset vs Liability Indicators by Sector

Primary Sector	Asset	Liability	Neither	Total
Environment	45	116	15	176
Health	9	9	10	28
Community	70	16	20	106
Economy	54	26	14	94
Policy	13	1	0	14
Total	191	168	59	418

3.2 Representing and Validating Results

3.2.1 Citation Network Analysis

A citation network analysis enables researchers to identify key articles, theories, and scholars that have had an impact in shaping the field. “Citation network analysis is an analytic method that systematically assesses the interconnectivity of research in a discipline” (Gustafsson, Hancock et al. 2014, p622). This method has been utilized across various disciplines from sport research, to scientific study, to education scholarship (Gustafsson, Hancock, and Côté 2014; Weller et al. 2018; Shibata et al. 2011). Using Citation Gecko, we were able to map both the “networks” of literature informing the studies collected for this project, as well as the research informed by (citing) this work. On the whole, there are limited connections or integration within this body of work. Based on the citation network analysis, Figures 4.0, 5.0, 6.0, and 7.0 show that the collected articles are not very connected. For example, in the Canadian literature, Figures 4.0 and 5.0, there are a couple of small clusters where urban sustainability is the focus of the articles, and where climate models are the focus. The app also allows us to look at the papers that cite the seed papers. In Figure 5.0, it is apparent that the climate modelling literature is quite self-referential. However, these articles are not well connected to the other articles that consider different aspects of sustainability.

Figure 4.0: Papers Cited-By Canadian Articles

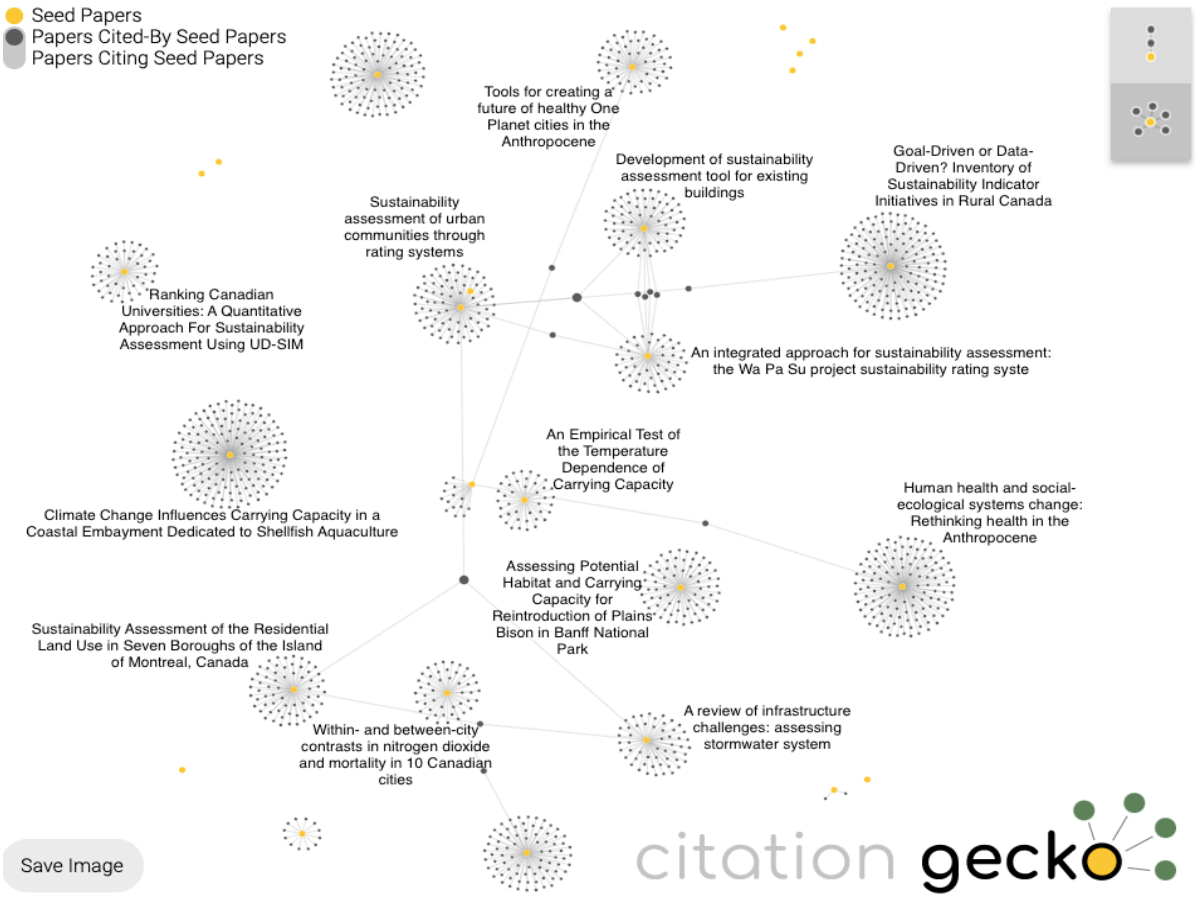
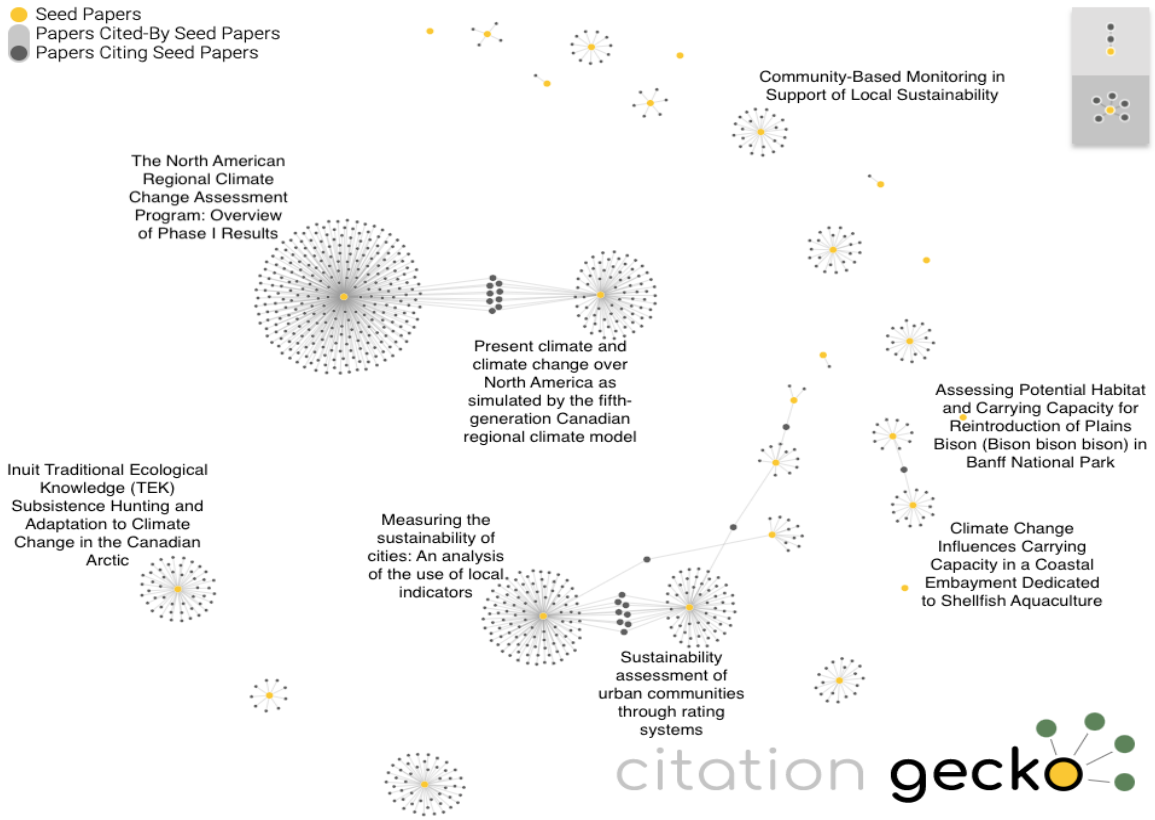


Figure 5.0: Papers Citing Canadian Articles



The international literature and relative comparator articles were also mapped into one citation map. Figures 6.0 and 7.0 (in the Appendix) show how the modelling and framework literature is somewhat overlapped. For example, in Figure 6.0 the triangle in the middle shows where the "Ecological Footprint Analysis and Index" is connected to "island ecosystem" and "evaluation model for urban carrying capacity." The 2 yellow dots in the triangle are addressing "urban carrying capacity" and "human carrying capacity in a regional assessment model". Figure 7.0, the "papers citing the seed papers" map, shows how some of the modelling literature is being cited.

Overall, the literature represented across these 4 maps is largely compartmentalized and while generally well referenced, is not linked into other research that is either localized or other projects of similar form and context. While there are variable degrees of impact factor, in terms of number of citations, across the literature, there are very few with instances of cross-cutting connections.

3.2.2 Consultations

Conducted virtually either through individual interviews or focus groups, consultations help validate the final conclusions from the project. Consultations are an important component of such a review, yet are often viewed as optional. Based upon prior experience with this methodology, including a consultative process is essential, and particularly so for this project as

it can: (1) both inform and validate the findings from the main scoping review (Arskey and O'Malley 2005); but also (2) provide critical inputs into the review component of the project.

Consultation participants were identified from the collected Canadian studies and contacted via an email invitation. Four experts responded to the invitation and participated in a focus group or individual interview. Every participant said that they were not surprised by the findings of this project. One participant said, "I was disappointed that I was not surprised." Specifically, participants were not surprised by the lack of intersectoral indicators used to measure carrying capacity across Canada. All of the participants recognized that ecological indicators and measures are well-developed, while good social indicators are lacking and overall, there is a poor understanding of how the economy is functioning in relation to other aspects of carrying capacity. One participant indicated that while there has been a lot of rhetoric about the need for integration, across government, academia, and other sectors, there has been a general lack of operationalization. This participant suggested that funding agencies, government departments, researchers and practitioners need to work together to change this reality, especially as governments work towards a "sustainable recovery" post-COVID-19.

One scholar who works internationally was surprised by Canada's poor data quality, availability and overall infrastructure, in comparison to other developed states, and in Europe specifically. They contended that poor data infrastructure makes the monitoring of carrying capacity very difficult. In countries where measurement and indicators are standardized, complex aspects of carrying capacity and sustainability can be compared across jurisdictions, reported on regularly, and used to monitor and evaluate relevant policies, which can keep policy-makers and governments accountable for their actions on issues related to carrying capacity. This participant suggested that moving forward in the Canadian context, a strong methodology and framework for measuring and improving integrated aspects of carrying capacity must be developed and implemented. They contended that this framework must be based on a clear vision that is developed in consultation with local communities, the general public, and other stakeholders so that everyone is invested in the project. Even if data is lacking, at least a standard framework provides a place to start. Another participant also commented on the importance of involving the public in such frameworks in order to make projects relevant to local contexts and to push policy-makers to take action that extends beyond election cycles.

Issues related to terminology, equity, and the ever-expanding number of indicators used were also raised. Each participant mentioned, in different capacities, issues with the terminology of carrying capacity. Participants suggested that the term carrying capacity is very similar in some ways to other terms that seem more popular and perhaps more expansive and relevant to the issues discussed, such as sustainability, and questioned why the term carrying capacity was chosen and its importance to the project. One participant indicated that issues of equity need to play a larger role in this type of research and marginalized and vulnerable populations need to be specifically considered in frameworks and measurement approaches. They also suggested that while indicators keep expanding, few indicators are ever retired. Standardization of measurement is needed nationally, including a decision on which indicators and frameworks should be used and which should be retired so that resources are not being wasted.

4.0 Implications and Discussion

The findings of this project speak directly to the 4 intersecting knowledge synthesis objectives, as outlined previously.

Synthesis Objective (SO) 1: Evaluate whether and how relevant indicator frameworks, measurements and data collection reflect balance or bias.

Across Canada and the globe, individuals, groups and governments appear to be measuring what they want, and how they want. There is inconsistency across the literature and a lack of intersectoral indicators, especially in the academic literature which tends to take place at the micro-meso level and is largely driven by disciplinary factors rather than broader concerns about anthropogenic effects. This may be a result of research funding in Canada and how SSHRC/NSERC and CIHR structure their call for proposals and parameters for successful grant applications. While the grey-literature attempts to be more integrated, this does not mean that it is without its flaws. Because non-academic studies may not have access to the same resources, academic expertise, and academic review processes and standards, non-academic studies can face challenges with methodological rigour, analytic capacity, reporting, and review.

Ecologically related themes, issues, and data are the most represented across the literature, while socio-demographic and economic themes were included much less. The bias in sheer number of indicators was clearly toward the environmental sector. Out of the six projects selected for detailed analysis of indicators, almost all authors had a majority of their indicators measuring the environmental sector, and two of the six focused exclusively on environmental variables. In total, environmental indicators made up 179 out of the total (n=418).

Significant data gaps were also identified across the literature, including missing data from rural, northern and remote communities. These literature and knowledge gaps are visually presented in the study location map. Recognized data gaps in Canada include a lack of data on Indigenous peoples and communities, rural and remote communities[1], and members of other marginalized groups such as LGBTQ2S+ communities (BCCIC 2019). A lack of high quality data on marginalized populations, such as First Nations, limits its utility for communities and policy-makers (McBride 2016). For example, Indigenous knowledge has not been integrated into measurement approaches. While the importance of Traditional Ecological Knowledge (TEK) has been recognized by some climate change reports, its role in the adaptation policy process and measurement of sustainable development is not recognized (Pearce, Ford et al. 2015).

Synthesis Objective (SO) 2: Assess the factors that facilitate implementation and uptake by policy actors in the Canadian context.

While the literature points to gaps in Canadian policy and room for improvement, there is little uptake by government leaders or policy-making and an overall lack of knowledge concerning the issues. Despite the many policy-orientated solutions that have been put forward, economic growth and GDP continues to be the top policy priority for governments across the globe, at the

[1] The Canadian Standards Group (CSA) is currently creating rural data standards (2020-2021).

expense of an integrated understanding of carrying capacity which includes environmental, economic, health and socio-demographic data, measurements and indicators (Waterloo 2016). The world is changing rapidly and as the Earth's carrying capacity diminishes in the Anthropocene, the need for systemic and sustained change has become increasingly urgent. Thus, a number of implications for policy makers, actors and governments are suggested below.

Specifically:

1. Attention needs to be paid to: how carrying capacity is conceptualized; the different understandings of carrying capacity; and, the application of carrying capacity at scale, from the micro, local, to global population and planetary health;

How carrying capacity is understood is incredibly important because it helps determine well-targeted policies and assumptions, which underlie government and development agency programs, and identify the cause of ecological disaster, which if corrected would "solve" the problem. For example, if neo-Malthusian theory is correct than the solution should be population programs which limit population growth. However, this is an oversimplification as these theories, and others, may simultaneously operate at varying scales, and could all be correct. Neo-Malthusianism has resulted in an overly reductionist view of population-environment interactions. Human interactions with the environment are more complex as "populations are composed of people who collectively form societies, and people and societies cannot easily be reduced to food and material demands that result in some aggregate impact on the environment" (de Sherbinin et al. 2007, p363). Understanding the theoretical and methodological underpinnings of carrying capacity and assumptions behind the use of the term are integral to the implementation of future policy.

2. Cross-sectional and longitudinal data must be identified, collected and measured across the country while simultaneously facilitating attention to place-based approaches and measurement; and,

The findings demonstrate that carrying capacity is being measured inconsistently across Canada. For example, out of the six studies analyzed, only a handful of indicators out of 418 were replicated across data sets.

It is evident that national targets and indicators, that speak to local, regional, and national priorities and complement international goals, should be developed in an effort to promote consistency and the collection of longitudinal data that can be used for comparison purposes across the country. However, policy direction and implementation in this area was severely lacking in Canada. For example, a comprehensive review of the 2030 Agenda argued that while the Agenda is significant in its scope and scale, covering economic, social and environmental dimensions of sustainable development, and applying to domestic and foreign policies, governments and other stakeholders face the massive challenge of ensuring an integrated and coherent approach to the Agenda's implementation at the local, national, and global levels (Kindornay and Gendron 2020, p26). However, national priorities, targets and indicators have yet to be identified for 2030 Agenda implementation, and an analysis of Canada's implementation of the 2030 Agenda recommended more cohesive, comprehensive, equitable,

and transparent federal policies moving forward (BCCIC 2019). Data gaps present barriers to the effective measurement of progress across the country, as baselines and priorities for improving the availability of statistics to monitor 2030 Agenda implementation have yet to be established. The literature also suggests that part of the national strategy for Canada's 2030 Agenda should also be supporting provincial, territorial, municipal and Indigenous governments to assess their own policy and gaps in order to localize the Agenda (BCCIC 2019).

3. Policy-makers and governments must pay attention to explicit linkages and measurements across sectors, including ecological, health, socio-demographic, and economic factors.

This project demonstrates that despite repeated and ongoing calls for integrated approaches and measurements of carrying capacity, this is not happening within the research community. The importance of integration cannot merely be stated but must also be actively measuring and comparing data consistently across sectors, regions, and population dynamics (Hancock 2011; Parkes et al 2019).

Synthesis Objective (SO) 3: Identify best practices for learning system development moving forward.

The lack of applied studies means that very little is known about best practices regarding the measurement of the relationship between environmental carrying capacity and society in Canada. Of the 46 Canadian studies collected for this project, only six were identified as useful examples of the measurement of integrated, holistic carrying capacity in Canada. Since there are no clear best practices, a number of value-based recommendations should inform public policy moving forward:

1. Comparability: The absence of national targets and indicators, clear definitions of human carrying capacity and sustainability, and measurement and data collection standards, means that it is incredibly difficult, if not impossible in some instances, to compare different aspects of the human-environment relationship across the country. The comparability of indicators, definitions, targets, and measurements needs to be reconciled with local utility and usability.
2. Standardization: Standardization of indicators, measurements, and data collection is crucial to understand and effect the relationship between Canadian populations and the environment. Standardized benchmarks, that permit local adaptability, need to be set and implemented nationwide.
3. Recognition of Place: The importance of place-based (local) values, meaning, and interpretability must be recognized moving forward. Recognition and attention to local realities is vital to any progress at a national scale.
4. Integration: Integration at all levels must be understood as more than single or bi-sectoral data and analyses. Rather, integration needs to be conceptualized as multi-sectoral, complex, and involving differing aspects of human carrying capacity.
5. Liability and Assets: Asset-based, positive measures of carrying capacity must be balanced with indicators focused on measuring liability (negative values). This project found that currently, liability measures are used overwhelmingly more often than positive measures.

6. Equity: Equity within and across ecosystems and populations/sub-populations must be considered across all aspects of human carrying capacity.

Synthesis Objective (SO) 4: Mobilize knowledge to influence the knowledge, use and refinement/innovation of inter-sectoral carrying capacity indicator frameworks, indices and indicator suites via extant knowledge networks.

Despite increased theoretical and methodological support for improved integration within and across indicators, data sets, and measurement frameworks addressing carrying capacity and sustainability, the mechanisms, and political support, to put this into practice are lacking within Canada and globally. The need to mobilize knowledge regarding carrying capacity to influence the knowledge, use and refinement of inter-sectoral carrying capacity is significant, both within and across academic centres, community and non-profit organizations, governments, and other organizations measuring carrying capacity and collecting data.

In order to mobilize knowledge, (1) capacity to engage with the results of this project across scales must be built, and (2) citizen interaction with science and the data needs to be facilitated. Research suggests that community-based measurement and monitoring may increase citizen engagement in ecosystem management and environmental planning, enhance community influence on policy directions, and contribute to policy implementation (Pollock and Whitelaw 2011). Bridging networks and capacity between academic work and applications of carrying capacity that is being done by NGOs and other non-profits working with communities will result in increased knowledge and better integration across all sectors and themes. The knowledge mobilization activities are significant, broadly focused, and ongoing. These activities will work to mobilize knowledge on integrated carrying capacity and the specific findings from this report which can inform change.

5.0 Conclusion and Future Directions for Research

The objective of this project was to assess the state of knowledge and usage of integrated carrying capacity measurement approaches primarily within Canada, but also globally. The primary objective was to not only synthesize the evidence about the populations, consumption and thresholds implicit to the limits of growth (Meadows, Meadows et al. 1972), but ultimately to position that knowledge in support of how responses to systems-level changes (such as climate change) are designed, implemented and assessed. Questions guiding this process included: What information and data is being collected? Who is collecting it? How is it being collected? And, what is it being used for? Overall, the findings from this project broadly suggest that very little is known about carrying capacity and society in Canada or globally. Various individuals and groups across the country and the world are attempting to measure very discrete indicators in specific places, but there is no uniformity across the Canadian literature, nor a comprehensive perspective on what exactly an integrated understanding of carrying capacity is and how it can be measured.

Specifically, the findings from this project show that the carrying capacity literature is select and specific, barely aggregated, and largely ecologically focused. The literature is mainly focused on measuring discrete nonhuman and human activities in specific and bounded environments. Few studies approach human carrying capacity and the relationship between humans and the environment holistically and with the aim of understanding and measuring the human footprint. This reality is evident in the approaches of studies to measurement and data collection. While a lot of data is being collected, the metadata shows a lack of intersectoral indicators, temporal inconsistency across indicators, and where there is consistency, a reliance on a small number of indicators. The majority of the indicators used to measure carrying capacity are single indicators, focused on collecting data on one specific thing, and are not aggregated indices which attempt to integrate multiple measures. The lack of uniformity and standards regarding data collection also plays a role here. Data collection is variable, with a large bias towards ecological and environmental priorities and with large collection gaps across rural and northern contexts. Across the literature, measurement approaches, and data collection, the focus is largely on understanding, measuring, and representing ecological aspects of carrying capacity, and not the integrated and holistic realities of the relationship between humans and the environment.

The central goal of this review was to better conceptualize what is being measured in order to inform public policy. This project found that the carrying capacity literature is largely focused on measuring local, niche ecosystem dynamics or select nonhuman populations. When considering the human species, the vast majority of the research is focused on understanding the specific and less the holistic, complex realities of the human footprint.

Moving forward, a number of key questions should guide future research:

1. What are the models or theoretical assumptions that might facilitate more integrative perspectives on the relationships between population, resources and consumption?
2. What are the ethical/equity-based considerations that are neglected? What results from their inclusion?
3. How does socio-demographic stratification impact local/regional perspectives and realities of carrying capacity?
4. Does carrying capacity have utility for public policy and practice in Canada as a concept "in practice"?
5. How can Canada overcome the geographic/rural/northern gaps for both data and policy-driven intervention?
6. What role can/should/might market instruments play?

6.0 Knowledge Mobilization Activities

The knowledge mobilization activities listed below are an important step toward improved and increased knowledge to action (K2A) through: (1) converting data to knowledge (D2K), (2) applying knowledge to influence performance (K2P). Both academic and non-academic (policy and practitioner) audiences will be targeted in knowledge mobilization, including organizational and community-based decision makers, policy makers, and the private sector. The dissemination activities include the use of a variety of communication networks including those outside of existing contacts base, with regular reminders and requests for feedback.

In addition to the required SSHRC report and evidence brief, the outputs of this project include:

- A project report covering the results of the scoping review (D2K)
- A summary report (1-3-25pp format) for broader distribution (D2K)
- A working paper for supporting public policy-based discussions and deliberation (K2P)
- A Prentice Institute-format policy brief and policy blast (K2P)
- A series of content specific webinars targeting rural, environmental, health, impact assessment, informatics, policy and integrated audiences (K2P and K2A)
- Conference and workshop presentations to local and regional audiences such as watershed management bodies, local public health authorities, member of the civil service, and other research groups (K2P and K2A)

The research outputs will serve as both a source of knowledge and practical tools for the development of the next generation of integrated data frameworks, but also the generation of an innovative Integrated Environment, Community and Health Policy Learning System (IECHPLS). The working paper will act as a scenario model foundation for policy and research–based discussions of the scoping review findings, including an inventory and categorization of the collected literature based on community capital impacts.

Each member of the team has access to widespread online networks through which will be sent the research outputs and event reminders. Outputs will be distributed online via listservs and at various conferences and stakeholder gatherings. Similarly, the more condensed outputs facilitate dissemination to a broader range of audiences, with the “backstop” of project reporting and communication supports provided through the project team and the capacity of the Prentice Institute. Existing social media pages and newsletters of the research team and their organizations will be utilized to advertise the knowledge mobilization efforts. Due to the financial and temporal challenges of attending multiple conferences, and impact of the global pandemic on travel, this project will also provide the content for a number of webinars targeting different sectoral and integrated audiences.

The diversity and breadth of the knowledge mobilization activities listed above demonstrate the urgency of this work and its integrated nature. Addressing the Earth’s decreasing carrying capacity and ability to support human life demands a rapid and integrated approach from academics and researchers, governments and policy-makers, and other organizations.

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8.0 Appendices

8.1 Location of Canadian Studies

Table 12.0: Canadian Studies by Study Location

Province	City or Region	Study Title	Date	Subject/Sector
British Columbia	Vancouver	An Empirical Test of the Temperature Dependence of Carrying Capacity	2017	Environment
British Columbia	Victoria, Vancouver,	Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort	2015	Environment, Health
British Columbia	Port Alberni, Parksville, Nanaimo	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
British Columbia	Vancouver	Ranking Canadian Universities: A Quantitative Approach For Sustainability Assessment Using UD-SIM	2011	Environment, Community
Alberta	Lubicon Lake, Beaver, Tallcree and Little Red River Cree First Nations	Subsistence, regional planning and the cultural carrying capacity of First Nations in Alberta, Canada	2019	Environment, Community, Economy
Alberta	Edmonton	An integrated approach for sustainability assessment: the Wa Pa Su project sustainability rating system	2014	Environment, Health, Community
Alberta	Banff National Park	Assessing Potential Habitat and Carrying Capacity for Reintroduction of Plains Bison in Banff National Park	2016	Environment
Alberta	Calgary	State of our City 2020: An Urgent Call for a Just Transition	2020	Environment, Health, Community, Economy
Alberta	Edmonton	Ranking Canadian Universities: A Quantitative Approach For Sustainability Assessment Using UD-SIM	2011	Environment, Community

Alberta	Canmore, Banff, MD of Bighorn no. 8, Turner Valley, Black Diamond, Okotoks, Pincher Creek, The Piikani First Nation, Norwood	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
Alberta	Edmonton	Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort	2015	Environment, Health
Manitoba	Winnipeg	Our City: A PEG Report on Winnipeg and the Sustainable Development Goals	2019	Health, Community
Manitoba	Winnipeg	Food insecurity and self-reported psycho-social health status in Manitoba First Nations Communities	2011	Health, Community
Manitoba	Winnipeg	Learning From the Census: The Socio-economic Factor Index (SEFI) and Health Outcomes in Manitoba	2012	Health, Community, Economy
Manitoba	Winnipeg	Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort	2015	Environment, Health
Ontario	Windsor, Sarnia, London, Hamilton, Toronto	Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort	2015	Environment, Health
Ontario	Ottawa	A First Nations Data Governance Strategy	2020	Environment, Health, Community, Economy

Ontario	Ottawa	Achieving a Sustainable Future: A Federal Sustainable Development Strategy for Canada 2019-2022	2019	Environment, Health, Community, Economy
Ontario	St. Catharines	A review of infrastructure challenges: assessing stormwater system	2014	Environment, Community
Ontario	Glanbrook, Lakefield, Peterborough, Flamborough, Hamilton	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
Ontario	Hamilton	Health in Hamilton neighbourhoods: Exploring the determinants of health at the local level	2009	Health, Community
Ontario	Toronto	Ranking Candian Universities: A Quantitative Approach For Sustainability Assessment Using UD-SIM	2011	Environment, Community
Quebec	Montreal	Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort	2015	Environment, Health
Quebec	Montreal	Sustainability Assessment of the Residential Land Use in Seven Boroughs of the Island of Montreal, Canada	2014	Environment, Community
Quebec	Pointe-Fortune, Otterburn Park	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
Quebec	Montreal	Ranking Canadian Universities: A Quantitative Approach For Sustainability Assessment Using UD-SIM	2011	Environment, Community
Newfound-land	St. John’s	Ranking Canadian Universities: A Quantitative Approach For Sustainability Assessment Using UD-SIM	2011	Environment, Community

Newfound-land	St. John's	Living Within the Earth's Carrying Capacity: Reflections from Memorial University	2020	Environment, Economy
Prince Edward Island	St. Peter's Bay	Climate Change Influences Carrying Capacity in a Coastal Embayment Dedicated to Shellfish Aquaculture	2015	Environment
New Brunswick	Bay of Fundy	A comparison of sustainability objectives: How well does the Canadian Fisheries Research Network framework compare with fisheries, forestry, and aquaculture certification schemes?	2020	Environment
New Brunswick	Fredericton, Canaan-Washademoak watershed, Moncton, Bouctouche, St. Andrews, Saint John	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
Nova Scotia	Sydney-New Waterford area, Glace Bay	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community
Northwest Territories	Rae-Edzo, Déline, Inuvik	Community-based Monitoring In Support Of Local Sustainability	2011	Environment, Community

Note: 26 of the 46 Canadian studies did not include a formal study location and are not included in the table above. These studies were either nationwide or global in scope, or were focused on general carrying capacity knowledge, literature reviews, or designing frameworks or models.

8.2 Data Set Content in Relation to Study Type

Table 13.0: Individual Data Set Content in Relation to Study Type

	Number of Academic Articles	Number of Grey Literature Studies	Total
Ecological Data	**12**	2	14
Health Data	2	0	2
Ecological/Health Data	**8**	0	8
Ecological/Economic Data	4	0	4
Health/Economic Data	0	1	1
Ecological/ Socio-demographic Data	**5**	**3**	8
Socio-demographic/Economic Data	3	0	3
Health/Socio-demographic Data	3	2	5
Ecological/Health/Economic Data	1	0	1
Ecological/Socio-demographic/Economic Data	2	0	2
Ecological/Health/Socio-demographic Data	1	1	2
Health/Socio-demographic/Economic Data	0	2	2
Ecological/Health/Socio-demographic/Economic Data	4	**8**	12
No Data Present	38	7	45
Total Count	**83**	**26**	**109**

8.3 Literature and Data Set Theme Tables

Table 14.0: Literature and Data Set Themes Present in Relative Comparator Studies

	Number of Studies by Literature Theme	Percentage of Studies by Literature Theme	Number of Studies by Data Set Theme	Percentage of Studies by Data Set Theme	Ratio (in %) of Literature Theme to Data Set Theme
Ecological Theme	7	58.3%	4	28.6%	175%
Health Theme	0	0%	2	14.3%	200%
Socio-demographic Theme	3	25%	5	35.7%	166.67%
Economic Theme	2	16.7%	3	21.4%	150%
Total	12	100%	14	100%	

Table 15.0: Literature and Data Set Themes Present in International Studies

	Number of International Studies by Literature Theme	Percentage of International Studies by Literature Theme	Number of International Studies by Data Set Theme	Percentage of International Studies by Data Set Theme	Ratio (in %) of Literature Theme to Data Set Theme
Ecological Theme	51	43.6%	27	40.3%	188.89%
Health Theme	22	18.8%	18	26.9%	122.22%
Socio-demo-graphic Theme	22	18.8%	12	17.9%	183.33%
Economic Theme	22	18.8%	10	14.9%	220%
Total	117	100%	67	100%	

8.4 Indicator Groupings

1. Land quality and wildlife
2. Water quality and wildlife
3. Air quality and wildlife
4. Arctic and Antarctic efforts
5. Harmful chemicals in land, sea, air, and animals
6. Household impacts on environment
7. Industrial impacts
8. Biodiversity concerns
9. Conservatory efforts
10. Energy sector
11. Climate and temperature
12. Life expectancy and death rates
13. Overall health; self-reported
14. Chronic conditions including obesity
15. Drugs and alcohol
16. Pediatric and infant health
17. Access to care and support
18. Injury and acute conditions
19. Education
20. Infrastructure
21. Indigenous-focussed
22. Crime and ethics
23. Risk
24. Social capital
25. Health, including mental health
26. Arts and culture
27. Wages, income and salary
28. Broader market measures
29. unemployment/employment
30. Goods and services
31. Poverty and wealth
32. Unions
33. Taxes
34. Democratic process
35. Socio-demographic policies
36. Rules, laws, and guidelines
37. Political funding

8.5 Indicator Groupings by Sector

Table 16.0: Indicator Groupings in the Environment Sector

Indicator Grouping	Number of Indicators	Percentage of Whole
Land quality and wildlife	13	7.34%
Water quality and wildlife	33	19.21%
Air quality and wildlife	32	18.08%
Arctic and Antarctic efforts	5	2.82%
Harmful chemicals in land, air, sea, and animals	26	14.69%
Household impacts on environment	14	7.91%
Industrial impacts	15	8.47%
Biodiversity concerns	2	1.13%
Conservatory efforts	22	12.43%
Energy sector	8	4.52%
Climate and temperature	6	3.39%

Table 17.0: Indicator Groupings in the Health Sector

Indicator Grouping	Number of Indicators	Percentage of Whole
Life expectancy + death rates	4	14.29%
Overall health; self-reported	8	28.57%
Chronic conditions including obesity	3	10.71%
Drugs + alcohol	2	7.14%
Pediatric and infant health	4	14.29%
Access to care and support	6	21.43%
Injury + acute conditions	1	3.57%

Table 18.0: Indicator Groupings in the Community Sector

Indicator Grouping	Number of Indicators	Percentage of Whole
Education	23	21.69%
Infrastructure	18	16.98%
Indigenous-focussed	2	1.88%
Crime and ethics	6	5.66%
Risk	1	0.94%
Social capital	50	47.16%
Health, including mental health	2	1.88%
Arts and culture	4	3.77%

Table 19.0: Indicator Groupings in the Economic Sector

Indicator Grouping	Number of Indicators	Percentage of Whole
Wages, income, and salary	11	11.70%
Broader market measures	39	41.49%
Unemployment/employment	15	15.96%
Goods and services	7	7.45%
Poverty and wealth	17	18.09%
Unions	1	1.06%
Taxes	4	4.26%

Table 20.0: Indicator Groupings in the Political Sector

Indicator Grouping	Number of Indicators	Percentage of Whole
Democratic process	6	42.86%
Socio-demographic	3	21.43%
Rules and guidelines	4	28.57%
Political funding	1	7.14%

8.6 Citation Mapping

Figure 6.0: Papers Cited-By International and Relative Comparator Articles

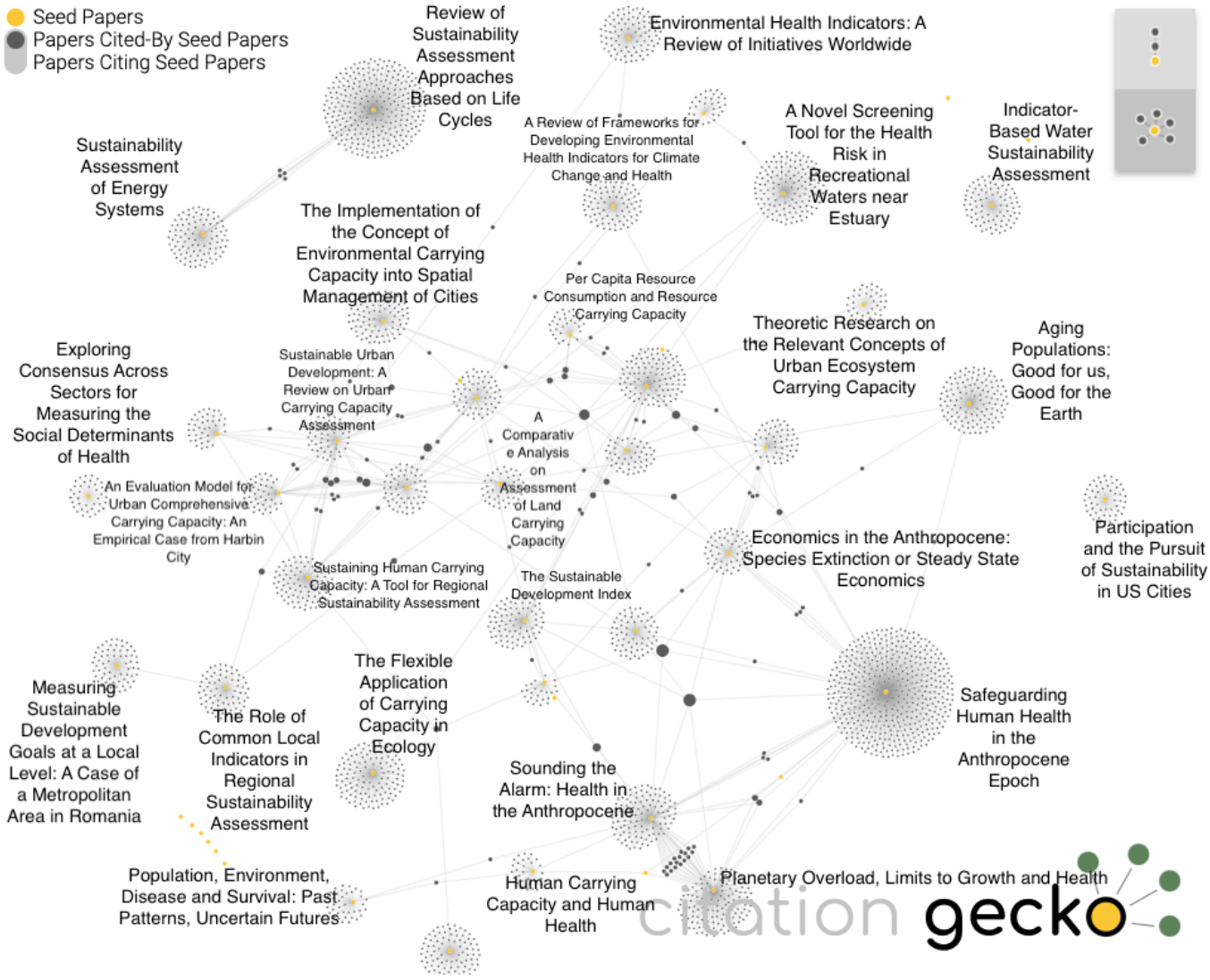

Figure 7.0: Papers Citing International and Relative Comparator Articles